

# **TUNNELING EFFECT MITIGATION THROUGH ARTIFICIAL NEURAL NETWORK BASED HEAD UP DISPLAY SWITCHING SYSTEM**

A thesis

submitted in fulfillment of the requirement of  
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Submitted by

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## CERTIFICATE

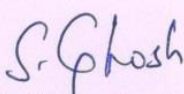
I hereby certify that the work that has been presented in the thesis entitled "**Tunneling Effect Mitigation through Artificial Neural Network based Head Up Display Switching System**" in fulfilment of the requirement for the award of degree of "Doctor of Philosophy" and submitted in the Department of Electrical and Instrumentation Engineering of Thapar University, Patiala, India, is an authenticate record of my own work. This work has been carried out under the supervision of Dr. Smarajit Ghosh and refers other research work, which are duly listed in the reference section.

The matter presented in this thesis has not been submitted for the award of any other degree of this or any other university.

  
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This is to certify that the above statement made by the candidate is correct and true to the best of my knowledge.

  
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**(Vinod Karar)**

## DEDICATION

*एक समर्पण 'समर्पित' के नाम...*  
*Dedicated to my dearest son 'Samarpit'.*



## ABSTRACT

Traditional aircraft cockpit contains a host of display systems with vital flight information like airspeed, artificial horizon, navigation, radar display, altitude, angle of attack, etc. displayed in different formats on separate instruments panels in the cockpit display suite. Such kind of cockpit arrangement requires the pilot to split his attention between outside world and different instrument panels. In fast-moving aircraft, flying close to the ground, operational environment changes so rapidly that pilot has little time to look down at head-down displays to obtain aircraft flight status information. This degrades his situation awareness. Pilot has to cope with continual eye adjustments (focus, luminance etc.) required in changing his line of sight between various displays and the outside world. This results in longer reaction times, pilot fatigue and decreased efficiency.

In order to facilitate the view of all these displays without having to divert attention, display systems like head-up display (HUD) and helmet-mounted display (HMD) have been developed. The primary role of HUD is to provide flight, navigation, and guidance information to the pilot in forward field of view on a transparent screen known as beam combiner (hereafter referred in thesis as combiner). Its use avoids need of splitting pilot's attention between aircraft and outside world events which facilitates instant decision making. Main advantages of HUD as compared to head-down displays (HDD) include reduced scanning distance between instrument panels/gauges and outside world, improved situation awareness (SA) of outside world due to more visual attention to outside world, less head-down and look around time as well as less visual misaccommodation due to collimation principle of HUD. Therefore, HUD theoretically allows for optimal control of an aircraft through simultaneous scanning of both instrument data as well as out-of-the-window (OTW) scene.

Although HUD improves flight performance, there are perceptual and cognitive issues that need to be addressed. There are number of issues related to distribution of pilot's near

and far domain attentional resources because of the compellingness of symbology elements on HUD. The phenomenon is regarded as attention or cognitive capture. HUDs may decrease pilot's SA in tasks that require continuous monitoring of information in the environment. In extreme cases, HUD lowers SA to an extent that pilot may fail to detect potentially critical discrete events in the environment.

As a practice, pilot views aircraft information, flight information and outside world as per situation requirement and not in a sequential manner. Data displayed on HUD may tunnel pilot's attention which may result in failure to notice events and objects other than those presented on HUD display. Thus, HUD results in formation of an attentional trap drawing pilot's information processing resources to HUD and slowing down processing of external events.

Attention tunneling is caused by various parameters like clutter, information and work overload, misaccommodation, misconvergence, symbol format and location, symbol salience and clutter, limited field of view (FOV) and few others. Among other factors which may significantly affect attention tunneling are: relative HUD symbology luminance (SL), ambient luminance (AL) and symbology luminance non-uniformity (NU). Various attention optimization measures have been proposed over the years like superimposed and scene-linked symbology, use of peripheral symbology, synthetic vision, use of few prevention technologies and more practice of using HUD and actual flight scenario, NASA's runway incursion prevention system (RIPS), synthetic vision system (SVS) , etc. However, such studies address only a single source of attention tunneling at any given time.

Exclusive studies have been performed in this work to understand the effect of key factors viz. limiting FOV and luminance factors in contributing attention capture, also known as tunneling. The individual effect of these parameters along with their interaction effect has been studied using statistical tools. The methods used for the purpose basically relate to inferential statistics domain. Application of paired t-test over experimental data, spanning

luminance range from 50 cd/m<sup>2</sup> to 30,000 cd/m<sup>2</sup>, established that luminance affects level of event detection on HUD symbology as well as outside scene significantly. Further, p-value found through ANOVA showed that percentage of event detection gets significantly affected due to AL and SL both.

It could also be inferred from the results that non-uniformity of HUD display causes differential luminance across the HUD display area. Experimental studies revealed that (i) at higher AL, NU causes more degradation in HUD event detection as compared to outside events and (ii) at low ambient lighting conditions, degradation in both the events is significant with HUD event detection getting affected more adversely. It was also observed that at lower AL, prominence of SL variation forces pilot to get engaged in HUD events and in the process he also loses focus on outside events.

Another set of experiments conducted to understand effect of limiting FOV due to combiner structure showed that combiner frame provide obscuration in front view of the pilot in total field of view (TFOV) as well as in instantaneous field of view (IFOV). The angle of combiner frame structure and its width present different degrees of obscuration to the pilot within head motion box (HMB). These limitations make pilot compromise simultaneous attention on outside events and aircraft events as he has to adjust his head position to view the obscured part of the outside world. The net result is obscuration of pilot's forward view of outside world suggesting that optimized frame thickness and inclination angle is essential for minimizing tunneled vision through HUD.

This work reports a new approach to detect and mitigate attention tunneling taking place while use of HUD in aircrafts. The detection mechanism developed is based on fuzzy decision making using texture features of image extracted from HUD charge coupled device (CCD) camera video. Attention tunneling mitigation is achieved through development of Assistive Attention Tunneling Mitigation system.

Texture analysis employed for detection of attention tunneling utilized composite image comprising forward view and symbology captured by HUD camera. Texture analysis could reveal discriminating features necessary to classify tunneled and the normal HUD display. The GLCM features like contrast, homogeneity and correlation of image were used for HUD symbology classification. Extracted texture features were utilized for developing a fuzzy inference system based detection of attention tunneling. Each of the input was divided into three membership functions each. Sugeno type fuzzy model was chosen for the purpose.

For attention tunneling mitigation two approaches were worked upon – adaptive neuro fuzzy (ANFIS) based mitigation and artificial neural network (ANN) based mitigation. System primarily works in as assistive mode currently and gives the pilot freedom to take inputs from AATMS for SL adjustment.

Initially, ANFIS based mitigation system approach was adopted which helped in automatic luminance adjustment of symbology according to ambient lighting conditions at time of flight operation. The implementation results showed improved balance for event detection on HUD as well as outside world during medium AL range. However, still there existed imbalance for high and low AL conditions. This required further improvement in system design.

The drawback of misbalance in high and low AL operation observed during ANFIS implementation motivated for developing individual models for both day and night mode operations. From experimental studies, optimum contrast ratio (CR) for different ranges of AL was identified. Another data set was then generated with parameters: current AL, current SL, desired SL (derived keeping in mind optimum CR) for both day and night luminance conditions. The whole data set for each case was then divided into training data, validation data and testing data to train ANN.

Two ANN models for day mode and night mode operation were developed and further integrated to form a complete attention tunneling mitigation package – ‘AATMS’

which runs in two modes: offline mode and online mode. Offline mode was developed to check the functionality of AATMS and make any improvements required. Online mode operation when selected by the user takes HUD camera input feed and check for attention tunneling condition. In case of attention tunneling taking place, AATMS generates an alert for the user and on user choice may predict SL value as well.

The novelty of the proposed approach lies in the fact that this system is adaptive to day and night mode flying operations. It is a unique attempt in the direction of online attention tunneling detection & mitigation.



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# **LIST OF ABBREVIATIONS**

<b>Acronym</b>	<b>Meaning</b>
AATMS	Assistive Attention Tunneling Mitigation System
AHRS	Attitude Heading and Reference System
AL	Ambient Luminance
AMLCD	Active Matrix Liquid Crystal Display
ANFIS	Adaptive Neuro Fuzzy Inference System
ANN	Artificial Neural Network
ANOVA	Analysis of Variance
CCD	Charge Coupled Device
CR	Contrast Ratio
CRT	Cathode Ray Tube
DEP	Design Eye Position
EFIS	Electronic Flight Instrument System
EVGS	Enhanced Visual Guidance System
FOV	Field of View
FIS	Fuzzy inference systems
FPM	Flight Path Marker
FPV	Flight Path Vector
GPS	Global Positioning System
HDD	Head Down Display
HITS	Highway in the sky
HFDS	Head-up Flight Display System
HGS	Head-up Guidance System
HUD	Head Up Display

HMB	Head Motion Box
HMD	Helmet Mounted Display
IFOV	Instantaneous Field of View
IL	Image Luminance
IMC	Instrument Metrological Conditions
IMU	Inertial Measurement Unit
MANOVA	Multivariate analysis of variance
MFD	Multi-Function Display
NCL	Nose Clearance Line
OTW	Out the window
PBC	Primary Beam Combiner
PDT	Peripheral Detection Task
PFD	Primary Flight Display
SBC	Secondary Beam Combiner
NU	Non-Uniformity
ROTO	Rollout and turn off
RMSE	Root Mean Square Error
SL	HUD Symbology Luminance
SDU	Stand by Display Unit
TCAS	Traffic Collision Avoidance System
TFOV	Total Field of View
UAV	Unmanned Air Vehicle
UFOV	Useful Field of View
VGS	Visual Guidance System
VMC	Visual Metrological Conditions
VFR	Virtual Flight Rules

## List of Symbols

<b>Symbol</b>	<b>Meaning</b>
$A_i$	Linguistic Label
$f_i$	Fuzzy Rule
$n_1$	Number of Samples in Group 1
$n_2$	Number of Samples in Group 2
$P_{(i,j)}$	Matrix of Relative Frequency Distribution of Gray Level 'I' W.R.T Another Gray Level 'J'.
$S_D$	Standard Deviation of the Differences
$SE$	Standard Error
$\bar{X}_1$	Mean of Group 1
$\bar{X}_2$	Mean of Group 2
$\bar{X}_D$	Mean of Difference Between Pairs
$Var_1$	Variance of Group 1
$Var_2$	Variance of Group 2
$\mu_0$	Constant
$\mu_{Ai}$	Node Function
$\omega_i$	Normalized Firing Strength of Rule
$\sigma$	Standard Deviation



# CHAPTER 1

## INTRODUCTION

With today's high end technology, operating high-speed aircraft in ever increasingly crowded airspace requires a pilot to make split second decisions. In fast-moving aircraft flying close to the ground, operational environment changes so rapidly that the pilot has little time to look down at head-down displays to obtain aircraft flight status information and this may degrade his situation awareness. Pilot cannot cope with the continual eye adjustments (focus, luminance etc.) required in changing his line of sight between various displays and outside world. This results in longer reaction times, pilot fatigue and decreased efficiency. It is especially dangerous in modern passenger aircraft where lives of hundreds of passengers depend on pilot's decisions. Therefore, modern aircraft cockpit is generally based on the glass cockpit concept and contains various display systems for displaying critical flight information like altitude, airspeed, angle of attack, artificial horizon, navigation, radar display etc.

In these modern aircrafts under present flight scenario, pilot cannot afford to divert his attention from the target ahead. The display systems like HUD and HMD facilitate the view of all multiple display information on single screen without having to divert attention. The see through HUD and HMD gather data from various instruments in the cockpit and present it to the user in an easily perceivable form. The graphic display of all the meter reading is superimposed over outside world on aircraft windscreen.

### 1.1 HEAD-UP DISPLAY

HUD is a means of presenting information to the pilot in line of his external forward vision. It projects key flight instrument data onto a 'see-through' screen positioned just in front of the pilot to look ahead out of the aircraft. HUD (Fig. 1.1) optically projects image of

the instrument panel information at infinity so that the pilot can see all flight parametric information superimposed on the image of real world.

In the beginning, HUD was installed in all A-7D and A-7E Corsairs. Each of these HUD system consisted of a pilot's display unit and a miniature digital computer [Electronics and Power (1974)]. Subsequently, a new type of HUD deflection coil, the X29/2421, had been designed for use with 20 mm cathode ray tubes suited particularly for applications such as avionic head-up displays, projection displays, scanning electron microscopes and specialised video display equipment [Electronics and Power (1975a)]. Advanced HUD weapon-aiming systems were fitted to F16s used by US Air Force [Electronics and Power (1975b)]. Troxell *et al.* (1997) proposed reconfigurable HUDs for enhanced vehicle to driver communication. It was reported that it had potential for improved vehicle to driver communication with features like highway in the sky (HITS). In order to best address this opportunity, reconfigurable high luminance active matrix vacuum fluorescent HUD was proposed, which could provide a luminance of 9600 fL, luminous efficiency of 14 lumens/W, and a small package size comparable to existing production fixed format vacuum fluorescent display systems. Successful use of HUDs in aircraft motivated for its application in automobile industry as well. Laser projection system, capable of projecting moving colour images onto any surface with image quality equivalent to existing LCD screens, were proposed to be used for car HUDs [IEE Review News (2004)].

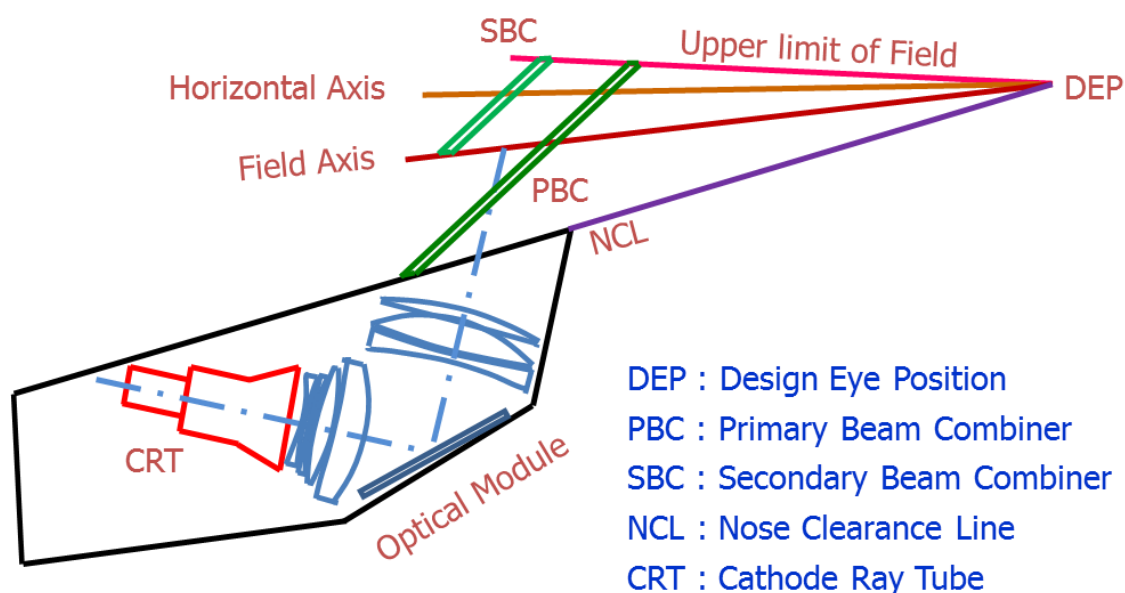
HUD occupies prime location in an aircraft cockpit. It, through its property, helps in doing away with the requirement to look at various instruments panels to read flight, aircraft and weapon data, and then integrate all the presented information. Its use results in avoiding need of splitting pilot's attention between aircraft and outside world events, helping the pilot in taking instant decisions. It also removes the requirement of continuous scanning to his line of sight to view outside world ahead and around as well as between various displays [Newman (2000); Wood and Howells)]. The most important role of HUD is in reducing the

fatigue of pilot thus enhancing his performance [Electronics and Power(1975a); Dopping-Hepenstal (1981); Todoriki *et al.* (1994); Hueschen *et al.* (1998)]. Main advantages of HUDs as compared to HDDs include reduced scanning distance between instrument panels/gauges and the outside world; improved SA of outside world due to more visual attention to outside world; less head-down and look around time as well as less visual misaccommodation due to collimated display [Chen *et al.* (2011)]. Another major advantage is ease in viewing in both directions, transition between control of the aircraft by reference to flight along with other vital information displayed on HUD and by reference to external cues [Hueschen *et al.* (1998); Ververs and Wickens (1998.)].

In HUD, information is formed on a very high intensity display device. The control panel allows selection by the pilot of various display options. The symbology is collimated using complex set of optical glasses and mirror. Main task of reflecting collimated image towards pilot and transmitting forward outside view is carried by wavelength selective glass known as combiner. It is made highly frequency selective to reflect only the display source light wavelength and to transmit all other visible wavelengths. HUD uses the technique of placing symbology collimated at optical infinity in pilot's forward view. This allows pilots to access outside world and aircraft information displayed on HUD display simultaneously in same area of fixation and accommodation [Wood and Howells (2001); Jukes (2004); Jarrett (2005); Moir *et al.* (2006b); Moir *et al.* (2006a)].

Early HUD typically provided a combination of situational and guidance data. Most of this was taken from the primary flight display (PFD) HDD or equivalent analogue instruments. As compared to early days of Electronic flight instrument systems (EFIS), size of HDD EFIS screens has now increased considerably. More information can now be displayed on a PFD as well as on corresponding HUD. Original airspeed, altitude, localizer and glide-slope were quickly joined by key derivative information on energy status of the aircraft - a flight path (trend) vector (FPV). This was followed by a flight-path marker, an

airspeed trend vector, angle of attack indication and notional depiction of runways. Some systems also have few or all of landing flare cues, tail strike warning, unusual attitude and wind shear detection and recovery guidance, stall margin indications and Traffic collision avoidance system (TCAS) alerts and advisories. For landing or rejected take off in low visibility, runway distance remaining and ground deceleration displays can be a crucial aid in preventing runway excursion. One deceleration display currently available gives braking performance as 1, 2, 3 or MAX, which correspond directly to auto-brake settings so that for the landing roll, a clear display of any unexpected runway surface contaminant status is provided [Wood and Howells (2001); Jukes (2004); Jarrett (2005); Moir *et al.* (2006b); Moir *et al.* (2006a)].



**FIGURE 1.1 BASIC LAYOUT OF A HEAD UP DISPLAY**

Till recently, use of HUD was primarily done for the fighter aircraft only. Military applications had led the way but following the introduction of first civil HUD application in 1993, both general aviation as well as airline applications had grown considerably. HUD on multi-crew civil aircraft had been limited to single side installation with only Boeing C-17 and Lockheed C130J military transports having completely independent dual installations. Now, however, customer demand has driven the development of a dual LCD head-up

guidance system for the Embraer 190. All major avionics manufacturers, who originally developed equipment for the military market, are now also supplying to civil markets. There are some alternative names for HUD like VGS - Visual guidance system, HGS – Head-up guidance system and HFDS - Head-up flight display system. While HUDs are of immense use for critical tasks like bad weather take-off and landing, they are also of immense value in other precision flying tasks such as cargo drops in remote areas, formation flying, refuelling for transport aircraft etc. Its use primarily in a fighter aircraft was to provide target data for weapons, guidance and flight data. Thus, it facilitated pilot maintain complete awareness of situation with respect to all the flight critical parameters without having to look towards other panels and instrument cluster present in the cockpit [Tufano (1997); Houten (1999); Calhoun *et al.* (2005); Pope (2006); Zheng *et al.* (2007. ); Chen *et al.* (2011)].

Successful use of HUDs in aircraft motivated for its application in automobile industry as well. With advent of new gadgets based on principle similar to HUD, like wearable and mobile devices e.g. Google glass, HMD, popularity of HUD is being translated to necessity and hence there is significant reduction in costs of modifications required to suit new applications. There are, however, human psychological and ergonomics factors which are required to be considered before actual use [Ablassmeier *et al.* (2007)]. As per proximity compatibility principle [Doshi *et al.* (2009)], information relevant for a common task should be shown in proximity in the perceptual space [Crawford and Neal (2006)]. Principle and current use of HUD meet this requirement by displaying task-critical information in perceptual neighbourhood [He (2013)], which results in reduced eye scanning as compared to a HDD or a vehicle instrument environment [Steven *et al.* (2000)].

## **1.2 HUMAN FACTOR ISSUES RELATED TO HUD**

Achieving SA is the primary preference for an aviation pilot. A commonly accepted definition of SA divides it into three levels: “Level 1) the perception of the elements in the environment within a volume of time and space, Level 2) the comprehension of their

meaning, and Level 3) the projection of their status in the near future” [Endsley (1995a); Endsley (1995b)]. Presence and use of HUD in cockpit adds to already complex system. Constant addition of new gadgets in cockpit may lead to human factors problems, which include workload and sensory overload.

HUD use may cause inappropriate attention capture and consequently tunneling (also called as cognitive tunneling). Cognitive tunneling can be defined as the phenomenon which causes delay in pilot’s response time w.r.t HUD as well as outside events detection due to the existing cognitive load [Ververs and Wickens (1998.)]. Reasons of cognitive load may be over engrossment in a scene or too much concentration on the symbology.

Pilot views aircraft and flight information as well as outside world as per the situation requirement and not in a sequential manner. Data displayed on HUD tunnels pilot's attention which may result in failure to notice events and objects other than those presented on HUD display. Thus, HUD results in an attentional trap drawing information processing resources to it and slowing down the processing of external events. This, regarded as attentional tunneling, is deterioration in peripheral presentation due to narrowing of the focus of attention [Weintraub *et al.* (1985); Ververs and Wickens (1998.); L *et al.* (2007); Hofmann *et al.* (2008); Kim and Dey (2009)].

### **1.2.1 ATTENTION CAPTURE**

Attention capture refers to situation where pilot or driver may be totally lost in thought, a condition which, in particular, could impair SA. Attention or cognitive capture is typically used w.r.t inefficient attentional switching (from HUD, to primary task) when using HUDs. This may result in missing external targets, delayed responses to external events and asymmetrical transition times (longer to switch from HUD to external visual processing and vice versa) [Verver and Wickens (1996)]. This effect describes degradation of responses to external targets due to processing of information from a HUD image. As such, it principally involves cognitive operations of selective attention, divided attention and attention switching.

Wherever emotional content (i.e., personal involvement) in a conversation is high, such as arguing with someone over the phone, likelihood of cognitive capture taking place is more. Instruments that require some level of cognitive involvement thereby could lead to loss of SA and increase the risk of unwanted situations like a crash. Users are much better at detecting events taking place in outside environment if their attention is focused on the display area in which those events occur. However, attention is a resource with limited capacity. Under some circumstances, a single task or aspect of environment would capture all of the individual's attention. If an individual focuses attention in this way then he or she will filter out unattended information and may not detect task-critical information.

It is believed that cognitive capture results because of observer's tendency to develop inefficient attentional switching strategies in presence of HUDs. Assuming that an attentional switch is required to acquire information from 'far-domain' (i.e., the forward driving scene) after attending to 'near-domain' (i.e., the HUD), cognitive capture of HUDs occurs when performance on 'far' task (i.e., missed targets, slower response time) is degraded in presence of HUD. It has been suggested that cognitive interference in driver's responses to external targets is more likely when number of targets and distracters (in HUD as well as external scene) is large, when spatial and temporal uncertainty of critical (external) targets is high, when conspicuity of critical targets is low and when relative event rate for salient targets in forward driving scene (i.e., those requiring "effortful" or controlled, as opposed to automatic, processing) is lower than that for HUD stimuli [Gish and Staplin (1995); Verver and Wickens (1996); Wickens and Hollands (2000); Klein (2007)].

### **1.2.2 COGNITIVE TUNNELING**

The cognitive tunneling is defined as "the allocation of attention to a particular channel of information, diagnostic hypothesis, or task goal, for a duration that is longer than optimal, given the expected cost of neglecting events on other channels, failing to consider other hypotheses, or failing to perform other tasks". Cognitive tunneling can also be regarded

as degradation in peripheral performance attributable to narrowing of focus of attention. In literature, this term is used interchangeably with “cognitive capture” and “cognitive tunneling” [Martin-Emerson and Wickens (1997)].

It is expected that HUD would enhance a pilot’s ability to detect events in external world because pilot does not have to switch attention back and forth between HDD and external environment. Results of studies suggest that HUD symbology can capture pilot’s attention, and impair pilot’s ability to detect events in external environment [Crawford and Neal (2006)].

Critical flight phases require effective division of attention between relevant information domains, including OTW view, instruments and the flight path. Distance between information sources (in terms of visual angle) can lead to serious costs of scanning, especially when going from head-up to head-down and vice versa. HUD has the advantage that attention can be distributed between information domains with minimal scanning costs. The phenomenon of attentional tunneling can occur when the operator becomes focused on an element of the synthetic vision symbology (or objects to which attention is directed by the synthetic symbology) to such an extent that other important objects or events in the sensor imagery are left unattended [Yantis (1993); Zheng *et al.* (2007. )].

### **1.3 GAPS OF RESEARCH**

Literature reports that attention tunneling is caused by various parameters such as information and work overload, misaccommodation, misconvergence, symbol location and clutter, symbol salience, symbology format and salience, limited FOV and few others. However, such studies address only a single parameter at a time. Some of the identified research gaps are as follows:

- i. Attentional tunneling causing factors like limiting FOV due to combiner and luminance factors including NU in contributing attention capture and tunneling need to be understood in more detail.

- ii. Image attentional tunneling characteristics of the HUD display need to be derived so that an automatic tunnel mitigation scheme could be employed dynamically.
- iii. Correlating experimental data through statistical estimation and evaluating image characteristics.
- iv. Area of automatic tunneling mitigation has not been explored.

## **1.4 OBJECTIVES OF RESEARCH WORK**

The objective of the research work is to:

- i. Study all technical aspects of HUD leading to the problem of tunneling.
- ii. Develop real time image processing system to capture HUD image data for logging, enhancement and feature extraction.
- iii. Creating training and testing data set from simulator for validation of artificial neural network system.
- iv. Develop an artificial neural network based system for decision support for enabling the HUD display for mitigating tunneling effects.

## **1.5 OUTLINE OF THESIS**

The thesis is organized under seven chapters. Chapter 1-‘Introduction’ gives a glimpse of the problem area. It is to familiarize a reader with working basics of HUD. The chapter also gives a brief introduction about attention capture and cognitive tunneling. It also covers the existing research gaps and objectives of the presented research work.

Chapter 2 - ‘Literature Survey’ presents an extensive survey of research papers in the field. This chapter helps in laying foundation of the research work. It also discusses the various factors affecting attention tunneling and results of the earlier reported studies conducted by other researchers.

Chapter 3 - ‘Technical Aspects of HUD Leading to the Problem of Tunneling’ describes the experimental work carried out in pursuit of first research objective. This chapter

explains the effect of luminance (AL, SL, and NU) and field of view over attention tunneling. It further includes experimental details of the work done to interpret the effect of aforementioned factors on attention tunneling.

Chapter 4 - 'Real Time Image Processing System Developed for HUD Image Capturing and Data Logging' discusses details of system developed for feature extraction of captured HUD image. Also, it elaborates fuzzy inference system developed for detection of attention tunneling based on the extracted texture features of HUD CCD image.

Chapter 5 - 'Collection of Data for Generation of Training and Testing Database' gives an account of the primary and secondary data collected through the experiments. It reports sample of texture feature set data generated for detection of attention tunneling as well as event detection data set used for training and testing of ANN based system for tunneling mitigation.

Chapter 6 - 'Artificial Neural Network Based Decision Support System for Tunneling Mitigation' discusses the two approaches (ANFIS and ANN) used for developing tunneling mitigation system. It includes details of training the network, validating performance of trained networks and results of developed system. It also discusses complete working of the developed Assistive Attention Tunneling Mitigation system step by step.

Chapter 7 - 'Conclusion' summarizes results of all the identified objectives in the beginning of the work. It concludes all the findings of experimental work carried during the course of this study. Also, it includes future scope of the work.

## CHAPTER 2

### LITERATURE SURVEY

Head-up Display has a pivot role in the aircraft cockpit. But as it is said in old times “with every good there comes some bad”, same is true for HUD as well. Potential advantages of HUD have been very high but they do come at some cost. These issues, probable solutions and existing difficulties reported by researchers over the time are discussed here in detail. Also, pros of HUD use in aircrafts motivated its application in the field of automobile industry as well. Since, the phenomenon of attention capture/tunneling is similarly applicable in automobiles as well, relevant studies are also discussed.

Dopping-Hepenstal (1981) reported that HUD provided a flight and weapon aiming display, which enhanced safe operational flight envelope and flexibility of weapons delivery. Pilot, though, had another responsibility of cross monitoring between traditional pilot's instrument panel which consisted of both main and standby instruments laid out in a prescribed pattern for efficient scanning and for making a judgment in the event of deviance. Since pilot was required to do monitoring over a larger scan area, it resulted in significant increases in physiological and psychological workload. This first generation of HUDs earned themselves a reputation for poor reliability and for a high occurrence of erroneous, but plausible displays. Reising *et al.* (1988) reported that one of the main purpose of HUDs in modern fighter aircraft was to provide attitude information to the pilot allowing him/her to focus attention on outside world simultaneously. It was also reported that attitude symbology was deficient in its ability to answer important pilot questions about unusual attitude recovery. The results of study indicated that inclusion of multicolour coding and a fixed point of rotation for the dynamic pitch-ladder symbology resulted in better unusual attitude recovery.

Hartley and Pulliam (1988) discussed use of HUD, speech recognition and speech synthesis in controlling a remotely piloted space vehicle analysed through experiments conducted with HUDs, voice input/output and experimental pilot console developed interactively during the simulation of remotely piloted space vehicles (RPSVs) and US Space Station operations. The experiments included heads-up reticle displays, heads-up data displays, and selection of displays by voice command, use of voice command to call for range and rate data and the voice annunciation of alarms.

Summers and Hammontre (1994) discussed image quality issues for an enhanced vision HUD. They performed part task simulation study to determine ability of pilots to land an aircraft using HUD guidance symbology overlaying emulated millimeter wave imagery. The study involved tasks to land in Category IIIa weather at a Category I facility with three variable image parameters: image update rate, image processing latency and luminance contrast ratio of runway image to background noise. Instrument Landing System (ILS) beam bending that was representative of a Category I facility was randomly varied across the experimental runs. Nine pilots completed the test matrix. The only variable that made a significant difference was runway to background contrast ratio. Wisely (1994) discussed design of wide angle HUDs for enhanced and synthetic vision. Todoriki *et al.* (1994) discussed applications of HUD for in-vehicle navigation/route guidance based on the results of preliminary experiments and kinds of information displayed by HUDs to assure ease of recognition by the driver. Finally, based on these considerations, a HUD system was proposed as a visual interface for future in-vehicle navigation/route guidance systems.

Yakimenko (1997) proposed short cut time spatial trajectories on-board optimization and their cognitive HUD visualization for pilot's control actions during manoeuvring support. They considered general aspects of mathematical foundation of on-board universal pilot's support subsystem. It provided pilot with control actions support during more or less long term manoeuvres, such as take-off and climbing, flight on a route, surface based target attack

(in case of military aircraft), descent and landing via short cut time spatial trajectories on-board optimization and their HUD in the view of 'road-in-the-sky' image visualization for its further tracking in direct with foresee regime or (semi) automatic mode. Two specially designed modifications of direct method of variation tasks solution were proposed. First was based on 5<sup>th</sup>-7<sup>th</sup> power polynomials optimal trajectory approximation for short term trajectories with strong restrictions on control functions. The second one was based on spline approximation for long-term flight on route trajectories. Hueschen *et al.* (1998) provided description of flight test of a rollout and turnoff (ROTO) HUD guidance system. It resulted in mean ROT values essentially the same as those for current clear-weather operations and standard deviation ROT values a factor of 1.5 to 2.0 less depending on exit comparison. It was assumed that pilots could follow the guidance in low visibility conditions. These ROT values implied that clear-weather runway capacity could be maintained in low visibility conditions. All the pilots liked the system and found the guidance easy to follow after a couple of training runs. In general, pilots were able to control the aircraft ground speed along the runway to within 10 knots of commanded ground speed from the ROTO guidance.

Billingsley *et al.* (1999) discussed HUD symbology for ground collision avoidance tested using a fixed-base T-38 simulator with a projection screen and simulated HUD. When given a standard Break-X, pilots were able to spend only 40% of the flight time between desired altitudes and crashed in 20% of the runs. Horizontally and vertically moving chevron symbols allowed 70% and 80% of the flight time to be spent at the desired altitude respectively and resulted in a crash in 8% of the runs. A preview depiction using a perspective elevated surface at the desired altitude was the best display for the task investigated, allowing 90% of the time to be spent at desired altitude with a crash rate of 2%.

Ercoline (2000) emphasized on various issues with HUD. He summarized many good and bad features of HUD. He emphasized on HUD education and training programs. General aviation pilots possess least instrument experience of all flyers and HUD was not intuitive,

which required training and continual practice. Except in a very few specific commercial aviation cases, HUD did not lower weather minimums required to execute an approach.

Zuschlag (2001) discussed issues and research needs concerning the use of HUDs in air transports with option of manual approaches, landings and take-offs in poor visibility. HUDs made it possible to overlay and augment the real world image with conformal symbols such as a flight path marker (FPM), which indicated the direction the aircraft is heading within the OTW view. They discussed clutter w.r.t civil transports. Burch and Braasch (2002) described enhanced HUD for general aviation aircraft. When instrument meteorological conditions (IMC) prevailed, pilot must rely on his or her ability to navigate and safely land the aircraft using instrumentation. They discussed the usage of gauges and dials which were used to determine the spatial orientation of the aircraft rather than the intuitive 'out the window view' used during visual meteorological conditions (VMC). VMC flight required far less skill and was inherently safer than IMC flight, particularly for low time instrument rated pilots. They further emphasized that GA cockpit needed to be modernized by combining an attitude and heading reference system (AHRS) and a Global positioning system (GPS) receiver with advanced display technology. Overlapping the display with outside world provides pilot with a better understanding of aircraft flight path. It ensured that one was not spending valuable time struggling to determine aircraft's position and orientation relative to the runway.

Snow and French (2002) discussed effects of primary flight symbology on workload and SA in a head-up synthetic vision display. They described about human factors issues associated with synthetic vision in a HDD which were different from those associated with a head-up synthetic vision display, especially when the displays were used as primary flight references. Among these issues were the use of colour, ability to see through the display, symbology clutter, compatibility between head-up and head-down displays, and attentional factors. They reported the results of a study in which HUD experienced pilots flew simulated

complex precision approaches to landing in three visibility conditions, with and without synthetic terrain, using either pathway-in-the-sky symbology or more traditional military standard HUD symbology.

Wisely (2002) discussed applications of HUDs to reduce both controlled flight into terrain and approach and landing accidents through enhanced SA. They described an enhanced visual guidance system (EVGS) to assist the safe operation of aircraft by increasing pilot's situational awareness during critical phases of flight, both in Visual flight rules (VFR) and IMC conditions. It contained images of flight testing with millimeter wave radar sensors at different frequencies, which graphically illustrated the power of the system to control flight into terrain and approach and reducing landing accidents, and it's potential to increase terrain awareness in the future.

French and Schnell (2003) reported terrain awareness and pathway guidance results for HUDs (tap-guide) through a simulator study of pilot performance. The study evaluated flight technical performance, workload, and SA of pilots flying a low level curved approach to an austere airfield. The flight technical data indicated that both pathway formats (paver and tunnel) were superior to the baseline symbology format. For all practical purposes, paver and tunnel formats performed equally well. Head-up guidance with terrain and pathway information provided much tighter flight technical performance than conventional head-up guidance. Thus, they concluded that the mission capability of the potential military users could be substantially increased.

McKinley *et al.* (2005) discussed flight testing of an airborne SVS with highway in the sky on a HUD. The results of study conducted by NASA small aircraft transportation system (SATS) in a Cessna 402B using a HUD and HITS symbology showed the utility of synthetic imagery using real time aircraft data for aircraft guidance and improved SA. Comparable piloting accuracy was demonstrated with HITS as that achievable using only HUD flight director and velocity vector guidance. Pilot preference for HITS over traditional

HUD guidance cues was mixed, but consistently agreed that a combined HITS-HUD improved SA of the aircraft's relative location with respect to the approach course. This flight test also proved the feasibility of an inexpensive synthetic vision system to generate HITS imagery with EVS on a low cost HUD.

Ertem (2005) discussed airborne synthetic vision system with HITS symbology using X-Plane for a HUD. They reported that trajectories and symbology were generated for GPS WAAS (wide area application services augmentation) approach procedures developed for the NASA SATS demonstration flights. Aircraft position and attitude data collected using an integrated inertial measurement unit/global positioning system (IMU/GPS) were used to render synthetic ground imagery and HITS symbology using the X-Plane program in real time. Flight testing showed that synthetic imagery using actual aircraft data could be used for aircraft guidance and for situational awareness, as well as for post flight playback and analysis. Availability of high quality scenery and elevation data as well as the existence of a software development kit allowed the use of the X-Plane flight simulation program as a high performance and inexpensive rendering platform. This proved the feasibility of building an inexpensive SVS to generate synthetic imagery on a low cost HUD designed for GA type aircraft.

Evans *et al.* (1989) discussed initial research extending the use of HUD technology to motor cars. Potential benefits of HUD to the driver were discussed with practical factors for the design of practical systems, suitable technologies for the display source, projection optics and integration of the combiner into car windscreen along with the advantages offered by use of a holographic combiner. Merryweather (1990) discussed concepts of HUD for automotive use. They further discussed developments done in HUDs for military aircraft over last 15 years with adaption for use in automotive applications. Eliasson and Groves (1992) discussed rationale behind car HUD intended for use within the Prometheus program to achieve

demonstration of HUD technology, demonstration of future traffic information content and evaluation of potential advantages to the driver.

Ward *et al.* (1994) reported the effects of background scene complexity on legibility of HUDs for automotive applications. The study involved subjects viewing video footage following a car on an open road with low, moderate and high scene complexity and then to track lead vehicle and identify HUD presented targets of a specified orientation and specified changes in a HUD presented speedometer. The results indicate that: 1) HUD legibility deteriorated with increased visual complexity of the background scene; and 2) positioning HUD on the roadway ameliorated the effect. Okabayashi *et al.* (1997) discussed how angle of depression affects perception of displayed image in automotive HUDs. They described the relation between perception of displayed image and angle of depression in automotive HUDs and pointed out problems of misconception of displayed information, if the angle is very small in practical HUDs

Charissis and Naef (2007) emphasized that contemporary automotive navigation and infotainment requirements evolved traditional dashboard into a complex device that could often distract driver. They discussed that HUD use results in reduction of driver's reaction time. Improving spatial awareness with aptitude of the proposed HUD interface depended on driver's focusing ability to HUD interface and actual traffic. Ablasmeier *et al.* (2007) described that to minimize mental workload of the driver and to keep increasing amount of easily accessible information, sophisticated display and interaction techniques were essential. This contribution focused on a user centred analysis for an authoritative grading of HUDs in cars. Two studies delivered the required evaluation data. In a field test, potential and usability of HUD were analysed. According to driving situations, special display needs and requirements of the users were identified and compared with in-car displays. As major result, a high acceptance of HUD by driver and a good performance compared to other in-car displays had been reached.

Tonnis *et al.* (2007) reported the results of studies on visual longitudinal and lateral driving assistance in HUD of cars. They reported that most car accidents occurred due to longitudinal collisions or lane departure. They assumed that number of such accidents could be reduced, if driver knows more precisely, where the car is heading and at which distance it can stop. To provide drivers with this kind of anticipation, they had developed two augmented reality based visualization schemes for longitudinal and lateral driver assistance in HUD of cars. One presentation scheme indicated the braking distance by a virtual bar on the road. The second scheme added visualization of a drive path between car and the bar, zoning the entire region that the car would pass before coming to a complete halt. Their results indicated among other findings that bar is preferred, that it supports driving performance and that it did not increase mental workload.

Cheng *et al.* (2007) proposed a laser based wide area head up windshield display and its evaluation for assisting a driver to comply with speed limits. They performed comparative experimental evaluation with an instrumented vehicle of four different types of display protocols. They obtained dynamic active display - speed control system, a part of the dynamic active display concept of presenting safety-critical visual icons to the driver in a manner that minimized deviation of his or her gaze direction without adding to unnecessary visual clutter. The experimental system made use of GPS information to locate the vehicle on an annotated map with speed limits; novel HUD and three biologically inspired alerts, to present speed and speed limit information on this display. Each alert strategy was tested on actual roadways and compared with the situation of having to rely only on the dash indicators. Given the inclination, drivers who were given an over-speed warning alert reduced the amount of "time to slow back down" to speed limit by 42% as compared to drivers not given the alert. Ultimately, each of these alerts exhibit strengthened in complementing ways, indicating that a combination of these alerts would provide the best strategy for promoting speed limit compliance.

Doshi *et al.* (2009) proposed a novel active HUD for driver assistance capable of actively interfacing with a human as part of a driver assistance system. Dynamic active display (DAD), a unique prototype interface, presented safety-critical visual icons to driver in a manner that minimized the deviation of his or her gaze direction without adding to unnecessary visual clutter. As part of an automotive safety system, DAD presented alerts in field of view of the driver only, if necessary. This was based upon the state and pose of the driver, vehicle and environment. They examined the effectiveness of DAD through a comprehensive comparative experimental evaluation of a speed compliance driver assistance system, which was implemented on a vehicular test bed. Three different types of display protocols for assisting a driver to comply with speed limits were tested on actual roadways, and these were compared with a conventional dashboard display. Alerts decreased distraction levels by reducing time spent looking away from the road, thus proving utility and promise of the DAD system.

Karvonen *et al.* (2006) explored the use of ubiquitous computing in cars from a user psychological point of view. They studied the human dimension of in-car ubiquitous computing with a new driver tutoring system which gives guidance messages for a safer and more economical driving style. The system was tested in a driving simulator and both qualitative and quantitative data was collected. They concluded by presenting the key enhancements revealed in the experiment and by discussing the initial results from the perspective of user psychology.

An application of HUD technology to manual manufacturing processes in the form of augmented reality was proposed by Caudell and Mizell (1992). They also described the design and prototyping steps for implementation of a heads-up, see-through, head-mounted display (HUDset). Combined with head position sensing and a real world registration system, this technology allowed a computer-produced diagram to be superimposed and stabilized on a specific position on a real-world object. Successful development of the HUDset technology

enabled cost reductions and efficiency improvements in many of the human-involved operations in aircraft manufacturing by eliminating templates, form-board diagrams and other masking devices.

In the next section, various theories of attention have been discussed followed by discussions on various human factors causing attention capture and tunneling in systems employing HUDs and its variants.

## **2.1 THREE BASIC MODES OF ATTENTION**

Prinzel and Risser (2004) discussed basic concepts attached to attention capture related to HUDs. Three basic modes of attention w.r.t. to HUD included selective attention, focused attention and divided attention. While selective attention serially determines what relevant information in the environment needed to be processed, focused attention referred to ability to process only the necessary information and filters out the unnecessary. The divided attention referred to means to concurrently process more than one attribute or element of the environment at a given time.

Wickens *et al.* (1998); Crawford and Neal (2006) proposed display features that encouraged divided attention in such a way to inhibit person's ability to focus attention on specific aspects of the display and vice versa. For example, putting similar objects together might support divided attention but made it difficult to focus attention on one particular object within the display. Similarly, an element of a domain that had dynamic properties, such as motion, may capture attention and be so compelling that it consumed the majority of the attentional resources, so that there was insufficient attentional capacity to view other visual elements concurrently.

Yantis and Jonides (1984); Martens and Winsum (2000) described phenomenon of 'cognitive tunneling' or 'attentional tunneling' as indicative of a shift towards increasingly selective patterns of attending. It is a measure of cognitive selective attention, since experimental evidence had shown that if peripherally located stimuli were relevant to the

performance of a primary centrally located task, decrements in performance did not occur [Yantis and Jonides (1984)]. The phenomenon was, however, usually associated with stress instead of with workload. Illustrations of this were the clear occurrences of tunnel vision under severe fatigue.

## **2.2 SPACE AND OBJECT-BASED THEORIES**

Duncan (1984); Kramer and Jacobson (1991); Wickens (1997); Houten (1999) discussed two types of theories to describe the allocation of attentional resources over space. According to space based theories, attention is directed at all elements within a spatially defined region. According to object based theories, complex scenes were parsed into groups of objects, with attention focused on only one object at a time. Objects could be defined by contours, rigidity of motion, colour equality, etc. A disadvantage of interfaces applying superimposed symbology was that the display got increasingly cluttered such that the focused attention tasks (readout) were harder to perform, although it was suggested that selective attention tasks (search) were most influenced

Object based models proposed by Kahneman and Treisman (1984); Foyle *et al.* (1993) assumed that complex scenes were visually parsed into groups of objects. These perceptual groups control the distribution of spatial attention across the visual field, with attention focused only on one group at a time. Concurrent processing of two sources of information was only possible if they were part of same object. Relative motion and display format were two salient cues that might cause visual system to parse HUD symbology and terrain into two separate objects. Since HUD symbology occurred in a fixed screen location as vehicle moved through the terrain, HUD symbology and terrain information had differential motion. Additionally, these two sources of information also differed in their display format (pictorial terrain information and HUD information). Therefore, HUD information and terrain information might segregate into separate objects, thereby preventing concurrent processing.

Location based models of attention as proposed by Brickner (1989); Foyle *et al.* (1993) held that concurrent processing of two sources of information was only possible if they were located near one another. Location of HUD symbology might have affected the ability to use both path and altitude information in aircraft flight simulation experiments.

## **2.3 FAR AND NEAR-DOMAIN PERCEPTUAL PROCESSING**

Uses of far and near domain and space and object based processing concepts were important considerations for a psychological understanding of the benefits and costs of HUD usage as described by Wickens (1997); Prinzel and Risser (2004). Tasks could involve focus of attention either on far domain (e.g., traffic), or near domain (e.g., airspeed information), or integration of related or redundant information between the two domains (e.g., a spatial symbology such as a runway outline represented an object in far domain). So, processing of HUD information could be divided into three states of required attention: far domain consisting of objects such as other aircraft that need to be detected and processed; near domain required attentional processing of display information; and aircraft domain required allocation of attention for aircraft control and flight path maintenance. Psychological mechanisms of attention could be associated with each of the tasks. Sources of information in the near and far domain required focused attention, whereas flight path control required allocation of divided attention because it integrated information from far and near domain while other sources of information must be extracted from scanning the HDDs. Superimposition of HUD information allowed the pilot to maintain awareness of the instruments (near domain) and outside the cockpit (far domain) in the forward FOV.

## **2.4 FACTORS CAUSING ATTENTION CAPTURE**

### **2.4.1 INFORMATION AND WORK OVERLOAD**

Information and work overload had been discussed in detail by Larish and Wickens (1991); Gish and Staplin (1995); Dowell *et al.* (2002); Crawford and Neal (2006).

Information overload refers to the state having too much information at same time. It leads to user inability to perceive the important information. For instance car integrated HUDs showed significant information, such as speed limits or safe distance information to the driver. In matters of keeping driver informed, large amount of diverse informational signs could be displayed, but the effect of information overload should thereby stay in mind. If cognitive tunneling was caused by limitations in attentional capacity, increasing workload further reduced pilot's available capacity, thereby aggravating tunneling effect. In a study, two levels of turbulence (high and low) were used to vary the workload for instrument rated pilots in a flight simulator. Study investigated the pilot workload while taxiing. High fidelity investigations were made into study of workload during commercial flight operations involving high and low levels of turbulence to vary the workload for instrument rated pilots in a flight simulator. The differences in response latency to unexpected events between HUD and HDD conditions were greater under high levels of workload, suggesting that workload increased cognitive tunneling. Contrary to expectations, opposite effect was found for detection of expected events. Pilots using HUD were faster at detecting expected events in the near domain than pilots using HDD, and this difference was stronger under high workload conditions. It was suggested that in a high workload situation, HUD might induce narrowing of attention to avoid distraction from the superimposed images, or a change to the pilot's scan pattern, due to superimposed images. Hence, it might be concluded that dividing attention between two overlapping sources was a difficult and unnatural cognitive task that might exhaust resources in high workload situations. Positive evaluations of the HUD provided by the pilots occurred despite the fact that HUD produced an increased number of missed events. These results suggested that cognitive tunneling effect is counter intuitive, and that many pilots were not aware of its existence.

Martens and Winsum (2000); Brown et al. (2004); Hagen et al. (2007); He (2013) discussed that heavy workload could induce low utility of HUD due to large response time,

clutter, reduced FOV, etc. Effect of workload or driver distraction by means of the 'peripheral detection task' (PDT) during driving with in-vehicle equipment were reported by Verver and Wickens (1996). The results favoured cognitive tunneling hypothesis. In-vehicle systems might have a negative effect on safety if they increased workload or distracted the driver. Sudden increases in workload could occur during interaction of driver with in-vehicle system, since driver had to divide his/her attention between outer world and system inside the vehicle. Even if system did not required driver to look inside the vehicle on a display, the system might distract by providing information to the driver (e.g. speech messages) or performing actions that the driver did not expect or initiate. In another study involving detecting variation in workload and its effect on tunneling using PDT showed that more complex driving situations result in larger response times (RT) or higher fractions of missed signals and in this condition PDT could be considered as sensitive to variations in workload. Average RT and fractions of missed signals were compared with what was considered to be the easiest situation, straight road driving with 80 km/h speed limit on rural road and normal driving with speed limit of 120 km/h on the motorway. The results indicated that both RT and misses were sensitive to differences in driving situation. Situations that required immediate actions and that were characterized by a sudden and unexpected change in criticality result in deteriorated performance on the PDT. Hence, the effect criticality of traffic scenario on RTs, and especially on the fraction of missed signals, was statistically significant. Similar study conducted by Duncan and Humphreys (1989) driver simulator having HUD showed that while participants performed well in maintaining speed but performed poorly in maintaining lane positions indicating workload induced tunneling effect.

#### **2.4.2 FAILURE TO NOTICE SUDDEN CHANGES OR CHANGE BLINDNESS**

Change blindness was discussed in detail by Simons (2000); Lisa (2001); Klein (2007); Nikolic *et al.* (2004) discussed about failure detection, which could be detected as an obvious change. In human-computer interaction it occurred when more than one change was

happening at a display at same time or user's attention is distracted. The user had to memorize the state before the change and in comparison had to detect new state to recognize that a change had already happened [Yantis and Jonides (1984)].

In a study on visual displays for evaluating reference effects on spatial judgments and change detection on cognitive tunneling effect conducted by Klein (2007), participants were presented with a variety of tasks. In this experiment, three display conditions consisting of different frames of reference were compared. The tethered display was created as an exocentric 3-D display showing the terrain from a vertical rotation angle of 60°. The self-pan immersed display was composed of two distinct views displayed simultaneously. The auto-pan immersed display was visually identical to the immersed display suite, but the panning feature was automated. In change detection performance, the results indicated that type of change played a much more significant role than did the display condition. Object disappearances were more difficult to detect than either appearances or status changes. Despite identical views displayed, the auto-pan immersed condition participants showed significantly worse performance on the disappearances and status changes than the self-panning immersed. It was also determined that changes located in the periphery of tethered view and outside the initial FOV of immersed views were detected less often than centrally located (initial FOV) changes. This finding provides some evidence that salience of information influenced cognitive tunneling, even in static exocentric views. Computer-based questions were divided into three categories: distance judgments, direction judgments, and counts of visible enemy questions. Count of visible enemy results suggested that cognitive tunneling was in fact an issue for both immersed display conditions, illustrated by the drop in performance on PR-inset questions as compared to tethered condition's performance.

### **2.4.3 LOCATION OF SYMBOLOGY RETICLES**

Foyle *et al.* (1993); Foyle *et al.* (2001); Dowell *et al.* (2002); Crawford and Neal (2006) reported results of studies carried out to investigate effect of location of symbology

(on HUD display) on attention capture and tunneling. The study carried in simulated flight environment focused on study of effect of location of altitude symbology on HUD display on ability of pilot in following designated path. It reported that on few occasions pilots failed to attend simultaneously to both the HUD symbology information and the outside world information and after landing. Even after many trials of practice, aircrafts unexpectedly moved onto the runway from the taxiway. Pilots continued their landing as if the aircraft was not blocking the runway, suggesting that they were not able to adequately monitor forward visual scene upon which HUD symbology was superimposed. These failures occurred because HUD caused pilot's accommodation to move inwards toward the resting dark focus level away from optimal infinity focus. It was found that there is a performance trade-off between path tracking performance (an OTW) and altitude maintenance performance (HUD task). For example, superimposed HUD altitude information presented in center of the screen yielded better altitude maintenance, but with decreased OTW path performance). Without HUD digital altitude information, altitude maintenance was poor, but path following ability was improved. Failure to efficiently process superimposed HUD symbology and OTW path information was found only when these two information sources were presented visually near each other, less than  $8^\circ$  visual angle apart. When HUD symbology was more than approximately  $8^\circ$  from the OTW path information, performance trade-off was eliminated, and efficient processing of both HUD and path information was achieved.

Effects of changing location of non-conformal symbology were presented by Foyle *et al.* (1993); Dowell *et al.* (2002); Crawford and Neal (2006). They presented results of investigations carried out to study whether changing the location of non-conformal symbology alleviated cognitive tunneling effect. In an assessment of effect of positioning altitude information in three locations on HUD, investigations were made on ground path performance, altitude maintenance and concurrent processing of display and external scene. The results indicated that when altitude and path information were superimposed, participants

were unable to attend to HUD and outside world simultaneously. Furthermore, when altitude information was over the path, there was a trade-off between altitude and path performance, with an increase in altitude performance and a decrease in path performance. It had been suggested that the results may have been due to attention being focused on the altitude information and hence, the inefficient processing of the path information. When the altitude information was placed higher up in HUD, away from ground path, the trade-off was not apparent.

Results of study on attentional effects of superimposed symbology, effects of visual location of superimposed symbology on cognitive tunneling and scene linked symbology conducted by Foyle *et al.* (1993); Dowell *et al.* (2002); Crawford and Neal (2006) found no effect of contrast for both altitude and path root mean squared error dependent measures. Altitude maintenance performance without a HUD digital display (HUD absent condition) was worse than when HUD altitude information was presented in any location. When HUD altitude information was displayed in center location, path tracking performance was worse than when presented in any other HUD locations or when HUD was absent. Additionally, path tracking performance for mid-upper and lower HUD locations was equal (not significantly different) to performance when no HUD was presented (HUD absent).

Result of another study carried out by Roscoe (1987); Brickner (1989); Foyle *et al.* (2001) showed that efficient joint processing of the HUD and OTW scene only occurred when an eye movement was required. One possibility was that when HUD symbology was directly superimposed, one may not had conscious access to what was, and what was not, being attended, and this might be the source of the inefficient processing. Foyle *et al.* (1993); Foyle *et al.* (2001) discussed that on placing symbology away from OTW information, required eye movement might act as a cue by which one was made aware of this, so that more efficient processing occurred. This suggested that visual/spatial attention could not be directed to both HUD information and OTW information simultaneously when directly

superimposed. In contrast, the ability to use both, the altitude display and the OTW path information, when HUD and world information were not directly superimposed was attributed to the breaking of cognitive tunneling on HUD, possibly due to required eye movements.

The effect of symbology referenced to different surfaces were discussed by Herdman C M (2005). These experimental and neuropsychological studies showed that attention was referenced to perceptual groups or objects within the visual field. This was regarded as the object based attention hypothesis. In accordance with Gestalt principles, perceptual groupings of HUD symbology could be formed based on colour, proximity, closure, ground separation and importantly, common motion. It was suggested that coherent motion of head referenced symbols caused these symbols to be perceived as an object layer that existed separately from symbols that were aircraft referenced. Mechanisms underlying object based attention allowed head referenced layer to be perceptually differentiated from the aircraft referenced symbols and thereby efficiently tracked, apprehended and interrogated.

#### **2.4.4 SYMBOLOGY CLUTTER**

Ververs and Wickens (1998.); Houten (1999); Simons (2000); Horrey and Wickens (2004); Nikolic *et al.* (2004); Hofmann *et al.* (2008) had concluded from their studies that symbology clutter occurred when multiple information sources were displayed on the same location resulting in reduction in scanning but with increased probability of attentional tunneling. Clutter was one of the causes of cognitive tunneling and might interfere with processing of information in both the near and far-domains.

Crawford and Neal (2006) had discussed about the clutter related HUD experiments. Number of incident reports had highlighted problem of clutter. In a military incident, pilot failed to detect a barrier on a runway. It appeared that level of luminance of HUD and amount of symbology led pilot to fixate on display and, hence, missed the barrier. In a similar incident, the United Kingdom's Air Accidents Investigations concluded that pilot of a

Tornado aircraft that collided mid-air with a Cessna 152 might not have seen the Cessna due to clutter of Tornado's HUD. It was reported that "it was possible that effects of clutter in HUD reduced the probability of detection at a critical moment". May and Wickens (1995); Boston and Braun (1996) proposed that clutter could be reduced with the use of conformal displays. This helps reducing time that took for a pilot to detect an obstacle in far domain, by highlighting salient information and by reducing luminance of information that might be less important and distracting.

Calhoun *et al.* (2005) proposed use of separate displays reduces clutter on sensor imagery. They, however, also found that the scanning time involved in using a separate display was often more costly than the additional clutter imposed in overlaying synthetic vision onto existing sensor imagery display. Having information overlaid conformally on camera display might have reduced scan time, minimized division of attention and improved information retrieval, but with potential cost of additional clutter and possibility of cognitive tunnelling.

Boot *et al.* (2005) proposed mixed referencing configuration of symbology which made useful symbology visible to pilot during manoeuvres that involved looking to the side of the aircraft (e.g., during hoisting and sidestep) but without cluttering with all of the symbologies. While using HMD, a potential problem was that, depending on moment to moment positioning of head, one or more of head referenced symbols might overlap with aircraft referenced symbols which might create intolerable perceptual/cognitive confusion. That had been evaluated in HMD experiment where the symbology for rotary aircraft developed by members of the Technical Co-operation Panel-2 consisted of mixed frame of reference where symbols portraying spatial analogue information were aircraft referenced, whereas non-spatial symbols (torque, altitude and airspeed) were head referenced.

#### 2.4.5 MISACCOMMODATION

Weintraub and Ensing (1992) proposed that misaccommodation of eye occurs when focus is drawn inward by something close. That was considered to be a problem because it impaired pilot's ability to detect targets and to judge their distance and size. HUDs were collimated to provide symbology at optical infinity to overcome problem of misaccommodation.

Weintraub *et al.* (1985); Iavecchia *et al.* (1988); Duncan and Humphreys (1989); Weintraub and Ensing (1992); Newman (1995); Wickens *et al.* (2003); Wolfe and Horowitz (2004) discussed collimation w.r.t to accommodation. Collimation was intended to put HUD symbology at the same optical depth as the external world, which in principle, should assist accommodation and reduced time necessary to refocus. Collimation did not pull pilot's focus outward to optical infinity or that collimated HUDs might even exacerbate misaccommodation. It had been suggested that collimated HUDs did pull the pilot's focus outward, even if it was not always to optical infinity. High quality images, whether generated by the HUD or from the external environment, drew focus outward used a relatively poor quality HUD image superimposed over a high quality image of terrain, causing focus to be drawn inward. In contrast, it had been argued that if external image is of poor quality (e.g., because of fog or rain) high quality HUD images would actually pull pilot's focus outward, partially offsetting tendency for the resting point of accommodation to be closer than objects in external environment.

Weintraub *et al.* (1985); Roscoe (1987); Larish and Wickens (1991) had discussed effect of HUD combiner glass as a source of misaccommodation. Combiner's, its frame and lack of movement compared with external world could act as source of misaccommodation. These items might provide perceptual clues that HUD was closer than the outside scene. However, same was true of dirt, rain, and glare on the windshield. Combiner assembly's design and position was different in civilian aircrafts than in military aircraft. Effect of

Combiner frame, which was more visible in military aircraft HUDs, was more likely to cause tunneling through misaccommodation than in civilian HUDs. Though, there was currently no strong evidence available to assess whether combiner glass significantly increased risk of misaccommodation, over the risk posed by the contaminated windscreen itself as discussed by Crawford and Neal (2006).

#### **2.4.6 DETECTION OF EXPECTED AND UNEXPECTED EVENTS**

Yantis and Jonides (1984); Fadden *et al.* (1998); Prinzel and Risser (2004) had conducted various studies on detection of expected and unexpected events while using HUD. The use of HUD was associated with improved event detection for all tasks except approach and landing. In other words, it leads to improved event detection when the event was expected, but impaired event detection when the event was unexpected. Most studies presented expected events during cruise flight, and unexpected events during approach and landing, possibly accounting for differential effects of HUDs on event detection across phases of flight. Use of conformal symbology was associated with improved tracking performance and event detection for all tasks.

Fischer E (1980); Weintraub *et al.* (1985); Simons (2000); Lee *et al.* (2007) studied effects of cognitive tunneling on the detection of unexpected events. Comparison of HUDs with HDDs showed that landings were more accurate using HUDs for commercial airline pilots using a fixed base simulator. However, there was a longer response time to an aircraft that was located on duty runway which was being approached. Therefore, it was possible that superior flight performance that had previously been observed with HUDs could be attributable to the quality of instrumentation, or fact that image was collimated, rather than the position of the image. The key outcome measure was response time to detection of expected and unexpected events in external scene and on display. General flight performance, in terms of vertical and lateral tracking ability and speed and heading control, was also measured. The results showed that pilots took longer to detect unexpected events in the near

and far domain when HUD was used. On the other hand, pilots did detect expected events on their display more quickly when HUD was used.

#### **2.4.7 CONFORMAL SYMBOLOGY**

Newman (1995) had defined conformal display as one “in which the symbols appear to overlie the objects they represent”. Duncan and Humphreys (1989); Wickens (1997) discussed that overlaying of images facilitate concurrently viewing, which helped in reducing cognitive tunneling effect.

Wickens and Long (1994); Boston and Braun (1996); Martin-Emerson and Wickens (1997); Fadden *et al.* (1998); Ververs and Wickens (1998.); Steelman *et al.* (2011) proposed benefits of conformal symbology such as reduced scanning, less distracting, requiring less effort to attend to environment, faster change detection in symbology as well as traffic and increased flight path tracking accuracy. Yantis and Jonides (1984) studied pilot’s performance and detection of events in case of employing conformal and non-conformal symbology. The study was performed with HUD and HDD employing flight performance measures. It was observed that benefits control was better for HUD condition with conformal symbology. This response was slower in case of HUD use with far domain. Conformal symbology reduced cognitive tunneling and pilot was able to switch his attention between HUD symbology and the outside world.

Foyle *et al.* (1995); Gish and Staplin (1995) investigated pilot’s taxiing performance, SA and workload while taxiing with three different HUD symbology formats: command-guidance, situation-guidance and hybrid. It was observed that cognitive tunneling was induced by command guidance symbology which was non-conformal symbology. Conformal route information of situation guidance and hybrid HUD formats provided a common reference with the environment, which might had provided better distribution of attention.

Results confirmed the hypothesis that pilots taxiing with situation guidance and hybrid symbology showed increased SA, increased taxi speeds and decreased workload. The

hybrid format produced most accurate centreline tracking in straight segments, and equal to that of the situation-guidance format in turns. Command guidance format produced worst centreline tracking performance. Hybrid symbology, combining conformal route information with a command guidance cue, produced best overall centreline tracking accuracy. Taxi performance measures were mostly consistent with workload and SA measures. Both taxi speed and accuracy were generally better with situation guidance and hybrid symbology than with command guidance symbology. This was seen in both subjective SA ratings and objective detection of unexpected OTW events. When non-conformal representations were used (i.e., the command guidance format), objective and subjective SA were decreased. Pilots taxiing using only the command guidance tracking cue may have experienced cognitive tunneling due to the non-conformal nature of HUD symbology. Constant corrective action to maintain centreline position required by control commands of command guidance tracking cue, produced increased workload and increased centreline deviation. This, coupled with non-conformal nature of command guidance tracking cue, might have induced cognitive tunneling. In contrast, conformal route information provided optical flow cues, left error judgment and subsequent control decisions to the pilot, perhaps allowing for increased division of attention and reduced workload.

#### **2.4.8 LUMINANCE AND CONTRAST RATIO**

May and Wickens (1995); Verver and Wickens (1996) discussed role of symbology intensity on event detection. Display or symbology luminance and hence CR played a crucial role in performance enhancement of HUD. When CR of HUD symbology was same as that of HDD, detection of events in both near and far domain was superior to HUD condition. Low lighting the additional information, however, provided pilots with a sense of what was important on the display and distraction from far domain elements was less likely. Results from this study suggested that putting symbology into an appropriate location on the HUD, and ensuring an appropriate level of symbology intensity as well as contrast with the

environment, improved HUD performance. However, both studies described reflected results for cruise flight and not the landing phase. Therefore, these results might not generalize to other phases of flight.

Houten (1999) proposed that tunnel-in-the-sky with a deviating colour could improve flight path control, but there was a serious risk that it attracted too much attention, leading to inefficient attention switching strategies when other tasks were involved. The study focused on attentional phenomena in situations where both flight path tracking and instrument information were superimposed on the OTW scene. It showed that accuracy of flying through tunnel was higher when tunnel colour deviated from the instrument symbology colour, especially when workload was high. It might be due to the reason that it was easier to attend guidance task because tunnel could be more easily distinguished from environment. When same colour was used for instrument and tunnel-in-the-sky symbology, it might be possible that (in terms of object based theories of attention) users were forced into one object. At the same time, other characteristics (especially movement) were forcing two objects to appear. This un-restfulness might be prevented by a deviating colour. However, there was a risk that tunnel-in-the-sky in a deviating colour might actually become too compelling, with increased risk of attentional tunneling.

Attention capture can be improved by means of salience imparted in displays through momentary flashing of the desired information to make user notice important events [Nikolic *et al.* (2004)].

#### **2.4.9 SPATIAL DISORIENTATION**

It was reported by Newman (1980); Zenyuh *et al.* (1987); Zuschlag (2003) that HUD was associated with an increased risk of spatial disorientation. Use of HUDs in IMC had raised concerns that they might contribute to spatial disorientation. Early HUDs were designed to be used as gun sights and not as a PFD. Their symbology might not have been adequate to support the pilot in IMC. This would be particularly important for recovery from

unusual attitudes. Changes to the symbology, including use of compression pitch ladder, appeared to have alleviated the problems. Change in focus from HUD to external world produced spatial disorientation. It had been argued that distance of HUD should be at least that of conventional HDD, so change in accommodation from the HUD to the external world should not cause spatial disorientation. Modern HUDs did not cause spatial disorientation and their advantages far outweigh any such disadvantage. It had been reported that there were eight HUD characteristics like clutter, framing, and accommodation traps, poor upright compared with inverted cues, digital data and rate information, full scale pitch angles, pitch ladder and velocity vector control that might produce difficulty in interpreting orientation cues.

#### **2.4.10 FIELD OF VIEW (FOV) OF HUD**

Beringer and Ball (2001); Crawford and Neal (2006) discussed tunneling aspects w.r.t HUD FOV. Limited TFOV and IFOV in azimuth and elevation limit the presentation of symbology (e.g., traffic) which might contribute to attentional narrowing. FOV is governed by the cockpit geometry and application. TFOV is defined for head movement within the HMB, the total movement distance is generally 130 mm. IFOV is defined for angle of view seen from two points separated by a distance of 65 mm. This distance corresponds to average distance between the two eyes. Thus, pilot has limited FOV to look through HUD to gather outside scene as well as the symbology. This limitation, in a way, forces pilot to look through a tunnel. Both these parameters restricts the efficacy of conformal symbology as outside world onto which HUD symbology is superimposed and must be limited within this small angular window. Further, smaller FOV also restricts amount of data that can be shown at one time. More data/information displayed on HUD may result in visual clutter degrading view of external targets. Combiner frame further complicates the issue of limited FOV [Billingsley *et al.* (1999)].

Viewing within a small angular window limits pilot's capability to gather information from the outside scene beyond the HUD combiners. Further, combiner frame obstructs pilot's forward view. HUD CCD camera used to capture HUD image also contributes in adding obstruction and limiting IFOV.

## **2.5 MEASURES TAKEN SO FAR FOR MINIMIZING ATTENTION CAPTURE AND TUNNELING**

Yantis and Jonides (1984); Foyle *et al.* (1995); Levy *et al.* (1998); Stuart *et al.* (2001); Prinzel and Risser (2004) discussed attention capture optimization measures like superimposed and scene linked symbology, use of peripheral symbology, synthetic vision, use of few prevention technologies and more practice of using HUD and actual flight scenario to minimize attention capture due to HUD use. Problem of attention capture had been often attributed in many researches to near and far domain perceptual grouping, it had been suggested that scene linked symbology might be a potential solution to the problem. Scene linked symbology was projected at a specific location in the scene such that it appeared to move with the scene allowing it to undergo same optical transformations as far domain objects. It essentially made symbology appear as a real world object itself. It had also been suggested that scene-linking only encouraged a partial division of attention between altitude gauges and the far domain. It yielded a more efficient serial extraction of path related and altitude related information than in the superimposed condition. The scene linking produced a complete division of attention, enabling fully parallel perceptual processing of task relevant information in scene linked symbols and far domain or processing. It also supported a cognitive integration of the two tasks so that they became, in effect, one task rather than two.

Stuart *et al.* (2001); Prinzel and Risser (2004) explained peripheral symbology as perception segmented into separate perceptual modes. Peripheral symbology could ease concurrent attention directed to visual and auditory modes or, within vision, to foveal and

peripheral vision. Because of the significant number of auditory alarms and annunciations, latter might offer a possible avenue for reducing clutter and enhancing event detection.

Jones *et al.* (2001) reported another solution in form of runway incursion prevention technologies, such as NASA's runway incursion prevention system (RIPS), which alerted pilot of other aircraft that presented a danger while on approach. The NASA's RIPS technology was developed to reduce the number of runway incursions. RIPS integrated airborne and ground based technologies, which included flight deck displays, incursion alerting algorithms, on-board position determination systems, airport surveillance systems, and controller-pilot data link communications.

Prinzel *et al.* (2002) discussed NASA's SVS to enhance pilot's SA through synthetic display. SVS display would significantly augment hazard avoidance, including cooperative and uncooperative traffic, terrain, wildlife on runways and taxiways, weather and cultural features. It would present these hazards on HUD thereby minimizing the chance that pilot might not perceive them in far domain. A pilot would be able to de-clutter HUD and removed synthetic terrain and/or symbology thereby allowing him or her to better acquire the hazard in the real world. By alerting pilot to potential threats in near domain, it reduced potential that attention capture, if it occurred, would result in not detecting important events in far domain perceptual field.

Fischer E (1980); Stuart *et al.* (2001) suggested that training could of great help in reducing effects of attention capture through improvements human factors problems like detection of far domain events, detection of unexpected events, awareness of non-redundancy of the environment, etc.

## **2.6 SUMMARY**

This chapter discussed a range of issues of attention capture and tunneling related to HUD applications. Comprehensive literature survey was made on HUD and similar technologies for aviation and automobiles and prevalence of the phenomenon of attention

capture, tunneling and the associated safety issues. It was evident that there were a number of advantages in using HUDs, which included increase in flight path tracking accuracy, except during cruise flight; benefits for event detection, except in the approach and landing phase and for unexpected events; lower visibility take-off and landing; more accurate approach and landing; the elimination of head-down time; a reduction in the time taken to refocus between instruments and the external scene; and the potential to use overlaid symbology for the external scene when it was not visible, raster display during low light condition flights, and hence enhancing situation awareness.

Its negative sides were problems in switching attention between the internal and external scene and difficulties in detecting unexpected events. There were models of attention like selective attention, focused attention and divided attention; and governing theories of attention capture like top-down/bottom-up processing; space and object based theories; and far and near domain perceptual processing. Potential factors like information and work overload, failure to notice sudden changes or change blindness, location of symbology reticles, symbology clutter, misaccommodation, detection of expected and unexpected events, non-conformal symbology, luminance and CR, spatial disorientation, HUD FOV, etc. contribute in some way or the other in the attention capture and tunneling phenomenon. However, few measures like scene linked symbology, training, peripheral displays, prevention technologies and synthetic vision, as well as minimizing clutter help in minimizing the effects of attention capture.

# TECHNICAL ASPECTS OF HUD LEADING TO THE PROBLEM OF TUNNELING

Literature had reported various factors contributing in causing attention tunneling such as clutter, information and work overload, misaccommodation, misconvergence, symbol location and clutter, symbol format and salience, limited FOV and few others. However, such studies addressed only a single parameter at a time.

In this work, study of the effect of ambient luminance, symbology luminance, HUD symbology luminance non-uniformity and limiting FOV due to beam combiners, over attention tunneling is reported. Participant responses were recorded for varying AL, SL and NU conditions. These responses were further mathematically worked out to generate HUD and outside events detection datasets which also helped in accomplishment of the third objective.

### 3.1 THEORY

#### 3.1.1 HUD RELATED FACTORS AFFECTING ATTENTION TUNNELING

##### 3.1.1.1 Role of Combiner Frame in Tunneled Vision

The combiner is situated in front of pilot with image formed on it focused at infinity. Combiner may consist of single glass or a pair of glasses depending on vertical field requirement. Use of dual combiner glasses results in larger vertical field [Gish and Staplin (1995); Calhoun (2000); Micheal *et al.* (2000); Sebastian Klepper (2007)].

Typical IFOV of an aircraft HUD is  $22^\circ$  (azimuth)  $\times$   $20^\circ$  (elevation) depending on application. Further, TFOV may also vary from  $24^\circ$  to  $30^\circ$ . Both these parameters restrict the efficacy of conformal symbology as outside world onto which HUD symbology is

superimposed must be limited within this small angular window. Further, smaller FOV also restricts amount of data that can be shown at one time. More data/information displayed on HUD may result in visual clutter degrading view of external targets. Combiner frame further complicates the issue of limited FOV [Billingsley *et al.* (1999)].

The combiner frame thickness tends to result in misaccommodation which refers to inability of eyes to focus properly on an object. It also means the inability of eyes to relax or to stimulate accommodation maintaining clear and single binocular vision [Bhola (2006)].

Combiner glass, its mounting frame and its lack of movement compared with the outside world, are considered to be a source of misaccommodation. It may provide perceptual indications that HUD and hence the image displayed on it is closer than the outside scene. Combiner edges can be eliminated by using the aircraft windshield as combiner. Though, even when combiner edges are absent, HUD can still impart trap accommodation as the virtual image distances may look closer to average latent position of accommodation [Mandelbaum (1960); Wickens and Alexander (2009)].

Pilot's response is also significantly affected by vergence phenomenon. It refers to simultaneous movement of both eyes in opposite directions to obtain single binocular vision. Combiner frame thickness and tunneled section may cause changing focus of eyes to look at an object at a different distance, which will automatically cause vergence and accommodation, though vergence movements are far slower [Mandelbaum (1960); Goteman *et al.* (2007)]. Thus, HUD, due to its property of collimation and misaccommodation due combiner frame, tends to result in size misjudgement [Beringer and Ball (2001); Lawson *et al.* (2011)].

When inserted objects are located at different distances, objects situated closer to pilot's latent focus are likely to control the accommodative response. This implies that convergence-accommodation trap may be experienced by pilot as combiner edges will have the tendency to draw accommodation. It will result in decreased resolution for both, HUD

image as well as outside world. This happens as virtual image projected by HUD is in focus beyond the distance of combiner.

Edges of combiner can also cause misconvergence, or in other words, proximal vergence, in addition to misaccommodation. The resultant vergence response due to combiner edges can affect size perception, though at quite low level [Weintraub and Ensing (1992); Beringer and Ball (2001); Lawson *et al.* (2011)]. High workload flight conditions causes increased cognitive load on pilot and reduced useful FOV. Poor climatic conditions add to complexities that will result in increased attention and consequently efforts required to be allocated for completing the mission.

### **3.1.1.2 Relevance of HUD Image luminance, Contrast and Non-Uniform Luminance on Attention Capture and Tunneling**

HUD functionality is defined in two modes namely day and night modes corresponding to pure stroke mode of symbology and stroke in raster vertical flyback mode respectively. Stroke mode symbology is utilized during day mode operation for obtaining maximum luminance with dynamic contrast range. The absolute luminance range on display device is usually four orders of magnitude, i.e., 10,000:1, to span AL conditions ranging from bright sunlight to very low light conditions. Factors affecting visibility of HUD display as well as the outside scene on and through combiners are SL corresponding to the display symbology, Forward looking infrared camera (FLIR) videos or the outside view reflected or passed from the BC, sunlight and skylight scattered diffusely from the screen that combines with HUD image and lowers feature contrast, sunlight and skylight reflected from outer glass surfaces that causes shine reducing contrast further, and ambient light that decides adjustment of pilot's eye.

SL needed for adequate contrast against background lighting through combiner glasses is one of the main factors that affect HUD image readability. Literature suggests that an image contrast of at least 20% contrast is required to see image even against bright clouds.

The intra-ocular glare can reduce apparent contrast of HUD imagery substantially when background is very bright occurring in clear air and when flying towards the sun or when the sun is within about 30° of the aircraft nose. On the other hand, during night or twilight conditions, luminance of the display must be reduced considerably to let pilot maintain a minimum photopic adjustment.

Display, ambient and the relative luminance between the two contributes significantly in affecting the perception of image presented on a HUD during daylight. Although eye acclimatizes to luminance of HUD display, a brighter skylight can have an overriding effect. Range of luminance variations that carry display information must fall within distinctive dynamic range of spatial luminance variations that pilot can differentiate, i.e., between subjective black and subjective white which is dictated by combination of ambient and the display field.

Luminance non-uniformity (NU) of HUD display occurs due to several factors namely non-uniformity of CRT phosphor, improper functioning of video and blanking section, improper coating on HUD folding mirror responsible for folding the CRT image towards the BC, improper coating on the BC glasses resulting in non-uniform and wavelength variable reflections and improper overlapping of primary and secondary BC glasses [Jukes (2004); Moir *et al.* (2007)].

### **3.1.2 STATISTICAL ANALYSIS**

Statistics is the study of collection, organization, analysis, interpretation and presentation of data [Dodge (2003)]. Statistics have been actively used by the researchers in extracting meaningful information from huge/small piles of data generated during the course of experimentation. It is a branch of mathematics used for sorting, analysing, reducing redundancy and interpreting the data. Statistic tools along with other soft computing methods have also been used successfully for solving complex problems as well [Macas *et al.* (2012)]. Field of statistics is so vast that there are dedicated software tools available like Unscrambler,

Minitab, MATLAB – statistics toolbox, etc. In addition, many other open source statistical packages are also available.

In this chapter, statistical tools, which have been employed for data mining in the thesis work, are discussed to present a flavour of the basic functioning of these methods. The methods used basically relate to inferential statistics domains which have majorly been employed for testing of hypotheses in the present work.

### **3.1.2.1 t-test**

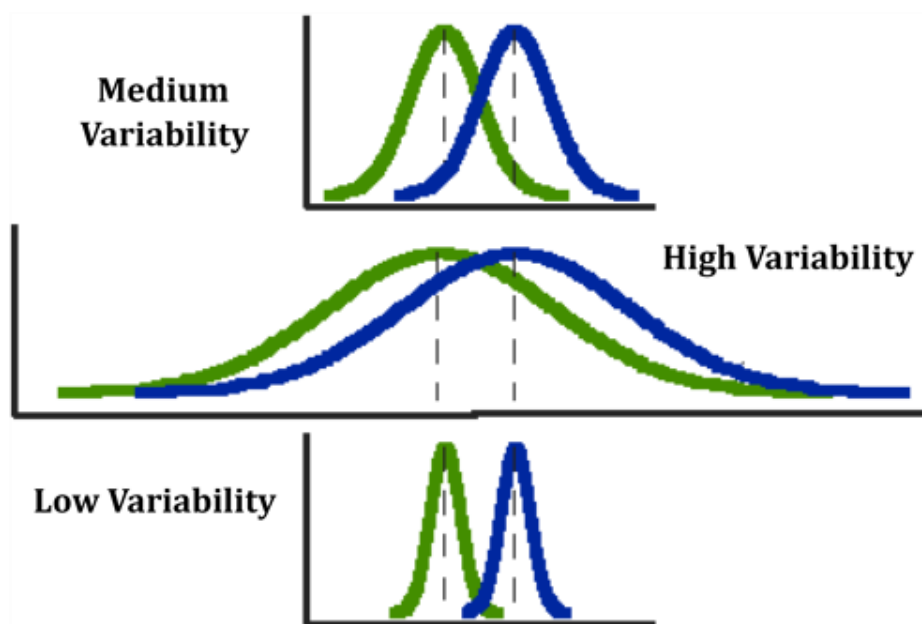
The t-test is one of the tests for validating statistical significance, which is used to estimate probability that a relationship observed in the data occurred only by chance; probability that the variables are really unrelated in the population. The t-test evaluates whether the means of two groups are statistically different from each other. A t-test's statistical significance specifies whether or not the difference between two groups' means most likely reveals a 'real' difference in the population from which the groups were sampled.

The t-tests can be used in following types of statistical tests:

- To test whether there are differences between two groups on the same variable, based on the mean (average) value of that variable for each group; for example, do scholars at private colleges score higher on the CAT test than scholars at public colleges?
- To test whether a group's mean (average) value is greater or less than some standard; for example, is the average speed of motorbikes on expressways in Chandigarh higher than 70 Kmph?
- To test whether the same group has different mean (average) scores on different variables; for example, are the same clerks more productive on manual writing or computer typing?

To understand what it actually mean when one says that averages for two groups are statistically different, let's consider three situations shown in Fig. 3.1. It can be observed that

difference between means is the same in all three cases. But, it should also be noticed that three cases don't appear to be same, they seem to be very different. The top example shows a case with moderate variability of scores within each group. The second case displays the high variability situation. The third shows the situation with low variability. Clearly, it can be concluded that the two groups appear most different or distinct in the bottom or low variability case, as there is comparatively less overlap between the two bell-shaped curves. In the high variability case, difference between the groups seems least prominent because the two bell-shaped distributions overlap so much. This leads to a very important conclusion: while considering at the difference between scores for two groups, one should also observe the difference between their means relative to the spread or variability of the data. The t-test exactly performs the same task.



**FIGURE 3.1 DIFFERENT SCENARIOS FOR VARIABLE MEANS**

### **3.1.2.2 Unpaired and Paired Two-Sample T-Tests**

#### **3.1.2.2.1 Independent (unpaired) samples**

A t-test is based on the assumption: individual measurements are independent of each other; each of the two groups being compared has a Gaussian distribution and standard deviation of groups may be equal or unequal.

Independent or unpaired samples t-test is used when two distinct sets of independent and identically distributed samples are obtained, one from each of the two populations being compared.

The test static for independent samples is calculated as a ratio, numerator of which is just the difference between two means or averages while denominator is a measure of variability or dispersion of scores. This formula is similar to the signal-to-noise ratio in electronics: difference between means is the signal i.e. program or treatment introduced into the data; denominator of the formula is a measure of variability which is the noise that may make it harder to see the group difference.

$$t - value = \frac{\text{difference between group means}}{\text{variability of groups}} = \frac{\text{signal}}{\text{noise}}$$

$$= \frac{\bar{X}_1 - \bar{X}_2}{SE(\bar{X}_1 - \bar{X}_2)} \quad (3.1)$$

Numerator of formula is easy to calculate i.e. difference between the means. Denominator is known as standard error (SE) of the difference. To calculate it, variance for each group is taken and divided by the number of samples in that group. Then the two are added and square root is taken.

$$SE(\bar{X}_1 - \bar{X}_2) = \sqrt{\frac{Var_1}{n_1} + \frac{Var_2}{n_2}} \quad (3.2)$$

Final formula for independent t-test is:

$$t - value = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{Var_1}{n_1} + \frac{Var_2}{n_2}}} \quad (3.3)$$

Degree of freedom for unpaired t-test is computed by adding up the number of observations for each group, and then subtracting the number two (because there are two groups).

### 3.1.2.2.2 Paired samples

Paired samples t-tests usually comprise of a sample of matched pairs of similar units, or one group of units that has been tested twice (a "repeated measures" t-test). A paired t-test measures whether means from a within subjects test group vary over 2 test conditions. The paired t-test is normally used to compare a sample group's scores before and after an intrusion. The test static for paired t-test is:

$$t - value = \frac{\overline{X_D} - \mu_0}{\frac{S_D}{\sqrt{n}}} \quad (3.4)$$

where  $\overline{X_D}$  is the mean of difference between pairs,  $S_D$  is standard deviation of the differences,  $n$  is the sample size, and constant  $\mu_0$  is non-zero if one wants to test whether average of the difference is significantly different from  $\mu_0$ . The degree of freedom used is  $n-1$ .

If computed t-value equals or exceeds the value of t indicated in t-distribution table, then it can be concluded that there is a statistically significant probability that the relationship between two variables exists and is not due to chance, and reject the null hypothesis.

While using MATLAB to perform paired t-test, two data vectors are 'x' and 'y' can be analysed using the command:

$$(h, p) = ttest2(x, y) \quad (3.5)$$

Above command performs a t-test of the null hypothesis that vectors x and y are independent random samples from normal distributions with equal means and unknown variances. This is with the alternate assumption that means are not equal. The tests result  $h = 1$  indicates a rejection of null hypothesis at 5% significance level while  $h = 0$  indicates a failure to reject null hypothesis at 5% significance level. The p value refers to the probability of observing a value as extreme/more extreme of the test statistics under assumption of null hypothesis.

### 3.1.2.3 Analysis of Variance (ANOVA)

Analysis of variance (ANOVA) is a collection of statistical models used to analyze the differences between group means and their associated procedures (such as "variation" among and between groups). In ANOVA setting, the observed variance in a particular variable is partitioned into components attributable to different sources of variation. In its simplest form, ANOVA provides a statistical test of whether or not the means of several groups are equal, and therefore generalizes t-test to more than two groups. Doing multiple two-sample t-tests would result in an increased chance of committing a type-I error. For this reason, ANOVAs are useful in comparing (testing) three or more means (groups or variables) for statistical significance.

ANOVA is a particular form of statistical hypothesis testing heavily used in analysis of experimental data. A statistical hypothesis test is a method of making decisions using data. A test result (calculated from the null hypothesis and the sample) is called statistically significant if it is deemed unlikely to have occurred by chance, assuming truth of the null hypothesis. A statistically significant result (when a probability (p-value) less than a threshold (significance level), justifies rejection of the null hypothesis. In typical application of ANOVA, the null hypothesis means that all groups are simply random samples of the same population. This implies that all treatments have the same effect (perhaps none). Rejecting the null hypothesis implies that different treatments result in altered effects.

Multivariate analysis of variance (MANOVA) is a statistical test procedure for comparing multivariate (population) means of several groups. Unlike ANOVA, it uses variance-covariance between variables in testing statistical significance of mean differences. It is a generalized form of univariate analysis of variance. It is used when there are two or more dependent variables. It helps to answer: 1) Do changes in the independent variable(s) have significant effects on the dependent variables? 2) What are the interactions among the dependent variables? and, 3) What are the interactions among the independent variables?

Statistical reports, however, will provide individual p-values for each dependent variable, indicating whether differences and interactions are statistically significant.

Use of ANOVA to study the effects of multiple factors has a complication. In a 3-way ANOVA with factors x, y and z, the ANOVA model includes terms for main effects (x, y, z) and terms for interactions (xy, xz, yz, xyz). All terms require hypothesis tests. The proliferation of interaction terms increases the risk that some hypothesis test will produce a false positive by chance. The ability to detect interactions is a major advantage of multiple factor ANOVA. Testing one factor at a time hides interactions, but produces apparently inconsistent experimental results.

## **3.2 EXPERIMENT**

### **3.2.1 STUDYING EFFECTS OF LIMITING FOV DUE TO HUD BEAM COMBINER FRAME**

In this experiment, effect of obstruction due to combiner frame in form of misaccommodation, misconvergence and limited horizontal FOV on attention capture of aircraft pilot were studied. While combiner frame is necessary to hold wavelength selective glasses, they provide obscuration in front view of pilot in both, TFOV as well as in IFOV. The angle of combiner frame structure and its width present different degrees of obscuration to pilot within head motion box (HMB). These limitations make pilot compromise simultaneous attention on outside events and aircraft events as he/she has to adjust his/her head position to view obscured part of outside world.

To validate above arguments, experiments were carried out by varying clear visible area through combiner frame used to hold wavelength selective glasses. Combiner uses a frame structure whose shape, size and thickness is decided based on size, weight and angle of combiner glasses mount. It is also dependent on severity levels of mechanical shock, which it is expected to experience during the course of its service life. To investigate the effect of

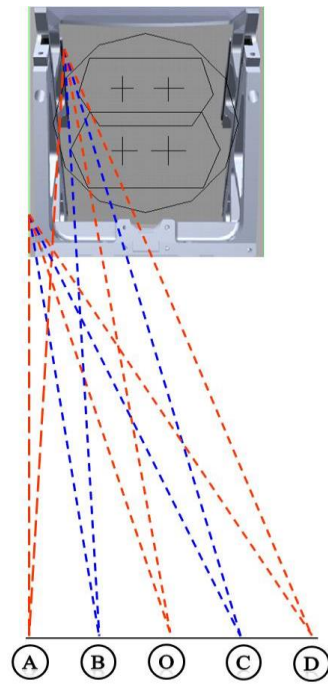
‘tunnel-vision’ due to combiner frame thickness and angle, its frame-work was modelled in three different configurations.

In the first configuration, combiner frame was provided an angle from front to the back section of frame. Idea was to simulate tunnel vision due to combiner frame. It also simulated the effect of thickness of frame structure visible from the front view of pilot in restricting useful FOV available to pilot, resultant misaccommodation and misconvergence. In the other two configurations, angle of the combiner frame was optimized and its thickness was varied to simulate obscuration.

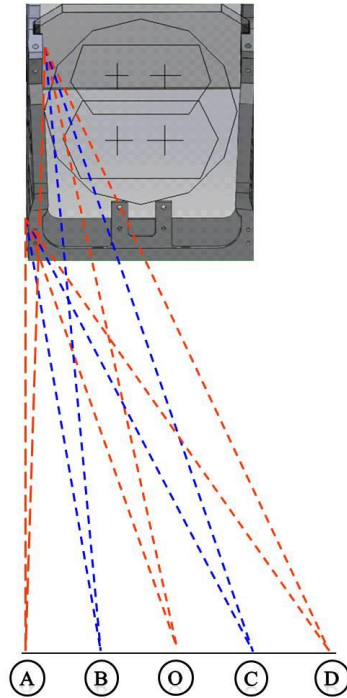
### **3.2.1.1 Results and Discussion**

Configuration-I shown in Fig. 3.2 illustrates obscuration in outside world due to angled combiner frame when viewed from locations within the HMB. In configuration-II as shown in Fig. 3.3, combiner frame was angled outwards such that its edges were seen as single line from design eye position (DEP) minimizing obscuration and hence tunneled vision was reduced. In this case, thickness of frame was kept at 11mm. Hence, obscuration was much lesser as compared to configuration-I.

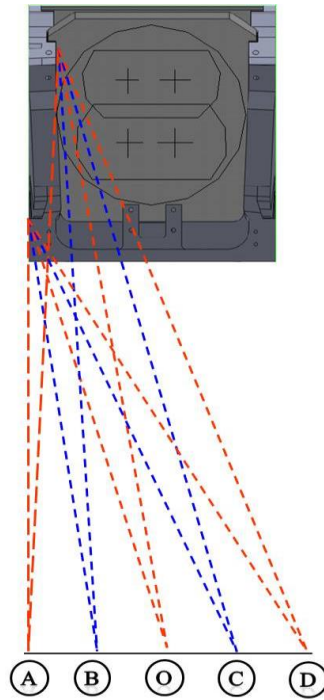
In configuration-III (shown in Fig. 3.4), condition of configuration-II was simulated but with slight variation. Thickness of frame was made 21mm, which may be required when combiner glasses are bigger. Thus, in configuration-III, obscuration in term of angles from different locations within HMB was less compared to that observed for configuration-I but more than observed for configuration-II. These configurations were experimented through simulations, which were subsequently translated into hardware to carry out actual measurements. Simulation results were correlated and validated with the experimental results.



**FIGURE 3.2 CONFIGURATION-I: HUD COMBINER WITH OBSCURATION IN OUTSIDE WORLD FROM LOCATIONS WITHIN THE HMB DUE TO INAPPROPRIATELY ANGLED FRAME VIEW**



**FIGURE 3.3 CONFIGURATION-II: HUD COMBINER WITH APPROPRIATELY ANGLED FRAME WITH REDUCED OBSCURATION IN OUTSIDE WORLD VIEW**



**FIGURE 3.4 CONFIGURATION-III: HUD COMBINER WITH APPROPRIATELY ANGLED FRAME BUT INCREASED COMBINER FRAME THICKNESS RESULTING IN INCREASED OBSCURATION IN OUTSIDE WORLD VIEW AS COMPARED TO CONFIGURATION-II**

Simulation results in terms of obscuration due to combiner frame and clear FOV of outside world for head positions within the HMB are shown in Table 3.1. Most important point to note here is that IFOV and TFOV for symbology on HUD was as per the designed value. This was because of fact that combiner glasses reflecting display source image presented full face to source light rays as well as to the pilot's eyes within HMB. However, same was not true with IFOV and TFOV parameters when defined for outside world view through combiner as shown through configurations I, II and III. In configuration-I, angled frame presented lesser outside world FOV both, in IFOV as well as in TFOV. However, FOV for outside world through combiner glasses in configurations II and III were same. In configuration-III, extra thickness of 10 mm from the configuration-II was towards the outer area. Thus, it did not affect clear view through combiner glasses. However, as thickness in configuration-III was more towards outside, there was more obscuration in the outside world outside the periphery of combiner glasses.

Combiner frame angle/slant and thickness of frame block outside world view seen by pilot from head positions within HMB. This resulted in limiting of IFOV and TFOV for outside world as seen by pilot for locations within the HMB. As shown in Table 3.2, configuration-I had lesser IFOV and TFOV values for outside world as compared to configuration-II. This was because of lesser obscuration due to combiner frame in configuration-II. Frame thickness difference for configurations II and III was 10 mm. It resulted in more obscuration in outside world for FOV falling outside combiner glasses area for configuration-III. The IFOV is generally defined for points located 65 mm apart corresponding to average distance between the centre of two eyes while TFOV is defined for total movement of eyes within the HMB, i.e., 130 mm for this case. Angle from point A to the right side obscuration edges of combiner frame is equal to the angle from point D to the left side obscuration edges of combiner frame. Similarly, the angle from point B to the right side obscuration edges of combiner frame is equal to the angle from point C to the left side obscuration edges of combiner frame.

The obscuration values in angle are shown for left side of the combiner frame only as right side of the frame is symmetrical to its left side. All measurements shown in Table 3.1 are relative measurements and are meant to show the effect due to beam combiner frame obscuration.

The results shown in Table 3.1 suggest that combiner frame obscure outside world view as apparent from angles shown from five different locations in horizontal positions in HMB along DEP. Obscuration is nothing but hindrance in viewing outside world. This is corroborated by measurement results as shown in Table 3.2. The obscuration due to combiner frame had limited the IFOV and TFOV values. This implies that pilot would not be able to view outside world scene without moving his head in horizontal direction, which otherwise he/she would have seen as also implied by the definition of IFOV. This also meant that pilot would be required to move his head more than the HMB limits to have required TFOV to

view the outside world. Though in all three configurations, symbology IFOV and TFOV was not affected. Thus, we see that though the system was designed for IFOV (Azimuth) and TFOV of 22° and 27° for both outside world as well as the symbology, but due to combiner frame obstruction, effective instantaneous (azimuth) and total FOV were reduced significantly.

Fig. 3.5 shows HUD combiner frame structure for holding single combiner glass with obscuration due to combiner frame angle, resulting in limited IFOV and TFOV for outside world view through combiner frame.

**TABLE 3.1 OBSCURATION DUE TO COMBINER FRAME TO CLEAR FOV OF OUTSIDE WORLD VIEW FOR HEAD POSITIONS WITHIN HMB (AT DISTANCE OF 410 mm FROM FRONT SECTION OF COMBINER FRAME)**

<b>Obscuration due to combiner frame*</b>	<b>I</b>	<b>II</b>	<b>III</b>
<b>Combiner frame Configuration</b>			
Angle of maximum obscuration from 65 mm left of DEP: $\angle A$	4.3°	3°	6.7°
Angle of maximum obscuration from 32.5 mm left of DEP: $\angle B$	7.3°	6.3°	9.9°
Angle of maximum obscuration from centre, i.e., DEP: $\angle O$	10.7°	9°	12.6°
Angle of maximum obscuration from 32.5 mm right of DEP: $\angle C$	12.3°	11.6°	16.24°
Angle of maximum obscuration from 65 mm right of DEP: $\angle D$	14.2°	13.5°	18.9°
Clear outside world through combiner frame	103 mm	142.4 mm	142.4 mm
Obscuration due to the combiner frame on either side	31 mm	11.3 mm	21 mm
IFOV - Outside scene (from DEP point) = angle subtended from the internal sides of the frame to the 32.5 mm left and 32.5 mm right around DEP point	19.7°	22.1°	22.1°

**TABLE 3.2 MEASUREMENT MADE WITH THEODOLITE FOR IFOV AND TFOV VALUES FOR OUTSIDE WORLD VIEW AS WELL AS FOR SYMBOLOGY THROUGH/ON COMBINER RESPECTIVELY (FROM LOCATIONS WITHIN HMB)**

	<b>I</b>	<b>II</b>	<b>III</b>
Effective IFOV (Azimuth) for outside world	19.8°	22.2°	22.2°
Effective TFOV for outside world	25.8°	27.4°	27.4°
Effective IFOV (Azimuth) for HUD symbology	22.1°	22.0°	22.1°
Effective TFOV for HUD symbology	27.4°	27.4°	27.4°
*Extra movement required to see missed outside information in IFOV (Azimuth) outside the combiner glass area	18 mm	6 mm	23 mm
Extra movement required to see missed outside information in TFOV outside the combiner glass area	22 mm	8 mm	27 mm
*Extra movement required to see outside world view beyond combiner frame edges			



**FIGURE 3.5 HUD COMBINER FRAME STRUCTURE WITH OBSCURATION DUE TO COMBINER FRAME ANGLE, DEMONSTRATING RESTRICTION OF IFOV AND TFOV**

Figure 3.6 demonstrates that combiner frame structure with less obscuration realized through appropriately angled frame structure for holding single combiner glass minimized

restriction in IFOV and TFOV for outside world view through combiner frame. It was also observed that objects in form of aircrafts (left and right bottom) in outside world were partially visible, as shown in Fig. 3.5 while they were fully visible, as shown in Fig. 3.6. This clearly shows outside events being missed which would make pilot to put extra efforts to channelize his attention to view aircraft and outside events appropriately. Thus, it was observed that combiner frame provided obstructions for both conditions, for frame meant to hold single combiner glass and also for frame meant to hold dual combiner glasses, though for dual beam combiner frame structure, obstruction was more.

To verify above observations, experiments were conducted with 10 participants with equal numbers of male and female participants. Experiments involved HUD unit driven by signal simulator generating customized symbology for testing with different sets of combiners corresponding to configurations I, II and III. Background scene was continuously varied to examine tunneling effect arising due to combiner frame structure, size and shape.

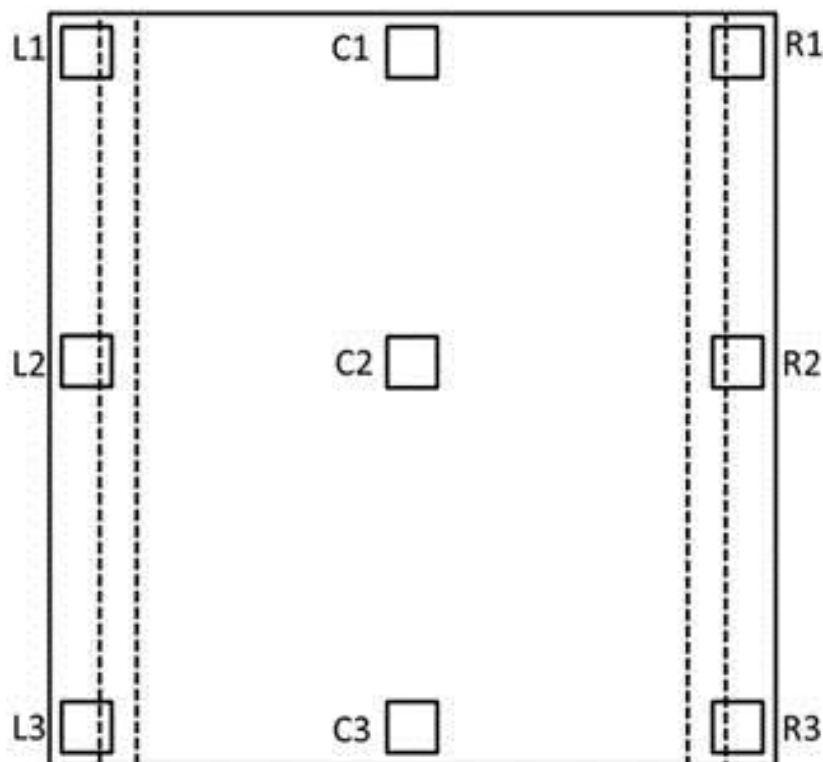


**FIGURE 3.6 HUD COMBINER FRAME STRUCTURE WITH LESS OBSCURATION DUE TO APPROPRIATELY ANGLED FRAME RESULTING IN REDUCTION OF RESTRICTION IN IFOV AND TFOV**

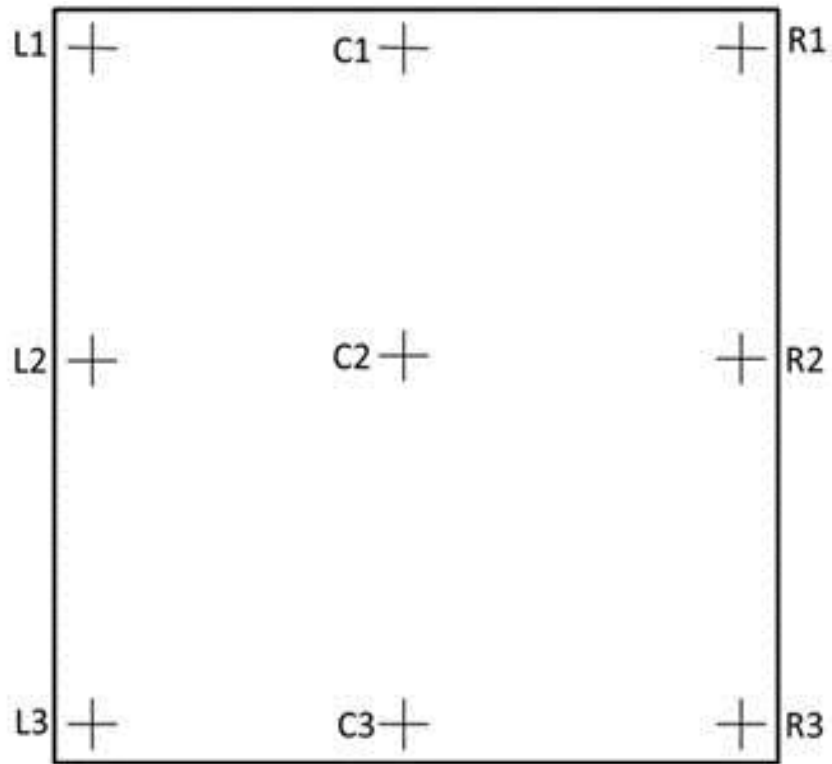
Symbology used for experiment was non-standard as the goal was to find the extent of tunneling due to combiner frame obscuration. Examples of objects inserted in the HUD symbology for experimentation are shown in Fig. 3.8 and Fig. 3.10. Total 10 such sets were

used in the experiment. Examples of objects inserted in outside scene for experimentation are shown in Fig. 3.7 and Fig 3.9, where vertical dashed lines represent inner and outer edges of beam combiner frame. Total 10 such sets were used in the experiment. Shapes of objects used in HUD symbology as well as in outside world scene were kept simple for easy judgment by participants. The experiment was conducted at ambient luminance of  $1000 \text{ cd/m}^2$  and symbology luminance was kept at  $2000 \text{ cd/m}^2$ .

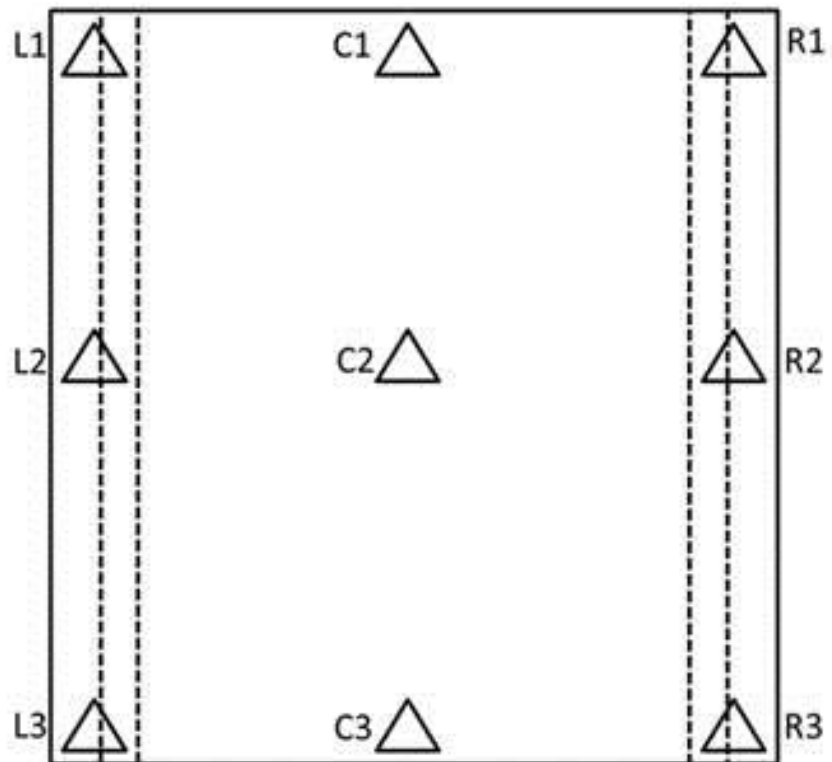
Results based on responses from participants were plotted and shown in Fig. 3.11 and Fig 3.12. Figure 3.11 suggests that combiner frame thickness did not affect events detection seen on HUD symbology. At centre locations corresponding to C1, C2 and C3, event detection on HUD symbology was close to 90% irrespective of the combiner frame structure, shape and size. On similar lines, outside event detection at centre locations of C1, C2 and C3 was on higher side ranging 93-94% as shown in Fig. 3.12.



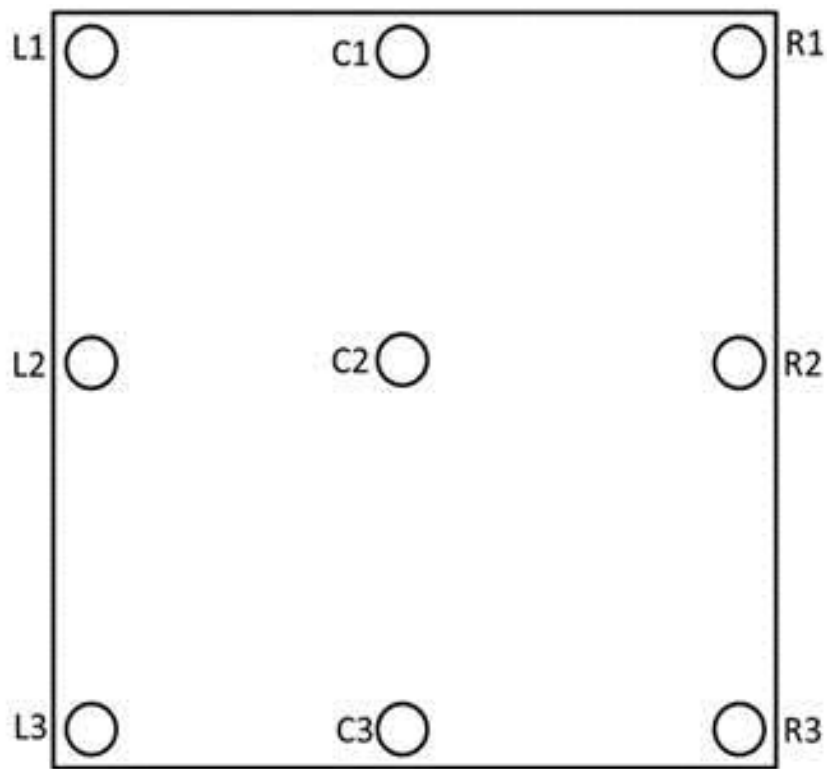
**FIGURE 3.7 OBJECTS INSERTED IN OUTSIDE SCENE FOR EXPERIMENTATION**



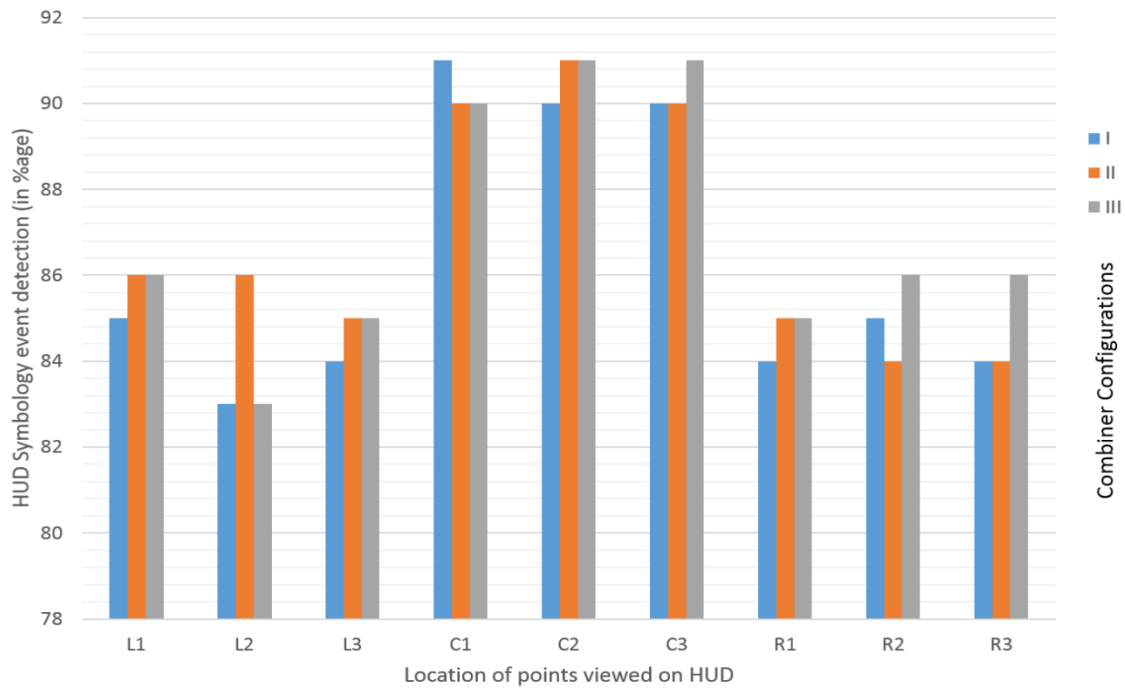
**FIGURE 3.8 OBJECTS INSERTED IN HUD SYMBOLOGY FOR EXPERIMENTATION**



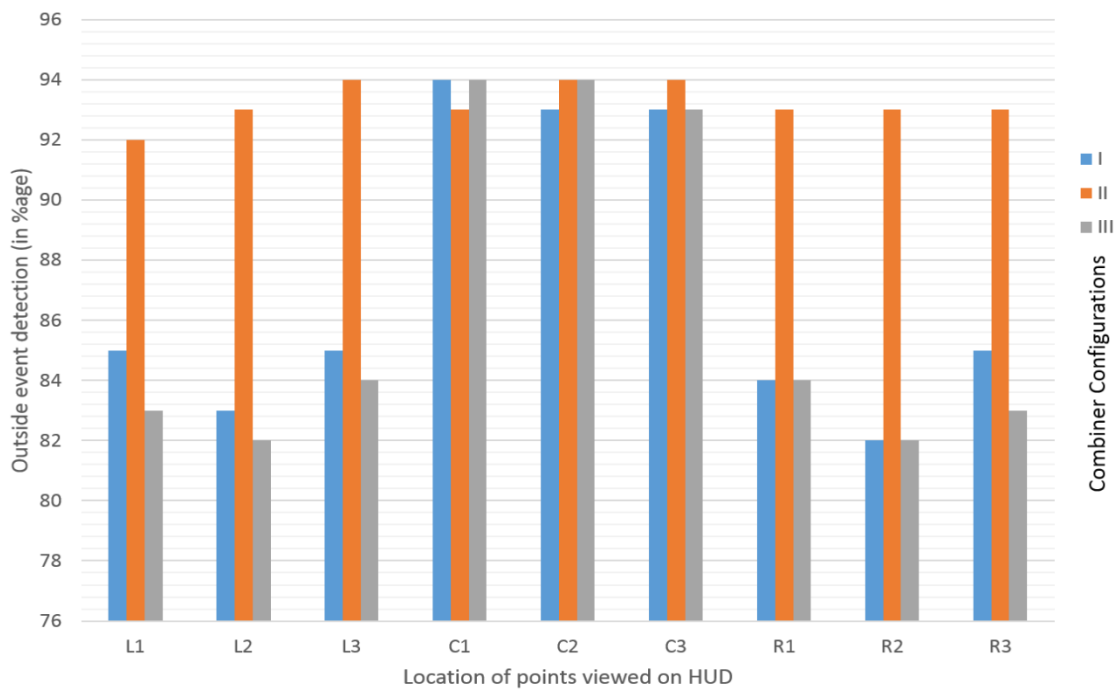
**FIGURE 3.9 OBJECTS INSERTED IN OUTSIDE SCENE WITH VARIATION FOR EXPERIMENTATION**



**FIGURE 3.10 OBJECTS INSERTED IN HUD SYMBOLOGY WITH VARIATION FOR EXPERIMENTATION**



**FIGURE 3.11 EVENT DETECTION ON HUD SYMBOLOGY IN PERCENTAGE OBSERVED FOR VARIOUS LOCATIONS ON HUD**



**FIGURE 3.12 OUTSIDE EVENT DETECTION IN PERCENTAGE OBSERVED FOR VARIOUS LOCATIONS THROUGH THE HUD**

However, at left and right corner locations corresponding to L1, L2, L3 and R1, R2, R3 respectively, event detection on HUD symbology deteriorated from range of 90-91% to range of 83-86% for all three combiner configurations. However, responses obtained for the outside events detection for left and right corner locations through HUD was quite different from what was obtained for centre locations. As shown in Fig. 3.12, it was different for all three configurations. With configuration-I, which had obstruction due to the frame structure angle, outside event detection was much lesser as compared to centre locations. It varied in the range 82-85%. However, for configuration-II having least obstruction among three configurations due to appropriately angled frame structure and less frame thickness, outside event detection was much higher compared to configurations I and III varying in range of 92-94%. For configuration-III with appropriately angled frame structure but having more thickness resulting in maximum obstruction among the three configurations, outside event detection was again lesser as compared to centre locations. It varied in range 82-84%. These results indicated that when obstruction due to appropriately angle frame and thinner structure was lesser, participants were able to attend both events simultaneously in an appropriate

manner. This happened as participants did not get distracted. However, for configurations I and III where obstruction was more, participants got distracted. In attempt of getting more of outside events, they lost on both accounts. They got tunneled to outside events to get more outside information beyond the obstructions. In the process, they also compromised on HUD symbology event detection.

### **3.2.2 EFFECT OF VARYING CONTRAST RATIO AND LUMINANCE NON-UNIFORMITY OVER HUMAN ATTENTION AND TUNNELING**

It has been observed that the symbology luminance (SL) plays a key role in affecting pilot's event detection capability. A set of experiment was conducted under varying AL conditions to understand effects of AL, CR and varying NU on capability of pilot to detect changes in events taking place on HUD and outside environment.

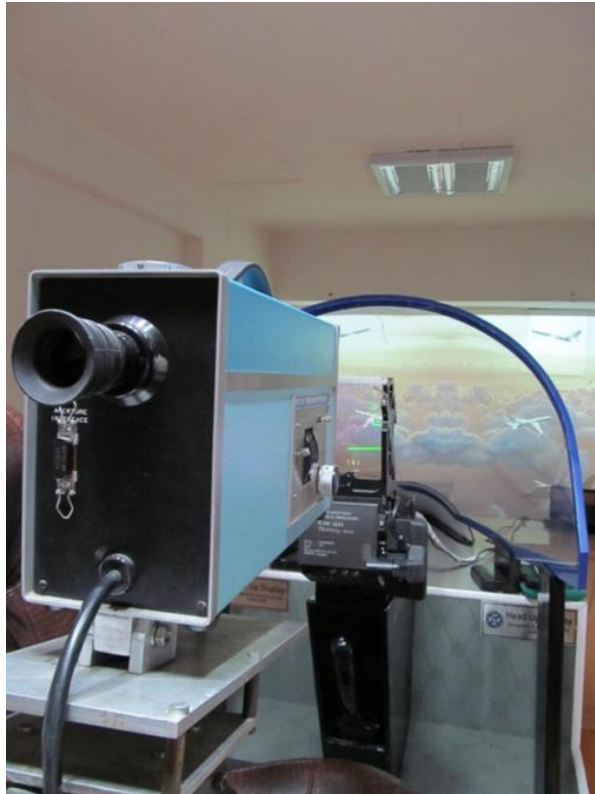
By AL we mean available light in the environment. CR is a property of a display system, we define CR as:

$$\text{Contrast Ratio} = \frac{\text{Symbol Brightness} + \text{Ambient Brightness}}{\text{Ambient Brightness}} \quad (3.6)$$

In the experimental setup (Fig. 3.13 and Fig. 3.14), CR range from 1 to 18 were simulated. NU for four different cases across the HUD combiners i.e. 1:1, 1:1.15, 1:1.29, and 1:1.47 were taken into consideration under AL range from 20 cd/m<sup>2</sup> to 40,000 cd/m<sup>2</sup>. Experiment was focused on how user would respond to events on HUD and outside world, when attention was modulated through AL, SL and NU, thus varying CR across HUD display area.

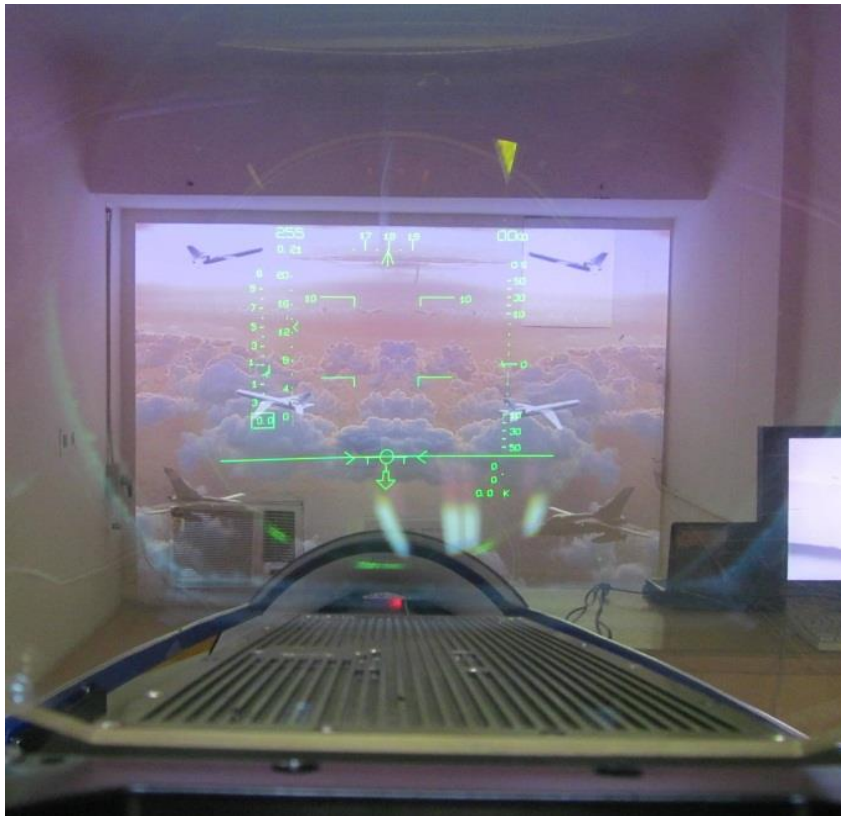
Experimental setup (Fig. 3.13 and Fig. 3.14) consisted of HUD system mounted on cockpit mock-up display simulator along with seat adjustment mechanism, HUD signal simulator, projector setup coupled with background simulation PC, light source and diffuser, photometer and a TV monitor. A light source capable of simulating light luminance of more

than  $85,000 \text{ cd/m}^2$  along with light diffuser were used to simulate ambient lighting for generating luminance from  $20 \text{ cd/m}^2$  to  $40,000 \text{ cd/m}^2$ .



**FIGURE 3.13 EXPERIMENTAL SET UP FOR EVALUATING HUD IMAGE LUMINANCE, CONTRAST AND NON-UNIFORM LUMINANCE ON ATTENTION CAPTURE AND TUNNELING**

The experiments were carried out with the participation of 22 people comprising of 12 males and 10 females in the age group of 24 to 32 years, all with engineering/technology as their academic background. Participants were asked to carry out two tasks: First, to report any detected changes in right, middle and the left portion of upper and the lower half of HUD display seen on combiners. Second, to report any changes observed in outside scene. Though, option of adaptive luminance control was available but it was disabled to control SL manually so that participant response could be recorded for single contrast setting. Participants first took up a training session on the setup to familiarize them with task and setup. Further, experiments were conducted in morning and afternoon to eliminate effect of fatigue factor on experimental results. During experimentation, simulated changes include: appearing/ disappearing shape/objects/characters from background image as well as on HUD display; change in status and location with changes taking place between scenes.



**FIGURE 3.14 HUD SYMBOLOGY AS SEEN THROUGH THE COMBINER**

Participants were also asked to answer a set of questions based on their observation during course of experimentation, which not only required them to make spatial and direction judgments but also to list observed changes and objects. Each symbology page scene limited to two questions with next symbology page automatically displayed once the set of question based on one set were answered. It meant that participants required telling changes observed by them in a scene followed by responding to associated query. Participants were not told about NU of HUD. One set of result was totally out of the trend hence not considered.

NU had the effect of causing differential luminance across HUD display. This effectively resulted in differential CR across display resultant because of patches of NU in the HUD display. This resulted in good luminance at some places and grading of reduced luminance on combiner at other places resulting in diverted attention of viewer on HUD as well as on outside events. NU was simulated with combiner, which had definite patches of NU areas corresponding to resultant CR values of 1:1, 1: 1.15, 1: 1.29 and 1:1.47.

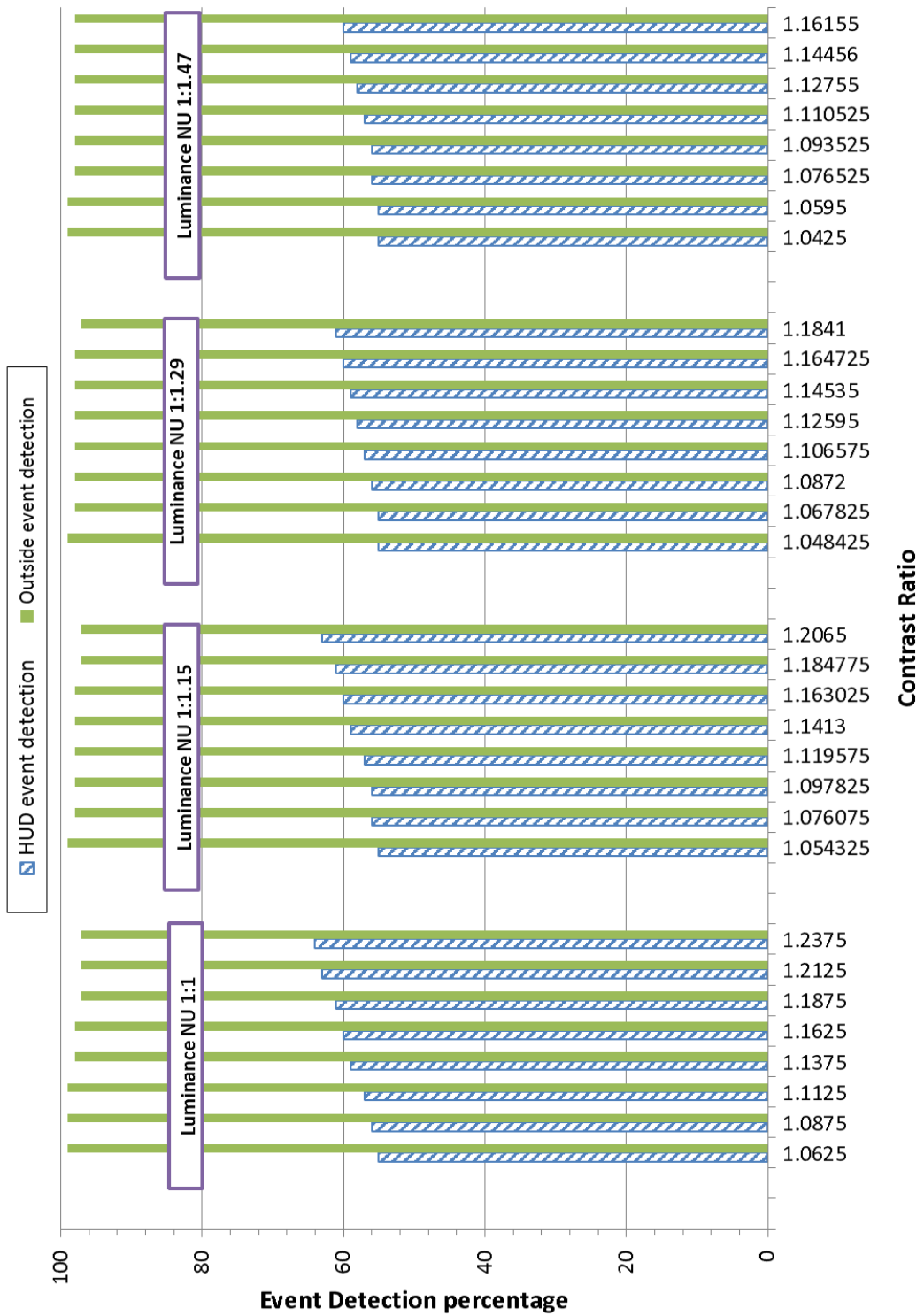
### 3.2.2.1 Results and Discussion

Results obtained while studying the effect of varying CR and NU are shown in Fig. 3.15, Fig. 3.16, Fig. 3.17, Fig. 3.18, Fig. 3.19, Fig. 3.20, Fig. 3.21, Fig. 3.22, Fig. 3.13 and Fig. 3.24. Study related to problem of attention capture and tunneling effect due to absolute, relative and non-uniformity of SL was undertaken. It was undertaken as it was observed during course of HUD testing that specification for HUD NU of 1: 1.5 caused stress on viewer while viewing HUD image and outside world simultaneously. Hence, it was thought that there is a definite relation between SL, CR against the variable AL and NU with attentional tunneling during HUD use.

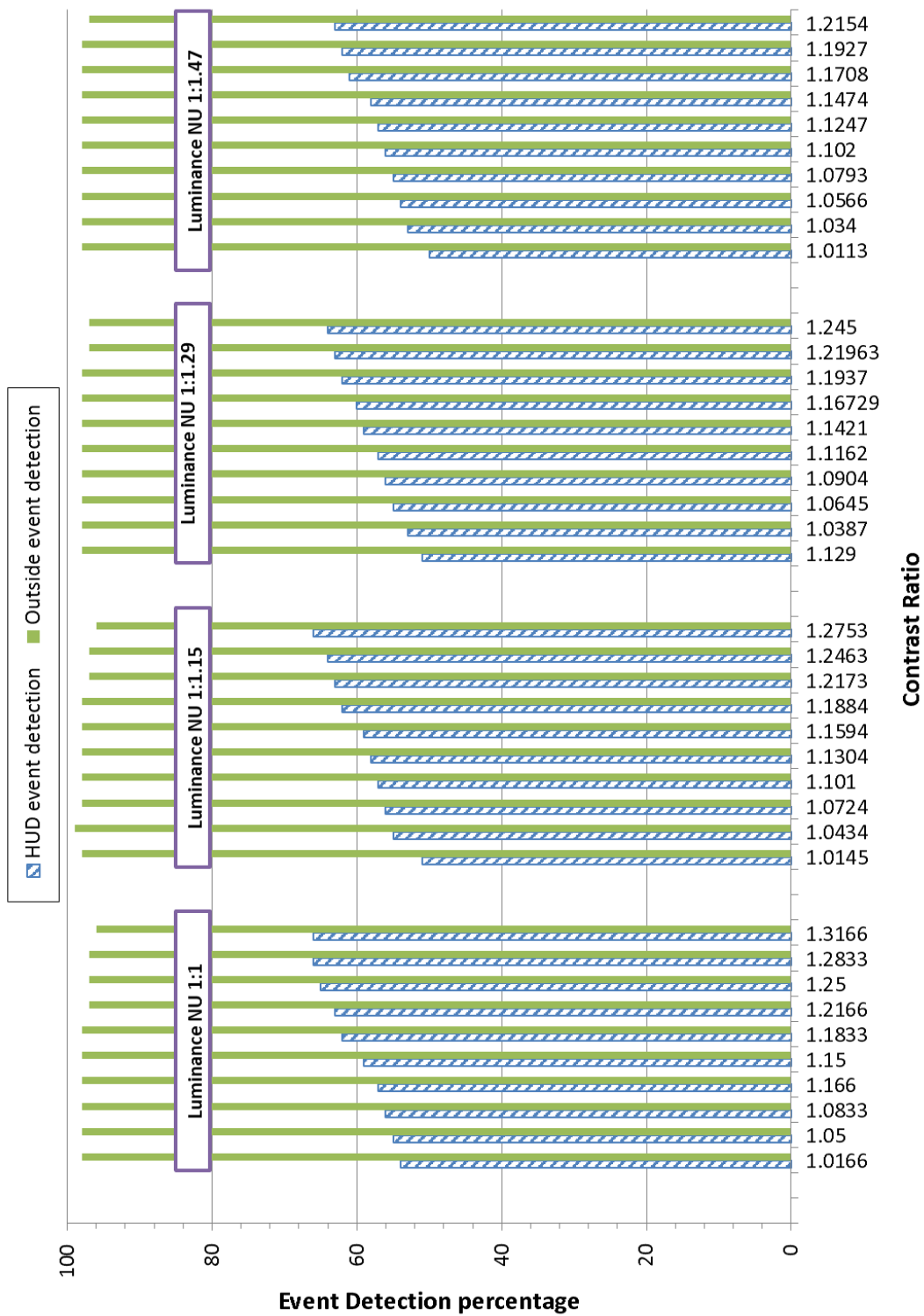
NU was observed on HUD display primarily due to inaccuracies of coating made on the combiner and folding mirror glasses. Though NU of CRT also contributed in HUD NU, but its effect was negligible. These inaccuracies caused variation of CR across the HUD display resulting in distraction to viewer. NU caused differential luminance of symbols across HUD display. It also resulted in variable transmission through HUD. Resultant differential contrast over a smaller area of HUD display forced pilot to divert his attention frequently between symbols and outside world. This might cause pilot to miss outside events as his/her attention is focussed more towards HUD events. The reason is obvious, by the time, pilot becomes accustomed to one luminance level, he needs to focus his attention towards other display area on other symbols which might be lesser or greater in the luminance levels to the one which are already scanned. Experiments conducted to simulate these conditions under variable ambient lighting conditions confirmed above thoughts. Experiments were confined only to the day mode of stroke symbology. Table 3.3 summarizes the results of in Fig. 3.15, Fig. 3.16, Fig. 3.17, Fig. 3.18, Fig. 3.19, Fig. 3.20, Fig. 3.21, Fig. 3.22, Fig. 3.13 and Fig. 3.24.

**TABLE 3.3 SUMMARY OF EXPERIMENTAL RESULTS**

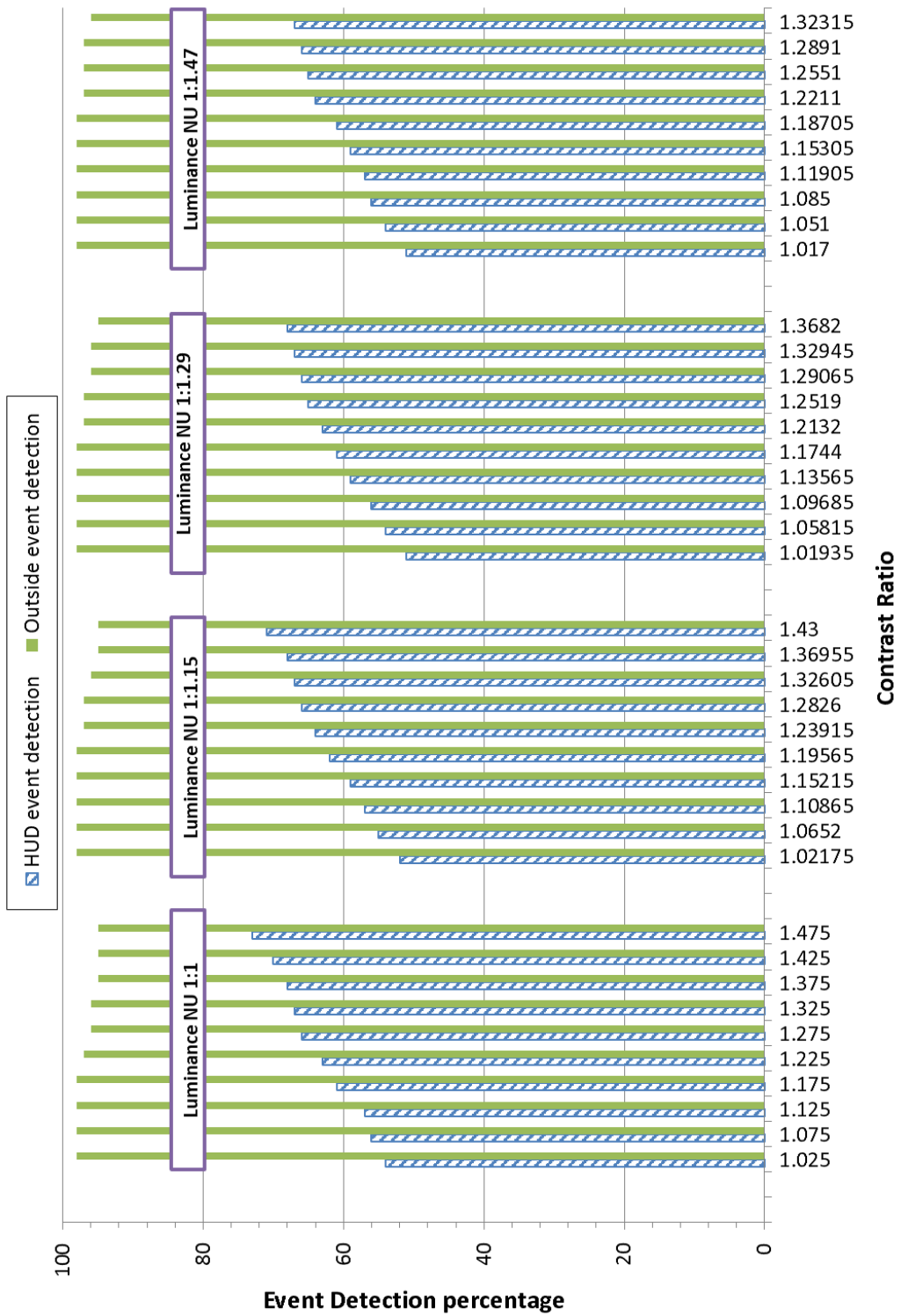
<b>Ambient luminance (cd/m<sup>2</sup>)</b>	<b>CR range due to HUD NU for single luminance setting</b>	<b>HUD event detection (%)</b>	<b>Outside event detection (%)</b>	<b>Variation in HUD event detection due to NU (%)</b>	<b>Variation in outside event detection due to NU (%)</b>
40,000	1.0425 - 1.2375	54 - 64	99 - 97	0 - 4	0 - 1
30,000	1.034 - 1.3166	54 - 66	98 - 96	0 - 3	0 - 1
20,000	1.051 - 1.475	54 - 73	98 - 95	0 - 6	0 - 2
10,000	1.034 - 1.95	54 - 81	98 - 95	0 - 7	0 - 2
5,000	1.068 - 2.90	55 - 90	98 - 92	0 - 6	0 - 3
1,000	1.068 - 5.5	55 - 95	98 - 83	0 - 8	0 - 5
500	1.136 - 10.00	59 - 98	98 - 75	0 - 8	0 - 5
100	1.068 - 10.00	56 - 98	98 - 73	0 - 9	0 - 6
50	1.136 - 15.2	59 - 99	95 - 69	0 - 4	0 - 6
20	1.70 - 18.0	76 - 99	95 - 64	1 - 8	1 - 7



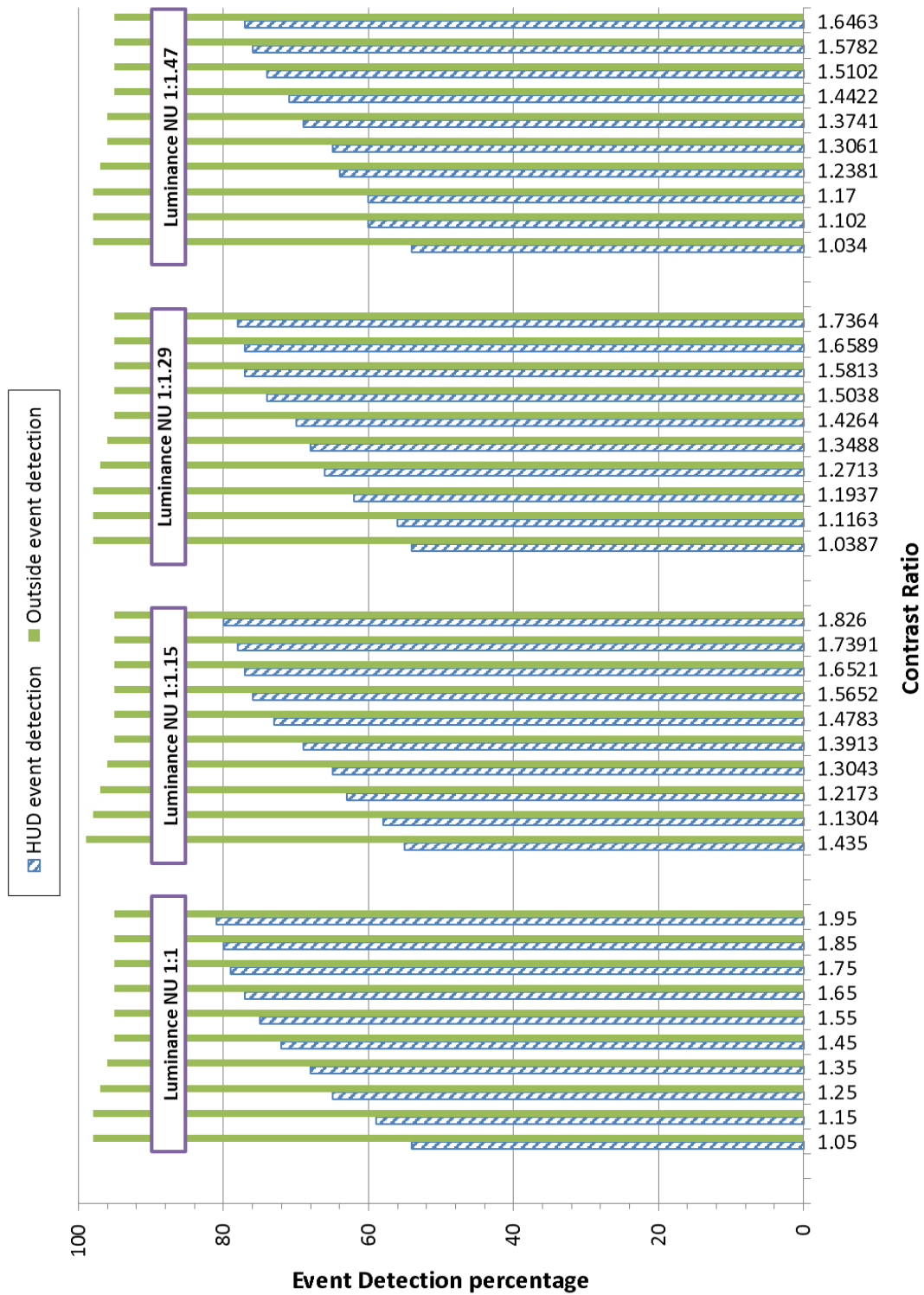
**FIGURE 3.15 COMPARISON OF HUD EVENT DETECTION WITH OUTSIDE EVENT DETECTION AT AMBIENT LUMINANCE 40,000 cd/m<sup>2</sup>: EFFECTS OF LUMINANCE NON-UNIFORMITY**



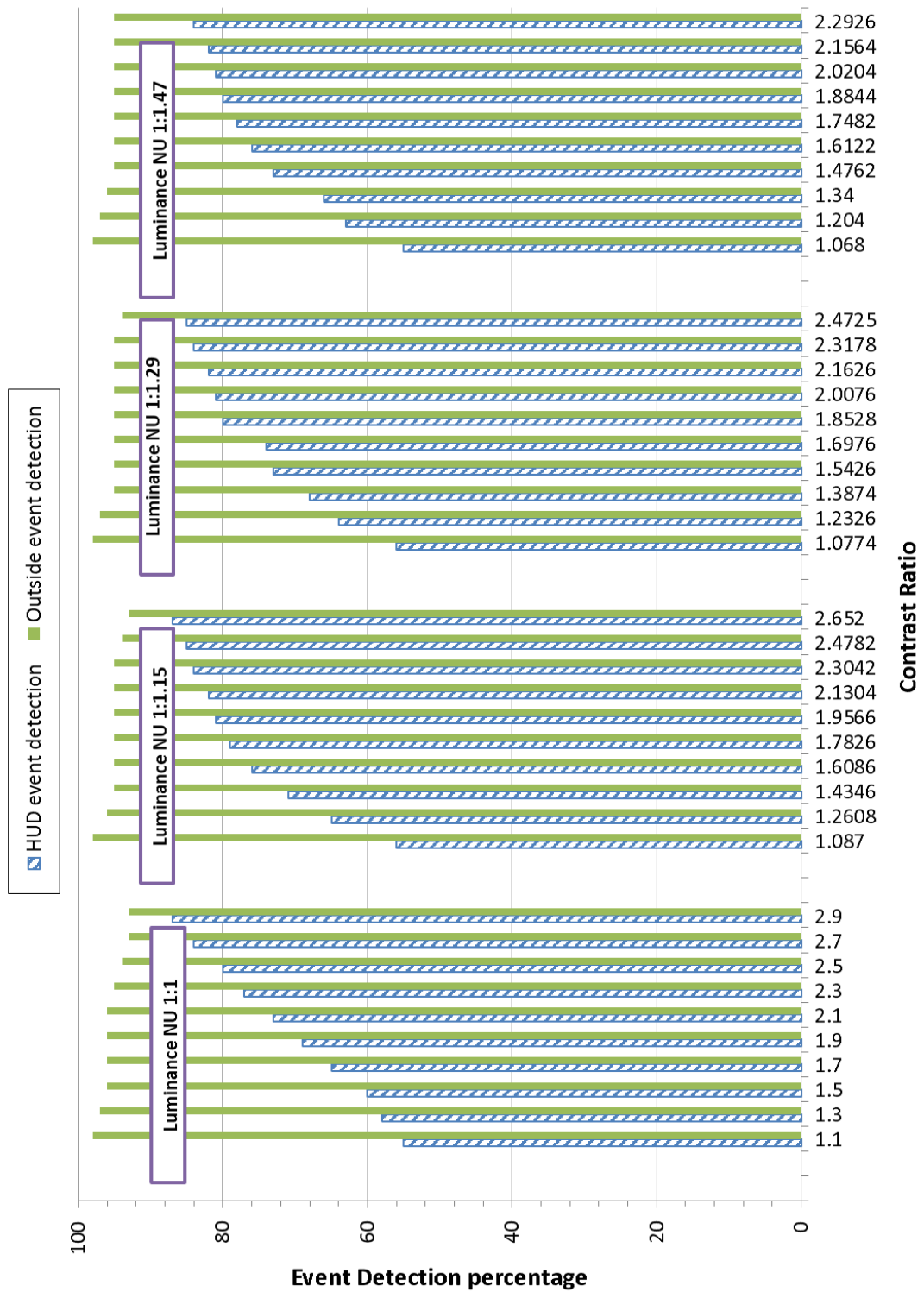
**FIGURE 3.16 COMPARISON OF HUD EVENT DETECTION WITH OUTSIDE EVENT DETECTION AT AMBIENT LUMINANCE 30,000 cd/m<sup>2</sup>: EFFECTS OF LUMINANCE NON-UNIFORMITY**



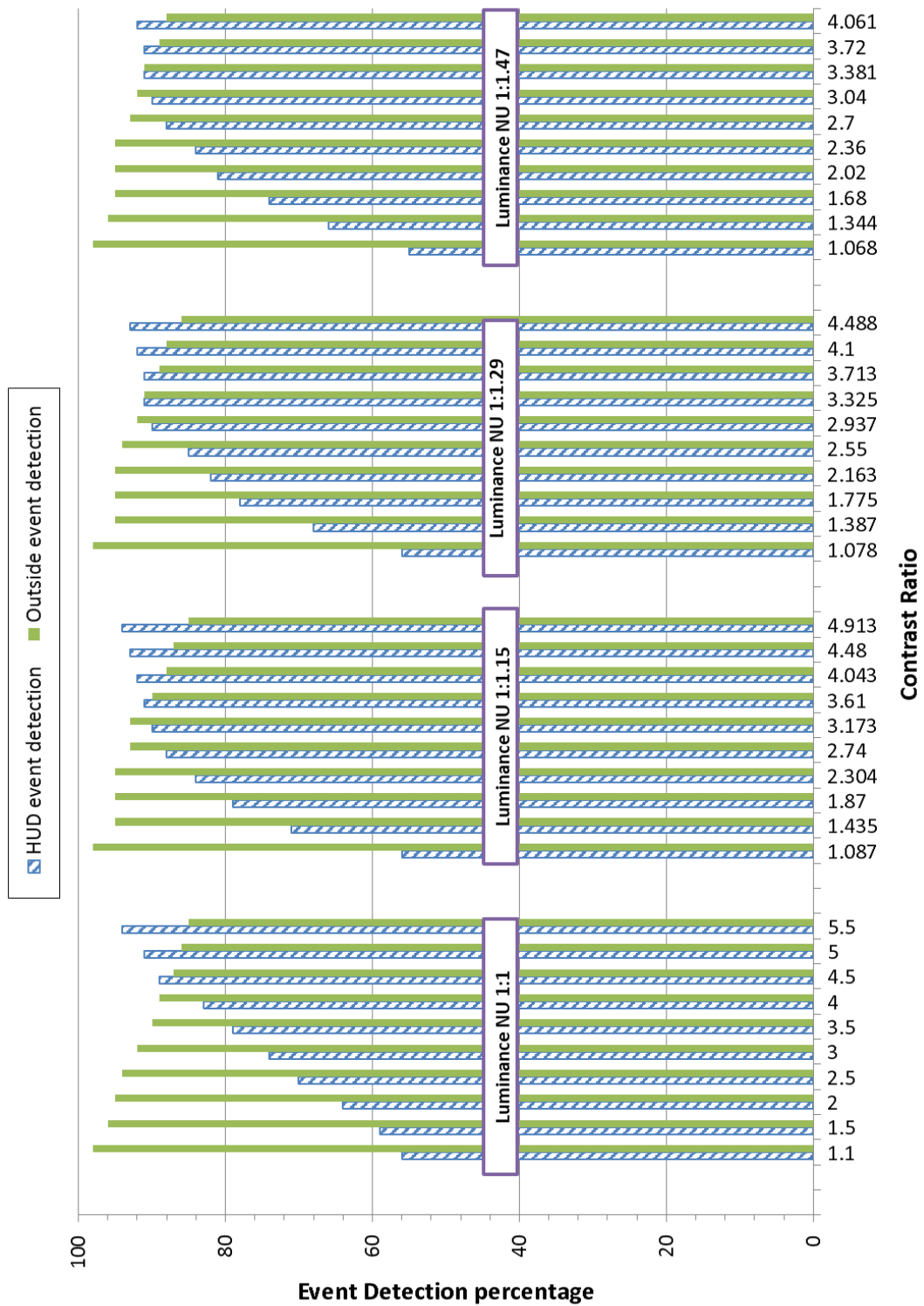
**FIGURE 3.17 COMPARISON OF HUD EVENT DETECTION WITH OUTSIDE EVENT DETECTION AT AMBIENT LUMINANCE 20,000 cd/m<sup>2</sup>: EFFECTS OF LUMINANCE NON-UNIFORMITY**



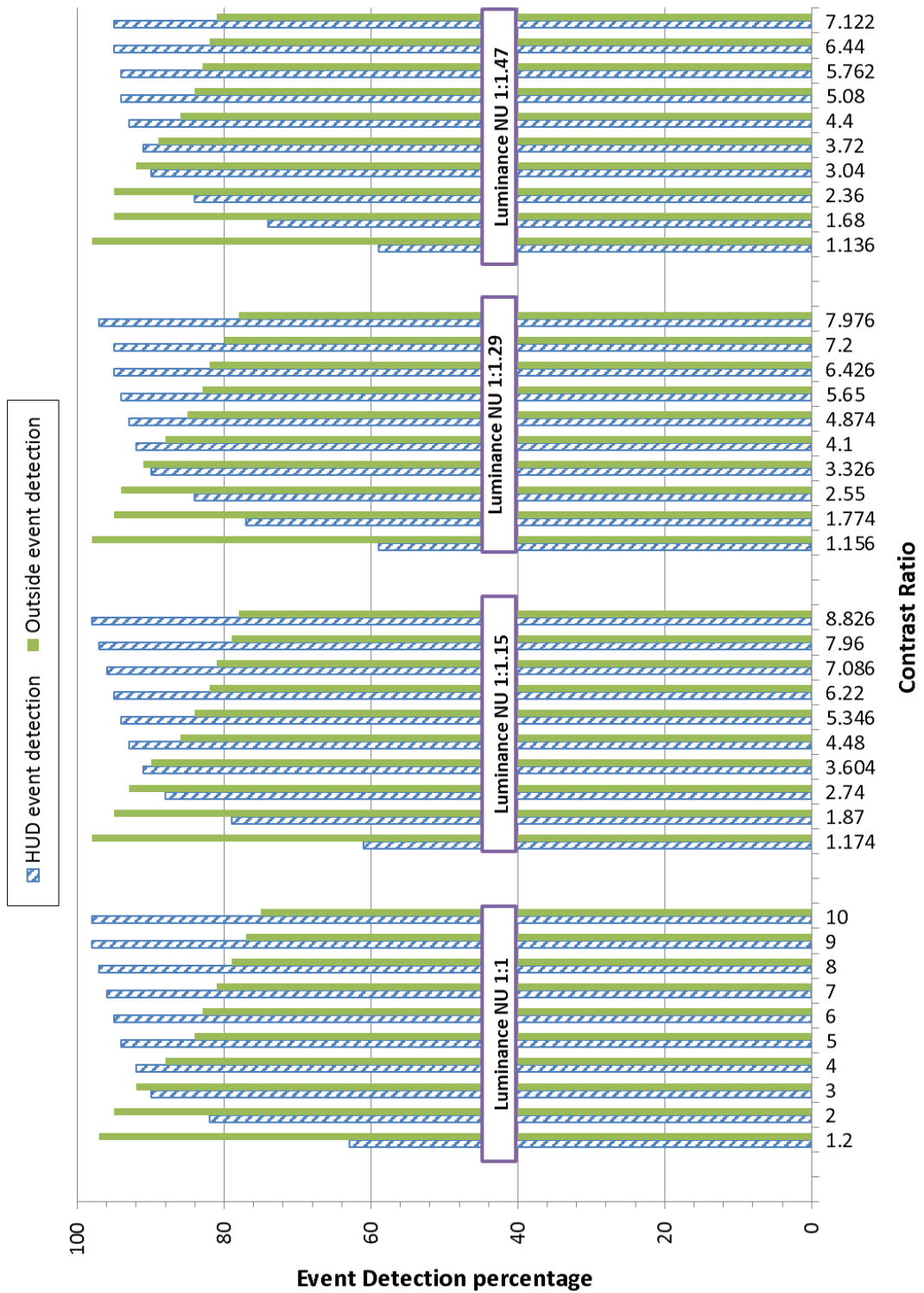
**FIGURE 3.18 COMPARISON OF HUD EVENT DETECTION WITH OUTSIDE EVENT DETECTION AT AMBIENT LUMINANCE 10,000 cd/m<sup>2</sup>: EFFECTS OF LUMINANCE NON-UNIFORMITY**



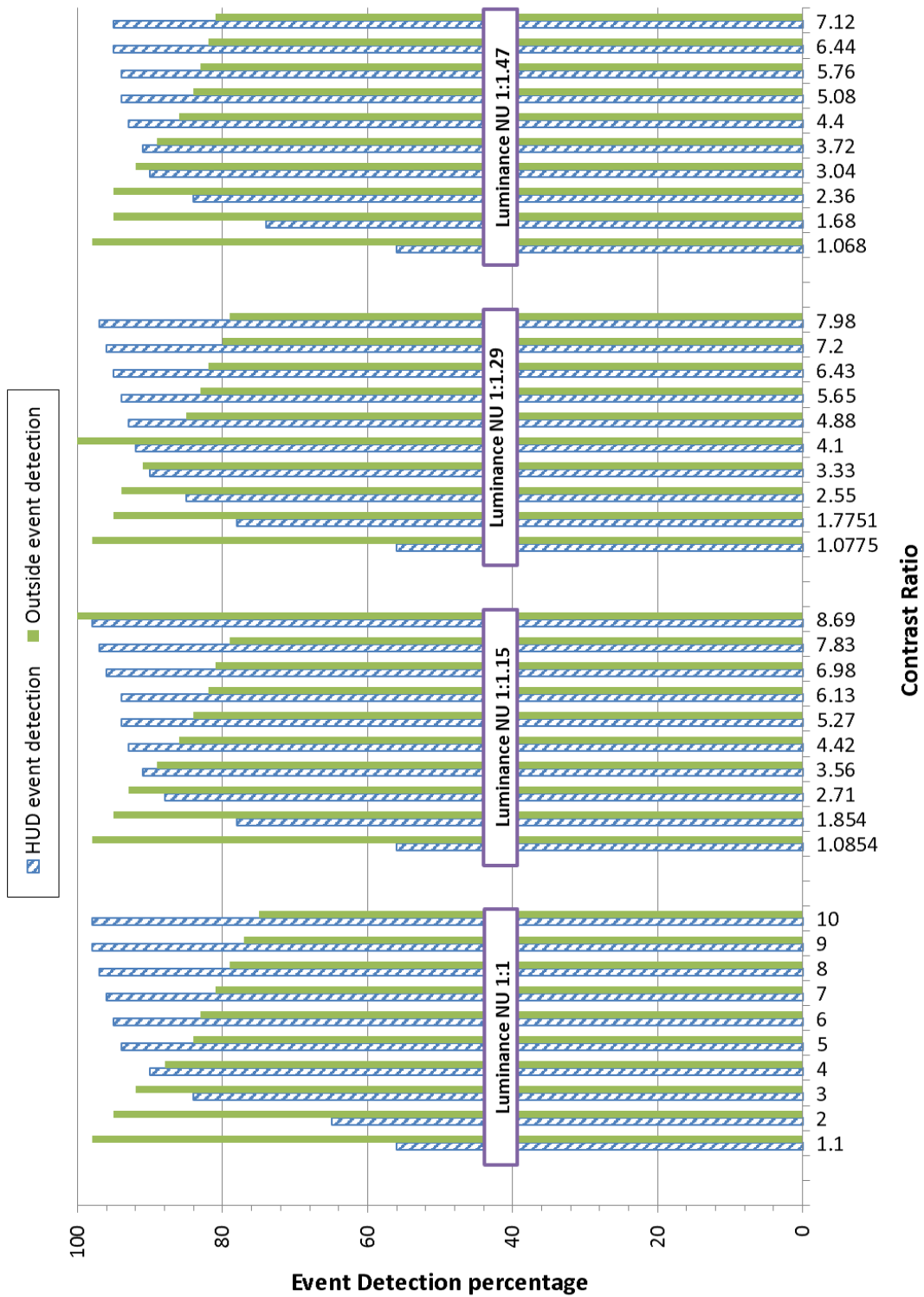
**FIGURE 3.19 COMPARISON OF HUD EVENT DETECTION WITH OUTSIDE EVENT DETECTION AT AMBIENT LUMINANCE 5,000 cd/m<sup>2</sup>: EFFECTS OF LUMINANCE NON-UNIFORMITY**



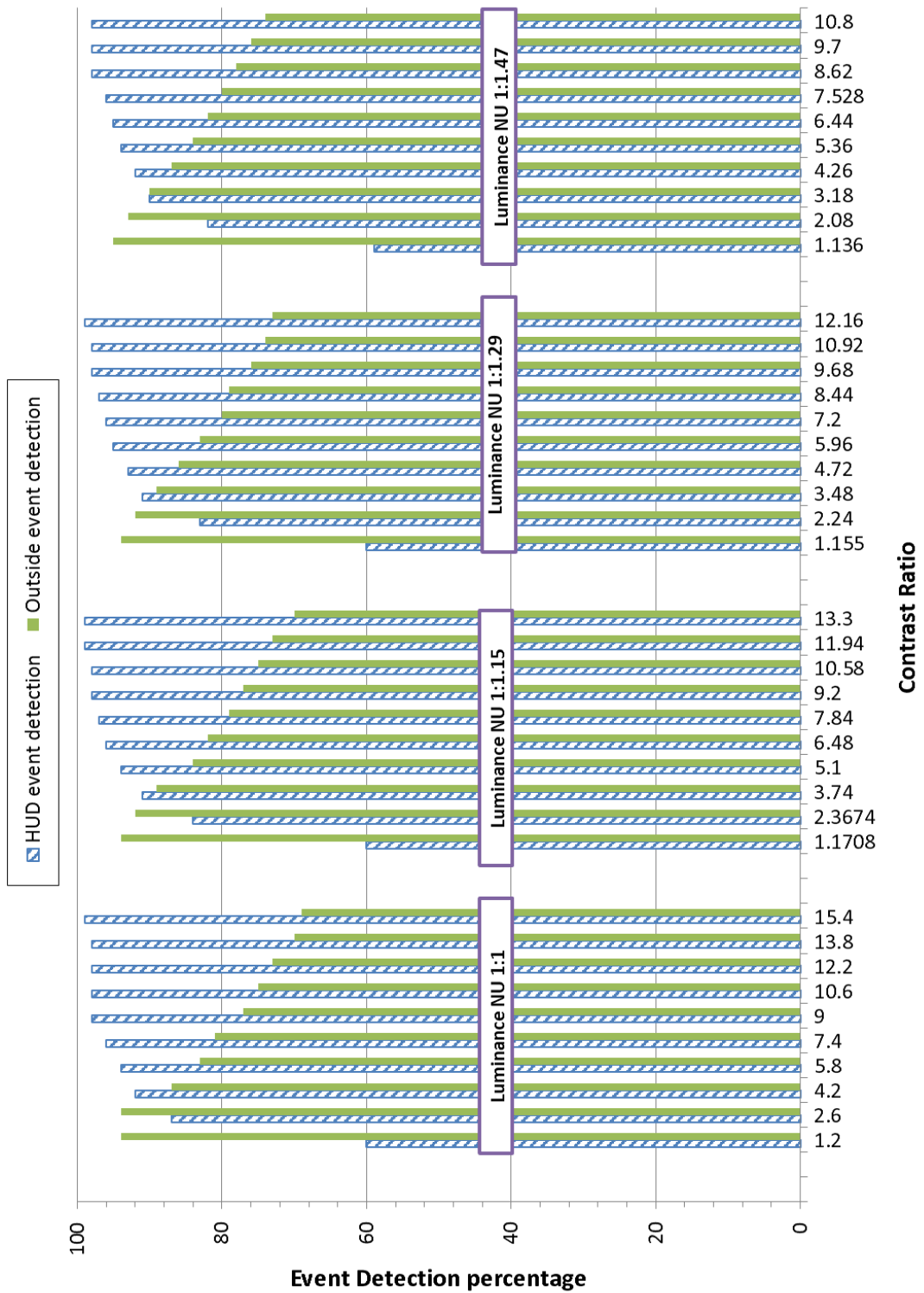
**FIGURE 3.20 COMPARISON OF HUD EVENT DETECTION WITH OUTSIDE EVENT DETECTION AT AMBIENT LUMINANCE 1,000 cd/m<sup>2</sup>: EFFECTS OF LUMINANCE NON-UNIFORMITY**



**FIGURE 3.21 COMPARISON OF HUD EVENT DETECTION WITH OUTSIDE EVENT DETECTION AT AMBIENT LUMINANCE 500 cd/m<sup>2</sup>: EFFECTS OF LUMINANCE NON-UNIFORMITY**



**FIGURE 3.22 COMPARISON OF HUD EVENT DETECTION WITH OUTSIDE EVENT DETECTION AT AMBIENT LUMINANCE 100 cd/m<sup>2</sup>: EFFECTS OF LUMINANCE NON-UNIFORMITY**



**FIGURE 3.23 COMPARISON OF HUD EVENT DETECTION WITH OUTSIDE EVENT DETECTION AT AMBIENT LUMINANCE 50 cd/m<sup>2</sup>: EFFECTS OF LUMINANCE NON-UNIFORMITY**

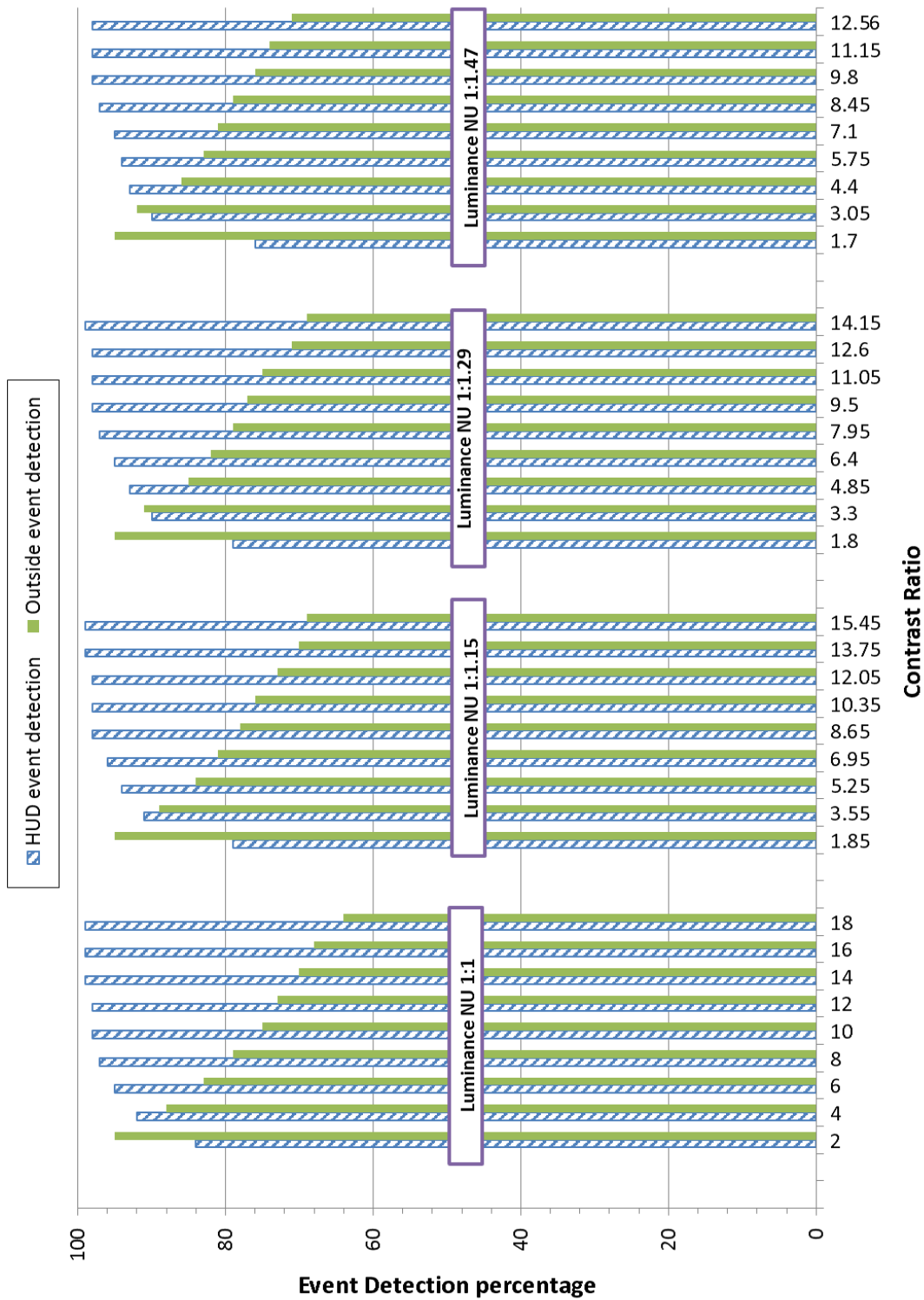


FIGURE 3.24 COMPARISON OF HUD EVENT DETECTION WITH OUTSIDE EVENT DETECTION AT AMBIENT LUMINANCE 20 cd/m<sup>2</sup>: EFFECTS OF LUMINANCE NON-UNIFORMITY

Results shown in Fig. 3.15, Fig. 3.16, Fig. 3.17, Fig. 3.18, Fig. 3.19, Fig. 3.20, Fig. 3.21, Fig. 3.22, Fig. 3.13 and Fig. 3.24 have been summarized through comparative data presented in Table 3.3.

When AL was very high (30,000 cd/m<sup>2</sup> and 40,000 cd/m<sup>2</sup>), HUD event detection varied in range 54% - 66% and outside event detection in range 99% - 96% as CR across HUD display was varied in range 1.034 - 1.3166. Very high AL limited display CR range. Lower and differential CR resulted in lower HUD event detection while high AL was reason for excellent outside event detection, which eased pilot's outside view. For same HUD luminance setting, available SL was reduced over the combiner area due to NU. This resulted in variation of detection percentage of HUD event and the outside event detection across the HUD display. For same luminance setting, differential luminance across HUD display caused variation in HUD event detection in range 0% - 4% though there was no significant variation (0% - 1%) in outside event detection.

When AL was medium and high (20,000 cd/m<sup>2</sup>, 10,000 cd/m<sup>2</sup> and 5,000 cd/m<sup>2</sup>), HUD event detection varied in range 54% - 90% and outside event detection in range 98% - 92% as CR across HUD display was varied in range 1.034 to 2.90. Still, AL values were high, thus limiting display CR range to maximum 2.90. Improvement in CR resulted in improved HUD event detection while reasonably high AL was the reason for excellent outside event detection. For same HUD luminance setting, available SL varied significantly over the combiner area due to NU causing wide range of variation in HUD event detection over combiner area. This resulted in variation of detection percentage of HUD event and the outside event detection across the HUD display. For same luminance setting, differential luminance across HUD display caused variation in HUD event detection in range 0% - 7%, though there was no significant variation (0% - 3%) in outside event detection.

When AL was low and medium (1,000 cd/m<sup>2</sup>, 500 cd/m<sup>2</sup> and 100 cd/m<sup>2</sup>), HUD event detection varied in range 55% - 98% and outside event detection in range 98% - 73% as CR

across HUD display was varied in range 1.068 to 10.00. Lower AL values improved display CR significantly, which resulted in improved HUD event detection. Reduced AL and high CR reduced outside event detection. For same HUD luminance setting, available SL varied significantly over the combiner area due to significant effect of NU causing wide range of variation in HUD as well as outside event detection over combiner area. For same luminance setting, differential luminance across HUD display caused significant variation in HUD event detection in range 0% - 9% and 0% - 6% in outside event detection.

When AL was low ( $50 \text{ cd/m}^2$ ), HUD event detection varied in range 59% - 99% and outside event detection in range 95% - 69% as CR across HUD display was varied in range 1.136 to 15.20. Low AL values improved display CR significantly which resulted in improved HUD event detection. Low AL and high CR reduced outside event detection significantly. For same HUD luminance setting, available SL varied significantly over the combiner area due to significant effect of NU causing wide variation in HUD as well as outside event detection over combiner area. For same luminance setting, differential luminance across HUD display caused relatively less significant variation in HUD event detection in range 0% - 4% and significant variation of 0% - 6% in outside event detection.

When AL was low ( $20 \text{ cd/m}^2$ ), HUD event detection varied in range 76% - 99% and outside event detection in range 95% - 64% as CR across HUD display was varied in range 1.70 to 18.00. Very low AL values improved display CR significantly which resulted in improved HUD event detection. Very low AL and high CR reduced outside event detection significantly. For same HUD luminance setting, available SL varied significantly over the combiner area due to significant effect of NU causing wide variation in HUD as well as outside event detection over combiner area. For same luminance setting, differential luminance across HUD display caused very significant variation in HUD event detection in range 1% - 8% and 1% - 7% in outside event detection.

### **3.2.3 STATISTICAL ANALYSIS IN ESTIMATION OF TUNNELING EFFECT DUE TO LUMINANCE NON-UNIFORMITY IN HEAD-UP DISPLAYS**

This experiment showed that HUD NU may force inappropriate distribution of attention between events shown on HUD symbology and the outside scene due to resultant differential contrast on HUD display. Results of statistical analysis demonstrate that there is a considerable effect of SL and AL as well as their interaction term on detection of events displayed on HUD and outside scene.

Among various factors associated with HUD which may cause tunneling are: relative HUD symbology luminance (SL) and ambient luminance (AL) [Martin-Emerson and Wickens (1997); Prinzel and Risser (2004)]. HUD luminance non-uniformity (NU) is a related parameter. This parameter refers to differential symbology or image or outside scene luminance within display field of HUD combiner. Effect of these three parameters on attention capture and tunneling during HUD use were studied experimentally and analysed statistically. Ultimate goal was to develop an understanding towards contribution of AL, SL as well as NU in causing attention tunneling.

As long as the luminance of an aircraft HUD image is kept appropriately between 1 cd/m<sup>2</sup> to 7500 cd/m<sup>2</sup>, a reasonable contrast can be obtained for ambient lighting ranging from twilight to bright sunny conditions. A display contrast of 1.2 is the minimum needed to barely view HUD display [Wood and Howells (2001); Jukes (2004); Moir *et al.* (2006b)].

Specification of HUD luminance is generally spelled as 'Luminance variations in nearby locations within the monocular field of view should not be more than +/-35%'. It may be too high for actual usage. Optical parameters in relation to HUD like image luminance, accommodation, vergence, and contrast within the instantaneous and total field of view must be uniform across the entire field [Moir *et al.* (2006b)].

### **3.2.3.1 Experiment to Carry out Statistical Analysis in Estimation of Tunneling Effect due to Luminance Non-Uniformity in Head-Up Displays**

Experiments were performed to understand attention capture and tunneling due to HUD usage under varying AL, SL and NU. Detection percentage of events embedded in HUD symbology and the outside scene observed during the experimental study were then analysed employing statistical tools to find out significance of the collected samples.

SL has a major effect on optimization of pilot's attention under various ambient lighting conditions. The experiment used HUD system in a simulated environment. The simulated environment consisted of: varying outside scene and HUD symbology, varying AL, differential contrast as well as luminance on and through combiners to examine how participants would respond to events displayed on HUD symbology and outside scene. Experimental setup is shown in Fig. 3.25. Outside scene was simulated using projector coupled with a computer while HUD symbology was generated using HUD signals simulator.

Ambient luminance during simulation was varied in three ranges: High AL (10,000 - 30,000 cd/m<sup>2</sup>), Mid AL (1,000 - 5000 cd/m<sup>2</sup>) and Low AL (50 – 500 cd/m<sup>2</sup>). The AL was varied using a floodlight in the room. The luminance was measured using a Pritchard photometer (part of experimental setup). The dot in the photometer eyepiece (aperture of photometer set at 2') was focussed on the desired point to measure luminance at that point. Further, AL measurements were made at a particular point say 'O' by blanking the symbology. The SL was adjusted to 17 fixed levels through software control. To measure SL, again the photometer was focussed on point say 'O' with SL set at the desired level. The intention was to understand response of participants to events on HUD symbology and outside scene, when attention was modulated through above discussed luminance parameters. Participants were asked to give their judgment by looking through HUD from a distance of 450 mm, which is generally the distance at which pilot sits away from HUD unit. Hence, symbology overlapped on the outside scene simulated exact aircraft condition.

HUD symbology variations contained diverse variations which were required to be detected by participants. Outside event change required participants to frequently alter their attention between events on HUD symbology and outside scene. It was expected that differential contrast across and through HUD symbology area due to combiner NU would cause delayed or missed detection of events. It varied depending on existing CR on that particular display field.



**FIGURE 3.25 EXPERIMENTAL SETUP TO SIMULATE HUD SYMBOLOGY AND OUTSIDE SCENE CHANGES**

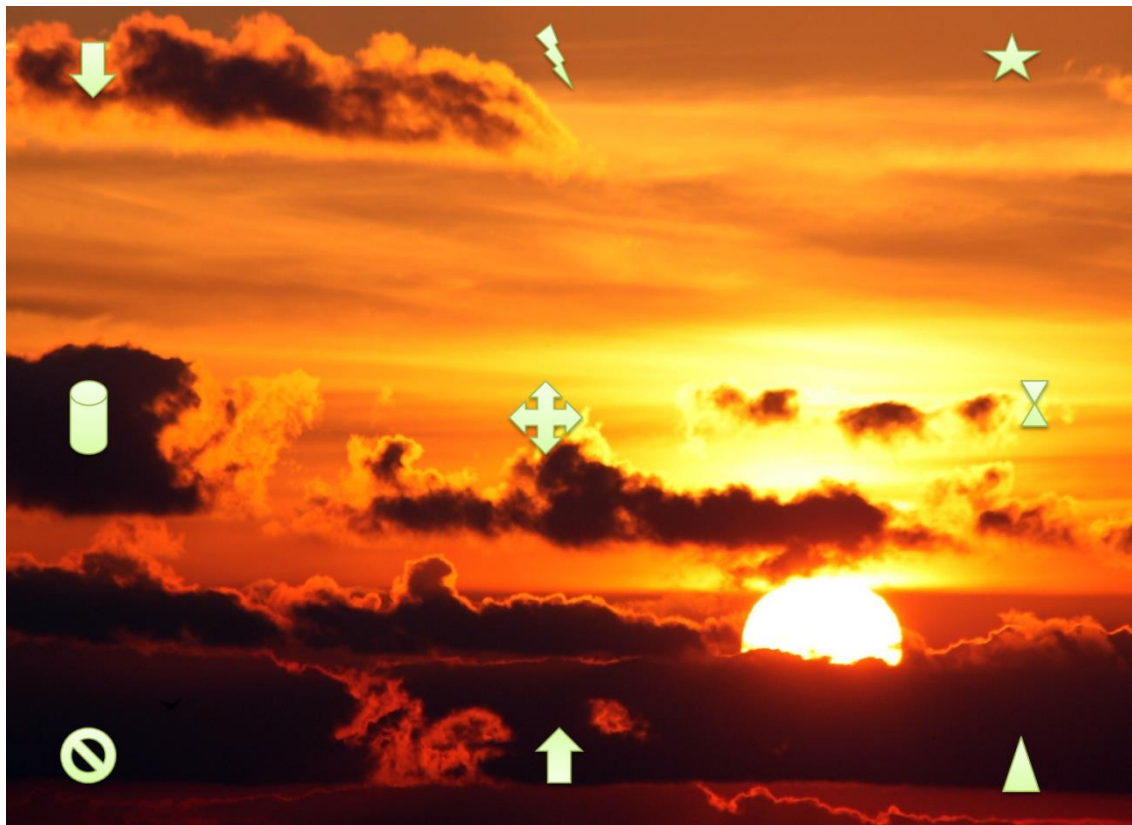
Correct adjustment of SL is necessary in achieving appropriate CR [Wood and Howells (2001)].

HUD symbology field was divided into zones covering entire field. Coating on combiner glasses caused differential transmission and reflection from them. Experiments were carried out with participation of 20 people involving equal number of males and females in age group of 22 to 28 years. Experiment was conducted over all the three ranges of AL with SL varying through its 17 levels and 4 levels of NU for each range. The aim was to study tunneling effect during high outside luminance conditions (sunny day), medium outside luminance (normal cloudy day) and low outside luminance (twilight conditions). Participants

were required to report about two event changes: First, to report about any noticed changes in designated areas on HUD display; Second, to report any noticed changes in outside scene.

Changes in the symbology field viz. 1) Horizon Line, 2) Airspeed, 3) Heading Scale, 4) Mach Number, 5) Angle of Attack 6) Vertical Velocity and 7) Instantaneous Velocity Vector were marked with numbers in Fig. 3.27.

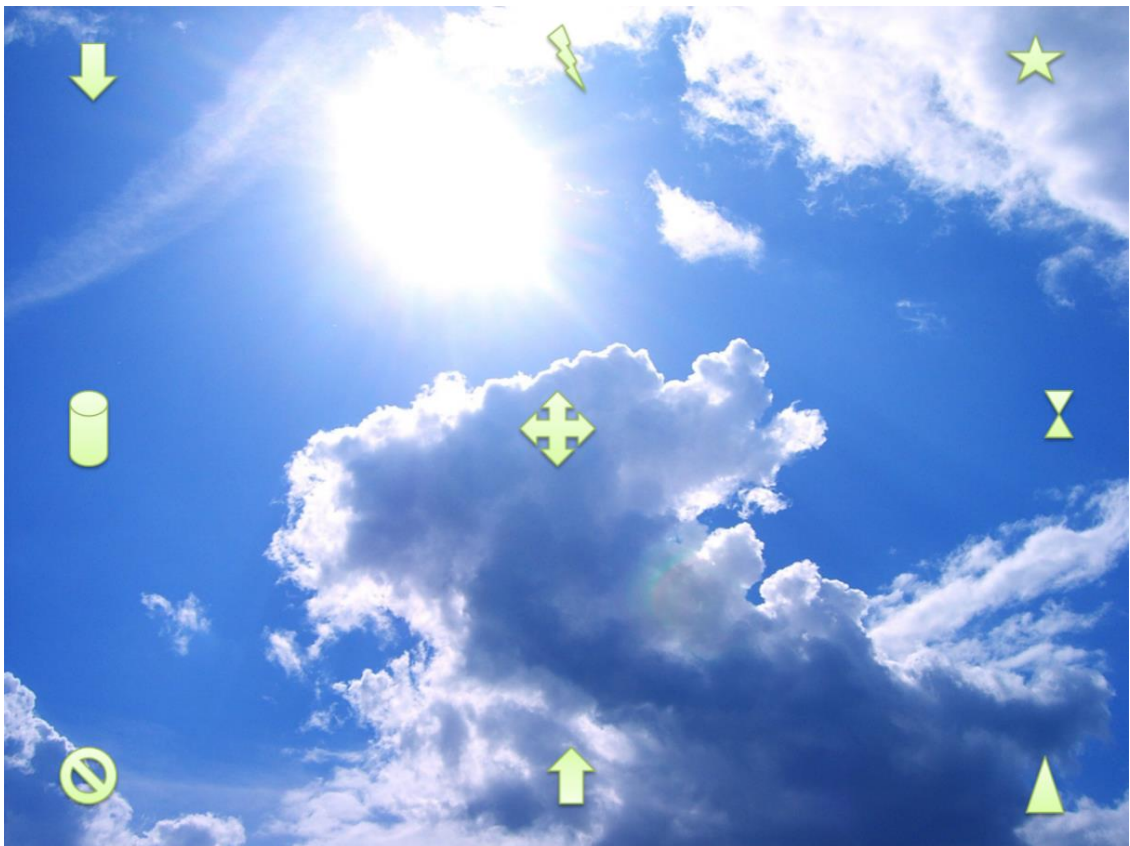
In outside scenery also, different symbols (which includes up arrow, down arrow, quad arrow, cylindrical shape, etc.) kept appearing and disappearing for checking awareness of user about outside scenery as shown in Fig. 3.26. Automatic luminance control was disabled so as to conduct experiments at uniform contrast setting. This ensured that all participants were provided with uniform test conditions.



(A)



(B)



(C)

**FIGURE 3.26 (A), (B), (C) SIMULATED OUTSIDE SCENE WITH APPEARING AND DISAPPEARING SYMBOLS**



both HUD event detection and outside event detection were averaged for each instance (for e.g.: event detection percentage for HUD and outside scene at AL value of '30,000 cd/m<sup>2</sup>', SL value of '100 cd/m<sup>2</sup>' and NU level of '1:1.3' averaged for all the participant scores). This final average score was used as the percentage observation value for the corresponding instance (operation variable values).

CR varied at different locations on combiner display area in experimentation carried out in this study due to two factors: (i) Ambient lighting prevailing through that particular location of the combiner, and (ii) Luminance of the symbology or image at that location which varies due to NU. After collection and mathematical processing of data, interpretation of data was performed to obtain the results.

### **3.2.3.2 Results and Discussions**

Data collected was extensive in nature. Data was divided into three broad ranges w.r.t AL level (High, Mid and Low). Within each range of AL, readings were collected for 17 levels of SL and 4 levels of NU for a selected AL value. For e.g.: in case of High AL: for AL of level 30,000 cd/m<sup>2</sup> readings for 17 levels of SL at 4 levels of NU were taken. Readings were taken at regular intervals in every range to ensure representation of all ambient conditions. CR as defined above was calculated simultaneously for all the instances. Variation in CR as observed over the combiner is presented in Table 3.4.

After collection of data, statistical analysis of the data was done using MATLAB platform. Paired t-test was performed to check whether the difference in event detection percentages for both cases i.e. event detection on HUD symbology and outside scene is significant or not.

All p values were found to be less than the significance level of 0.05 which indicates that means were different for event detection observed on HUD symbology and outside scene.

**TABLE 3.4 COMPARING CONTRAST RATIO OBTAINED FOR VARYING AMBIENT LUMINANCE FOR FOUR DIFFERENT NON-UNIFORMITY RANGES**

<b>Parameter</b>	<b>NU 1:1</b>	<b>NU 1:1.15</b>	<b>NU 1:1.30</b>	<b>NU 1:1.45</b>
<b>High AL</b>	1.003-1.8	1.002-1.695	1.002-1.615	1.0023-1.55172
<b>Mid AL</b>	1.02-9	1.017-7.956	1.015-7.153	1.013-6.517
<b>Low AL</b>	1.1-161	1.086-140.130	1.076-124.076	1.068-111.3448

Paired t-test was performed on two data vectors. In this study, two vectors were event detection on HUD symbology and outside scene. Thus, a paired t-test was performed with the null hypothesis that data in vectors HUD symbology and outside scene event detection are independent random samples from normal distributions with equal means (no difference between the two), against the alternative that means are not equal (two vectors are different from each other).

**TABLE 3.5 COMPARING P-VALUES OBTAINED FOR VARYING AMBIENT LUMINANCE FOR FOUR DIFFERENT NON-UNIFORMITY RANGES**

<b>Parameter</b>	<b>NU 1:1</b>	<b>NU 1:1.15</b>	<b>NU 1:1.30</b>	<b>NU 1:1.45</b>
<b>High AL</b>	2.4777e-024	2.5254e-025	5.7617e-026	1.7001e-026
<b>Mid AL</b>	0.0046	0.0109	0.0251	0.0455
<b>Low AL</b>	2.2923e-014	1.4890e-015	8.5354e-017	5.7107e-018

The paired t-test results  $h = 1$ , for all three ranges of AL as well as all three ranges of NU (resulting in differential contrast across display field) shows that the null hypothesis is rejected in both the groups. The p values calculated for data are listed in the Table 3.5.

These results establish the fact that there is a difference in level of event detection on HUD symbology and outside scene. But the question still remains whether this difference is significant as well as whether it is dependent only on varying AL or varying SL or the NU or all the three factors. To verify these assumptions, statistical tool ANOVA i.e. analysis of variance was used.

Initially, three-way ANOVA was performed using MATLAB platform. Three-Way ANOVA was performed for all three ranges of AL, corresponding SL and NU for event detection on both HUD symbology as well as outside scene. In ANOVA summary table, meanings of abbreviations are: SS = sum of squares; df = degrees of freedom; MS = mean square; F = F-value; P-value = probability or level of significance (rejection of the null hypothesis when p value < 0.05);  $F_{crit}$  = Critical f value (rejection of null hypothesis when test statistic < critical value i.e.  $F < F_{crit}$ ). Error MS was used to obtain the F values for both factors. The null hypotheses could be stated as:

- $H_{0A}$ : There is no difference in the percentage of event detection due to different AL.
- $H_{0B}$ : There is no difference in the percentage of event detection due to different SL.
- $H_{0c}$ : There is no difference in the percentage of event detection due to NU.
- $H_{0AB}$ : There is no interaction of varying AL and SL in causing significant difference in the percentage of event detection.
- $H_{0AC}$ : There is no interaction of varying AL and NU in causing significant difference in the percentage of event detection.
- $H_{0BC}$ : There is no interaction of varying SL and NU in causing significant difference in the percentage of event detection.
- $H_{0ABC}$ : There is no interaction of varying AL, SL and NU in causing significant difference in the percentage of event detection.

When ANOVA was attempted with three-way interactions and Type 3 sums-of-squares; all terms were marked by a # symbol. Thus, it becomes impossible to estimate three-way interaction effects, and inclusion of three-way interaction term in the model makes the fit singular. Also, p value found for three-way interaction term was much higher than 0.05.

Consequently a two way ANOVA examination was done. Here, the p-value for AL was less than 0.05 and the  $F > F_{crit}$ , so the hypothesis that there was no difference in the percentage of event detection due to different AL could be rejected. The p-value for SL was

also less than 0.05 and  $F > F_{crit}$ , hence the hypothesis that there was no difference in the percentage of event detection due to different SL could also be rejected. The p-value for interaction was also below 0.05, thus the null hypothesis  $H_{0AB}$  was also rejected; it means that their interaction was a significant factor contributing to the response “event detection”. Similar trends could be seen from ANOVA summary tables for other combinations i.e.,  $H_{0A}$ ,  $H_{0B}$ ,  $H_{0C}$ ,  $H_{0BC}$  and  $H_{0AC}$ . The results obtained are presented in the ANOVA summary tables (Table 3.6, Table 3.7, Table 3.8, Table 3.9, Table 3.10 and Table 3.11).

From Table 3.6, following results could be deduced: AL, SL and NU have a significant main effect on event detection from HUD image during high AL conditions. Interaction effect of (i) AL and SL, (ii) SL and NU, have a significant effect on event detection from HUD symbology during high AL conditions. Interaction effects of AL and NU have an insignificant effect on HUD event detection during high AL conditions.

**TABLE 3.6 RESULTS OF ANOVA PERFORMED ON EVENT DETECTION FROM HUD SYMBOLOGY WHEN AMBIENT LUMINANCE WAS HIGH**

Source	AL	SL	NU	AL*SL	AL*NU	SL*NU	Error	Total
Sum Sq	3174.7	7214.8	522.8	693.9	15.8	110.3	116.7	12005.6
d.f.	2	16	3	32	6	48	96	203
Mean sq.	1587.34	450.93	174.26	21.68	2.64	2.3	1.22	
F	1305.28	370.8	143.3	17.83	2.17	1.89		
Prob> F	0	0	0	0	0.0526	0.0042		

**TABLE 3.7 RESULTS OF ANOVA PERFORMED ON EVENT DETECTION FROM HUD SYMBOLOGY WHEN AMBIENT LUMINANCE WAS IN MID-RANGE**

Source	AL	SL	NU	AL*SL	AL*NU	SL*NU	Error	Total
Sum Sq	8594	2331.8	524	648.3	27.2	55.3	62.5	33226.2
d.f.	2	16	3	32	6	48	96	203
Mean sq.	4297	1457.18	174.68	20.26	4.53	1.15	0.65	
F	6600.2	2238.22	268.31	31.12	6.95	1.77		
Prob> F	0	0	0	0	0	0.0091		

From Table 3.7, following results could be deduced: AL, SL and NU have significant main effect on event detection from HUD symbology during medium AL conditions. Interaction effect of (i) AL and SL, (ii) SL and NU, and (iii) AL and NU, have a significant effect on event detection from HUD symbology during medium AL conditions.

**TABLE 3.8 RESULTS OF ANOVA PERFORMED ON EVENT DETECTION FROM HUD SYMBOLOGY WHEN AMBIENT LUMINANCE WAS LOW**

SOURCE	AL	SL	NU	AL*SL	AL*NU	SL*NU	ERROR	TOTAL
SUM SQ	1375.8	19486.6	96	2518.6	15.2	162.6	71.9	23764.9
D.F.	2	17	3	34	6	51	102	215
MEAN SQ.	687.9	1146.27	32.01	74.08	2.53	3.19	0.71	
F	975.8	1625.15	45.39	105.02	3.59	4.52		
PROB> F	0	0	0	0	0.0029	0		

From Table 3.8, following results could be deduced: AL, SL and NU have a significant main effect on event detection from HUD symbology during low AL conditions.

Interaction effect of (i) AL and SL, (ii) SL and NU and (iii) AL and NU, have a significant effect on event detection from HUD symbology during low AL conditions.

**TABLE 3.9 RESULTS OF ANOVA PERFORMED ON EVENT DETECTION FROM OUTSIDE SCENE WHEN AMBIENT LUMINANCE WAS HIGH**

Source	AL	SL	NU	AL*SL	AL*NU	SL*NU	Error	Total
Sum Sq	117.855	146.683	498.349	64.844	0.047	0.574	3.095	841.039
d.f.	2	16	3	32	6	48	96	203
Mean sq.	58.927	9.168	166.116	2.026	0.008	0.012	0.032	
F	1827.57	284.33	5151.92	62.85	0.25	0.37		
Prob> F	0	0	0	0	0.9601	0.9999		

From Table 3.9, following results could be deduced: AL, SL and NU have a significant main effect on outside event detection during high AL conditions. Interaction effect of AL and SL has a significant effect on outside event detection during high AL

conditions. Interaction effect of (i) SL and NU and (ii) AL and NU have an insignificant effect on outside event detection during high AL conditions.

**TABLE 3.10 RESULTS OF ANOVA PERFORMED ON EVENT DETECTION FROM OUTSIDE SCENE WHEN AMBIENT LUMINANCE WAS IN MID-RANGE**

Source	AL	SL	NU	AL*SL	AL*NU	SL*NU	Error	Total
Sum Sq	7902.8	5028.9	1629.2	4603.8	8.2	5.2	4.8	19182.7
d.f.	2	16	3	32	6	48	96	203
Mean sq.	3951.38	314.3	543.07	143.87	1.36	0.11	0.05	
F	79822.4	6349.28	10970.7	2906.31	27.47	2.18		
Prob> F	0	0	0	0	0	0.0006		

From Table 3.10, following results could be deduced: AL, SL and NU have a significant main effect on outside event detection during medium AL conditions.

Interaction effects of (i) AL and SL, (ii) AL and NU and (iii) SL and NU have a significant effect on outside event detection during medium AL conditions.

**TABLE 3.11 RESULTS OF ANOVA PERFORMED ON EVENT DETECTION FROM OUTSIDE SCENE WHEN AMBIENT LUMINANCE WAS LOW**

Source	AL	SL	NU	AL*SL	AL*NU	SL*NU	Error	Total
Sum Sq	50186.5	78887.1	1088.2	7787.4	89.4	143.1	5.8	139097
d.f.	2	17	3	34	6	51	102	215
Mean sq.	25093.3	4640.4	362.7	229	14.9	2.8	0.2	
F	16197.3	29942.9	2340.66	1477.92	96.14	18.11		
Prob> F	2.54E-01	2.03E-01	7.19E+0	4.71E-01	1.05E+0	2.78E+00		

From Table 3.11, following results could be deduced: AL, SL and NU have a significant main effect on outside event detection during low AL conditions.

Interaction effects of (i) AL and SL, (ii) AL and NU and (iii) SL and NU have a significant effect on outside event detection during low AL conditions.

Thus, it can be concluded from the above discussion that HUD can lead to attention capture and tunneling if relative SL and AL are not optimized with respect to each other.

### **3.3 CONCLUSION**

First objective of the work involved studying all technical aspects of HUD leading to problem of tunneling. In process of achieving this objective, first milestone covered was Literature Survey (as discussed in Chapter 2). Literature Survey helped in developing a better understanding towards research problem. In continuation, it was followed by a number of experiments to establish the role of factors affecting attention tunneling. Various conclusions drawn from these experiments are as discussed below.

#### **3.3.1 HUD LUMINANCE EXPERIMENT OUTCOMES**

Experimental results suggest that SL, CR and NU of HUD display play a definite role in attention capture and tunneling due to HUD usage. Pilot tends to pay more attention towards HUD display and slightly loses focus on outside scene when CR is more than 4.0. High contrast captures most of the pilot's attention which reduces optimal allocation of focus on both, HUD as well as outside events. This phenomenon happens when ambient lighting is less. When CR is less than 1.4 and ambient is very bright, pilot gets engaged more towards outside events as brighter ambient grabs most of his attention though HUD event detection improves as CR approaches 1.4. For same CR under less bright ambient lighting, pilot gets better distribution of his focus to both events than during brighter ambient conditions. Darker ambient reflection from combiner glasses adds to the confusion and further deteriorates attention capture distribution. Best trade-off performance was obtained at a CR of 2 - 3.5 which produced optimum attention capture distribution at all AL levels. It could thus be said that absolute luminance level of HUD display and ambient lighting significantly affects attention capture phenomenon. Brighter HUD display makes salience of changes against background more prominent which in turn could distract pilot and capture their attention and, therefore, increase response times to aircraft events. Alternately, it could be said that high CR would benefit display event more at the cost of aircraft event detection when compared to the case of lower CR. Therefore, a mid-level CR of 2 - 3.5 gave best results.

NU of HUD display results in differential luminance across HUD display. This leads to a condition of variable CR across HUD display. This further adds to the confusion as pilot has now to look differential luminance over a smaller area at the same time. At higher AL, non-uniform SL causes more degradation in HUD event detection than caused in outside events. At low ambient lighting conditions, degradation in both the events is significant with HUD event detection getting effected more adversely. At lower AL, prominence of SL variation significantly forces pilot to get engaged in HUD events and in the process he loses focus on outside events.

### **3.3.2 EFFECTS OF LIMITING FOV DUE TO HUD BEAM COMBINER FRAME**

Combiner frame tends to cause misaccommodation and misconvergence problems due to limited TFOV and IFOV. The net result is obscuration of pilot's forward view of outside world. Though, pilot gets HUD symbology in full IFOV and TFOV range but still he/she may miss some outside events due to combiner frame angle and its thickness. When pilot is required to move his head outside HMB to detect missing outside world events it results in attention tunneling.

From the study, another fact which could be stated is that collimation does not always pull pilot's visual focus outward to optical infinity. In fact, in some cases visual misaccommodation may become worse due to dominance of combiner frame obscuration over the collimation.

Fixed FOV in horizontal direction limits the presentation of symbology which also contributes to attentional narrowing. Thus, while designing combiner frame structure care must be taken to ensure that its edges are seen as single line when viewed from DEP. Further, thickness of frame needs to be optimized as lesser thickness causes lesser distraction thereby reducing chances of misaccommodation and misconvergence. This is also necessary to minimize attentional tunneling due to combiner frame obstructions. Based on participant's response, it was concluded that combiner frame causes tunneling, the extent of which is

dependent on amount of obscuration due to combiner frame. This results in failure of user to optimize his attention appropriately on HUD and outside events simultaneously. Thus, it could be concluded that optimized frame thickness and inclination angle are essential for minimizing tunneled vision through the HUD.

### **3.3.3 STATISTICAL ANALYSIS IN ESTIMATION OF TUNNELING EFFECT DUE TO LUMINANCE NON-UNIFORMITY IN HEAD-UP DISPLAYS**

Paired t-test results established the fact that there is a difference in level of event detection on HUD symbology as well as outside scene. To verify dependence and interaction effect of all contributing factors, ANOVA was used. The p-value found through ANOVA showed that percentage of event detection gets significantly affected due to AL and SL both. Statistical results obtained confirm dependency of attention tunneling phenomenon on symbology contrast.

It was observed that wherever CR on display area was less than 1.4, response of participants to the events displayed on HUD symbology appearing on those HUD areas was inferior. When CR was kept less than 1.4, percentage for events detection on HUD symbology varied from 47% to 70% while event detection in the outside scene lied in range of 98% to 94%. Through these areas, outside scene event detection was much better. Because of NU, there was possibility of CR in certain areas being more than 1.4 and in certain areas less than 1.4.

In cases where CR on display area was between 1.4 and 5, percentage of event detection on HUD symbology varied from 70% to 95% while for event detection in the outside scene it lied in range of 94% to 86%. Response of participants for events displayed on HUD symbology was found to be very good. However, through these areas of HUD, outside scene event detection deteriorated w.r.t previous case. Here, variation in CR due to NU caused less significant variation in event detection.

In case of CR being more than 5, percentage for event detection on HUD symbology varies from 95% to 99% while for event detection in the outside scene, it lied in range of 86% to 11%. Wherever CR on display area was more than 5, response of participants to the events displayed on HUD symbology appearing on high contrast areas was excellent. Through such areas, outside scene was poor for obvious reasons of attention tunneling. For CR beyond 7, effect of NU on detection of events on HUD symbology as well as outside scene was reduced. In such cases, event detection showed significant dependence on the AL, SL, and CR while less significantly on NU. The study resulted in generation of extensive amount of data which was further used in the research work to minimize attention tunneling effect while using HUDs.

# REAL TIME IMAGE PROCESSING SYSTEM DEVELOPED FOR HUD IMAGE CAPTURING AND DATA LOGGING

## 4.1 THEORY

### 4.1.1 TEXTURE ANALYSIS

Digital image processing involves image acquisition, pre-processing, filtering and post-processing. Since whole world now works with digital data mostly the area has high significance in the field of research. Significant applications include: image filtering, image compression, texture analysis, image segmentation, etc. [Karam *et al.* (1998); Karam (2009)].

Texture analysis is a broad area of image processing. The broadness of the term could be understood by the fact that there is not a single fixed definition of texture in the area of machine vision and image processing. Tuceryan and Jain (1998) have mentioned that the definition of texture is formulated by different people depending upon the particular application and that there was no generally agreed upon definition. Some are perceptually motivated, and others were driven completely by the application.

Texture analysis had been applied in a diversified manner for variety of applications. Various applications range from remote sensing, medical image analysis, document image processing, automatic inspection of defect in textile industry and others [Laddi *et al.* (2013)]. According to need of the task, texture analysis could be performed using statistical properties/geometrical properties/model based prediction/signal processing based techniques [Gonzalez (2009)].

Any image can be characterized by its primitives such as colour, shape and texture. Texture is one of the significant characteristics used to classify regions of interest or objects in an image. Interpretation of images can be done through pattern elements such as textural,

contextual and spectral features. Textural features include information about image texture characteristics such as gray-tone linear dependencies, contrast, homogeneity, complexity, and nature and number of boundaries existing in the image. Contextual features include information resultant from image data neighbouring the area under analysis. Spectral features contain tonal variations in bands of visible and/or infrared spectra [Haralick *et al.* (1973)].

Composite image captured by HUD camera could be very complex. Its texture analysis could reveal discrimination features necessary to classify tunnelled and the normal HUD display. Texture is an inherent property of nearly all the surfaces and carries useful discrimination features. It possesses important information about the structural arrangement of surfaces and their relationship to surrounding environment. Image texture can be characterized through descriptors like autocorrelation, central moments, directionality coarseness, etc. It can be described by number and types of its primitives and the spatial organization of the same. The spatial organization may be random, having a pair wise dependency of one primitive on a neighbouring primitive, may have a multiple dependency of  $n$  primitives at a time [Clausi (2002)]. In this study we used statistical method for analysis of HUD image.

Various texture features could be extracted using co-occurrence probabilities. A co-occurrence matrix also referred to as a co-occurrence distribution, is defined over an image image to be the distribution of co-occurring values at a given offset. Gray-level co-occurrence matrix (GLCM), a statistical method of exploring texture, takes into consideration spatial relationship of pixels. This matrix is formed by calculating how often a pixel with a particular gray level 'i' occurs either horizontally or vertically or diagonally to adjacent pixels with value 'j'. It is to be understood that there is nothing like texture of a point, it is a relative measure of adjacent areas, thus it is calculated over a spatial neighbourhood. The analysis was performed using Image Processing Toolbox of MATLAB [Mathworks, (2013)]. As it is

known, that any image processing task is performed over a gray scale image, texture analysis was also done using a gray image input.

Textures are generally random. However, textures possess consistent properties hence could be described in terms of their statistical properties. The gray level histogram computed for the HUD image could be used to calculate various moments. These could be used to illustrate statistical properties of the image. These histogram based measurements have a limitation that they carry no information regarding the relative spatial position of pixels with other pixels. Spatial dependence relationships were incorporated by considering the distribution of intensities as well as the position of pixels with equal or nearly equal intensity values. This involved statistically sampling the way certain gray levels occur in relation to other gray levels. Through this method, we obtained the GLCM of specified texture, which further gave various descriptors by measuring texture properties.

GLCM features like contrast, dissimilarity, homogeneity, entropy, energy, maximum probability, variance and correlation are primary texture features to describe an image and were used to describe HUD image extracted from the camera captured HUD video. Rest of secondary features like mean, median, standard deviation, etc. were derived from the primary texture features. All these GLCM texture features were used for HUD image classification in terms of tunneled and normal image [Haindl and Mikes (2008); Gonzalez (2009)].

GLCM is a second-order texture measure. Different GLCM parameters are related to specific first order statistical parameters. Association of a textural meaning to each of these parameters is very critical. GLCM is dimensioned to number of gray levels and stores the co-occurrence probabilities  $g_{ij}$ . To determine texture features, selected statistics are applied to each GLCM by iterating through the entire matrix [Mathworks (2013)].

Textural features are based on statistics, which summarize the relative frequency distribution, calculated in form of matrix  $p_{(i,j)}$ , that describes how often one gray tone 'i' will appear in a specified spatial relationship to another gray tone 'j' on the image. GLCM

contrast and homogeneity are strongly, but inversely correlated in terms of equivalent distribution in the pixel pair population. It means homogeneity decreases if contrast increases while energy is kept constant. Entropy is strongly, but inversely correlated to energy [Gonzalez (2009)].

In contrast, dissimilarity and homogeneity parameters, decision is made by assigning weights to intensity/gray value relationships of pixel pairs under evaluation. The contrast is a measure of intensity contrast between a pixel and its neighbour over the whole image. It is given by:

$$Contrast = \sum_{i,j} |i - j|^2 p_{(i,j)} \quad (4.1)$$

Where,  $p_{(i,j)}$  refers to relative frequency distribution of gray level 'i' w.r.t another gray level 'j'. It measures the spatial frequency of an image and is difference moment of GLCM. When i and j are equal, diagonal elements are considered and  $(i-j) = 0$ . These values represent pixels entirely similar to their neighbour, so they are given a weight of 0. When difference between i and j is more, contrast and weights are also more. Weights continue to increase exponentially as  $(i-j)$  increases. It is the difference between highest and the lowest values of a contiguous set of pixels. In Contrast measure, weights increase exponentially (0, 1, 4, 9, etc.) as one moves away from the diagonal.

Homogeneity of image has been obtained by assigning larger values for smaller gray tone differences in pair elements. It is represented by:

$$Homogeneity = \sum_{i,j} \frac{p_{(i,j)}}{1 + |i - j|} \quad (4.2)$$

It is more sensitive to presence of near diagonal elements in GLCM. This means that if weights decrease away from diagonal the result is larger for windows with little contrast.

Energy returns the sum of squared elements in the GLCM. It is expressed as:

$$Energy = \sum_{i,j} p_{(i,j)}^2 \quad (4.3)$$

It acquires high values when gray level distribution has a constant form. It has a normalized range and measures the textural uniformity and in process detects disorders in textures.

The Correlation was used to express gray tone linear dependencies in HUD image and expressed as:

$$Correlation = \sum_{i,j} \frac{(i - \mu_i)(j - \mu_j)p_{(i,j)}}{\sigma_i \sigma_j} \quad (4.4)$$

It is a measure of how correlated a pixel is to its neighbour over the whole image. Entropy also measures the disorder of an image. It is a statistical measure of randomness that could be used to characterize texture of input image. It is expressed as:

$$Entropy = -sum(p.* log2(p)) \quad (4.5)$$

where, p contains the histogram counts returned from *imhist*. Entropy of grayscale image  $E = entropy(I)$  returns E, a scalar value representing the entropy of grayscale image I. Entropy is large when image is not texturally uniform and many GLCM elements have very small values.

Mean of the matrix elements of an image is calculated by:

$$B = mean(A(:)) \quad (4.6)$$

where, the input image A can be numeric or logical. The output image B is a scalar of class double.

Standard deviation of matrix elements of an image is calculated by:

$$b = std(A(:)) \quad (4.7)$$

where, the input image A can be numeric or logical. The output image b is a scalar of class double [Haralick *et al.* (1973); (2013)].

## 4.2 EXPERIMENT - FEATURE EXTRACTION OF HUD IMAGES

CCD camera situated on HUD in front of combiners captures the composite image comprising forward view and symbology. Outside images encountered during various phases of flight are diverse in properties. Outside view could be sun diffused clouds, city buildings and trees during landing, normal clear sunny sky, low lighted outside view during dusk and dawn, dark ambience during night, etc. Thus it may contain variety of objects with varying frequency, varying colour patterns and shades, textures, etc. Symbology needs to be seen by the pilot against these backgrounds. Intensity and contrast patterns of symbology play an important role in maintaining adequate contrast against these backgrounds such that pilot is able to focus his attention optimally on these events. More symbol intensity in dark conditions result in reflection from the combiner glasses and windscreen preventing adequate outside view while higher background ambient necessitates setting of symbol intensity to higher level. These complexities of HUD operation have been studied through image analysis of HUD camera captured image.

Texture analysis of composite image captured by HUD camera could reveal discriminating features necessary to classify tunnelled and the normal HUD display. Texture possesses important information about structural arrangement of surfaces and their relationship to surrounding environment. Image texture can be characterized through descriptors like autocorrelation, central moments, directionality coarseness, etc.

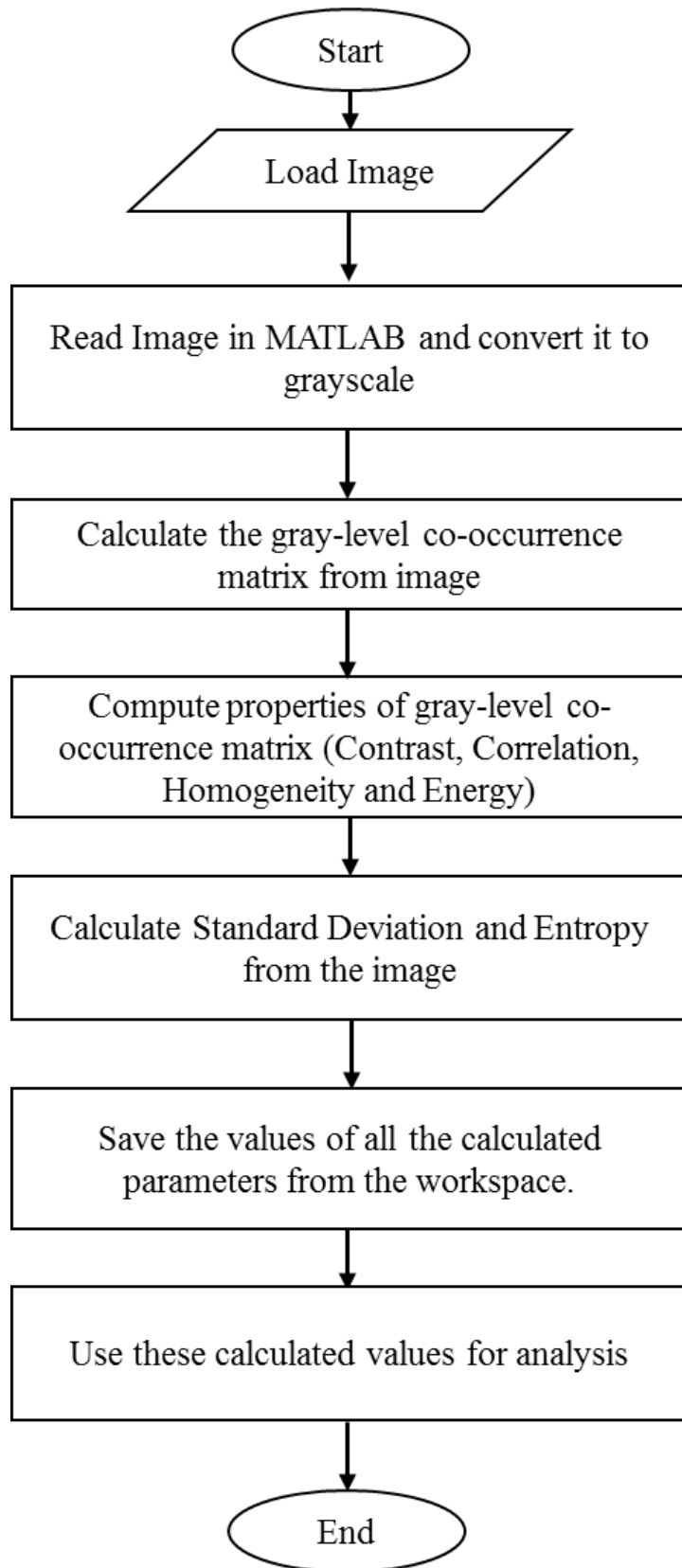
In captured imagery, outside world is with continuous gray levels and may have varying intensities and contrast throughout the scene while stroke form symbology has same luminance throughout. The luminance and contrast patterns of the symbology play an important role in maintaining adequate contrast against varying backgrounds. Image frames were extracted from the captured HUD videos and used as input image. Input image was converted to gray scale, *glcm* was calculated for the input image and properties of *glcm* were extracted using *graycoprops* function. The GLCM features like contrast, homogeneity,

energy and correlation are primary texture features to describe an image. All these GLCM texture features along with standard deviation and entropy of image were used for HUD image classification in terms of tunneled and normal image [Gonzalez (2009)].

Experimental setup as shown in Fig. 4.1 consisted of HUD unit, projector and computer for background scene, video recording mechanism, HUD signal simulator and mounting platform. Camera captured the same view as seen from front through the HUD. This captured video was broken into frames to analyse its texture characteristics for classifying HUD images. The symbology chosen for the purpose was a simulated flight page run on actual HUD unit with its luminance modulated through software. This ensured that maximum possible combinations of CRs were obtained to judge tunneling due to SL relative to ambient lighting. Examples of normal and the tunneled images used for experimentation are shown in Fig. 4.3, Fig. 4.4 and Fig. 4.5 while the methodology has been shown through flowchart in Fig. 4.2.



**FIGURE 4.1 EXPERIMENTAL SETUP FOR CAPTURING COMPOSITE VIDEO THROUGH HUD CCD CAMERA**



**FIGURE 4.2 FLOWCHART FOR EXTRACTING TEXTURE FEATURES OF HUD CAPTURED IMAGE**



**FIGURE 4.3 POTENTIAL TUNNELED HUD IMAGE WITH LOW SYMBOL SALIENCE**



**FIGURE 4.4 NORMAL OPERATION HUD IMAGE**



**FIGURE 4.5 POTENTIAL TUNNELED HUD IMAGE WITH HIGH SYMBOL SALIENCE**

#### **4.2.1 RESULTS AND DISCUSSION**

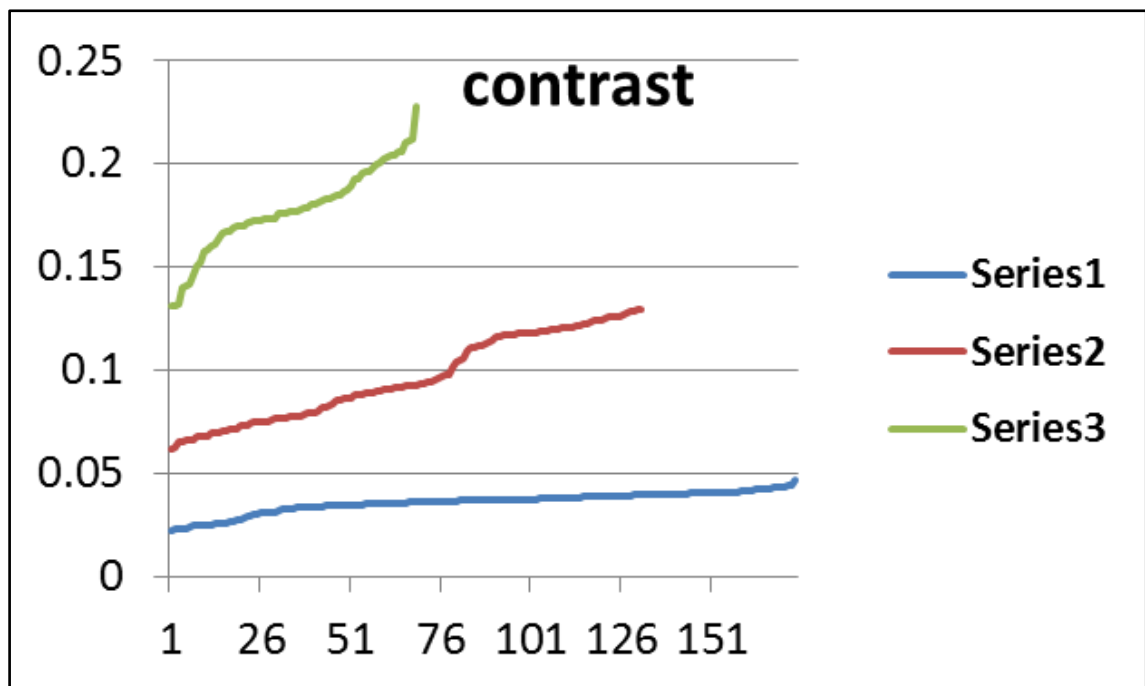
Present methods of detecting attention tunneling are offline and based on subjective judgment of people. However, manual methods were employed so far; an approach primarily assistive in nature to begin with, would be a step ahead towards automation. For the purpose, an algorithm was developed using the MATLAB platform to perform the texture analysis over HUD captured images. The trends obtained when the calculated parameters were plotted in form of graphs are as shown in Fig. 4.6, Fig. 4.7, Fig. 4.8, Fig. 4.9, Fig. 4.10 and Fig. 4.11.

Experiments simulated variety of conditions having different backgrounds and with varying SL. Attempt was made to evolve a pattern which could be used to classify HUD image conditions in terms of tunneled or non-tunneled cases.

Analysis of resultant graphs indicate that contrast, homogeneity and correlation parameters calculated for composite HUD images show significant clue regarding normal and the tunneled HUD images.

Blue lines in Fig. 4.6, Fig. 4.7 and Fig. 4.9 give a hint about HUD image having tunneling due to low symbology salience. Visual examination was supported by low contrast, high homogeneity and high correlation values. On the other hand, green lines in Fig. 4.6, Fig. 4.7 and Fig. 4.9 give a clue about HUD image having tunneling due to high symbology salience. This time visual examination was supported by high contrast, low homogeneity and low correlation values. Middle range values for these parameters shown in red colour in Fig. 4.6, Fig. 4.7 and Fig. 4.9 indicate an appropriately lit symbology which will essentially result in appropriately distributed attention.

Other three parameters viz. energy, entropy and standard deviation do not reveal any meaningful information regarding attention capture or symbology salience. Thus, luminance contrast between a pixel and its neighbour over the whole image, gray tone differences in pair elements and gray tone linear dependencies in a HUD image indicated by these parameters could give a definite verdict regarding the need to lower or increase SL to mitigate tunneling and optimizing the attention capture.



**FIGURE 4.6 CONTRAST VALUE FOR HUD IMAGE CALCULATED THROUGH TEXTURE ANALYSIS**

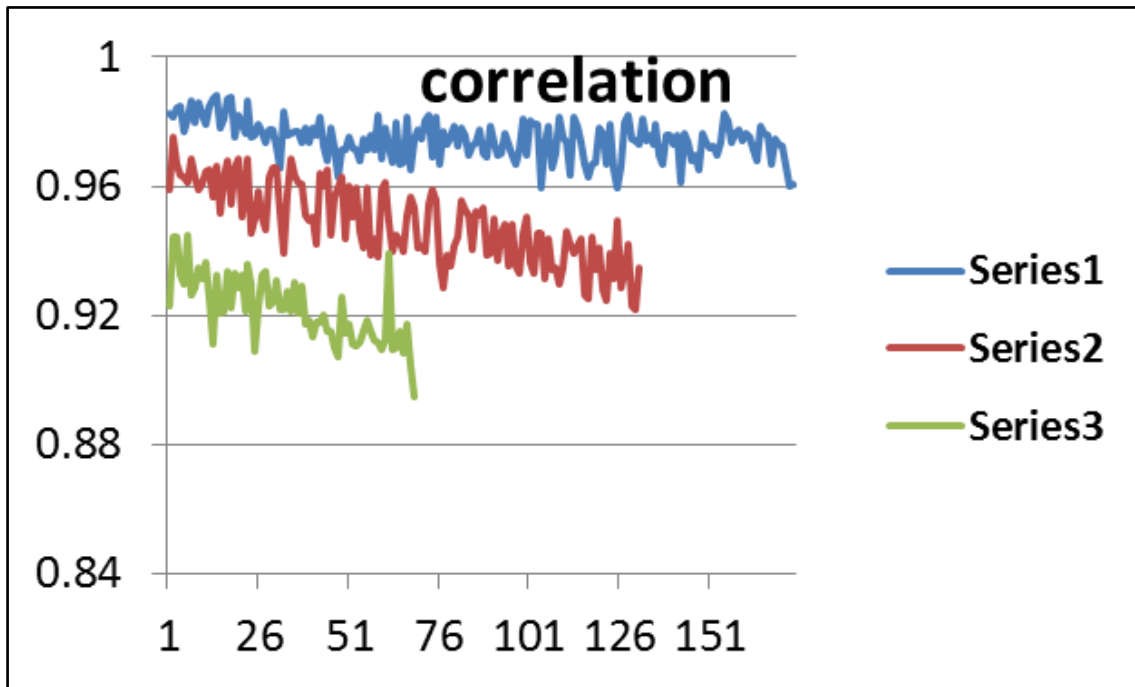


FIGURE 4.7 CORRELATION VALUE FOR HUD IMAGE CALCULATED THROUGH TEXTURE ANALYSIS

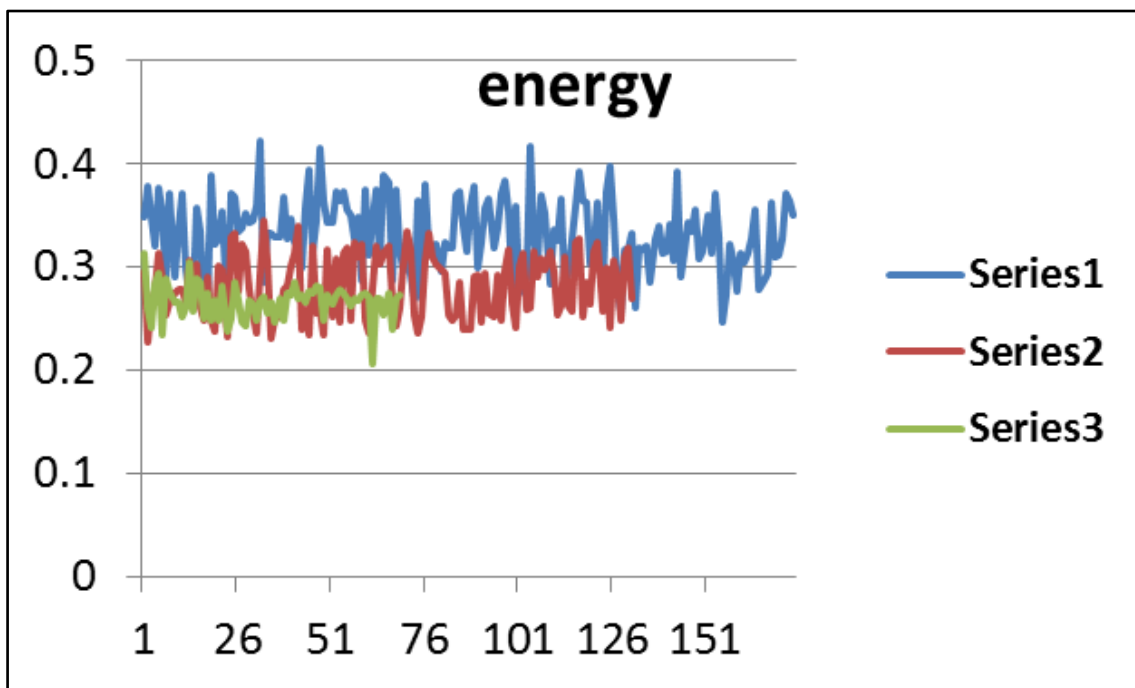


FIGURE 4.8 ENERGY VALUE FOR HUD IMAGE CALCULATED THROUGH TEXTURE ANALYSIS

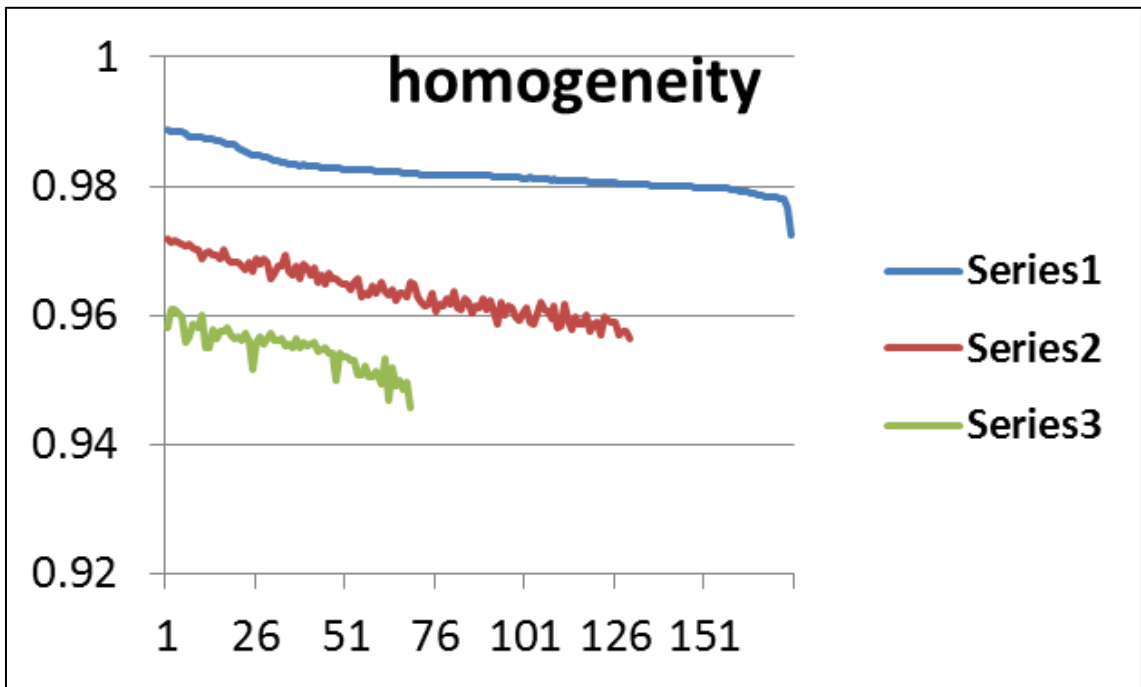


FIGURE 4.9 HOMOGENEITY VALUE FOR HUD IMAGE CALCULATED THROUGH TEXTURE ANALYSIS

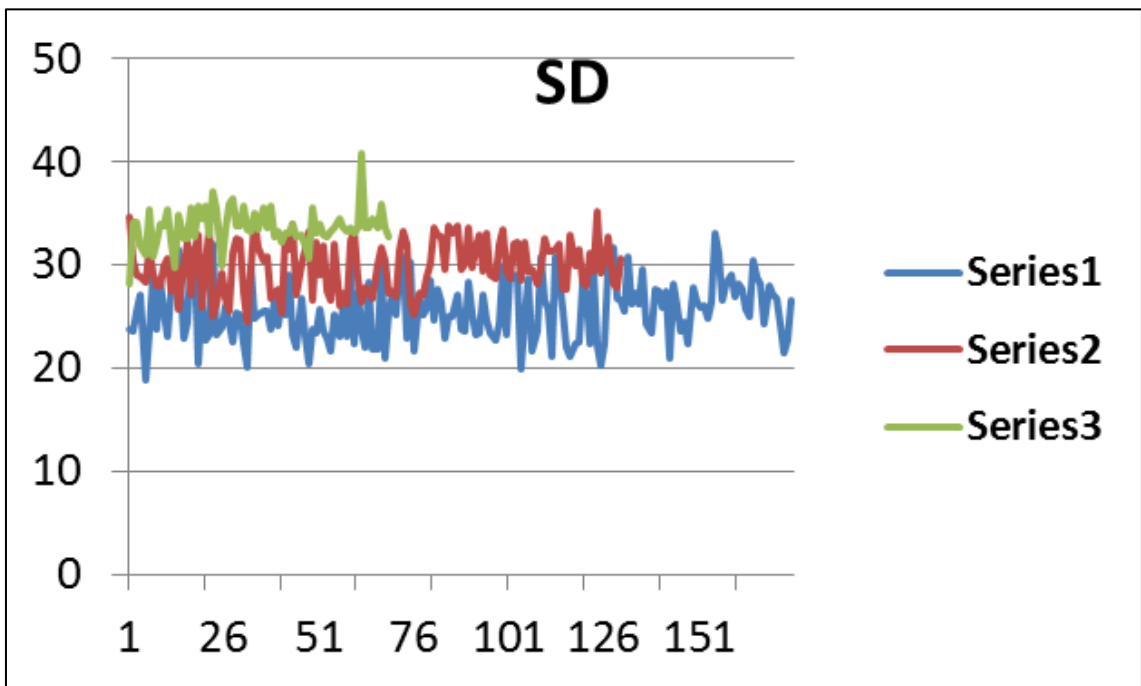
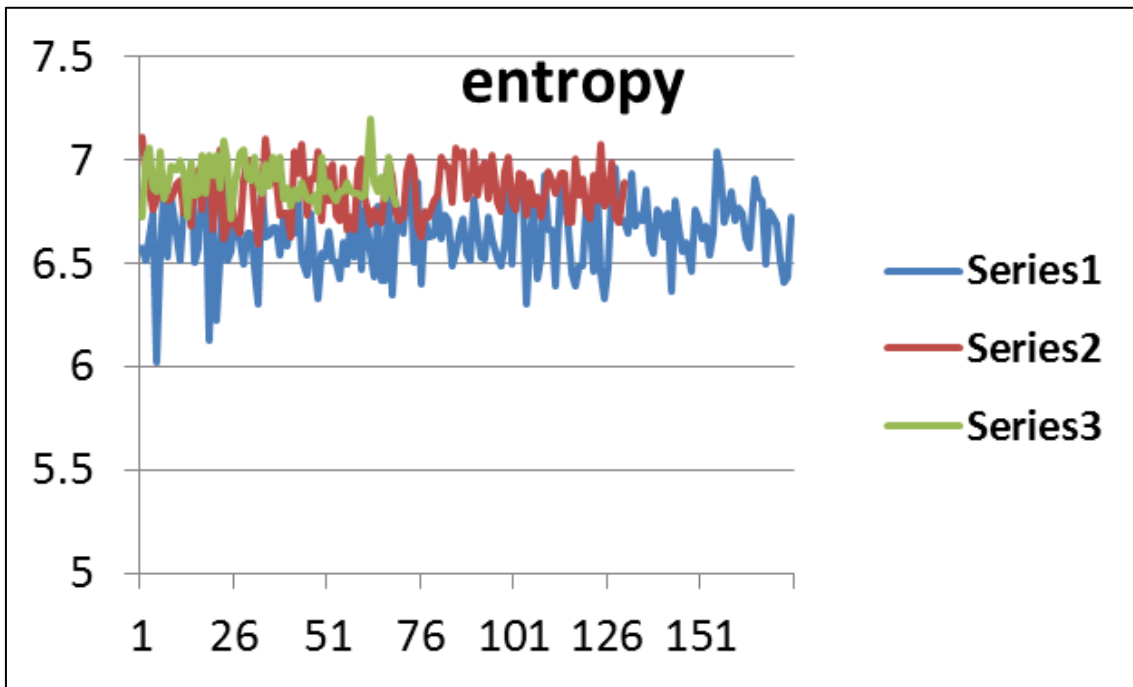


FIGURE 4.10 STANDARD DEVIATION VALUE FOR HUD IMAGE CALCULATED THROUGH TEXTURE ANALYSIS



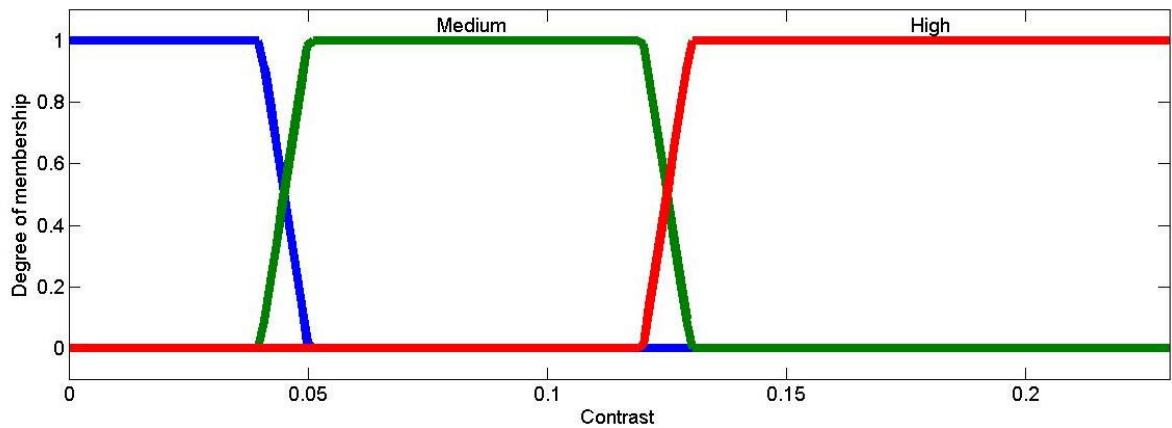
**FIGURE 4.11 ENTROPY VALUE FOR HUD IMAGE CALCULATED THROUGH TEXTURE ANALYSIS**  
 The maximum and minimum values of the parameter ranges are as listed in Table 4.1.

**TABLE 4.1 COMPARING THE CALCULATED PARAMETER RANGES FOR THE THREE IMAGE CATEGORIES:**

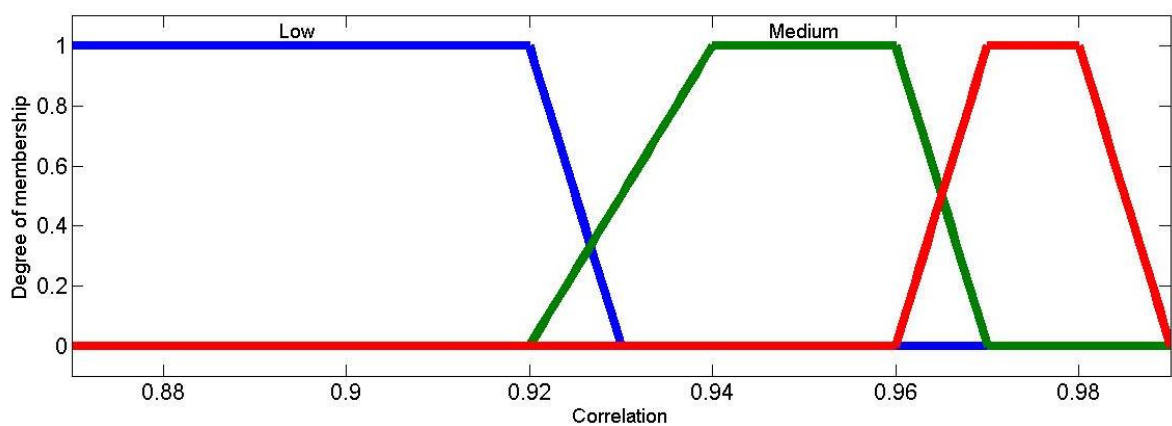
**SERIES 1- TREND FOR HUD IMAGES WITH LOW-SYMBOL SALIENCE; SERIES 2 - NORMAL OPERATION AND SERIES 3- TREND FOR HUD IMAGES WITH HIGH-SYMBOL SALIENCE**

Parameter	Series 1	Series 2	Series 3
Contrast	0.02 - 0.04	0.06 - 0.12	0.13 - 0.23
Correlation	0.96 - 0.99	0.92 - 0.97	0.89 - 0.94
Energy	0.24 - 0.42	0.22 - 0.34	0.20 - 0.31
Homogeneity	0.98 - 0.99	0.95 - 0.97	0.94 - 0.96
Standard Deviation	18.7 - 33.2	24.5 - 35.2	28.2 - 40.8
Entropy	6.02 - 7.04	6.6 - 7.11	6.72 - 7.20

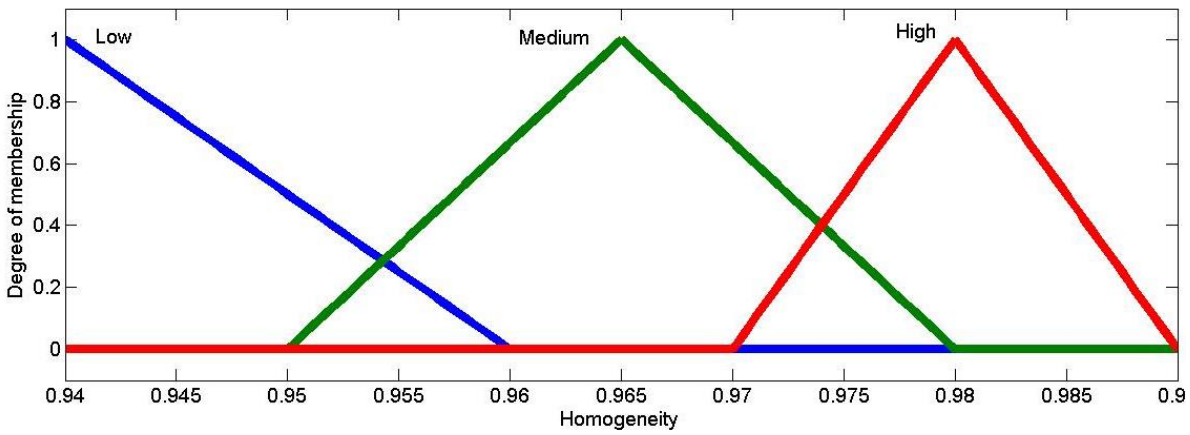
Contrast, correlation and homogeneity were used as input functions for the fuzzy system and each input was divided into three membership functions each. Sugeno type fuzzy model was chosen for the purpose and a total of 27 rules were made. The input membership functions are as shown in the Fig. 4.12, Fig. 4.13 and Fig. 4.14.



**FIGURE 4.12 INPUT MEMBERSHIP FUNCTION FOR CONTRAST AS INPUT FUNCTIONS FOR THE FUZZY SYSTEM**



**FIGURE 4.13 INPUT MEMBERSHIP FUNCTION FOR CORRELATION AS INPUT FUNCTIONS FOR THE FUZZY SYSTEM**



**FIGURE 4.14 INPUT MEMBERSHIP FUNCTION FOR HOMOGENEITY AS INPUT FUNCTIONS FOR THE FUZZY SYSTEM**

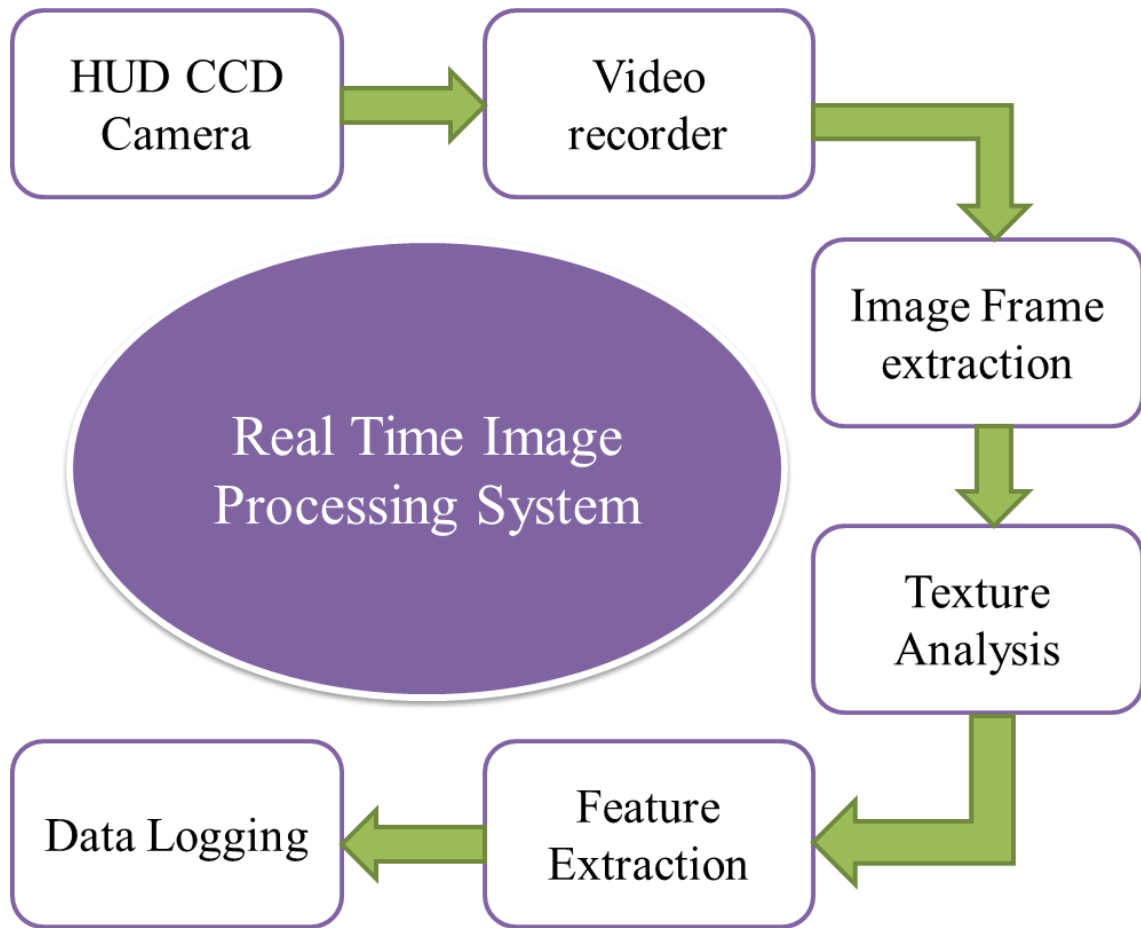
The GUI incorporating fuzzy system is shown in the Fig. 4.15.



**FIGURE 4.15 GUI REPRESENTING THE WORKING OF THE DEVELOPED FUZZY SYSTEM**

### 4.3 CONCLUSION

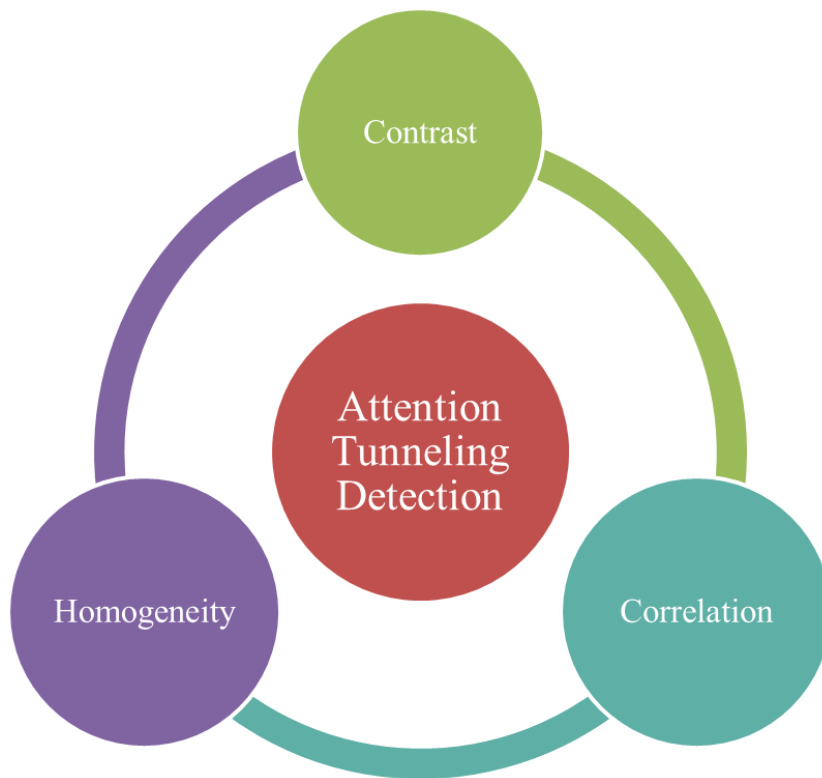
Experimental setup established for studying various factors of attention tunneling also involved real time capture of HUD camera video. This video was then further used to extract and generate image data set (Fig. 4.16). Generated image data set was saved and processing was done using these images.



**FIGURE 4.16 REAL TIME IMAGE PROCESSING SYSTEM DEVELOPED FOR HUD IMAGE CAPTURING AND DATA LOGGING**

#### **4.3.1 TEXTURE ANALYSIS FOR FEATURE EXTRACTION OF HUD IMAGES**

Texture analysis was used for detecting the attention tunnelling occurring while using HUDs. A total of six parameters were calculated for analysis, out of which three parameters namely: contrast, correlation and homogeneity were identified to show the distinction between normal and tunneled images effectively. These parameters served as identifying features to detect attention tunneling and were used for developing an automatic assistive decision making system based on fuzzy logic for adjusting the HUD symbology luminance for mitigating effect of tunnelling (Fig. 4.17).



**FIGURE 4.17 ATTENTION TUNNELING DETECTION USING FUZZY INFERENCE SYSTEM AND TEXTURE FEATURES**

## **CHAPTER 5**

# **COLLECTION OF DATA FOR GENERATION OF TRAINING AND TESTING DATABASE**

### **5.1 DATA COLLECTION**

Data collection is an important task which follows after formulation of research problem. Data could be classified as: primary data and secondary data. Primary data refers to original data collected by researcher on its own. Secondary data refers to data available already in the records and is then further utilized by researchers.

Data collection may be done in different forms according to the nature of experiment being carried out. While collecting primary data, in case of descriptive research, surveys form an important tool. The surveys could be conducted in a variety of ways: direct observation method, questionnaire or interviews. While collecting primary data a researcher needs to have a clear view of the research problem. The method of data collection needs to be formulated in a way that the exact information required for analysis could be extracted efficiently. Data collection, which involves recording participant's response, should be easy to understand. It will help participants to concentrate over task at hand more and they won't get distracted.

The work reported in this thesis primarily deals with human attention tunneling mitigation. Since, it involves human interaction significantly a variety of questionnaire has been designed to record participant's response in this study. The recorded data was then further analysed using various statistical tools. Also, recorded data was used as input while using different soft computing techniques.

### **5.2 TEXTURE FEATURE DATA SET**

HUD image frames extracted from the HUD video input were then used for extracting texture features. These texture feature data set was used for developing online attention

tunneling detection by means of a fuzzy inference system. The sample of texture feature sets extracted for: contrast, correlation, energy, homogeneity, standard deviation and entropy are shown in Table 5.1, Table 5.2 and Table 5.3

**TABLE 5.1 TEXTURE FEATURE SAMPLE DATA SET FOR CONTRAST AND CORRELATION**

<b>Contrast</b>			<b>Correlation</b>		
<b>Low Symbol Saliency</b>	<b>Normal</b>	<b>High Symbol Saliency</b>	<b>Low Symbol Saliency</b>	<b>Normal</b>	<b>High Symbol Saliency</b>
0.02250673	0.061914648	0.13088601	0.982552	0.959028	0.923056
0.02292782	0.062325103	0.13098765	0.981382	0.975185	0.944063
0.0229828	0.065197448	0.13242706	0.983973	0.967007	0.944235
0.02316888	0.065373315	0.1401759	0.985013	0.963386	0.932175
0.02323911	0.065802469	0.14117992	0.976827	0.962899	0.929708
0.0237093	0.066004146	0.14219577	0.980817	0.960912	0.944942
0.02466841	0.06627451	0.14653796	0.986334	0.968461	0.926023
0.02471234	0.067643881	0.15048412	0.979811	0.962585	0.928542
0.02475811	0.067749741	0.1523251	0.98585	0.959105	0.934613
0.02477896	0.067750865	0.15742798	0.982783	0.960806	0.931273
0.02486925	0.067827363	0.15884509	0.979129	0.964433	0.936212
0.02512111	0.069363395	0.1602398	0.984632	0.964874	0.925282
0.02545267	0.06994233	0.1610805	0.986869	0.956612	0.911027
0.0256286	0.070074349	0.16336321	0.988134	0.96612	0.932694
0.02573222	0.070196312	0.16678189	0.977927	0.951578	0.920703
0.02573222	0.070588235	0.16722429	0.98094	0.963031	0.920975
0.026679	0.071303345	0.16759248	0.987009	0.96773	0.93343
0.02694326	0.071326413	0.16899644	0.987538	0.954547	0.922135
0.0270312	0.071428571	0.16981481	0.975184	0.965609	0.932745

0.02718833	0.0727797	0.17022261	0.982197	0.968588	0.928411
0.02790392	0.07294765	0.17032922	0.979298	0.950258	0.9324
0.02881799	0.073436214	0.17158436	0.976187	0.960748	0.921105
0.02950671	0.07390668	0.17162055	0.986655	0.968521	0.935986
0.02991926	0.074587507	0.17230931	0.975317	0.945466	0.929882
0.03048945	0.074611791	0.17241109	0.975787	0.949897	0.909012
0.03058172	0.074972958	0.17294239	0.979078	0.958525	0.922516
0.03065844	0.075224913	0.17333333	0.977025	0.9507	0.93226
0.03121107	0.075289108	0.17334863	0.973568	0.946549	0.933367
0.03121759	0.076021546	0.17364198	0.977664	0.962594	0.922621
0.03133609	0.076370702	0.17375793	0.97746	0.965626	0.923851

**TABLE 5.2 TEXTURE FEATURE SAMPLE DATA SET FOR ENERGY AND HOMOGENEITY**

Energy			Homogeneity		
Low Symbol Salience	Normal	High Symbol Salience	Low Symbol Salience	Normal	High Symbol Salience
0.348234	0.295571	0.313009	0.988747	0.971894719	0.957999
0.378212	0.227508	0.259463	0.988536	0.971169463	0.960795
0.349292	0.264025	0.242162	0.988509	0.971502693	0.960774
0.32	0.278275	0.284013	0.988416	0.971310014	0.96019
0.376486	0.31368	0.29413	0.98838	0.970922721	0.959855
0.353411	0.290974	0.23374	0.988145	0.970757401	0.955864
0.28553	0.253496	0.289301	0.987666	0.970953701	0.956555
0.372327	0.265681	0.276569	0.987644	0.970418539	0.958674
0.290843	0.275271	0.265108	0.987621	0.970228758	0.958347
0.336971	0.277765	0.265817	0.987611	0.970212976	0.958039

0.37075	0.278124	0.252105	0.987565	0.96886789	0.960138
0.298089	0.266839	0.26025	0.987439	0.969569396	0.954943
0.271588	0.306121	0.305101	0.987274	0.969957318	0.954878
0.268649	0.270479	0.256438	0.987186	0.969284982	0.957861
0.356691	0.302443	0.289105	0.987134	0.969288735	0.956289
0.334856	0.260168	0.284728	0.987134	0.968735102	0.957597
0.270856	0.247594	0.249897	0.986661	0.970226836	0.957548
0.259018	0.290011	0.274284	0.986528	0.96870336	0.957916
0.389908	0.248153	0.248261	0.986484	0.968144944	0.956893
0.321981	0.237775	0.26713	0.986406	0.968215018	0.956273
0.327159	0.300985	0.248587	0.986048	0.968288752	0.956666
0.353403	0.296821	0.281369	0.985591	0.96773129	0.956122
0.256095	0.232633	0.23744	0.985247	0.966966259	0.957139
0.371932	0.328806	0.250833	0.98504	0.968310328	0.955999
0.368301	0.332857	0.285335	0.984755	0.966858963	0.951575
0.333885	0.277118	0.267988	0.984709	0.968794694	0.955881
0.338089	0.322378	0.24643	0.984671	0.967831164	0.956616
0.352159	0.316068	0.243268	0.984394	0.968762712	0.955651
0.343919	0.278524	0.267973	0.984391	0.968155994	0.956386
0.344842	0.255126	0.264713	0.984332	0.965682415	0.957077

**TABLE 5.3 TEXTURE FEATURE SAMPLE DATA SET FOR STANDARD DEVIATION AND ENTROPY**

Standard Deviation			Entropy		
Low Symbol Saliency	Normal	High Symbol Saliency	Low Symbol Saliency	Normal	High Symbol Saliency
23.77208	34.70122	28.2416	6.575803	7.113931	6.729231
23.66374	30.47217	34.16507	6.513182	6.933394	7.009785
25.58594	29.06259	34.16058	6.627147	6.85766	7.056777
27.11179	28.88561	31.79832	6.743504	6.764375	6.870188
18.77757	28.27395	30.96066	6.021316	6.81754	6.845021
23.51853	31.61101	35.33605	6.551744	6.955632	7.04377
29.07372	29.21833	30.85718	6.859679	6.875192	6.814229
23.80175	27.91824	32.14997	6.532576	6.800816	6.865625
28.5544	27.98132	34.03505	6.818785	6.809857	6.969339
25.47623	29.8797	33.76906	6.640251	6.881069	6.954921
23.09859	30.57219	35.39103	6.517465	6.905617	6.993974
27.56032	27.39873	32.26383	6.774855	6.74202	6.936626
30.18556	31.30766	29.70681	6.915454	6.930485	6.72547
31.60498	25.64985	34.81834	6.940543	6.679155	6.991979
22.89778	30.02128	32.5928	6.507166	6.90637	6.832259
24.42478	32.21636	32.56176	6.573663	6.95515	6.837647
30.51088	27.10297	35.63919	6.903781	6.765094	7.020533
31.71227	31.39296	32.82395	6.960678	6.976454	6.841011
20.49596	32.88451	35.72854	6.130499	7.01626	7.025039
26.38584	25.89051	34.58367	6.707591	6.660535	6.923557
22.79372	29.9385	35.69399	6.226999	6.830543	7.025182
23.17858	33.54547	33.01072	6.527762	7.052493	6.86242

32.10522	24.99529	37.10688	6.98379	6.616401	7.096599
23.19284	26.3297	35.39376	6.513717	6.679965	7.001632
24.0281	29.21378	30.00576	6.558636	6.842933	6.719135
26.07363	26.69816	33.37107	6.701914	6.694577	6.872731
24.5011	25.5208	35.8837	6.614789	6.64881	7.029924
22.55322	31.14224	36.40638	6.497809	6.910931	7.050779
25.37905	32.64841	33.80061	6.647382	7.000209	6.921563
25.23454	32.36789	33.78575	6.642308	6.995493	6.897672

### 5.3 EVENT DETECTION DATASET

Extensively collected experimental data was very large. For every domain of luminance ten set of readings were taken. Sample readings for all three ranges of AL are as shown in the Table 5.4, Table 5.5 and Table 5.6. From the collected experimental data, 75% data was used for the training, 15% for validation and 10% data was used for testing.

**TABLE 5.4 EXPERIMENTAL DATA FOR HIGH LUMINANCE**

<b>Ambient Luminance</b>	<b>Contrast Ratio</b>	<b>HUD Event Detection (%)</b>	<b>Outside Event Detection (%)</b>
32000	1.140625	59	98
32000	1.15625	60	98
32000	1.171875	61	97
32000	1.1875	61	97
32000	1.203125	62	97
32000	1.21875	63	97
32000	1.234375	64	97
32000	1.25	65	96
32000	1.265625	66	96

27000	1.185185	61	97
27000	1.203704	62	97
27000	1.222222	63	97
27000	1.240741	65	97
27000	1.259259	65	96
27000	1.277778	66	96
27000	1.296296	66	96
27000	1.314815	66	96
18000	1.194444	62	97
18000	1.222222	63	97
18000	1.25	65	96
18000	1.277778	66	96
18000	1.305556	66	96
18000	1.333333	67	96
18000	1.361111	68	95
18000	1.388889	68	95
18000	1.416667	68	95
18000	1.444444	70	95
18000	1.472222	70	95

**TABLE 5.5 EXPERIMENTAL DATA FOR MEDIUM LUMINANCE**

<b>Ambient Luminance</b>	<b>Contrast Ratio</b>	<b>HUD Event Detection (%)</b>	<b>Outside Event Detection (%)</b>
12000	1.208333	62	97
12000	1.25	65	96
12000	1.291667	66	96
12000	1.333333	67	96
12000	1.375	68	95

12000	1.416667	68	95
12000	1.458333	70	95
12000	1.5	72	95
12000	1.541667	73	95
12000	1.583333	75	95
12000	1.625	75	95
12000	1.666667	76	95
12000	1.708333	77	95
7500	1.2	62	97
7500	1.266667	65	96
7500	1.333333	67	96
7500	1.4	68	95
7500	1.466667	70	95
7500	1.533333	73	95
7500	1.6	74	95
7500	1.666667	76	95
7500	1.733333	77	95
7500	1.8	77	95
7500	1.866667	79	95
7500	1.933333	80	95
7500	2	82	95
7500	2.066667	82	95
7500	2.133333	83	95
5400	1.277778	65	96
5400	1.37037	68	95
5400	1.462963	70	95
5400	1.555556	74	95

5400	1.648148	75	95
5400	1.740741	77	95
5400	1.833333	78	95
5400	1.925926	80	95
5400	2.018519	82	95
5400	2.111111	83	95
5400	2.203704	84	95
5400	2.296296	84	95
5400	2.388889	84	95
5400	2.481481	85	95
5400	2.574074	85	94
2500	1.2	65	96
2500	1.4	70	95
2500	1.6	74	95
2500	1.8	77	95
2500	2	82	95
2500	2.2	84	95
2500	2.4	84	95
2500	2.6	86	94
2500	2.8	89	93
2500	3	90	92
2500	3.2	90	92
2500	3.4	91	91
2500	3.6	91	90
2500	3.8	92	90
2500	4	92	88
2500	4.2	92	88

2500	4.4	92	88
1000	1.5	72	95
1000	2	82	95
1000	2.5	85	95
1000	3	90	92
1000	3.5	91	91
1000	4	92	88
1000	4.5	92	86
1000	5	94	84
1000	5.5	95	84
1000	6	95	84
1000	6.5	96	82
1000	7	96	81

**TABLE 5.6 EXPERIMENTAL DATA FOR LOW LUMINANCE**

<b>Ambient Luminance</b>	<b>Contrast Ratio</b>	<b>HUD Event Detection (%)</b>	<b>Outside Event Detection (%)</b>
500	1.2	65	96
500	1.4	70	95
500	2.2	84	95
500	2.6	86	94
500	3	90	92
500	3.4	91	91
500	4	92	88
500	5	94	84
500	5.4	95	84
500	6	95	84
350	1.428571	70	95

350	1.857143	77	95
350	2.285714	84	95
350	2.714286	88	94
350	3.142857	90	92
350	3.571429	91	91
350	4	92	88
350	4.428571	92	87
350	4.857143	93	85
350	5.285714	94	84
150	1.333333	67	96
150	1.666667	74	95
150	2	82	95
150	2.333333	84	95
150	2.666667	86	94
150	3	90	92
150	3.333333	91	92
150	3.666667	91	90
150	4	92	88
150	4.333333	92	88
150	4.666667	93	85
150	5	94	84
50	2	82	95
50	2.5	85	95
50	3	90	92
50	3.5	91	91
50	4	92	88
50	4.5	92	86

50	5	94	84
50	5.5	95	84
50	6	95	84
50	6.5	96	82
50	7	96	81

## 5.4 CONCLUSION

Data sets were generated all the while when objectives I and II were under progress. The data sets consist of detection percentage for both HUD and outside events, based on participant's response. Also, data sets were generated comprising of textural features for identification of attention tunneling phenomenon.

Primary data generated through experiments consists of: Current AL, Current SL, participant response scores for HUD event detection and outside event detection.

Secondary data generated by using above mentioned primary data consists of: HUD event detection percentage, outside event detection percentage, CR, HUD image database and HUD image texture features (contrast, correlation and homogeneity).

# ARTIFICIAL NEURAL NETWORK BASED DECISION SUPPORT SYSTEM FOR TUNNELING MITIGATION

## 6.1 SOFT COMPUTING METHODS

Soft computing methods are essentially the application of computer science techniques to solve computationally hard tasks by using inexact solutions inspired mainly by the working of human mind. These methods differ from conventional hard computing methods in their ability of handling uncertainty and partial truth. Major techniques in the area of soft computing include: artificial neural networks; support vector machine; fuzzy logic; evolutionary computation; genetic algorithms etc [Sachdeva *et al.* (2011)]. Biologically inspired soft computing methods: particle swarm optimization, ant colony optimization, social impact theory based optimization techniques, human opinion formation theory etc. have been used for different applications like: optimize several hard computing problems, feature selection, pattern recognition etc. [Bhondekar *et al.* (2010); Bhondekar *et al.* (2011); Macas and Lhotská (2011); Kaur *et al.* (2012); Macaš and Lhotská (2012); Macaš *et al.* (2013)].

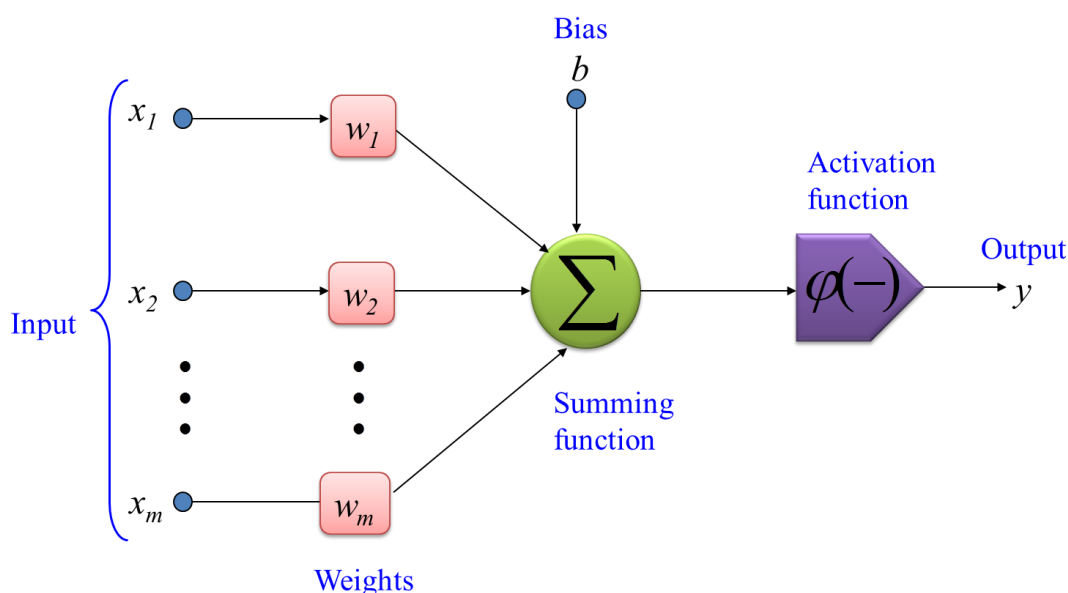
All the soft computing methods focus on using one or more of the human brain characteristics used while decision making/ analysis of a situation/ prediction etc. Since, practical issues at hand could be considered as computationally hard solving problems, soft computing methods are used for finding out a solution [Lhotska and Stepankova (2004); Lhotská *et al.* (2006)].

### 6.1.1 ARTIFICIAL NEURAL NETWORK

Artificial neural network (ANN) is one of the most important soft computing tools. ANN is basically simplified implementation of biological neuron networks. Key

characteristics of ANN include: tremendous mapping capability, generalization, parallel processing, robustness and fault tolerance. Their key feature used is the ability to predict results based on the past trends. Neural networks have been vastly used for solving fitting and pattern recognition problems [Vijaya *et al.* (1997); Bhattacharyya *et al.* (2008); Jana *et al.* (2011); Kumar *et al.* (2011)].

Major building blocks of an ANN consist of: neuron, architecture and learning algorithm. The basic unit of the network is an artificial neuron. Artificial neuron is also referred to as nodes/units or processing elements. A single neuron is composed of links, summation function and activation function (Fig. 6.1).

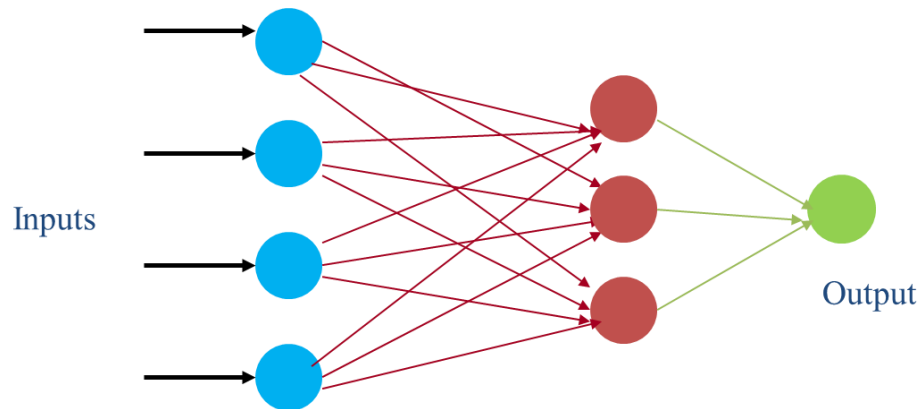


**FIGURE 6.1 STRUCTURE OF AN ARTIFICIAL NEURON**

ANN consists of such densely interconnected numerous nodes. These networks are highly adaptive in nature where learning takes place by means of examples or data sets. Network architectures could also be of varied types: single layer feed forward network, multilayer feed forward networks (Fig. 6.2), recurrent networks and other hybrid variants.

Single layer networks have only two layers: input layer and output layer. Input and output layers are connected with weighted links. Multi-layer networks comprise of many intermediate layers between the input and output layers termed as hidden layers. The purpose

of having hidden layers is to facilitate the intermediary computation. Both of these architectures follow a feed forward principle which means every weighted link is from the input to output but not vice-versa. Recurrent networks differ from the feed forward architectures in having at least a single feedback link present in the architecture [Kumar *et al.* (1991)].



**FIGURE 6.2 BASIC MULTI-LAYER NETWORK ARCHITECTURE**

The network structure is closely related with the learning algorithm to be used. Learning is the process by which networks adjust its weights and update its architecture to produce best results. ANN learn themselves by finding out the underlying relationship existing between input and output in the example training data.

Many learning algorithms have been proposed by various researchers over the time. Perceptron learning was the first primary and simplistic approach used initially. Back propagation algorithm has been mostly used in practical applications. Back propagation algorithm adjusts neural network weights so that the mean square error minimises.

#### **6.1.1.1 Adaptive Network Based Fuzzy Inference Systems (ANFIS)**

Neuro-fuzzy systems are fuzzy systems which use ANN theory in order to determine their properties (fuzzy sets and fuzzy rules) by processing data samples. Neuro-fuzzy systems harness the power of the two paradigms: fuzzy logic and ANNs, by utilising the mathematical properties of ANNs in tuning rule-based fuzzy systems that approximate the way man processes information. A specific approach in neuro-fuzzy development is the adaptive neural

fuzzy inference system (ANFIS), which has shown significant results in modeling nonlinear functions. ANFIS is a powerful means to model or represent vagueness in day to day activities or processes as they have the potential to adaptively control processes that present a difficulty to the conventional control techniques due to their ability to predict the likely outcome given a set of conditions or inputs. In ANFIS, membership function parameters are extracted from a data set that describes the system behaviour. ANFIS learns features in the data set and adjusts system parameters according to a given error criterion.

ANFIS refers to an inference system that integrates the best features of neural network and fuzzy logic. It is a system that predicts input/output relationship of given set of data. It consists of nodes and directional links through which the nodes are connected. Part or all of the nodes are adaptive, which means that their outputs depend on the parameter(s) pertaining to these nodes and the learning rule specifies how these parameters should be changed to minimize the error measure. ANFIS, which is derived from the term Adaptive network fuzzy inference system, was first proposed by Jang in 1993, and later changed to Adaptive neural fuzzy inference system. This system is designed to allow IF-THEN rules and membership functions (fuzzy logic) to be constructed based on the historical data and also include the adaptive nature for automatic tuning of the membership functions [Jang (1993)].

#### **6.1.1.2 Structure of ANFIS**

ANFIS is composed of five functional blocks, these are:

- A rule base containing a number of fuzzy IF THEN rules
- A database, which defines the membership functions of the fuzzy sets, used in the fuzzy rules
- A decision-making unit which performs the inference operations on the rules
- A fuzzification interface which transforms the crisp inputs into degrees of match with linguistic values

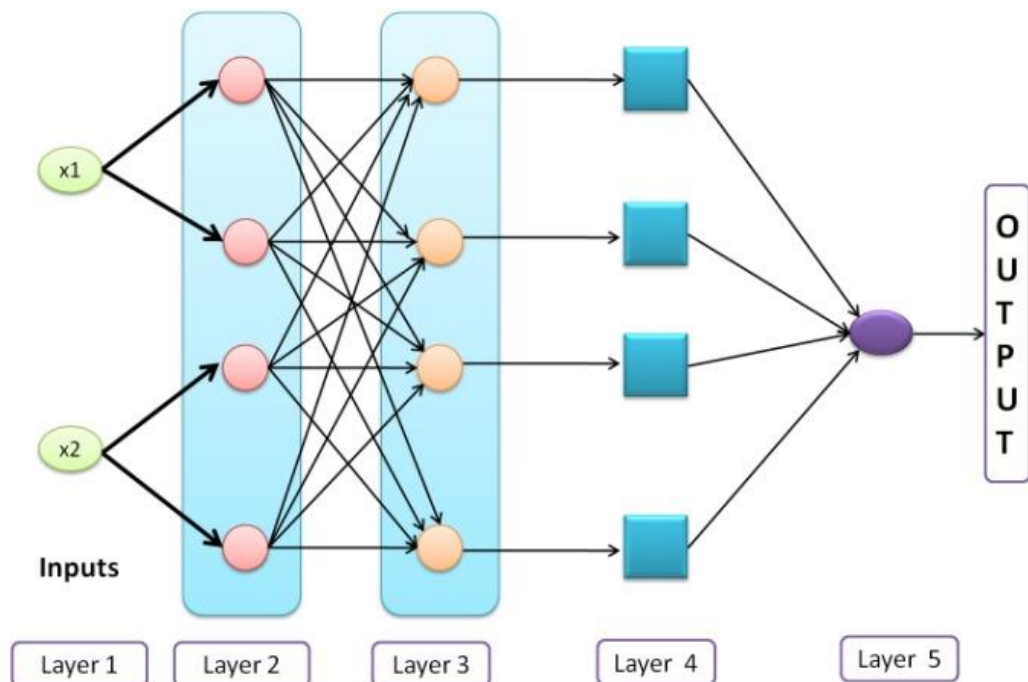
- A defuzzification interface which transform the fuzzy results of the inference into a crisp output.

Usually, the rule base and the database are jointly referred to as the knowledge base.

- Rules. The if-then rules have to be determined somehow. This is usually done by ‘knowledge acquisition’ from an expert. It is a time consuming process that is fraught with problems.
- Membership functions. A fuzzy set is fully determined by its membership function. This has to be determined. If it’s gaussian what are the parameters?

The ANFIS approach learns the rules and membership functions from data.

Adaptive networks cover a number of different approaches. The ANFIS architecture is shown in Fig. 6.3. The circular nodes represent nodes that are fixed whereas the square nodes are nodes that have parameters to be learnt.



**FIGURE 6.3 AN ANFIS ARCHITECTURE FOR A TWO RULE SUGENO SYSTEM**

For example consider a system having two inputs  $x$  and  $y$  with one output  $z$ . A two rule Sugeno fuzzy system has rules of the form:

$$\text{If } x \text{ is } A_1 \text{ and } y \text{ is } B_1 \text{ Then } f_1 = p_1x + q_1y + r_1 \quad (6.1)$$

$$\text{If } x \text{ is } A_2 \text{ and } y \text{ is } B_2 \text{ Then } f_2 = p_2x + q_2y + r_2 \quad (6.2)$$

where,  $p$ ,  $q$  and  $r$  are constants. For a zero order Sugeno system output is only a constant (i.e.  $p = q = 0$ ).

**Layer 1:** Every node  $i$  in this layer is a square node with a node function

$$O_i^1 = \mu_{A_i}(x) \quad (6.3)$$

Where,  $x$  is the input to node  $i$  and  $A_i$  is the linguistic label (high, medium, etc.) associated with this node function. It can be said that  $O_i^1$  is the membership function of  $A_i$  and it stipulates the degree to a given  $x$  satisfies quantifier  $A_i$ . Usually we choose  $\mu_{A_i}(x)$ , the node function, to be bell-shaped within range (0, 1) such as

$$\mu_{A_i}(x) = \frac{1}{1 + \left(\frac{(x-c_i)^2}{a_i}\right)^{b_i}} \quad (6.4)$$

where,  $\{a_i, b_i, c_i\}$  is the parameter set. The bell-shaped function varies according to change in parameter set values, thus exhibiting different forms of membership functions for  $A_i$ . In fact, any continuous and piecewise differentiable functions, such as commonly used triangular-shaped or trapezoidal membership functions, are also qualified candidates for node functions in this layer. Parameters used in this layer are called premise parameters.

**Layer 2:** Every node in this layer is a red circle node, which multiplies the incoming signals and sends the product out. For instance,

$$\omega_i = \mu_{A_i}(x) \times \mu_{B_i}(y); i = 1, 2 \quad (6.5)$$

Each node output represents the firing strength of a rule.

**Layer 3:** Every node in this layer is an orange circle node. The  $i^{th}$  node calculates the ratio of the  $i^{th}$  rule's firing strength to the sum of all rule's firing strengths:

$$\omega_i = \frac{\omega_i}{\omega_1 + \omega_2} \quad (6.6)$$

Outputs of this layer are called *normalized firing strengths*.

**Layer 4:** Every node  $i$  in this layer is a square node with a node function

$$O_1^4 = \omega_i f_i = \overline{\omega}_i (p_i x + q_i y + r_i) \quad (6.7)$$

Where,  $\overline{\omega}_i$  is the output of the layer 3, and  $\{p_i, q_i, r_i\}$  is the parameter set. Parameter in this layer are called as consequent parameters.

**Layer 5:** The single node in this layer is a purple circle node that computes the overall output as the summation of all incoming signals, i.e.

$$O_1^5 = \text{overall output} = \sum_i \overline{\omega}_i f_i = \frac{\sum_i \omega_i f_i}{\sum_i f_i} \quad (6.8)$$

This then is how, typically, the input vector is fed through the network layer by layer. We now consider how ANFIS learns the premise and consequent parameters for membership functions and rules [Jang (1993)].

### 6.1.1.3 Learning Algorithms

An adaptive neural network is a multilayer feed-forward network in which each node performs a particular function called node function on incoming signals as well as a set of parameters pertaining to this node. The formulas for the node functions may vary from node to node, and the choice of each node function depends on the overall input-output function, which the adaptive network is required to carry out. The links in an adaptive network only indicate the flow direction of signals between nodes; no weights are associated with the links. To reflect different adaptive capabilities, circle and square nodes are used in an adaptive

network. A square node, which is an adaptive node, has parameters. On the other hand, a circular node, which is fixed node, has none. The parameter set of an adaptive network is the union of the parameter sets of each adaptive node. In order to achieve a desired input-output mapping, these parameters are updated according to given training data and a gradient-based learning procedure.

There are two learning algorithms for adaptive networks. With the batch learning or off-line learning, the update action takes place only after the whole training data set has been presented, i.e., only after each epoch or sweep. On the other hand, if the parameters are to be updated immediately after each input-output pair has been presented, then it is referred to as the pattern learning or online learning.

Hybrid learning rule combines the gradient method and the least squares estimate to identify parameters. The gradient method and least squares estimate can be combined to update the parameters in an adaptive network. Each epoch of this hybrid learning procedure is composed of a forward pass and a backward pass. In the forward pass, input data is supplied and functional signals go forward to calculate each node's output until the matrices are obtained.

If the parameters are updated after each data presentation, then this is referred to as pattern learning or on-line learning. This learning paradigm is vital to the on-line parameter identification for systems with changing characteristics.

For the sequential least squares formula to account for the time-varying characteristics of the incoming data, there is need to decay the effects of old data pairs as new data pairs become available. The simplest method is to formulate the squared error measure as a weighted version that gives higher weighting factors to more recent data pairs.

### **6.1.2 Fuzzy If-Then Rules**

Fuzzy if-then rules or fuzzy conditional statements are expressions of the form IF A THEN B where, A and B are labels of fuzzy sets characterized by appropriate memberships

functions. Due to their concise form, fuzzy if-then rules are often employed to capture the imprecise modes of reasoning that play an essential role in the human ability to make decisions in an environment of uncertainty and impressions.

Another form of fuzzy if-then proposed by *Tskagi and Surgeon* has fuzzy sets involved only in the premise part. Both types of fuzzy if then rules have been used extensively in both modelling and control. Through the use of linguistic labels and membership functions, a fuzzy if then rule can easily capture the spirit of a “rule of thumb” used by humans. From another angle, due to the qualifiers on the premise parts, each fuzzy if-then rule can be viewed as a local description of the system under consideration. Fuzzy if-then rule forms a core part of the fuzzy inference system.

### **6.1.3 Fuzzy Inference Systems**

Fuzzy inference system (FIS) also known as fuzzy rule based system, fuzzy models, fuzzy associative memories, or fuzzy controllers when used as controllers. Basically a fuzzy inference system comprises of:

- A rule base containing a number of fuzzy if-then rules.
- A database, which defines the membership functions of the fuzzy sets, used in the fuzzy rules
- A decision making unit performs the inference operations on the rules.
- A fuzzification interface transforms the crisp inputs into degrees of match with linguistic values.
- A defuzzification interface transforms the fuzzy results of the interface into a crisp output.

The fuzzy reasoning steps performed by fuzzy inference systems involve:

- Fuzzification: comparison of the input variables with membership functions on the premise part to obtain the membership values of each linguistic label.

- Combine (through a specific T-norm operator, usually multiplication or min.) the membership values on the premise part to get firing strength (weight) of each rule.
- Generate the qualified consequent (either fuzzy or crisp) of each rule depending on the firing strength.
- Defuzzification: Aggregate the qualified consequent to produce a crisp output

Types of fuzzy reasoning decide classification of fuzzy inference systems:

**Type 1:** The overall output is the weighted average of each rule's crisp output induced by the rule's firing strength (the product or minimum of the degrees of match with the premise part) and output membership functions. The output membership functions used in this scheme must be monotonically non-decreasing.

**Type 2:** The overall fuzzy output is derived by applying "max" operation to the qualified fuzzy outputs (each of which is equal to the minimum of firing strength and the output membership functions of each rule). Various schemes have been proposed to choose the final crisp output based on the overall fuzzy output; some of them are centre of area, bisector of area, mean of maxima, maximum criterion, etc.

**Type 3:** Takagi and Sugeno's fuzzy if-then rules are used. The output of each rule is a linear combination of input variables plus a constant term, and the final output is the weighted average of each rule's output.

## 6.2 EXPERIMENT

### 6.2.1 ANFIS IMPLEMENTATION: HUD SWITCHING SYSTEM FOR MITIGATING TUNNELING EFFECT

While luminance of HUD display can make features embedded in the symbology significant, it can also force pilot's attention to focus on aircraft or outside event depending on the level of AL, SL and CR. In this section, ANFIS based technique used to adjust SL

according to the need of the hour, thus minimizing tunneling effect due to SL and resulting salience factors, is discussed.

It has been observed in various studies as well as during the course of testing and evaluation of HUDs that SL plays a key role in affecting pilot's event detection capability. In order to optimize the attention capture between aircraft and outside event, experiment was conducted for varying AL conditions. Following that, an ANFIS based system for automatic adjustment of SL was developed. In the process, effects of AL and CR with varying NU, on the capability of pilot to detect changes in events taking place on HUD/outside environment were observed.

To simulate range of AL expected during the course of day and night mode of operation, AL was varied in the range  $1 \text{ cd/m}^2$  to  $40,000 \text{ cd/m}^2$ , to simulate the lighting conditions possible during the entire day and night time. CR was varied from 1 to 18, as beyond this range, contrast ratio parameter results in uncomfortable luminance on the HUD display which may not be desired by the pilot at all.

To study effect of varying AL and CR on ability of pilot to discriminate events occurring in outside environment and on HUD, an experimental study was conducted. In the study, a group of 14 persons were made to distinguish the outside events and aircraft events in varying possible luminance and CR conditions with objects on HUD symbology and outside varying dynamically in a predetermined fashion. The observations made were recorded and were used as the training and testing data for the ANFIS structure.

Data was collected extensively for the whole range of luminance. Ambient luminance range was divided in three domains: high luminance, medium luminance and low luminance.

#### **6.2.1.1 Adaptive Neuro-Fuzzy Inference Systems (ANFIS)**

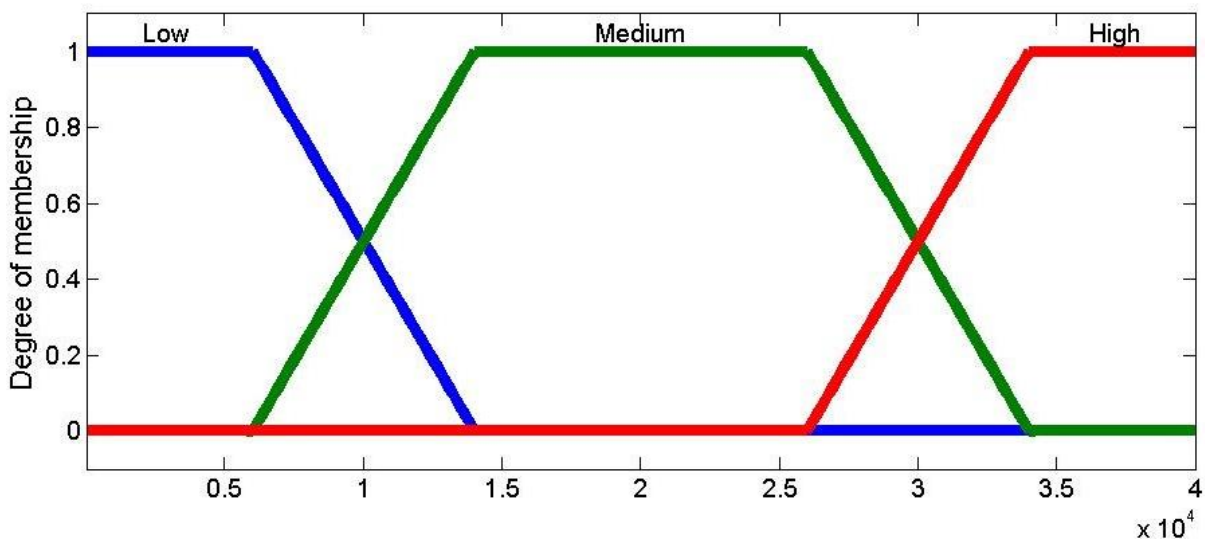
From the results obtained, a set of data was accumulated to train an ANFIS so that the luminance of HUD symbology could be modulated according to AL. During different times of day, the environment lighting is varying thus the value of AL keeps on changing and as

CR is a function of AL we observe a change in this parameter as well. As the pilot need to detect changes in event occurring on HUD as well as outside environment concurrently, it is required to have an optimum SL depending on the current AL to maintain adequate CR.

The experimental data collected thus helps in finding out the possible combinations, which will help in having better detection of HUD event as well as outside event. Using experimental data we have trained an ANFIS model. The neuro-adaptive learning method works in similar way as the neural networks. Neuro-adaptive learning techniques provide a method for the fuzzy modeling procedure to learn information about a data set.

Using a given input/output data set, a fuzzy inference system (FIS) is constructed whose membership function parameters are tuned using either a back propagation algorithm alone or in combination with a least squares type of method.

The ANFIS was constructed using the MATLAB platform. The input function chosen were: AL (20, 40000) cd/m<sup>2</sup> and CR (1, 18). ANFIS using these two input functions gives the display SL (10, 9500) cd/m<sup>2</sup> as output. Each input was distributed into three membership functions i.e. Low, Medium and High respectively. Fig. 6.4 and Fig. 6.5 present input membership function for AL and input membership function for CR respectively. Fig. 6.6 shows ANFIS structure generated using the experimental data.



**FIGURE 6.4 AMBIENT LUMINANCE - INPUT MEMBERSHIP FUNCTION FOR IMPLEMENTING ANFIS**

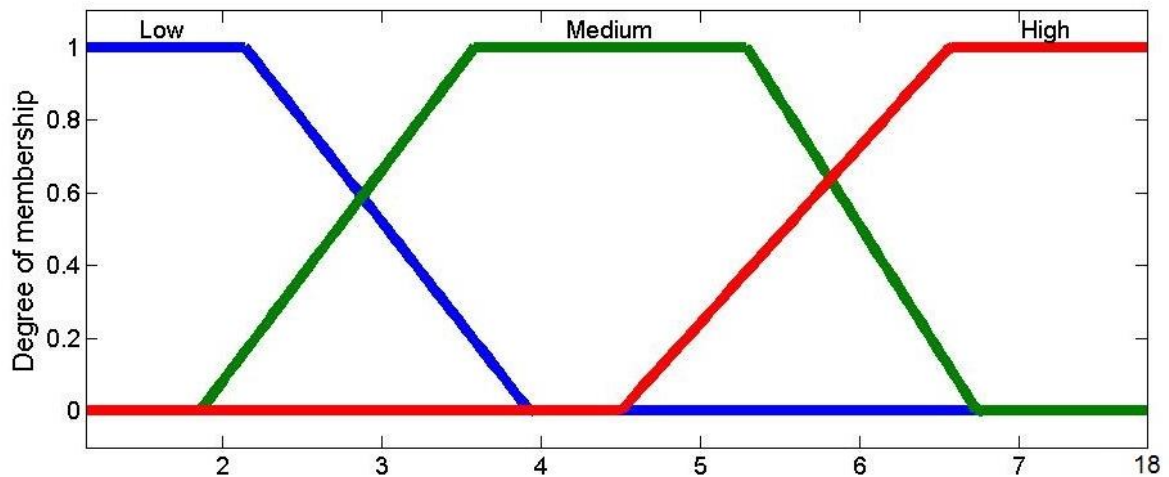
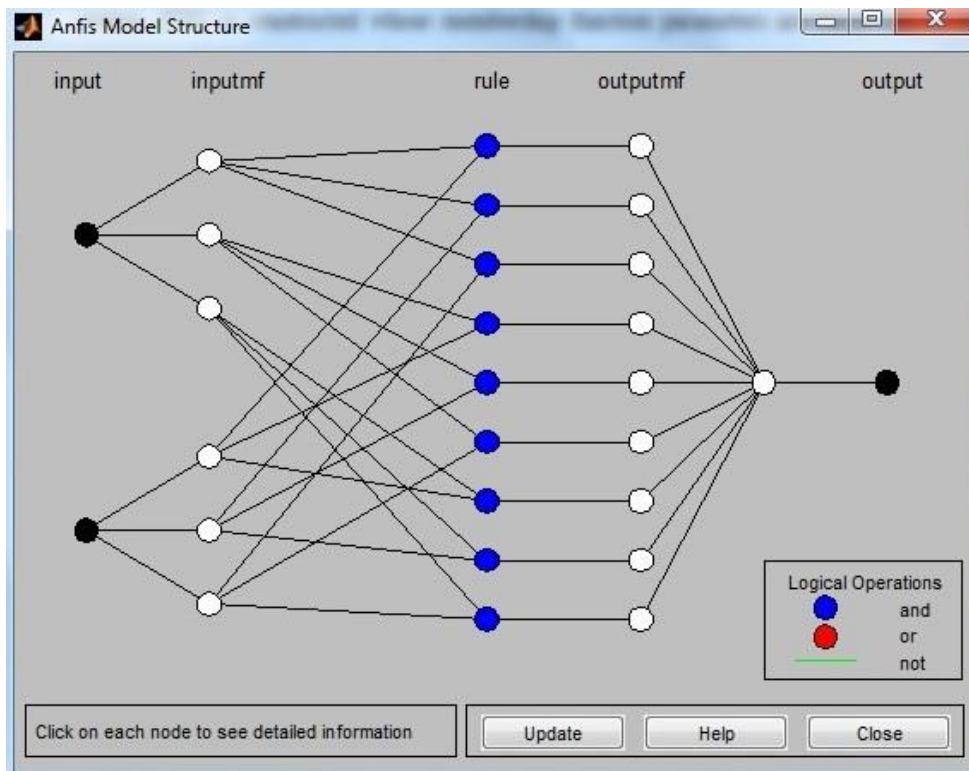


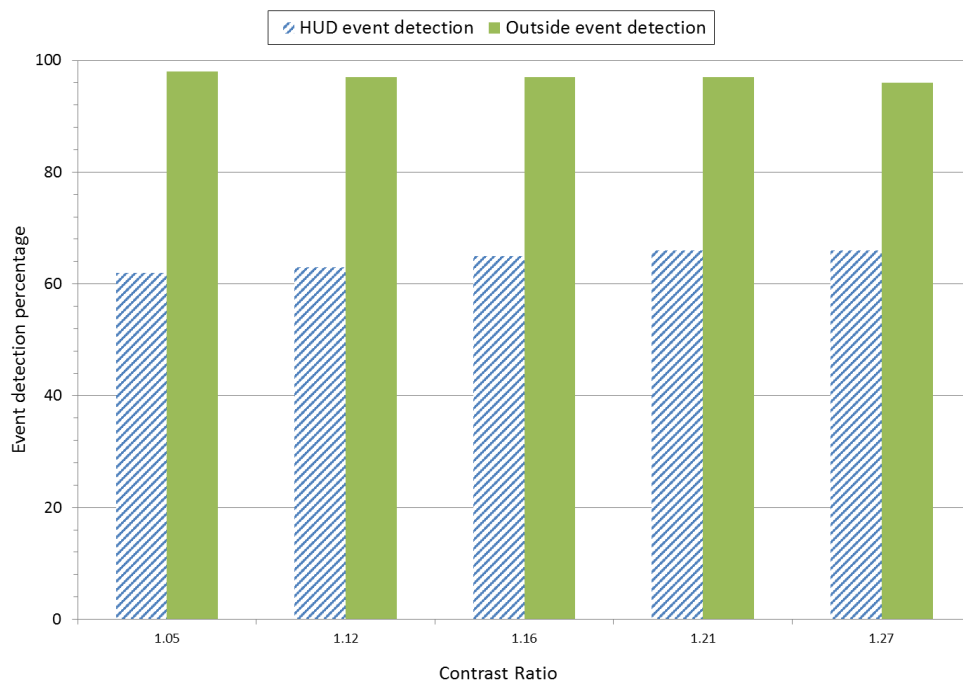
FIGURE 6.5 CONTRAST RATIO – INPUT MEMBERSHIP FUNCTION FOR IMPLEMENTING ANFIS

### 6.2.1.2 Results and Discussions

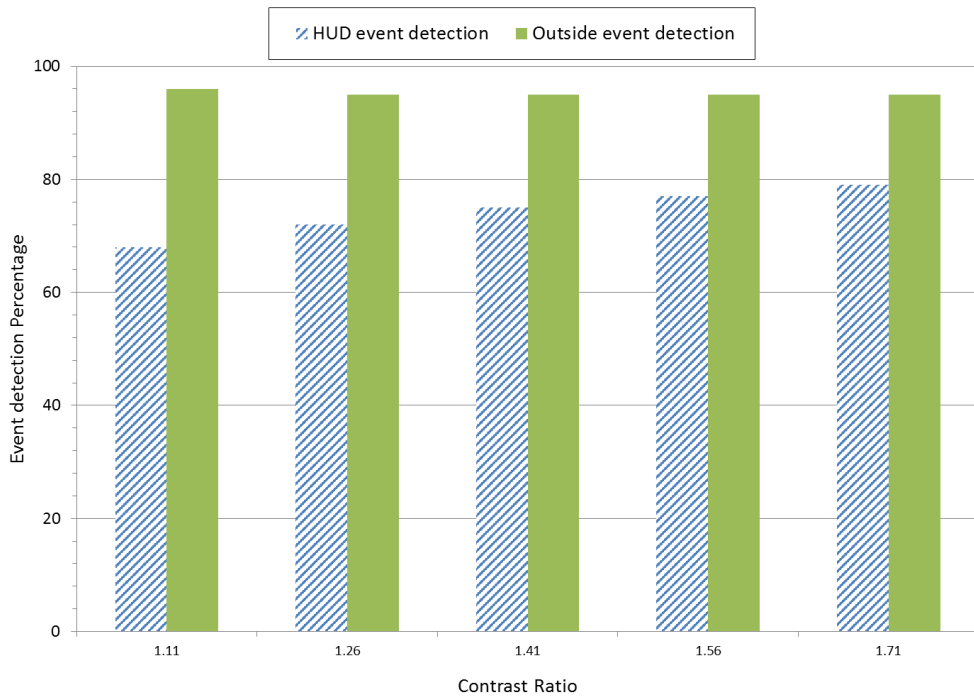
After training, ANFIS generates its output membership function itself. After training, system was subjected to the checking data and error was minimized. Once the training and testing is completed, system is ready to use. The system output was validated by checking the system output for five different AL ranges with varying CR conditions. The luminance value calculated by the ANFIS was used for display symbology and then the HUD/outside event detection was again observed. Output results are presented in Fig. 6.7, Fig. 6.8, Fig 6.9, Fig. 6.10, Fig. 6.11 and Fig.6.12. The developed ANFIS based system results in the automatic luminance adjustment of the symbology according to the AL. The resultant graph suggests that the luminance levels calculated by the system resulted in aircraft as well as the outside event detection in desired range of values for medium AL range. However for High and Low AL, the balance between HUD and outside event detection could still be improved.



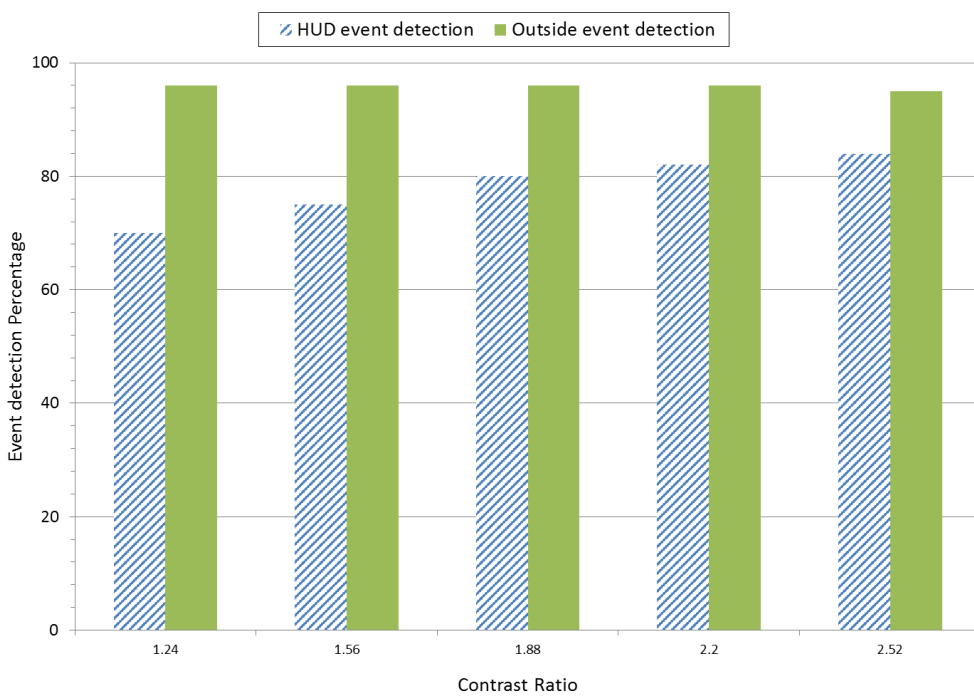
**FIGURE 6.6 ANFIS STRUCTURE GENERATED USING THE EXPERIMENTAL DATA**



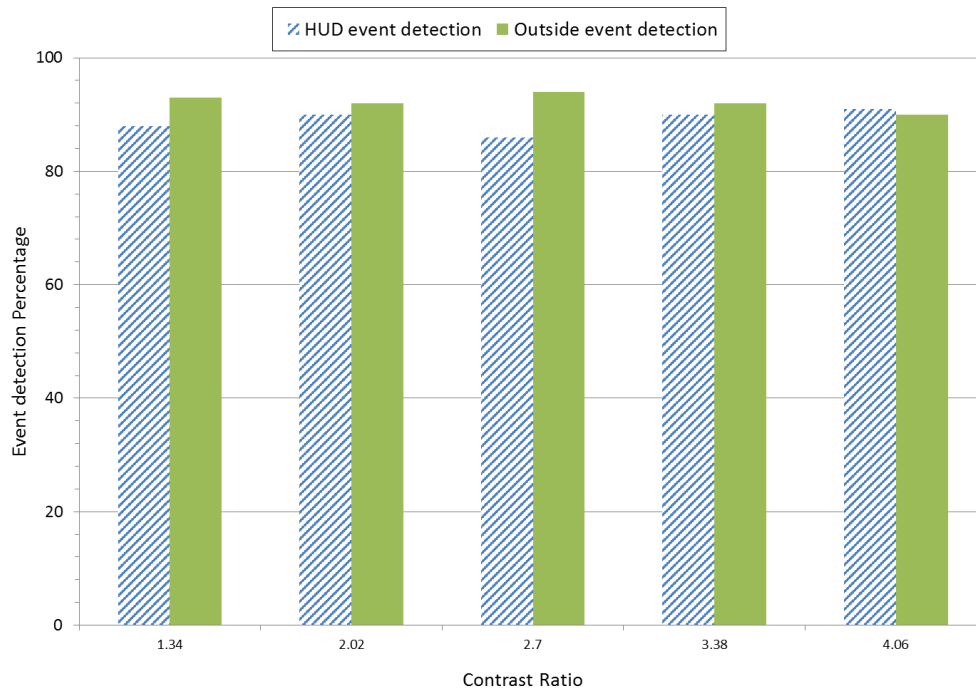
**FIGURE 6.7 COMPARISON OF AIRCRAFT EVENT DETECTION WITH OUTSIDE ENVIRONMENT EVENT DETECTION FOR SYMBOL LUMINANCE OUTPUT CALCULATED BY ANFIS AT AMBIENT LUMINANCE 35,000 cd/m<sup>2</sup>**



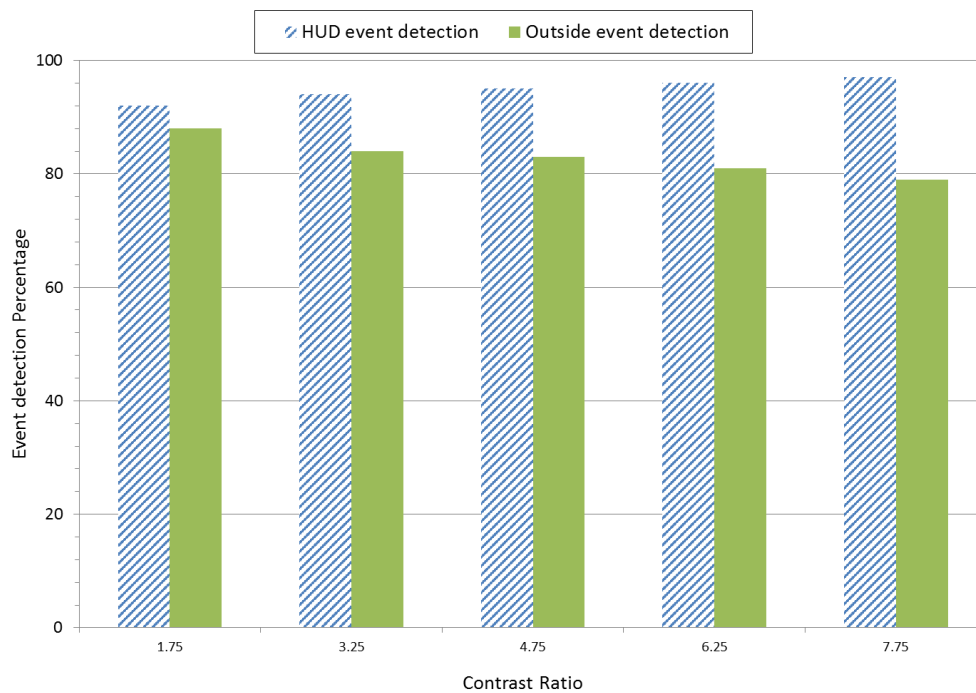
**FIGURE 6.8 COMPARISON OF AIRCRAFT EVENT DETECTION WITH OUTSIDE ENVIRONMENT EVENT DETECTION FOR SYMBOL LUMINANCE OUTPUT CALCULATED BY ANFIS AT AMBIENT LUMINANCE 15,000 cd/m<sup>2</sup>**



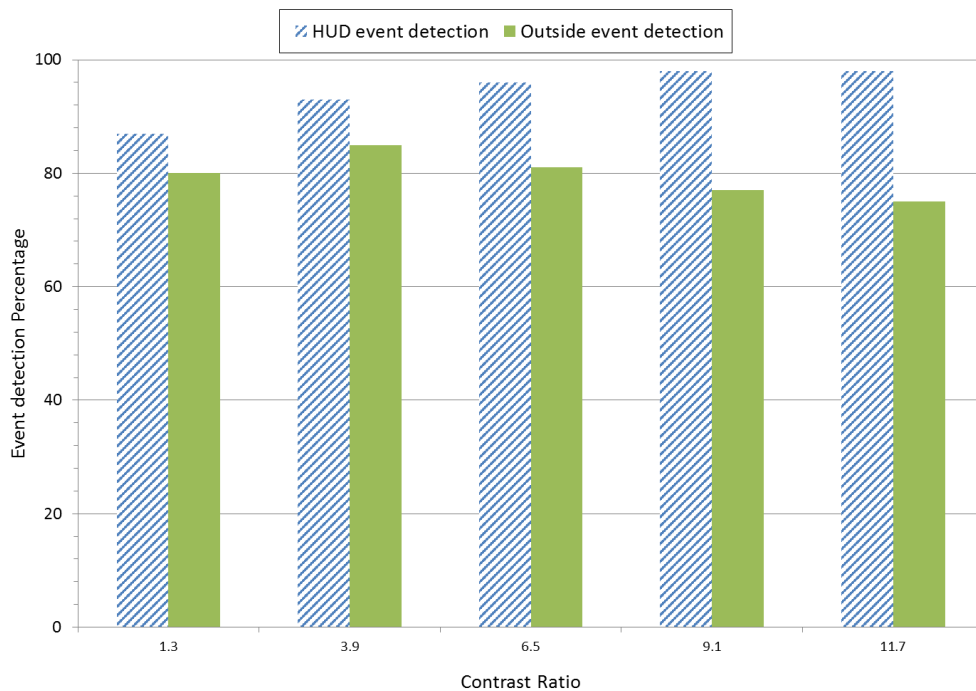
**FIGURE 6.9 COMPARISON OF AIRCRAFT EVENT DETECTION WITH OUTSIDE ENVIRONMENT EVENT DETECTION FOR SYMBOL LUMINANCE OUTPUT CALCULATED BY ANFIS AT AMBIENT LUMINANCE 8,000 cd/m<sup>2</sup>**



**FIGURE 6.10 COMPARISON OF AIRCRAFT EVENT DETECTION WITH OUTSIDE ENVIRONMENT EVENT DETECTION FOR SYMBOL LUMINANCE OUTPUT CALCULATED BY ANFIS AT AMBIENT LUMINANCE 2,000 cd/m<sup>2</sup>**



**FIGURE 6.11 COMPARISON OF AIRCRAFT EVENT DETECTION WITH OUTSIDE ENVIRONMENT EVENT DETECTION FOR SYMBOL LUMINANCE OUTPUT CALCULATED BY ANFIS AT AMBIENT LUMINANCE 750 cd/m<sup>2</sup>**



**FIGURE 6.12 COMPARISON OF AIRCRAFT EVENT DETECTION WITH OUTSIDE ENVIRONMENT EVENT DETECTION FOR SYMBOL LUMINANCE OUTPUT CALCULATED BY ANFIS AT AMBIENT LUMINANCE  $75 \text{ cd/m}^2$**

## **6.2.2 ARTIFICIAL NEURAL NETWORK BASED HUD SWITCHING SYSTEM FOR MITIGATING TUNNELING EFFECT**

Experiments conducted earlier generated a huge amount of data set. The data set generated consisted of following values: current AL, current SL, HUD event detection percentage and outside event detection percentage. After the ANFIS implementation and analysis of the results drawn from the developed system, it was observed that since the requirements of day and night mode flying are vastly different, there is a scope of improvement.

For the purpose, ANN based system was trained using MATLAB platform. From the earlier studies, range of optimum CR for different ranges of AL was identified. Another data set was then generated with following parameters: current AL, current SL and desired SL (derived keep in mind optimum CR).

Whole data set was then divided into three ranges: Training data, validation data and testing data. These data sets were then used to train the ANN. Since, the problem at hand is

much like fitting HUD SL according to optimum CR a fitting function based ANN model was selected for training. To cater the varying needs of day and night mode operation, two ANN systems were trained.

Both the developed ANN models were then further integrated to form a complete package – ‘Assistive Attention Tunneling Mitigation System’. AATMS was initially run in offline mode to check the functionality and make any improvements required. Further, an online mode operation was also developed which takes HUD camera input feed and predict whether attention tunnelling condition might be taking place and generates an alert.

### **6.2.2.1 Results and Discussion**

The range of AL to which a pilot is subjected to when flying an aircraft from day to night is huge. An important point to be considered while developing a switching system is to take care of the mode of flight mode. As variation in AL is large (500 - 1,00,000 cd/m<sup>2</sup>) in case of day mode operation while very small (as compared to day) at night times (0 -500 cd/m<sup>2</sup>), the developed ANFIS system showed inferior responses for high and low AL. Also, the system did not have the mode selection facility. Thus, in the developed system mitigation was achieved but there still existed a scope of improvement. For the purpose, ANN based system was developed with a mode selection capability. ANN was selected because of its merit in solving fitting problems. The problem at hand could also be considered as a fitting problem, where the input variables are the current ambient conditions while the desire output is to maintain symbology luminance at a level which could mitigate attention tunneling. Results of experimental studies conducted earlier establishes that the optimal CR to be maintained in case of day time operation is 2 - 2.5 and in case of night time operation it lies in range of 2.5 - 3. The ANN was trained to keep SL apt according to this criterion. Since, the variability in AL range was massive during day time; two separate ANN models were developed: Day Mode and Night Mode.

Both the ANN models were developed using MATLAB platform. The data generated in the earlier experiments was used to train these systems. The models were trained using MATLAB neural network GUI wizard. Initially, we require all the sample data to be classified under three headings: training data, validation data and testing data. Training data is actually used to train the network which adjusts its weights according to the error in training data set. Validation data is for checking generalization quotient of the network and its use is to stop training process when generalization stops improving. Testing data is used for checking the generated network performance.

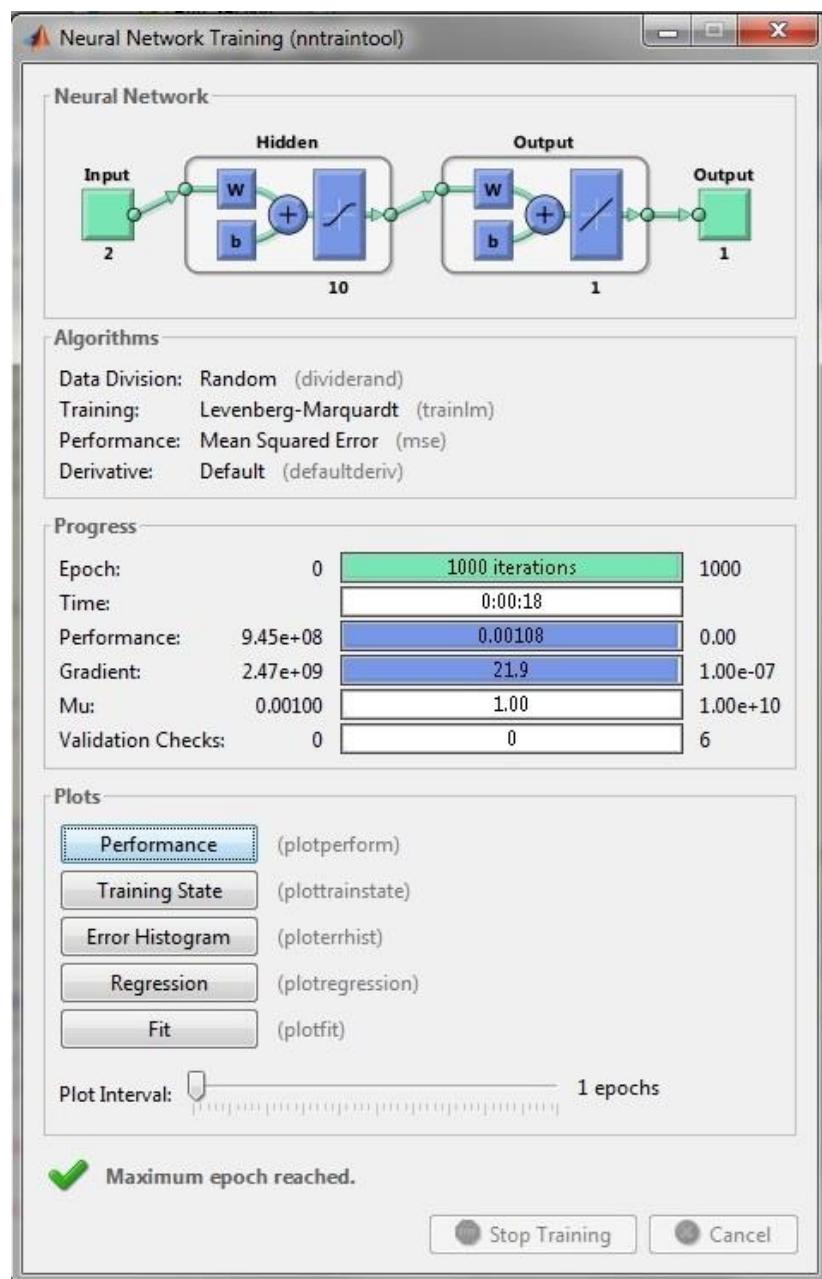
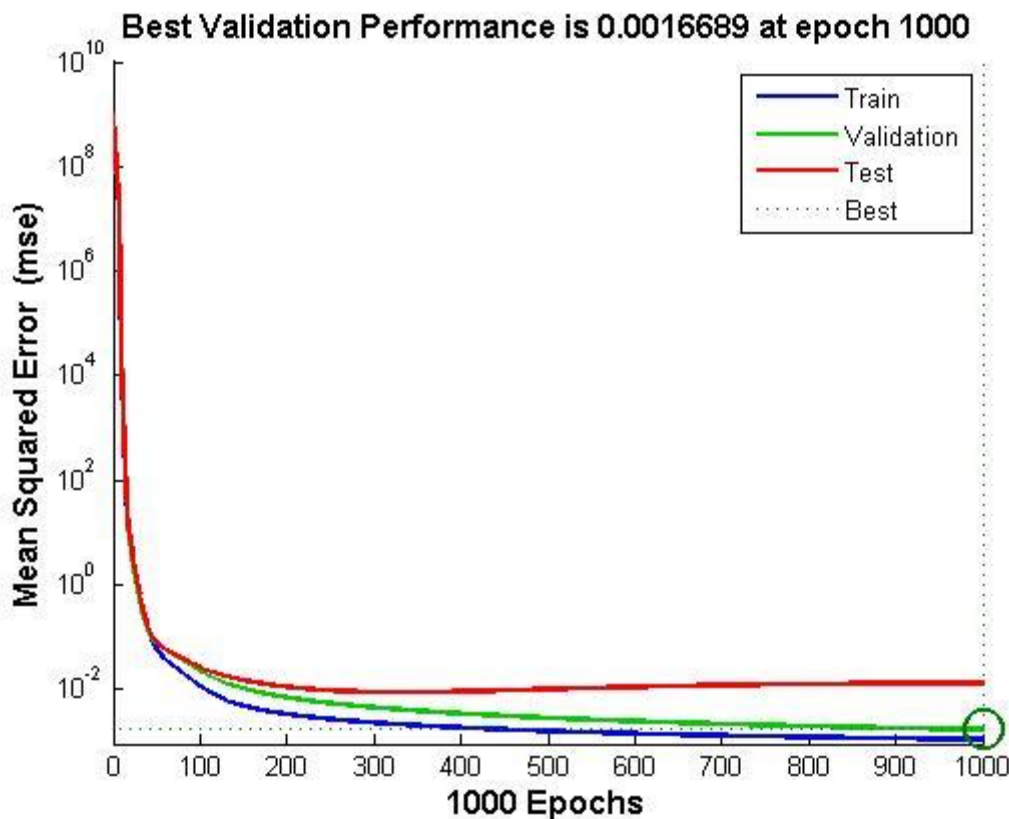


FIGURE 6.13 TRAINING WINDOW WHILE USING MATLAB TO TRAIN ANN

### 6.2.2.1.1 Day Mode ANN Model

For the purpose, the sample data set was divided into three categories: training data (80% samples), validation data (15% samples) and testing data (5% samples).

A fitting function ANN model was selected with 10 hidden layers. ANN was trained using the sample data set as described above (Fig. 6.13). The results of the trained network are as shown Fig. 6.14, Fig.6.15 and Fig. 6.16.

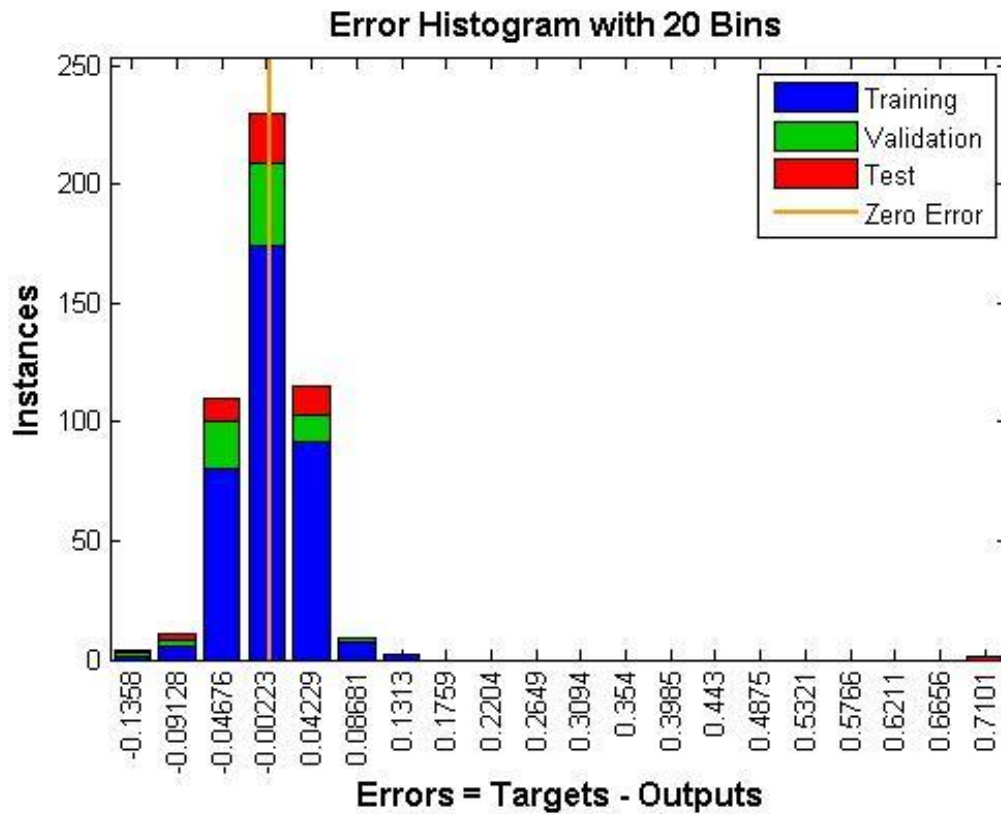


**FIGURE 6.14 PERFORMANCE PLOT OBTAINED AFTER COMPLETION OF DAY MODE ANN TRAINING**

To obtain verification of network performance error histogram plot and regression plot are studied.

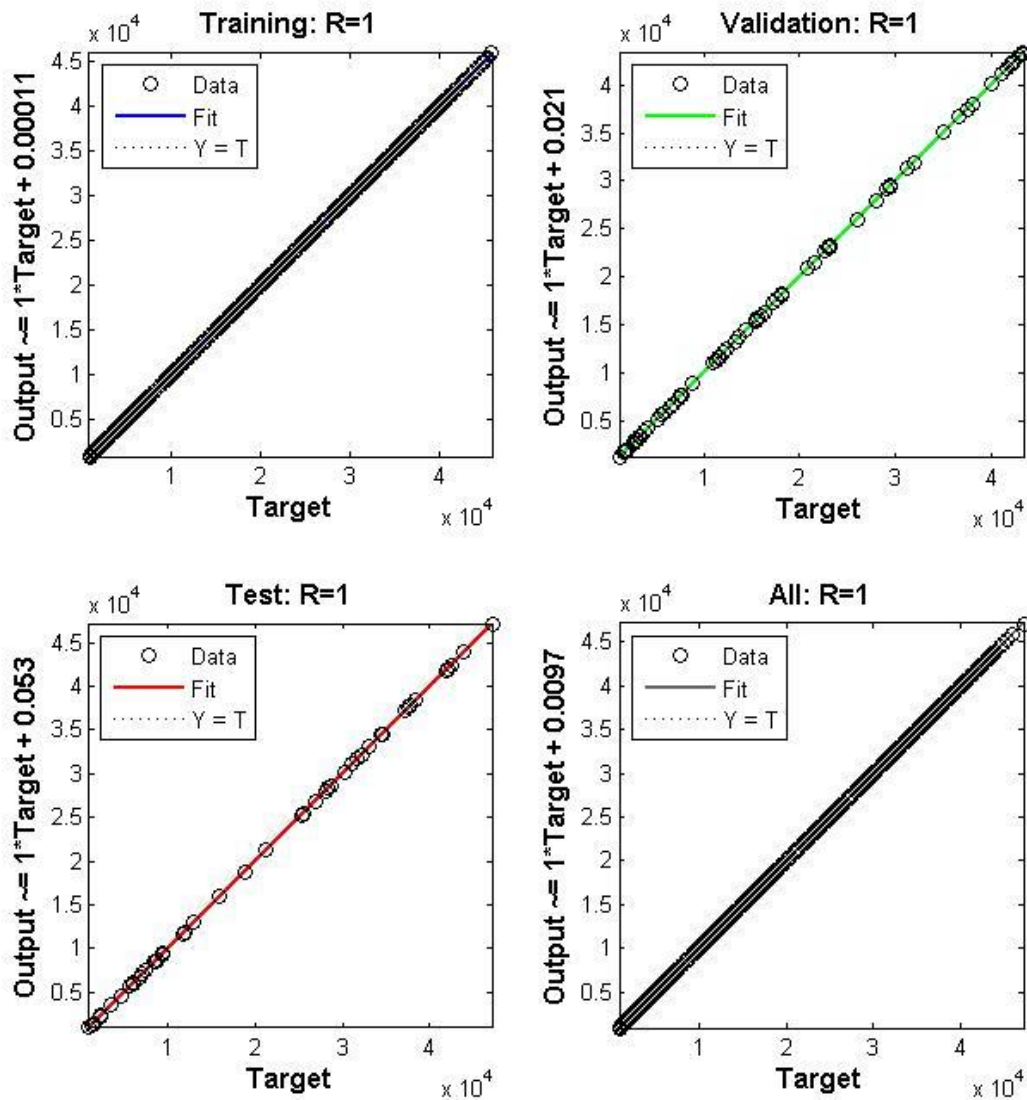
In the error histogram (shown in Fig. 6.15), blue bars represent training data, the green bars represent validation data, and the red bars represent testing data. An error histogram basically gives an indication of outliers in the dataset. Outliers are data those points where the fit is significantly worse than the majority of data. From the plot we can see

that the most errors fall between -0.13 and 0.71. Thus, the error after training of the network is minimal.



**FIGURE 6.15 ERROR HISTOGRAM PLOT OBTAINED AFTER DAY MODE ANN TRAINING**

Regression plot (Fig. 6.16) is another means to validate the network performance. It displays the network outputs with respect to targets for training, validation, and test sets. In case of a perfect fit, all the data falls along a 45 degree line, implying that network outputs are equal to the targets. For this problem, the fit is good for all data sets, as R values for each case equals to 1.0.

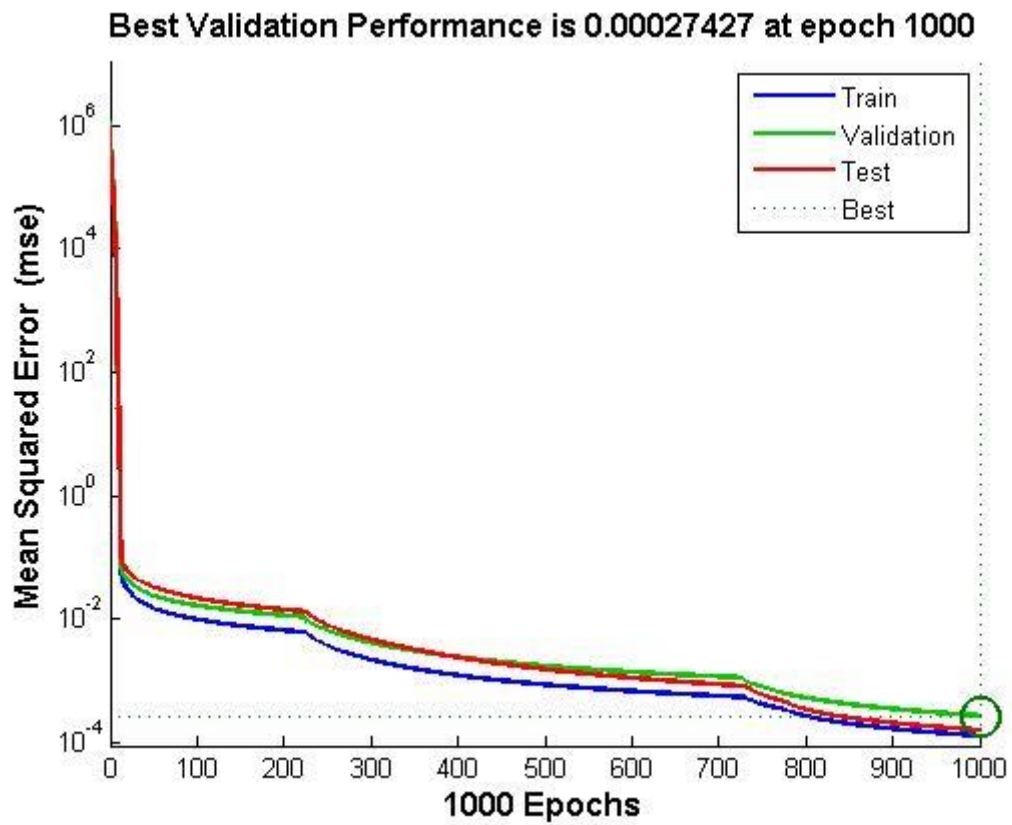


**FIGURE 6.16 REGRESSION PLOT OBTAINED AFTER DAY MODE ANN TRAINING**

### 6.2.2.1.2 Night Mode ANN Model

For the purpose, the sample data set was divided into three categories: training data (80% samples), validation data (15% samples) and testing data (5% samples).

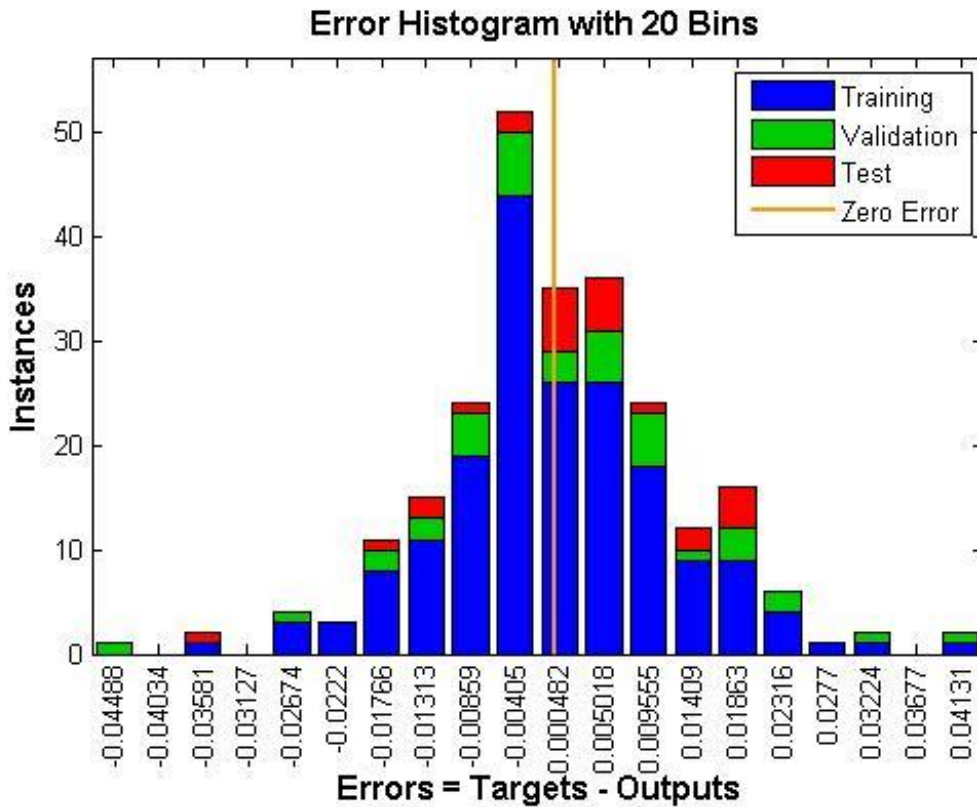
A fitting function ANN model was selected with 10 hidden layers. ANN was trained using the sample data set as described above. The results of the trained network are shown in Fig. 6.17, Fig.6.18 and Fig. 6.19.



**FIGURE 6.17 PERFORMANCE PLOT OBTAINED AFTER COMPLETION OF NIGHT MODE ANN TRAINING**

Error histogram plot (Fig. 6.18) for Night mode neural network indicates that the most errors fall between -0.045 and 0.043. Thus, the error after training of the network is minimal.

Also, the regression plot (Fig. 6.19) for this network shows that the fit is good for all data sets, as R values for each case equals to 1.0.



**FIGURE 6.18 ERROR HISTOGRAM PLOT OBTAINED AFTER NIGHT MODE ANN TRAINING**

Experiments were carried out with participants to analyze the mitigation ability of the neural network based system. Participants were asked to detect a number of varying events both in the outside environment and that occurring on HUD symbology page. All the participants used the system both in the day mode and night mode.

The event detection results obtained are as presented Fig. 6.21, Fig.6.22, Fig. 6.23 and Fig. 6.24.

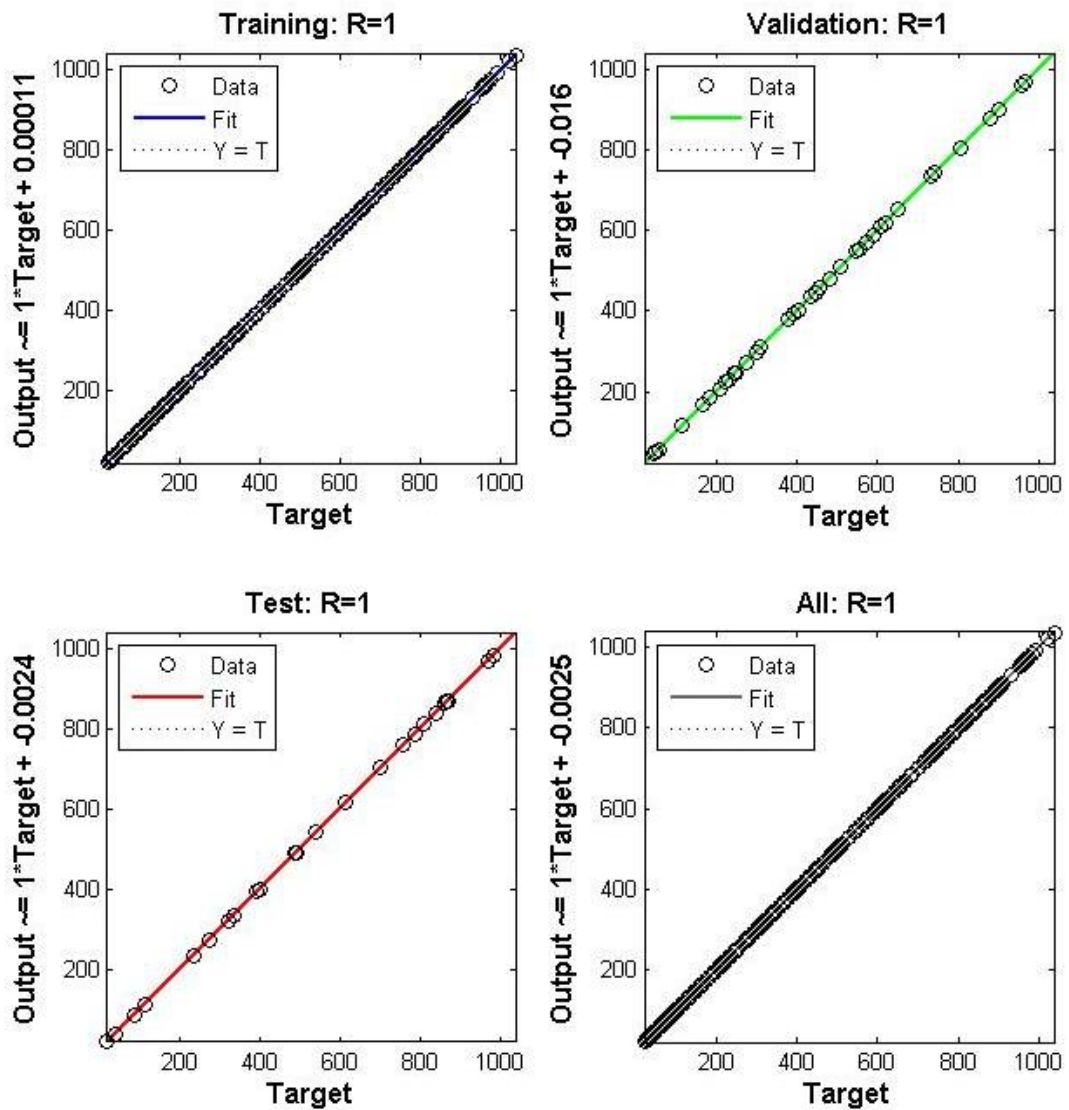


FIGURE 6.19 REGRESSION PLOT OBTAINED AFTER NIGHT MODE ANN TRAINING

The ANN architecture for both Day and Night mode network is as shown in Fig. 6.20.

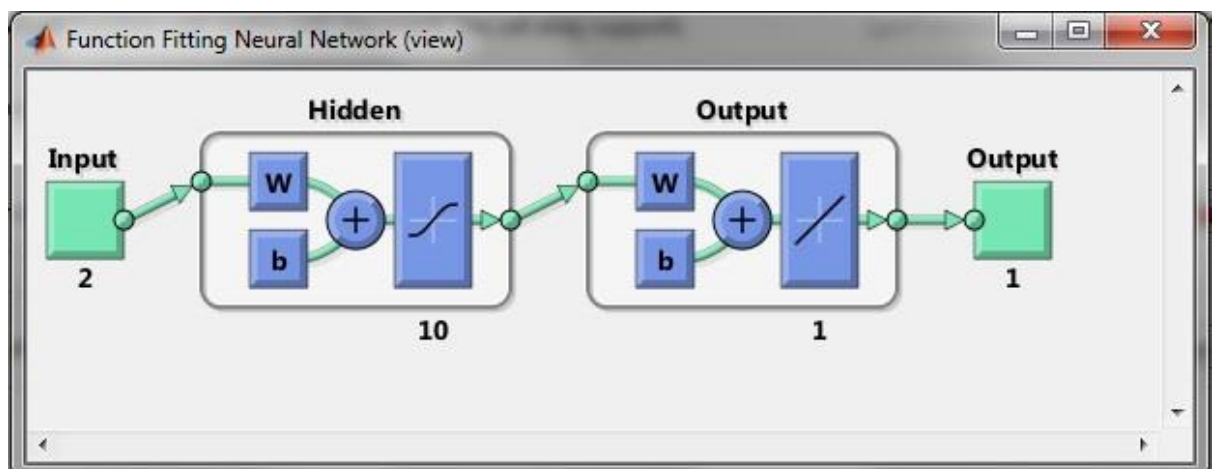
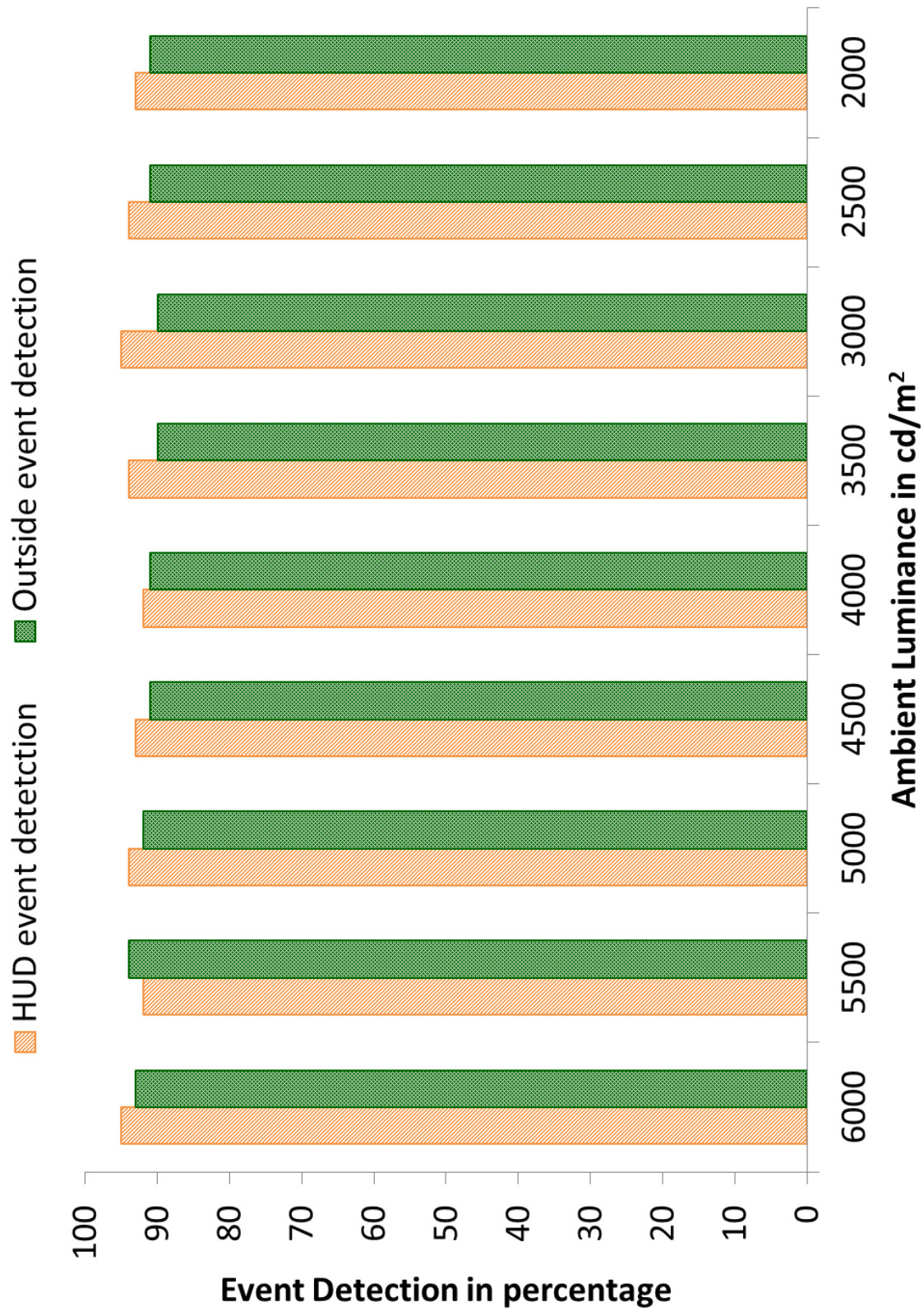
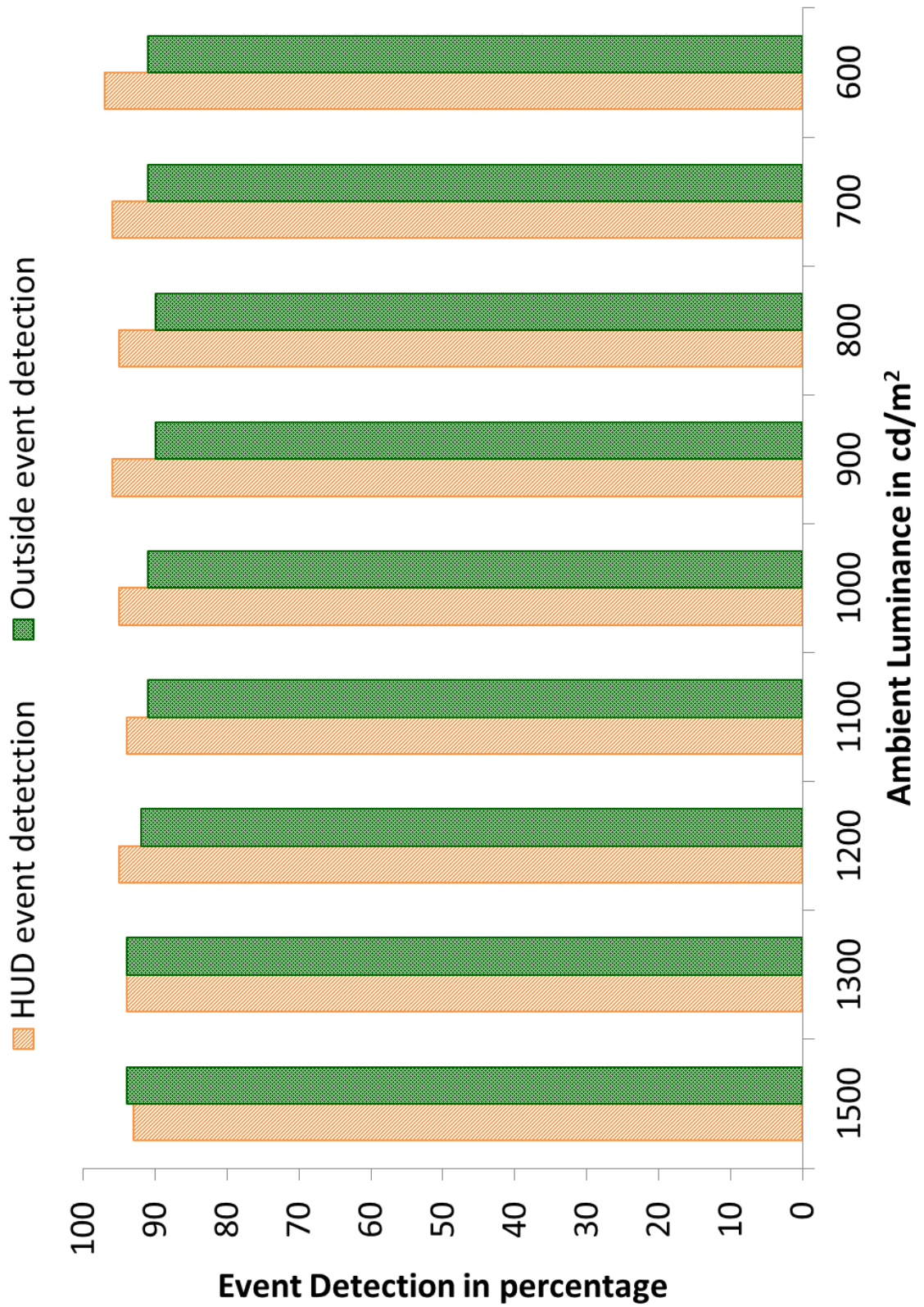


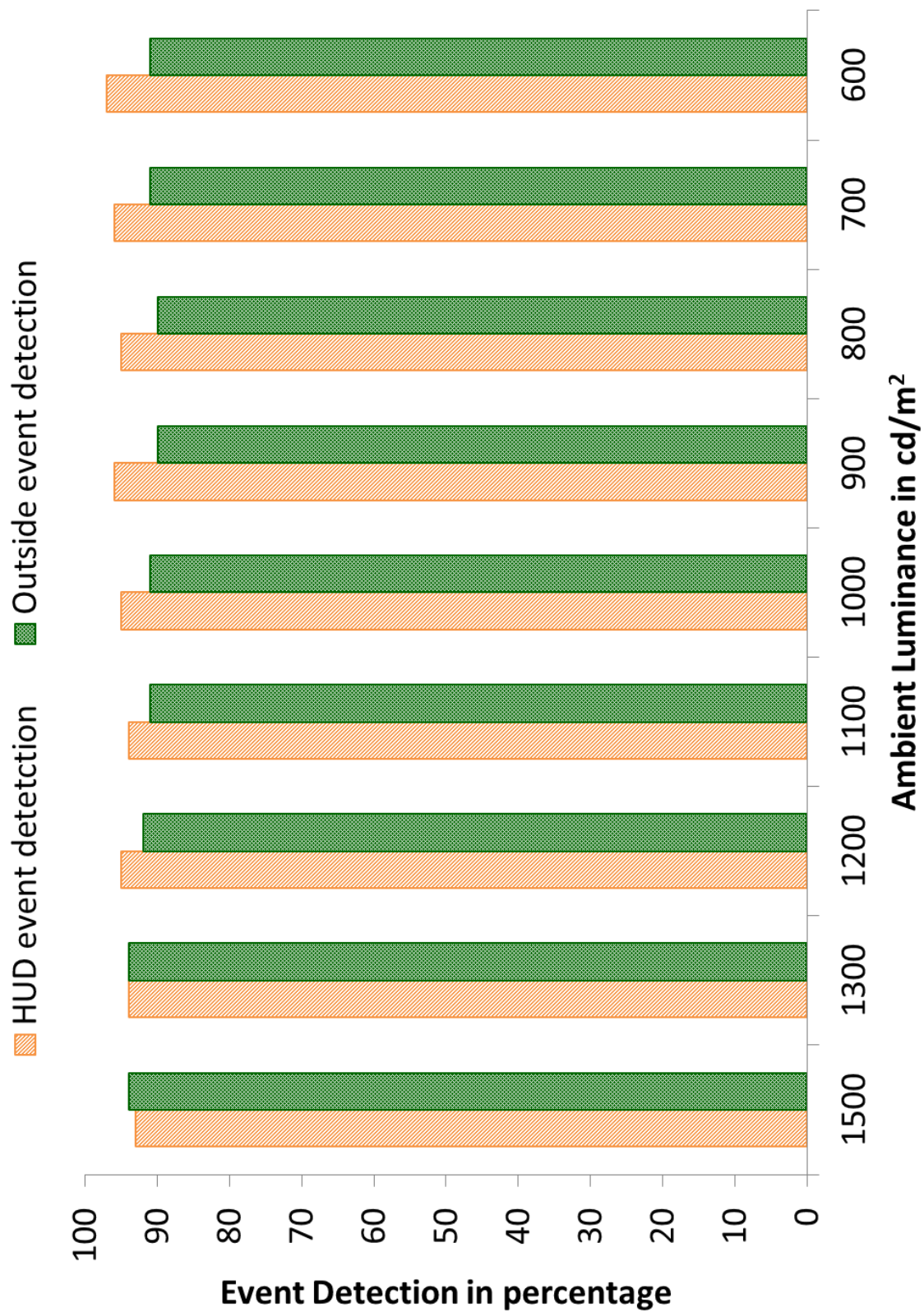
FIGURE 6.20 ANN ARCHITECTURE



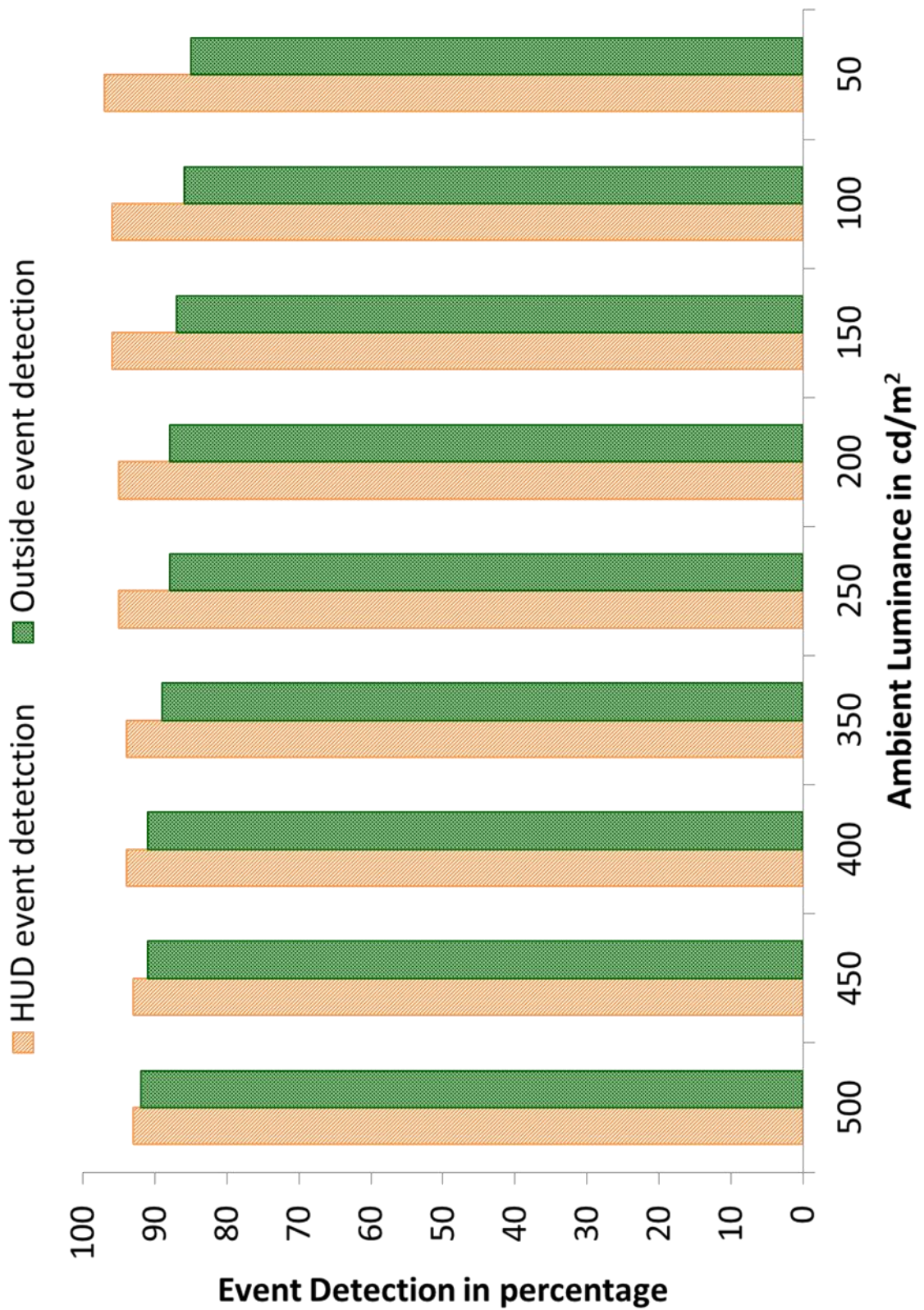
**FIGURE 6.21 COMPARISON OF HUD EVENT DETECTION AND OUTSIDE EVENT DETECTION WHILE USING ANN BASED MITIGATION SYSTEM DURING DAY MODE IN HIGH AL**



**FIGURE 6.22 COMPARISON OF HUD EVENT DETECTION AND OUTSIDE EVENT DETECTION WHILE USING ANN BASED MITIGATION SYSTEM DURING DAY MODE IN MEDIUM AL**



**FIGURE 6.23 COMPARISON OF HUD EVENT DETECTION AND OUTSIDE EVENT DETECTION WHILE USING ANN BASED MITIGATION SYSTEM DURING DAY MODE IN LOW AL**



**FIGURE 6.24 COMPARISON OF HUD EVENT DETECTION AND OUTSIDE EVENT DETECTION WHILE USING ANN BASED MITIGATION SYSTEM DURING NIGHT MODE**

### **6.2.3 ASSISTIVE ATTENTION TUNNELING MITIGATION SYSTEM (AATMS)**

All the extensive data collected was used for the development of an assistive attention tunnelling mitigation system. The system was developed using the Graphical User Interface of MATLAB platform.

The developed system has two variants namely ONLINE mode and OFFLINE mode and works in the following stages:

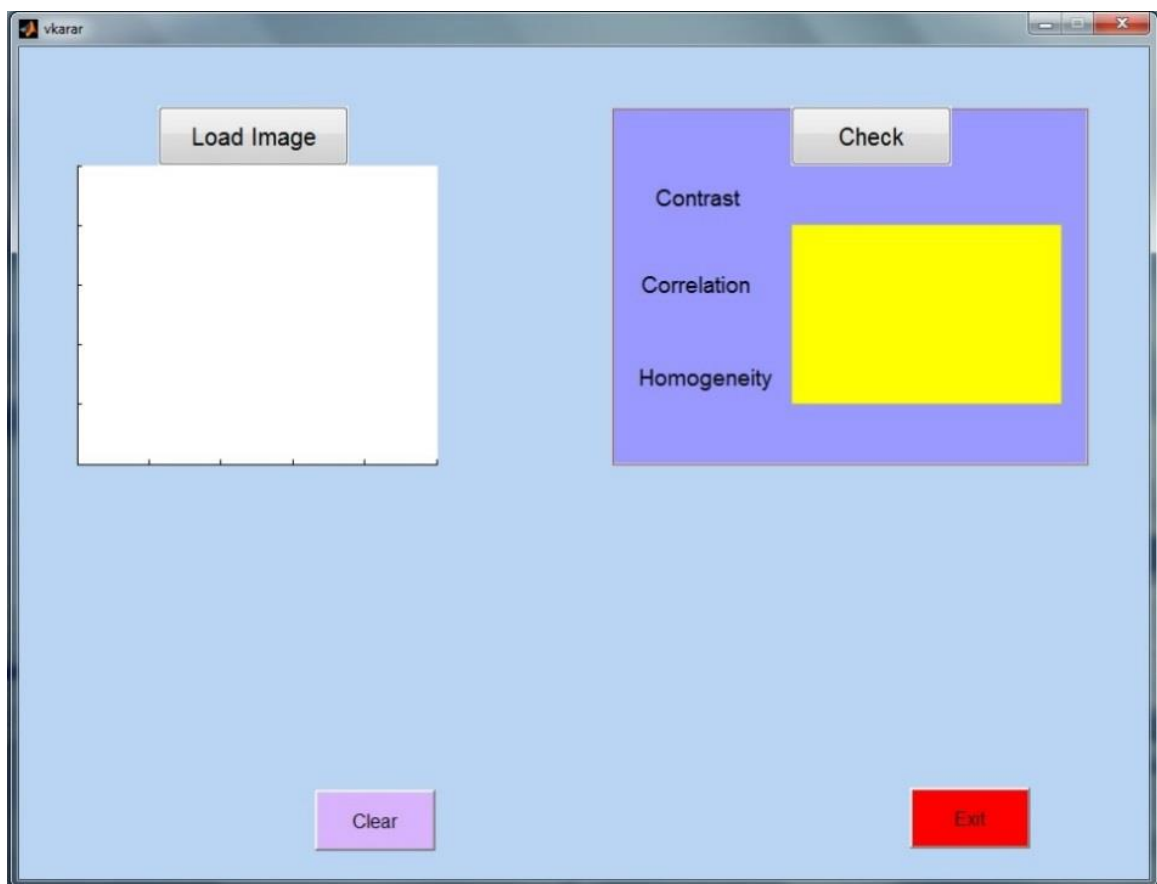
- Load the HUD image into the system
- Extract texture features of the image for classification i.e. contrast, correlation and homogeneity.
- Alert the user decision in case of attention tunnelling
- Predict the preferred symbology luminance to mitigate tunnelling on user choice.

The implantation scheme is as shown by a series of images highlighting the working of the developed AATMS.

#### **6.2.3.1 Offline Mode**

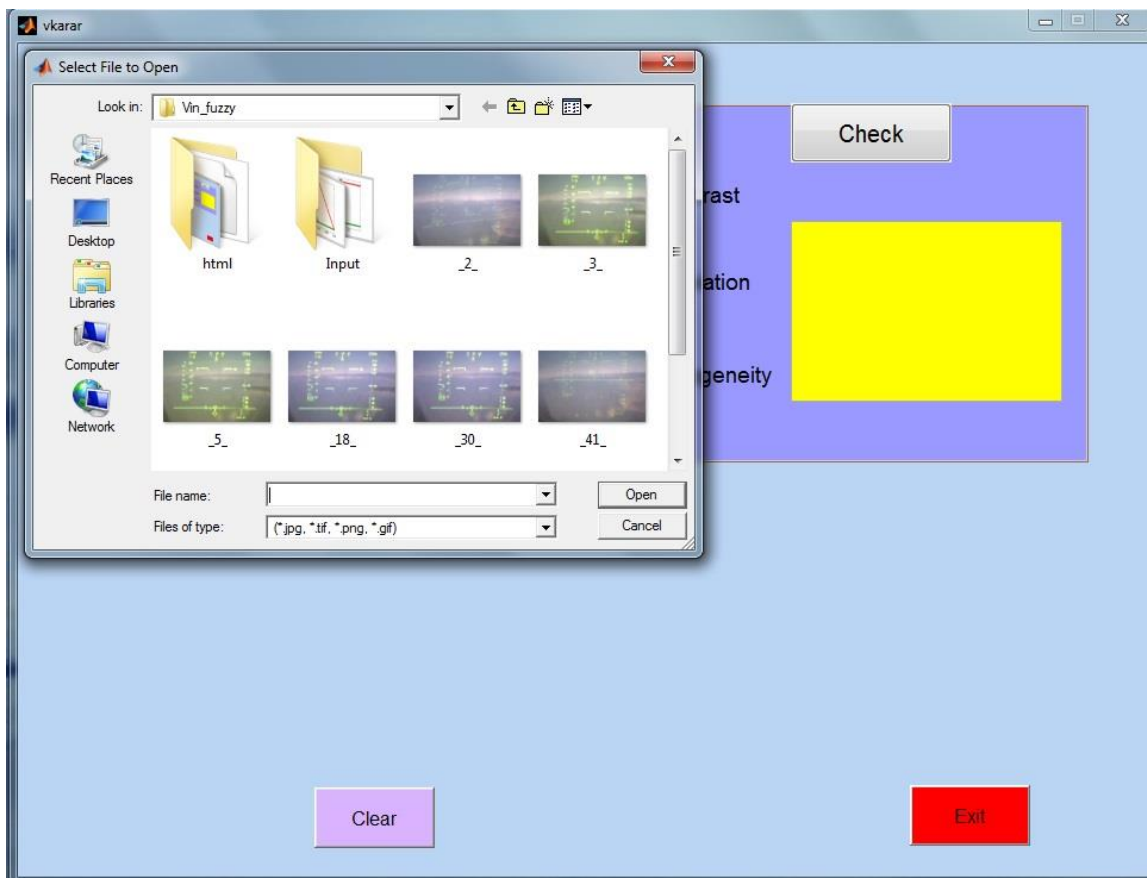
The offline version of the system takes an image frame in single feed and processes it. Steps of operation are as follows:

Step 1: Run the AATMS GUI. The opening page is shown in Fig. 6.25.



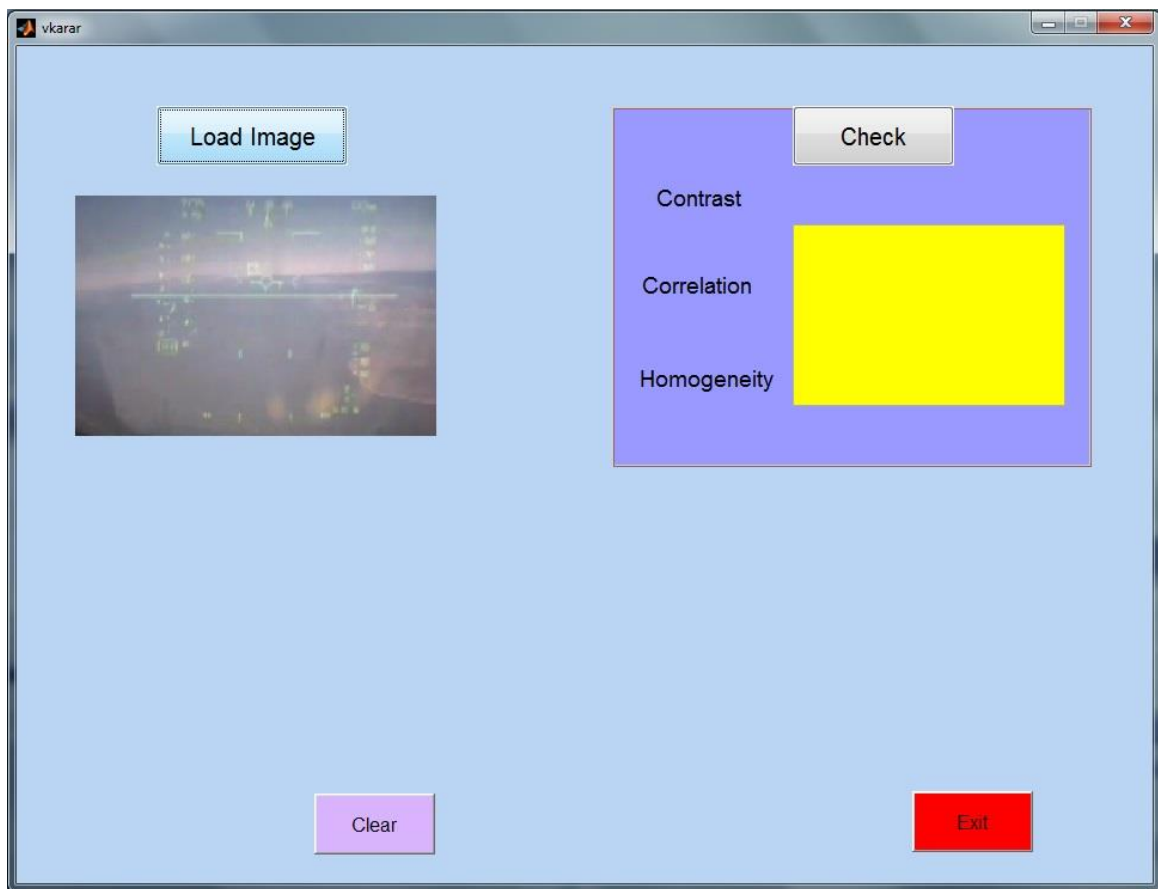
**FIGURE 6.25 OPENING GUI WINDOW FOR OFFLINE MODE OF AATMS**

Step 2: Click on the 'Load Image' button to select the image for processing. The folder in which the extracted frames are present opens up on the click (Fig. 6.26).



**FIGURE 6.26 GUI WINDOW FOR OFFLINE MODE OF AATMS SHOWING 'LOAD IMAGE' WINDOW TO SELECT THE IMAGE FOR PROCESSING**

Step 3: Select the image and click open. The image gets loaded and is displayed (Fig. 6.27).



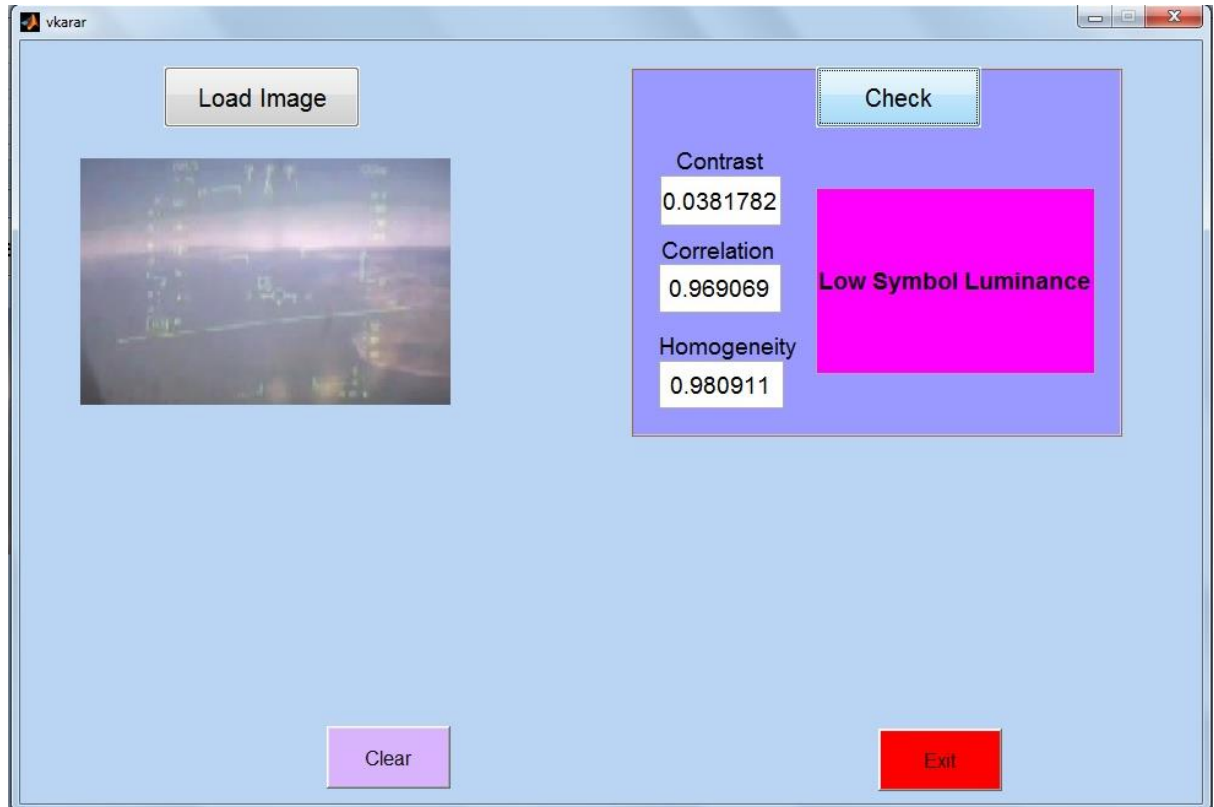
**FIGURE 6.27 GUI WINDOW FOR OFFLINE MODE OF AATMS SHOWING LOADED IMAGE FOR TUNNELING IDENTIFICATION**

Step 4: To find out whether the current scene is tunnelled or not click on the ‘Check’ button (Fig. 6.28).



**FIGURE 6.28 GUI WINDOW FOR OFFLINE MODE OF AATMS SHOWING RESULT FOR TUNNELED IMAGE IDENTIFICATION IN FORM OF NORMAL OPERATION**

The program calculates the value of contrast, correlation and homogeneity and displays the results. The three possible results are: Low IL (Fig. 6.29), Normal operation (Fig. 6.28) and High IL (Fig. 6.30).

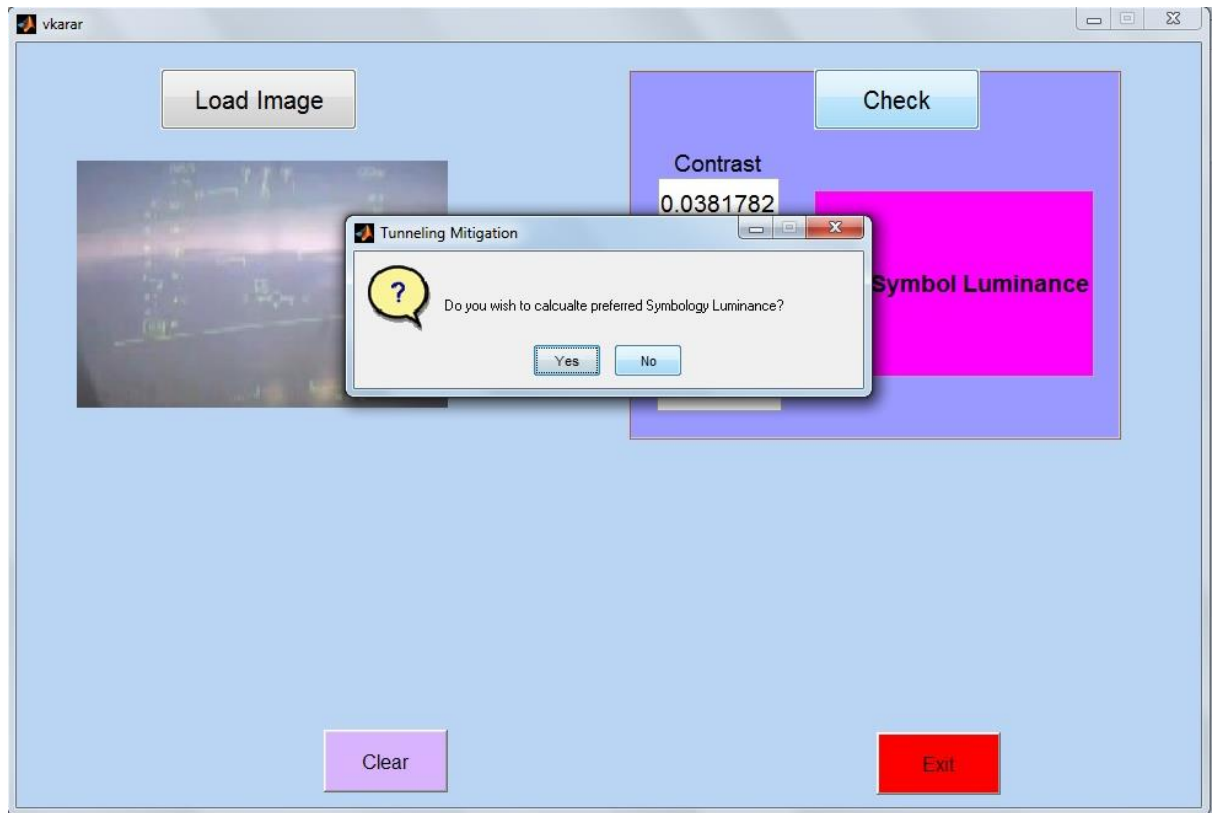


**FIGURE 6.29 GUI WINDOW FOR OFFLINE MODE OF AATMS SHOWING RESULT FOR TUNNELED IMAGE IDENTIFICATION IN FORM OF TUNNELED OPERATION DUE TO LOW IL**



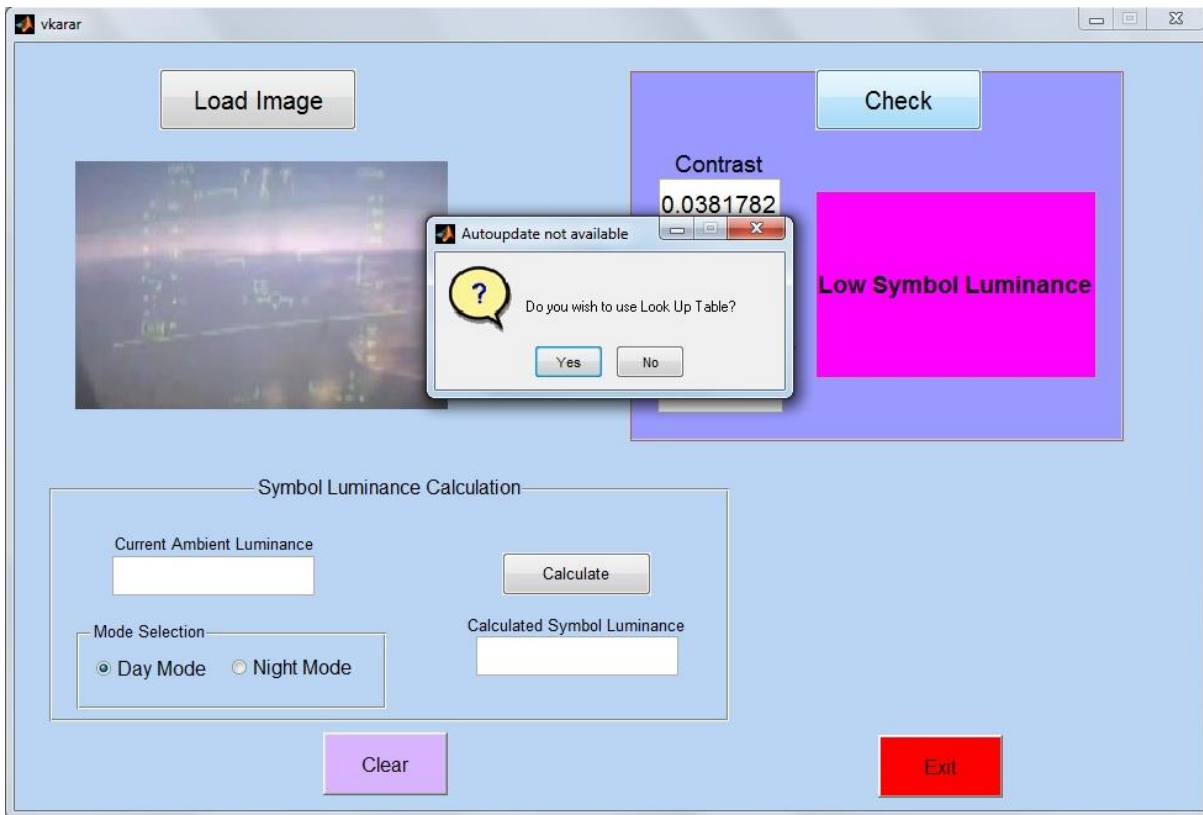
**FIGURE 6.30 GUI WINDOW FOR OFFLINE MODE OF AATMS SHOWING RESULT FOR TUNNELED IMAGE IDENTIFICATION IN FORM OF TUNNELED OPERATION DUE TO HIGH IL**

Step 5: When low IL or high IL is detected a choice to calculate preferred symbology pops up (Fig. 6.31).



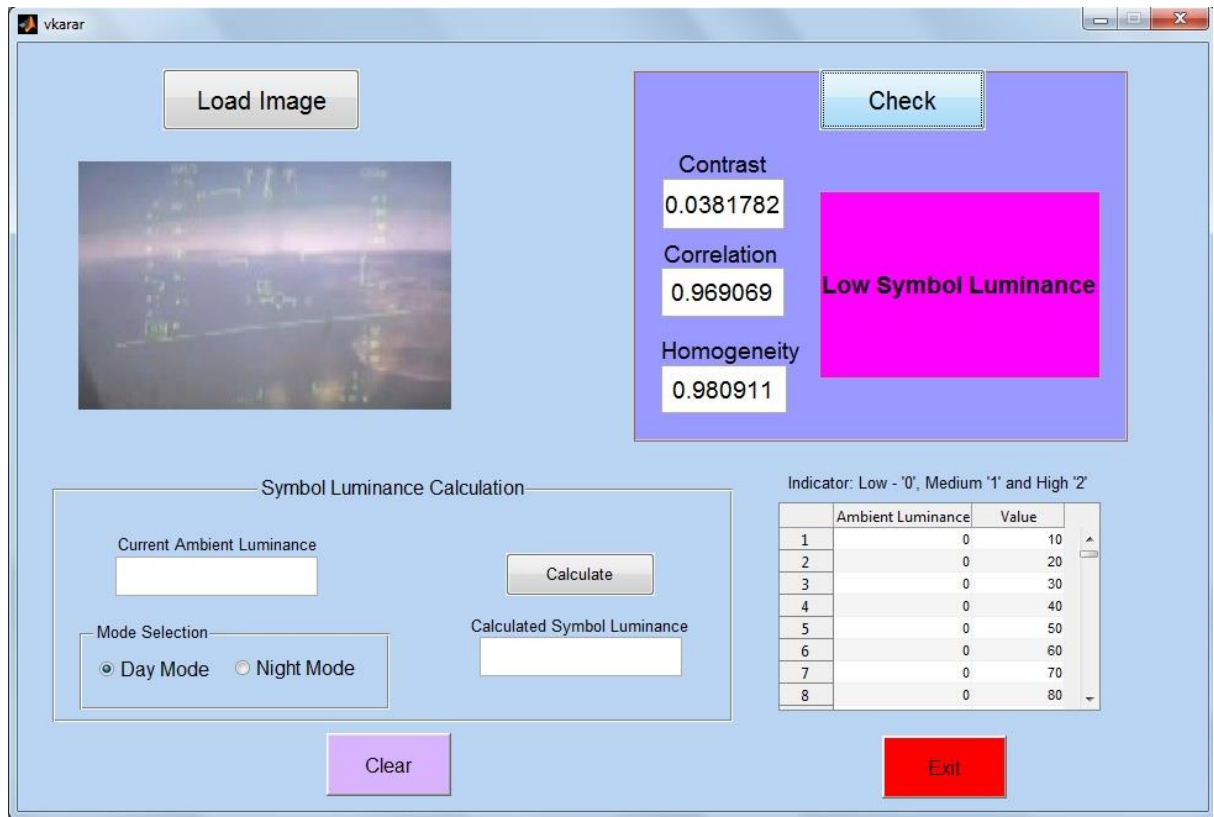
**FIGURE 6.31 GUI WINDOW FOR OFFLINE MODE OF AATMS SHOWING OPTION OF CHOICE TO CALCULATE PREFERRED SYMBOLOGY IN OF A TUNNELED IMAGE**

Step 6: Since, this GUI works in the offline mode, a provision of Look-up table is also provided for the ease of user if they wish to use it (Fig. 6.32).



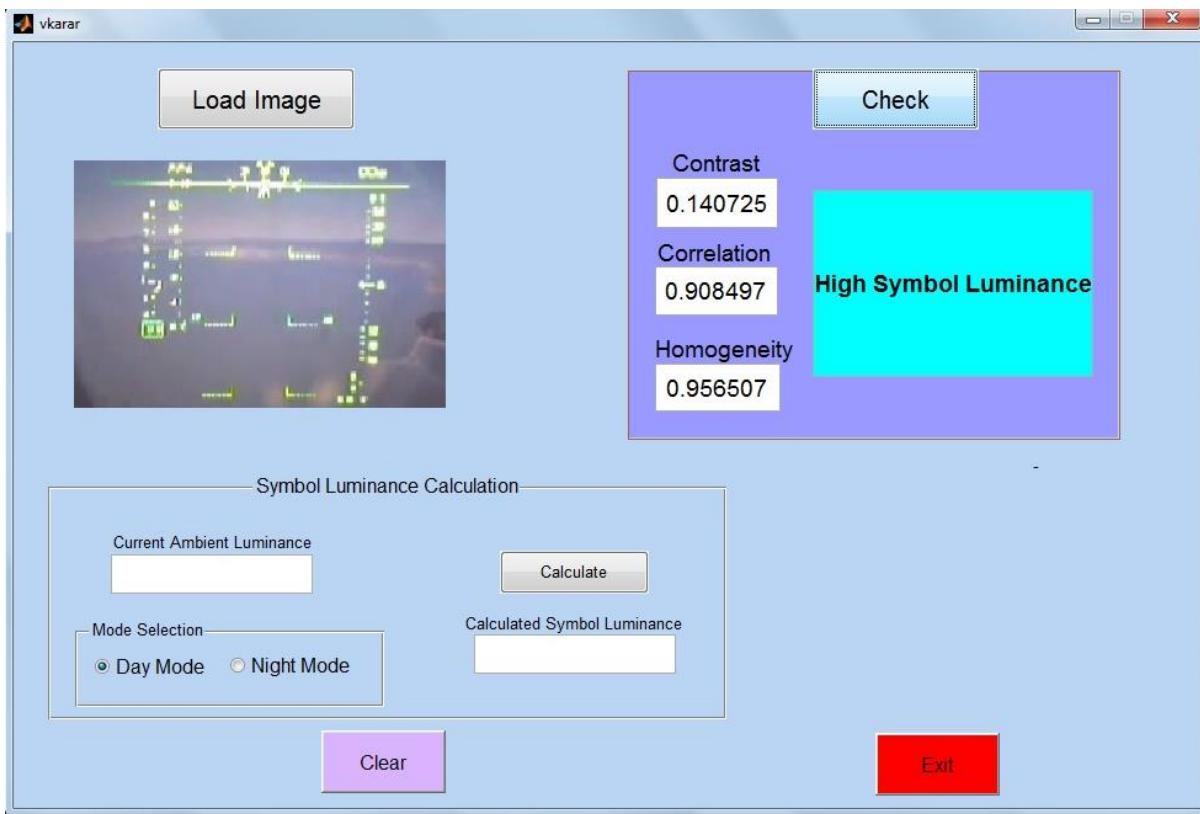
**FIGURE 6.32 GUI WINDOW FOR OFFLINE MODE OF AATMS SHOWING OPTION FOR CHOICE OF LOOK-UP TABLE FOR CHOOSING AMBIENT LUMINANCE RANGE FOR THE PURPOSE OF CALCULATING IL**

Step 7: If the user selects 'Yes' then the look up table opens adjacent to the IL calculation panel (Fig. 6.33).



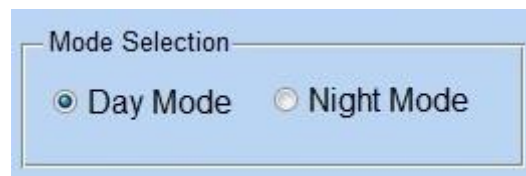
**FIGURE 6.33 GUI WINDOW FOR OFFLINE MODE OF AATMS SHOWING LOOK-UP TABLE FOR CHOOSING AMBIENT LUMINANCE RANGE FOR THE PURPOSE OF CALCULATING IL**

Step 8: If the user selects 'NO', following window appears (Fig. 6.34).



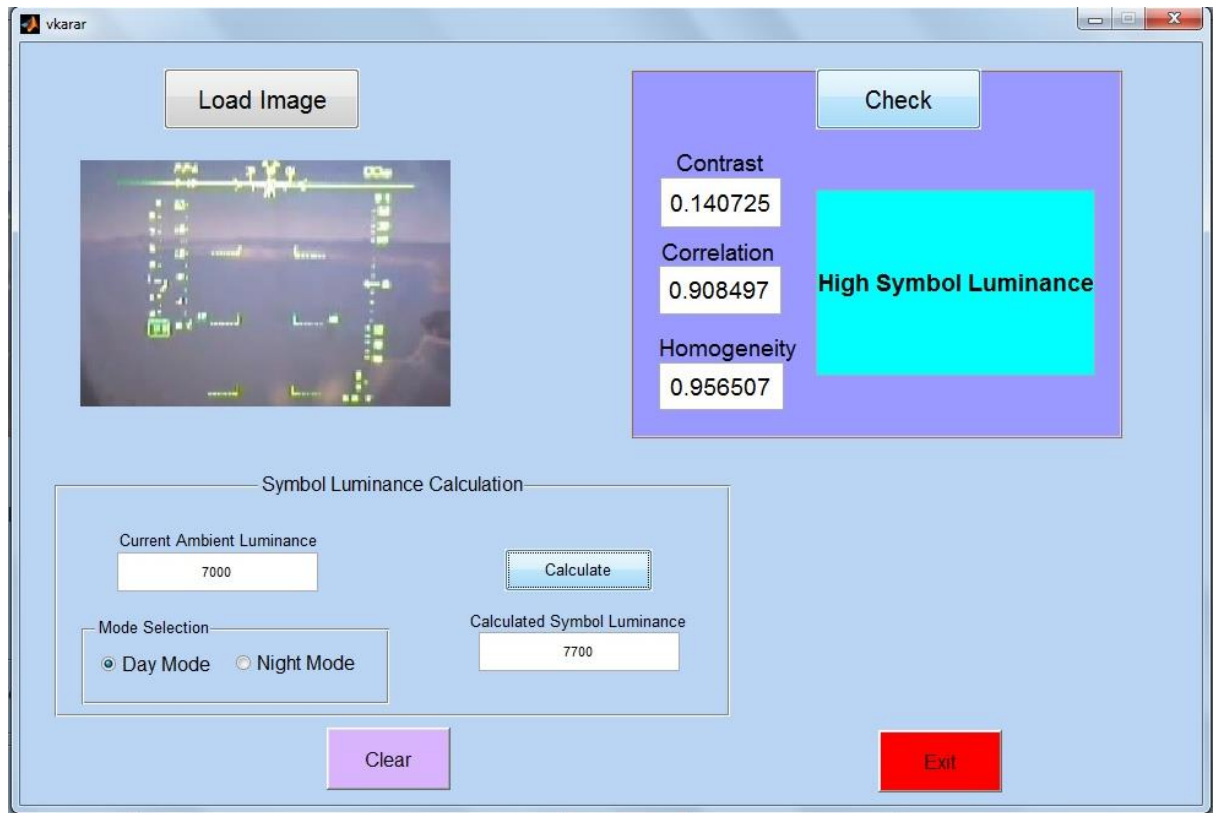
**FIGURE 6.34 GUI WINDOW FOR OFFLINE MODE OF AATMS SHOWING WINDOW WHEN OPTION OF 'NO' IS SELECTED AGAINST THE CHOICE TO USE LOOK UP TABLE WHILE CALCULATING PREFERRED SYMBOLOGY FOR A TUNNELED IMAGE**

Step 9: Select the mode of operation in the mode selection block (Fig. 6.35).



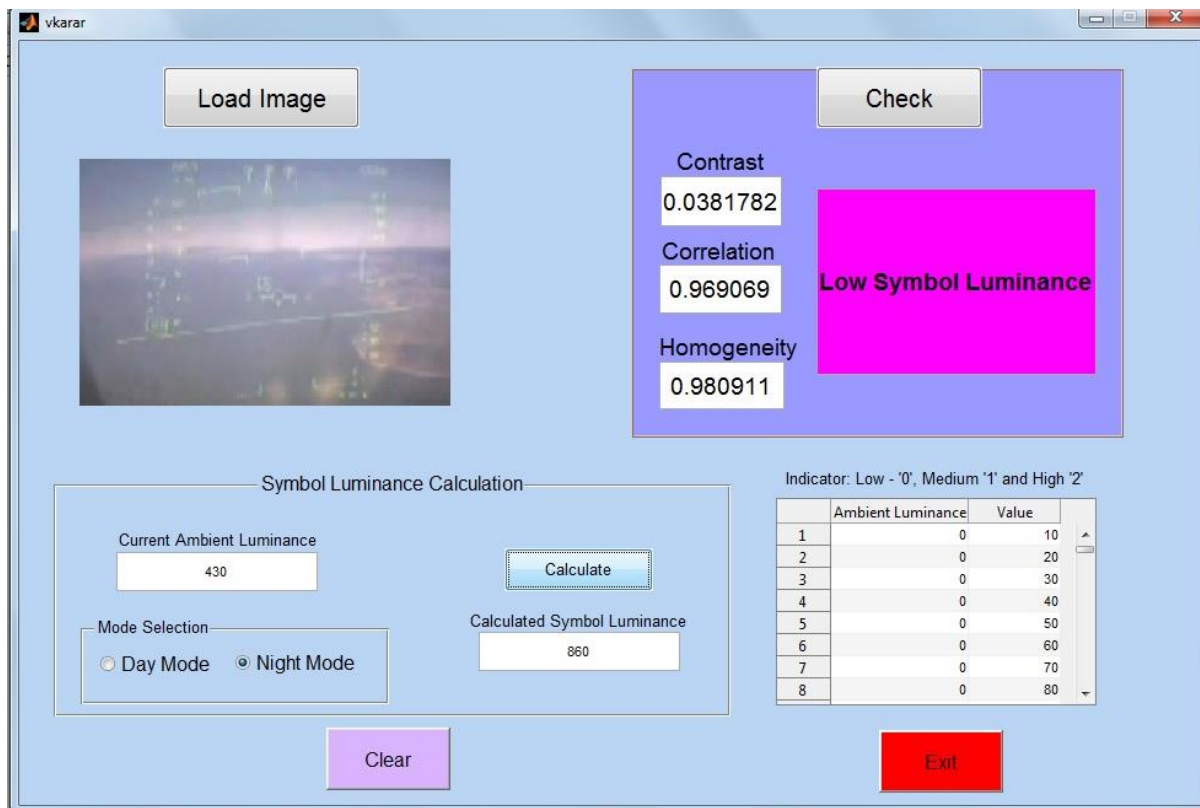
**FIGURE 6.35 OPTION OF 'DAY' AND 'NIGHT' MODE SELECTION FOR OFFLINE MODE OF AATMS TO ENABLE CALCULATION OF IL FOR A TUNNELED IMAGE**

Step 10: Enter the Current ambient luminance value for which preferred symbology luminance needs to be calculated and press 'Calculate' (Fig. 6.36).



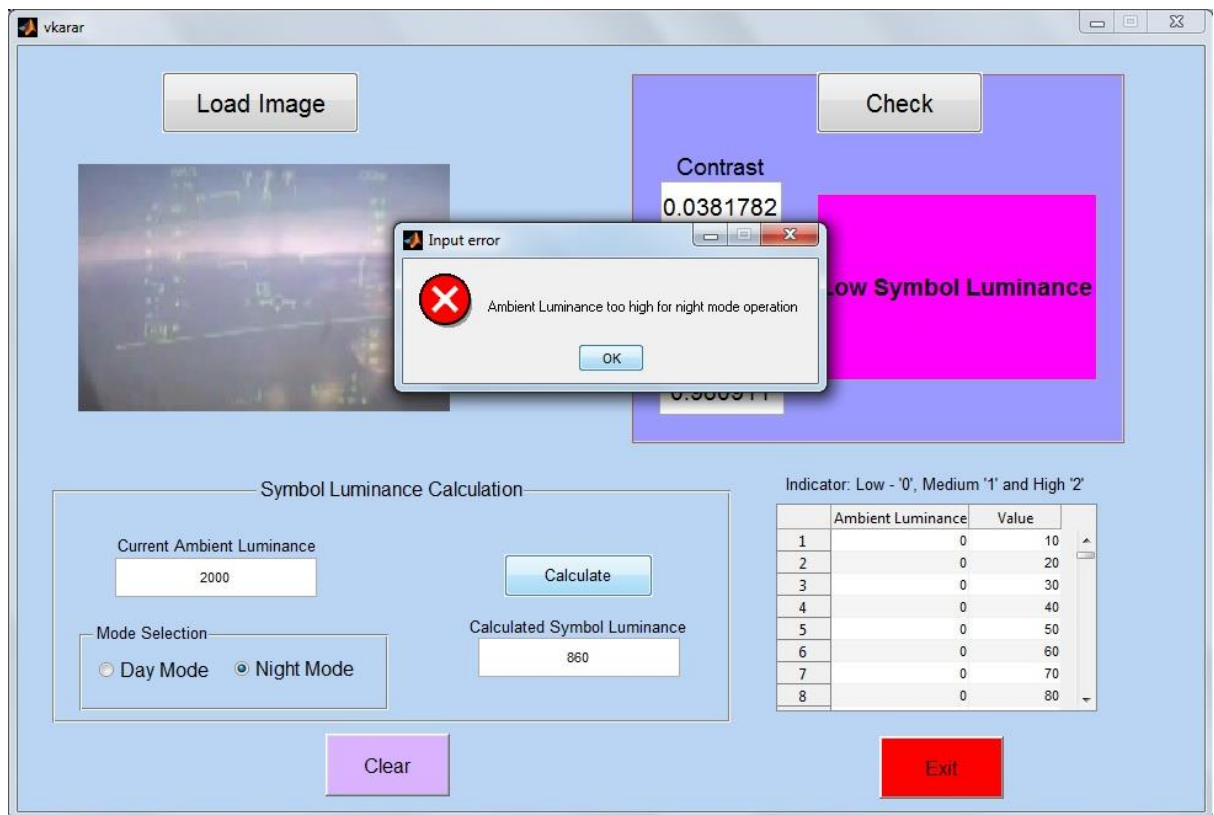
**FIGURE 6.36 GUI WINDOW FOR OFFLINE MODE OF AATMS SHOWING VALUE OF CURRENT AMBIENT LUMINANCE ENTERED AND THE CALCULATED IL DURING DAY TO CALCULATE PREFERRED SYMBOLOGY FOR A TUNNELED IMAGE**

Step 11: If the user selects night mode, the IL is calculated based on the current ambient luminance (Fig. 6.37).



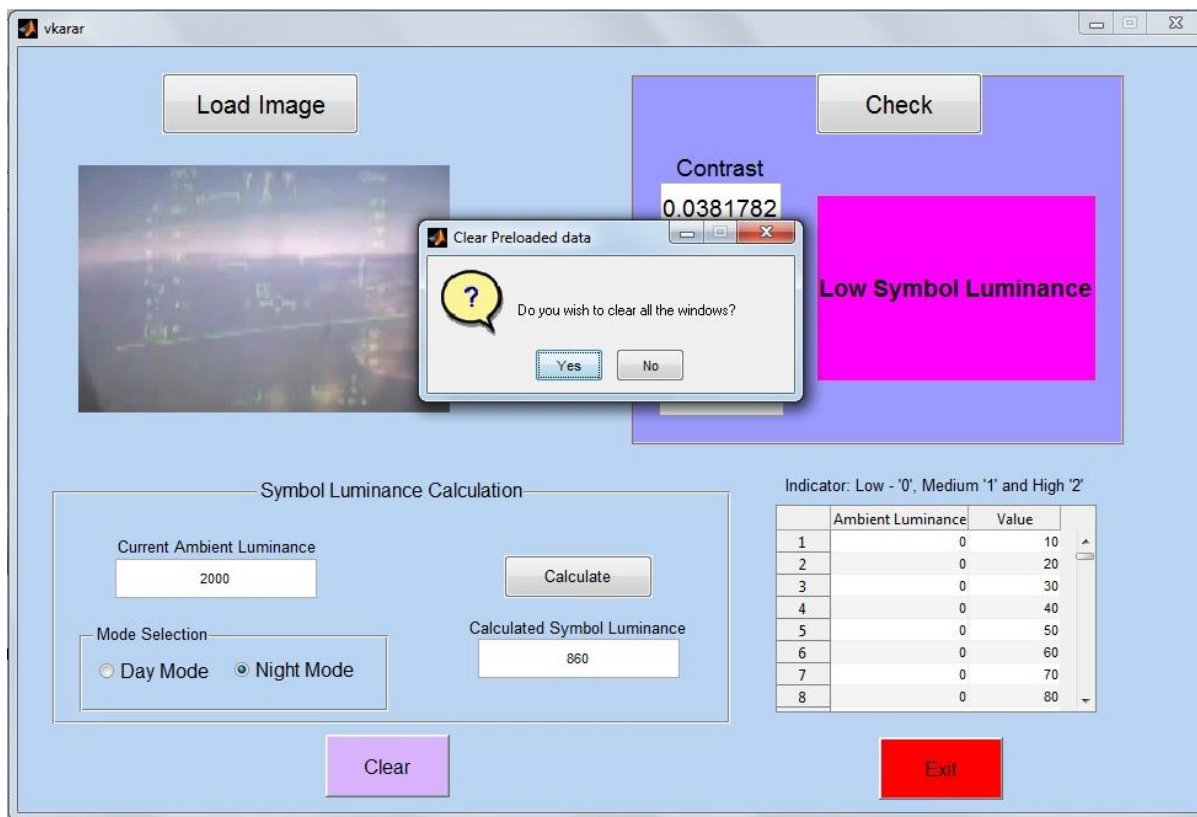
**FIGURE 6.37 GUI WINDOW FOR OFFLINE MODE OF AATMS SHOWING VALUE OF CURRENT AMBIENT LUMINANCE ENTERED AND THE CALCULATED IL DURING NIGHT MODE TO CALCULATE PREFERRED SYMBOLOGY FOR A TUNNELED IMAGE**

Step 12: If the entered range of luminance exceeds night time luminance limit an error message pops up (Fig. 6.38).



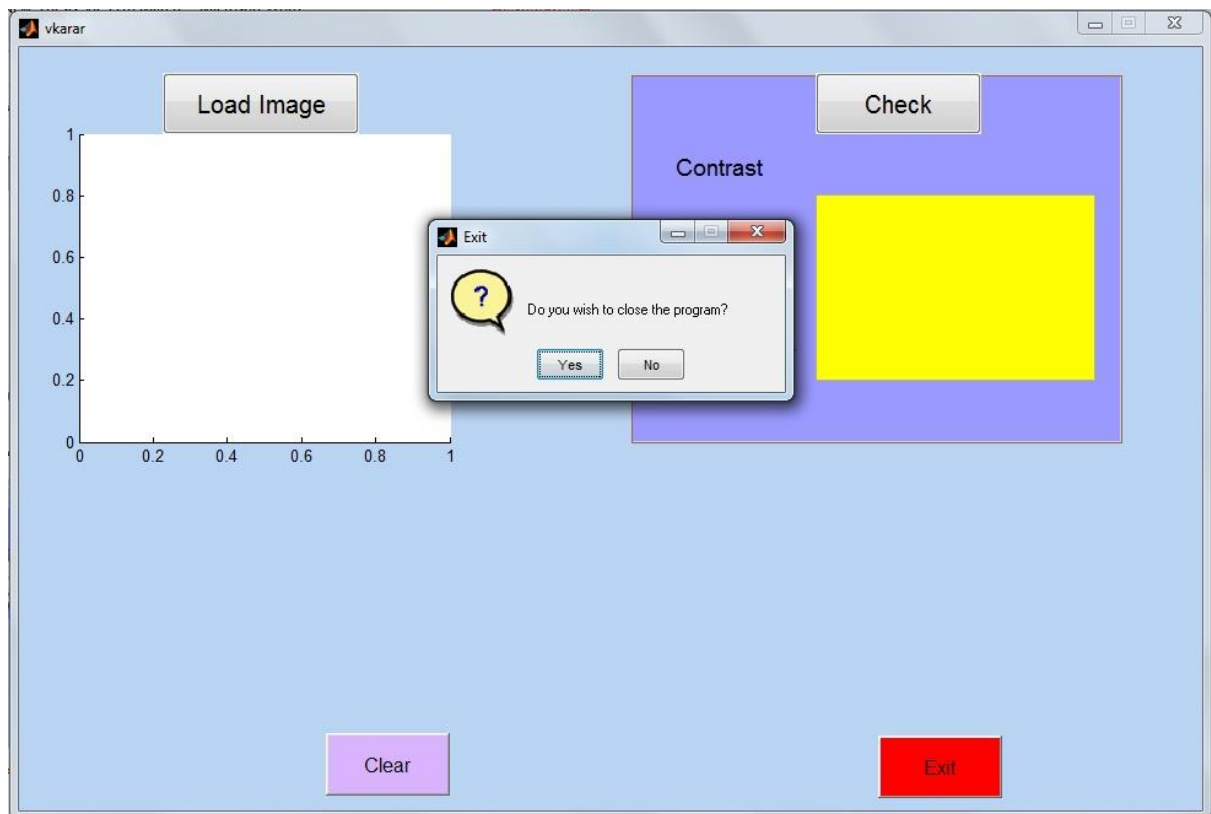
**FIGURE 6.38 GUI WINDOW FOR OFFLINE MODE OF AATMS SHOWING ERROR WINDOW WHEN ENTERED RANGE OF LUMINANCE EXCEEDS NIGHT TIME LUMINANCE LIMIT**

Step 13: If the user wishes to clear all the windows on the GUI panel and have a fresh start, user may click on the ‘Clear’ button, which gives user a choice of clear screen (Fig. 6.39).



**FIGURE 6.39 GUI WINDOW FOR OFFLINE MODE OF AATMS SHOWING OPTION TO CLEAR ALL THE WINDOWS ON GUI PANEL**

Step 14: When the user wants to close the program, user may click exit button (Fig. 6.40).



**FIGURE 6.40 GUI WINDOW FOR OFFLINE MODE OF AATMS SHOWING EXIT OPTION**

### **6.2.3.2 Online Mode**

The online version works in a continuous mode (Fig. 6.41). It reads the video from HUD camera input, extracts frames and predict preferred symbology luminance when selected.

## **6.3 CONCLUSION**

In the process of developing an ANN based decision support system two ANN variants were developed: i) an ANFIS based mitigation system and ii) an ANN based mitigation system. After analysing the results of both the variants, ANN based models were incorporated in the developed graphical user interface – Assistive Attention Tunneling Mitigation system (Fig. 6.41).



**FIGURE 6.41 GUI WINDOW FOR ONLINE MODE OF AATMS**

### **6.3.1 ANFIS IMPLEMENTATION: HUD SWITCHING SYSTEM FOR MITIGATING TUNNELING**

To add to some intuitiveness to the HUD operation, an ANFIS based system was developed. The ANFIS based system helped in automatic luminance adjustment of the symbology according to ambient lighting conditions at time of flight operation. The developed system was able to mitigate attention tunneling to some extent. The implementation results showed improved balance between event detection both for HUD and outside events during medium ambient luminance range but there still existed imbalance for high and low ambient luminance conditions. This required further improvement in the system design.

Since, pure ANN models are found to give better results in case of solving fitting function type problems, ANN based models were then developed to handle the large ambient luminance operation range.

### 6.3.2 ARTIFICIAL NEURAL NETWORK BASED HUD SWITCHING SYSTEM FOR MITIGATING TUNNELING EFFECT

The drawback of misbalance in high and low ambient luminance operation which was observed while ANFIS implementation motivated for developing individual models for both day and night mode operation.

Two ANN based models were developed for catering the variable needs of day and night mode flight operation. The use of the mode selection with corresponding ANN models proved to be an efficient solution for mitigating attention tunneling. The balance achieved in event detection percentage of HUD event detection and outside event detection is found to be satisfactory. The developed system works well in varying ambient conditions and provides user a comfortable viewing experience by adjusting HUD symbology luminance for achieving favourable CR. The development strategy used for developing ANN based mitigation system is shown in Fig. 6.42.

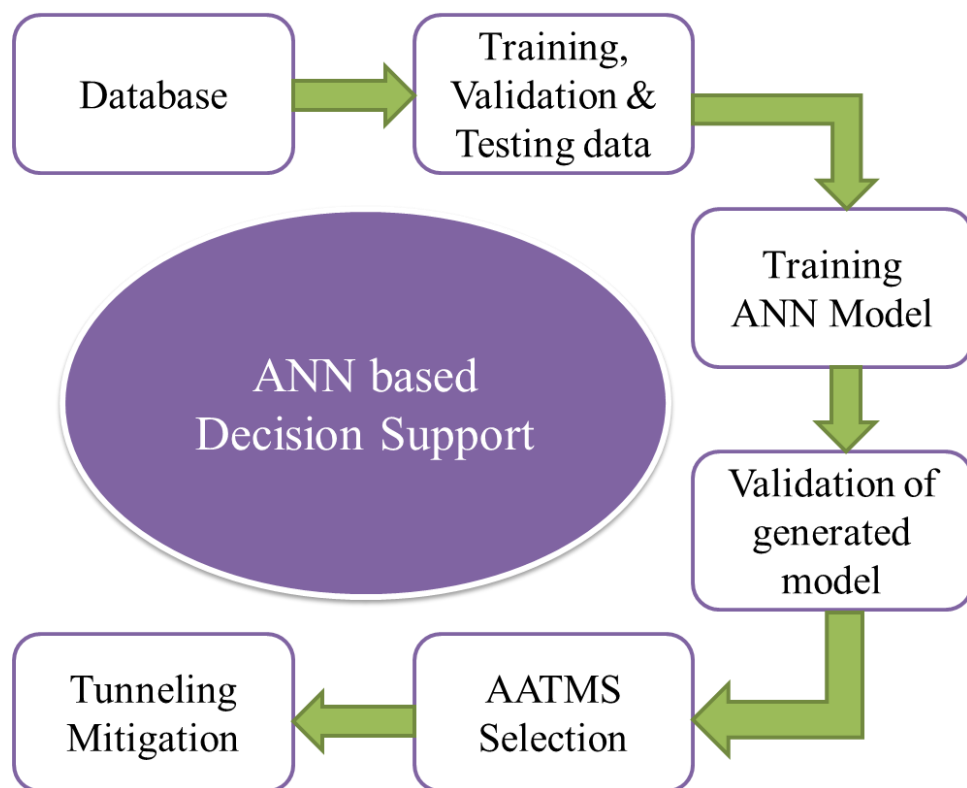


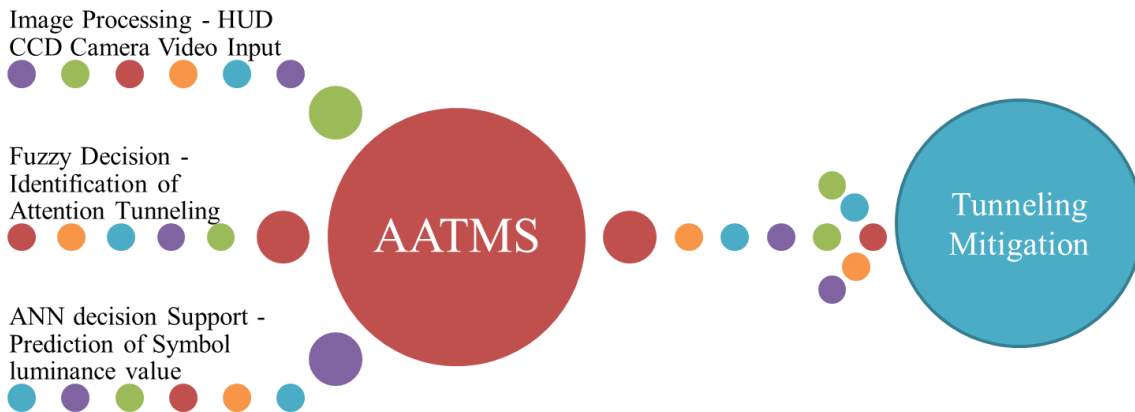
FIGURE 6.42 ANN BASED DECISION SUPPORT FOR TUNNELING MITIGATION

### 6.3.3 ASSISTIVE ATTENTION TUNNELING MITIGATION SYSTEM (AATMS)

A graphical user interface based assistive system has been developed (Fig. 6.43). The system has two versions: Online mode and Offline mode.

‘Online’ mode system takes inputs: current ambient luminance and mode of operation directly from the sensor and adjusts HUD symbology luminance. The system kicks into action when user wants AATMS to be active for tunneling mitigation. By default the system rests idle and needs to be activated for operation.

‘Offline’ mode system takes inputs: current ambient luminance and mode of operation entered by the user manually. When working in ‘Offline’ mode the system is capable of alerting the user about attention tunnelling situation taking place. User may choose to calculate the preferred symbology luminance using the AATMS or can choose to override the warning. This mode of operation is basically to demonstrate the functioning of AATMS as well as for testing and checking purpose.

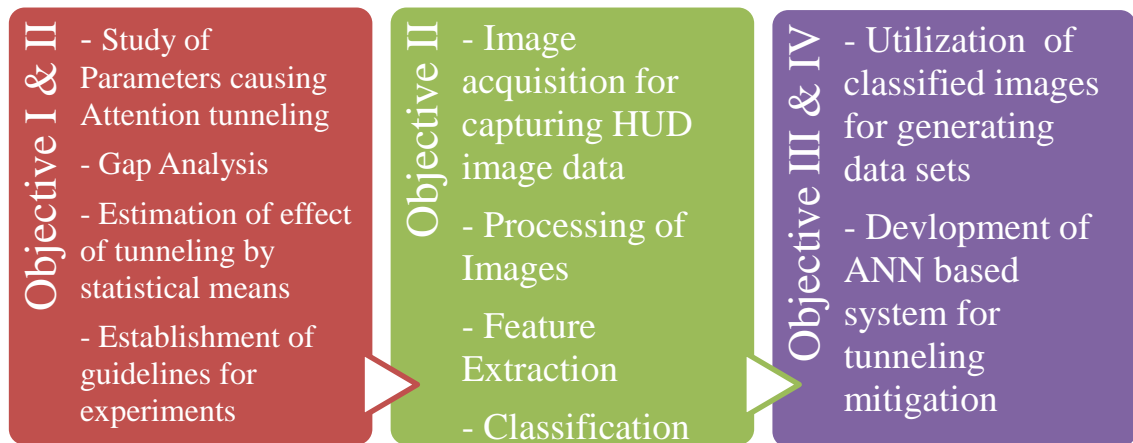


**FIGURE 6.43 ASSISTIVE ATTENTION TUNNELING MITIGATION SYSTEM**

AATMS is an attempt to automate the process of detecting attention tunnelling taking place while use of HUD and providing a solution to mitigate the effect of attention tunnelling in an efficient manner.

## CONCLUSION

The summary of work reported in the thesis is summarized in Fig. 7.1.



**FIGURE 6.44 SUMMARY OF WORK REPORTED IN THE THESIS**

The first objective of the work involved studying all technical aspects of HUD leading to the problem of tunneling. In the process of achieving this objective, first milestone covered was literature survey which discussed head-up displays and similar technologies for aviation and automobiles and prevalence of the phenomenon of attention capture, tunneling and associated safety issues. It was clear that there were a number of advantages in using HUDs, which include: increase in flight path tracking accuracy; lower visibility take-off and landing; accurate approach and landing; elimination of head-down time; reduction in time taken to refocus between instruments and external scene; potential to use overlaid symbology for the external scene when it was not visible; raster display during low light condition flights and hence enhancing situation awareness. Its negative sides include problems in switching attention between the internal and external scene as well as difficulties in detecting unexpected events. Potential factors which contribute in some way or the other in the attention capture and tunneling phenomenon are: information and work overload; change

blindness; misaccommodation; misconvergence; non-conformal symbology; symbology format and location; symbol salience; clutter; luminance and contrast ratio; spatial disorientation; limited field of view; etc. Literature reports study of effect of these parameters on attention tunnelling. However, such studies address only a single parameter at a time. Few preventive measures like scene-linked symbology, training, peripheral displays, prevention technologies, synthetic vision, minimizing clutter, etc. help in minimizing the effects of attention capture.

Literature survey was followed by a number of experiments to establish the role of factors affecting attention tunneling. HUD luminance experiment results suggest that HUD SL, CR and NU plays significant role in attention capture and tunneling while HUD usage. The non-uniformity of HUD display results in differential luminance across the HUD display. This leads to a condition of variable contrast ratio across the screen. At higher ambient luminance, non-uniform SL causes more degradation in HUD event detection as compared to outside events. At low ambient lighting conditions, degradation in both the events was significant with HUD event detection getting affected more adversely. At lower ambient luminance, prominence of SL variation significantly forces pilot to get engaged in HUD events and in the process he may lose focus on outside events.

The experiments conducted to understand effect of limiting FOV due to combiner shows that combiner frame provide obscuration in front view of the pilot TFOV as well as IFOV causing misaccommodation and misconvergence problems. The net result is obscuration of pilot's forward view of outside world. Though, the pilot gets HUD symbology in full IFOV and TFOV range but still he may miss some outside events due to combiner frame angle and/or its thickness. When the pilot is required to move his head outside HMB to detect missing outside world events it results in attention tunneling. From the study, another fact which could be inferred is that collimation does not always pull the pilot's visual focus outward to optical infinity. The fixed FOV in horizontal direction limits the presentation of

symbology which also contributes to attentional narrowing. It was concluded that combiner frame edge need to be seen as a single line when viewed from DEP along with optimized frame thickness.

The individual effect of AL, SL and NU along with statistical interpretation of their interaction effect is also reported in this work. Statistical tools relating to inferential statistics domains have been employed for data mining and testing of hypotheses in the present work. Paired t-test results performed over experimental data, performed over luminance range from 50 cd/m<sup>2</sup> to 30,000 cd/m<sup>2</sup>, established that luminance affects the level of event detection on HUD image as well as outside scene significantly. The p-value found through ANOVA showed that percentage of event detection gets significantly affected due to AL and SL both.

It was observed that wherever CR on display area was less than 1.4, response of participants to the events displayed on HUD image appearing on those HUD areas varied in range 47% - 70% while event detection in the outside scene varied in range 94% to 98%. In cases where CR on display area was in range 1.4 - 5, percentage of event detection on HUD image varied in range 70% - 95% while for event detection in the outside scene it varied in range 86% - 94%. Here, variation in CR due to NU caused less significant variation in event detection. In case of CR being more than 5, percentage for event detection on HUD image varied in range 95% - 99% while for event detection in the outside scene it varied in range 11% - 86%. For contrast ratio beyond 7, effect of luminance non-uniformity on detection of events on HUD image as well as outside scene was reduced. In such cases, event detection showed significant dependence on the ambient luminance, SL and CR while less significantly on luminance non-uniformity.

Data sets were generated all the while when objectives I and II were under progress. The data sets consist of event detection percentage for both HUD event and Outside event, based on participant's response. Also, data sets were generated comprising of textural features for identification of attention tunneling phenomenon. The primary data generated

through experiments consists of: Current AL, Current SL, participant response scores for HUD event detection and Outside Event Detection. The secondary data generated by using above mentioned primary data consists of: HUD event detection percentage, Outside Event Detection percentage, CR, HUD image database and HUD image texture features (contrast, correlation and homogeneity).

This work also reports a method of attention tunneling detection using image processing tools. The experimental setup established for studying various factors effecting attention tunneling also involved real time capture of HUD camera video. Texture analysis has been applied for detection of attention tunneling from the captured HUD camera image. Texture analysis could reveal discriminating features necessary to classify tunneled and the normal HUD display.

The GLCM features like contrast, homogeneity, energy, and correlation along with standard deviation and entropy of image were used for HUD image classification in terms of tunneled and normal image. A total of six parameters were calculated for analysis out of which three parameters namely: contrast, correlation and homogeneity were identified to show the distinction between normal and tunnelled images effectively. These extracted texture features were then utilized for developing a fuzzy inference system based detection of attention tunneling. This was then used for developing a decision making system for adjusting HUD SL for mitigating effect of tunnelling.

ANN based decision support system has been developed to mitigate tunneling effects during HUD usage. It involves an ANFIS based mitigation system and an ANN based mitigation system. ANFIS based mitigation system results in automatic luminance adjustment of the symbology according to ambient lighting conditions at time of flight operation. ANFIS was developed with input functions of ambient luminance (20, 40000  $\text{cd/m}^2$ ) and contrast ratio (1, 18) resulting in display symbology luminance (10, 9500  $\text{cd/m}^2$ ) as output. The implementation results showed improved balance between event detection both for HUD and

outside events during medium ambient luminance range but there still existed imbalance for high and low ambient luminance conditions.

The drawback of misbalance in high and low ambient luminance operation which was observed while ANFIS implementation motivated for developing individual models for both day and night mode operation. From earlier studies, the range of optimum CR for different ranges of ambient luminance was identified. Another data set was then generated with parameters: current AL, current SL, desired SL (derived keep in mind optimum contrast ratio). The whole data set was divided into training data, validation data and testing data which was subsequently used to train the ANN.

Both the developed ANN models were integrated to form a complete package – ‘Assistive Attention Tunneling Mitigation System’. AATMS was initially run in offline mode to check the functionality and make any improvements required. Further, an online mode operation was also developed which takes HUD camera input feed and predict whether attention tunnelling condition might be taking place based on which it generates an alert. Online mode system takes inputs: current AL, current SL and mode of operation directly from the sensor and adjusts HUD SL accordingly.

To summarise, this work report the results of individual and interaction effect of factors contributing towards attention tunneling while using HUD. A novel approach of detection and mitigation of tunneling using: classification based on HUD camera image texture features and ANN based SL setting for tunneling mitigation with day/night mode adaptability has been proposed. This will help adjust HUD display characteristics suitably to have non-tunneled HUD display thus enhancing its utility.

## **6.1 FUTURE SCOPE**

Attention Tunneling is a human behavioural issue which is very critical with respect to fighter aircraft operation. The area still holds many challenges for the researchers which includes real time implementation, optimization of FOV, minimization of obstruction to

pilot's view, etc. The focus of the work has been improving the working conditions w.r.t ambient luminance and symbology luminance while day and night mode operation. A large amount of research opportunities lay in the area of minimizing attention trap sources by combining automatic luminance control of the symbology in unison with reducing symbology clutter and further optimized symbology format w.r.t mode of operation and others. Developing a fully automated system with self-adaptive intelligence will be a major research challenge.

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## LIST OF PUBLICATIONS

### Journals

1. Vinod Karar, Smarajit Ghosh, "Attention Tunneling: Effects of Limiting Field of View due to Beam Combiner Frame of Head-up Display," *Display Technology, Journal of* , vol.10, no.7, pp.582,589, July 2014. doi: 10.1109/JDT.2014.2311159. (SCI IF 1.686)
2. Vinod Karar, Smarajit Ghosh, "Estimation of tunneling effect due to luminance non-uniformity in head-up displays", *Chin. Opt. Lett.* 12, 013301- (2014). (SCI IF 1.073)
3. Vinod Karar, Smarajit Ghosh, "Effect of varying contrast ratio and brightness non-uniformity over human attention and tunneling aspects in aviation", *International Journal of Electronics and Communication Engineering & Technology (IJCET)*, Vol. 3, Issue 2, July- September 2012, pp. 400-412. (Indexed in: Research Gate, Google Scholar )
4. Vinod Karar, Smarajit Ghosh, "Soft computing based HUD brightness switching system for mitigating tunneling effect", *International Journal of Electronics Communication and Computer Engineering (IJCCE)*, Vol. 3, Issue 5, September 2012, No. 5, pp. 919-925 (approved by National Science Library (NSL), National Institute of Science Communication And Information Resources (NISCAIR), Council of Scientific and Industrial Research, New Delhi, India)

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