Eye Gaze Tracking in Military Aviation

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Acknowledgement to Collaborators

- Indian Air Force
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Content

- State of the Art
- Eye Gaze Controlled Display
- VR Simulator
- Cognitive Load Estimation

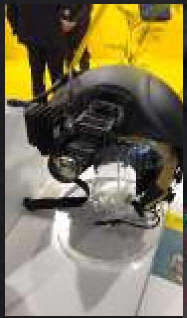
STATE-OF-THE-ART

Military Aviation

- Target Designation System
- Physical button
- Direct Voice Input
- Head movement tracker

Consumer Electronics / Automotive / Assistive Technology

- Eye gaze tracking
- Brain computer interface
- Gesture recognition
- Hand / finger movement tracker
- Spatial Audio
- Haptics Interface



*de Reus A.J.C. , Zon R. and Ouwerkerk R. , Exploring the use of an eye tracker in a helmet mounted display, Avionics Europe Conference & Exhibition, Munich, Germany, March 21-22, 2012

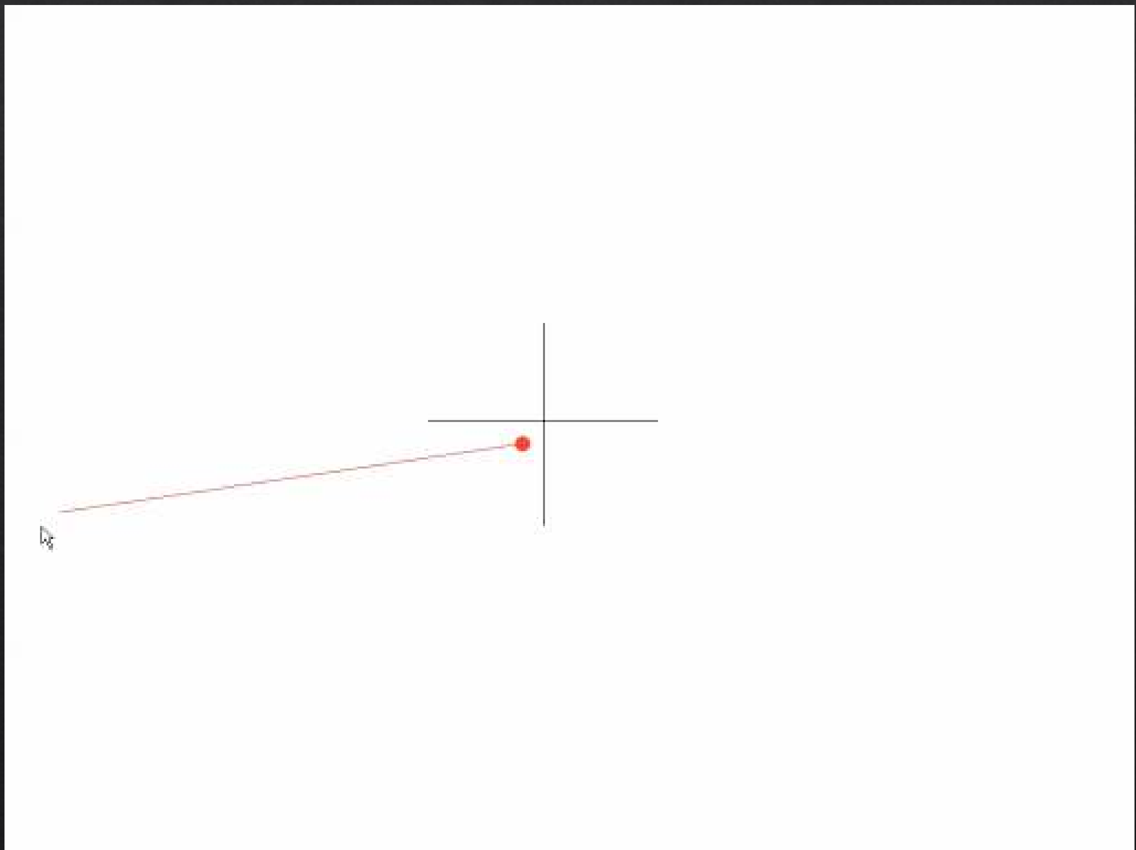
EXISTING PROBLEM

- Mission control requires significant secondary load to pilots
- HOTAS are overloaded with functions
- Existing DVI does not always provide accurate recognition even with limited vocabulary and are not extensively evaluated for non-native English speakers
- **Automatic estimation of Pilots’ Cognitive Load**
- **Undertaking studies in combat aircraft with high external validity**

PROPOSED APPROACH

- Integrating and exploring COTS based eye gaze controlled interface for existing and new platforms
- Proposing new algorithms to improve pointing and selection times in gaze controlled interface
- Developing and Testing algorithms to estimate cognitive load of combat pilots
- Collecting data from pilots undertaking representative combat tasks in real aircraft

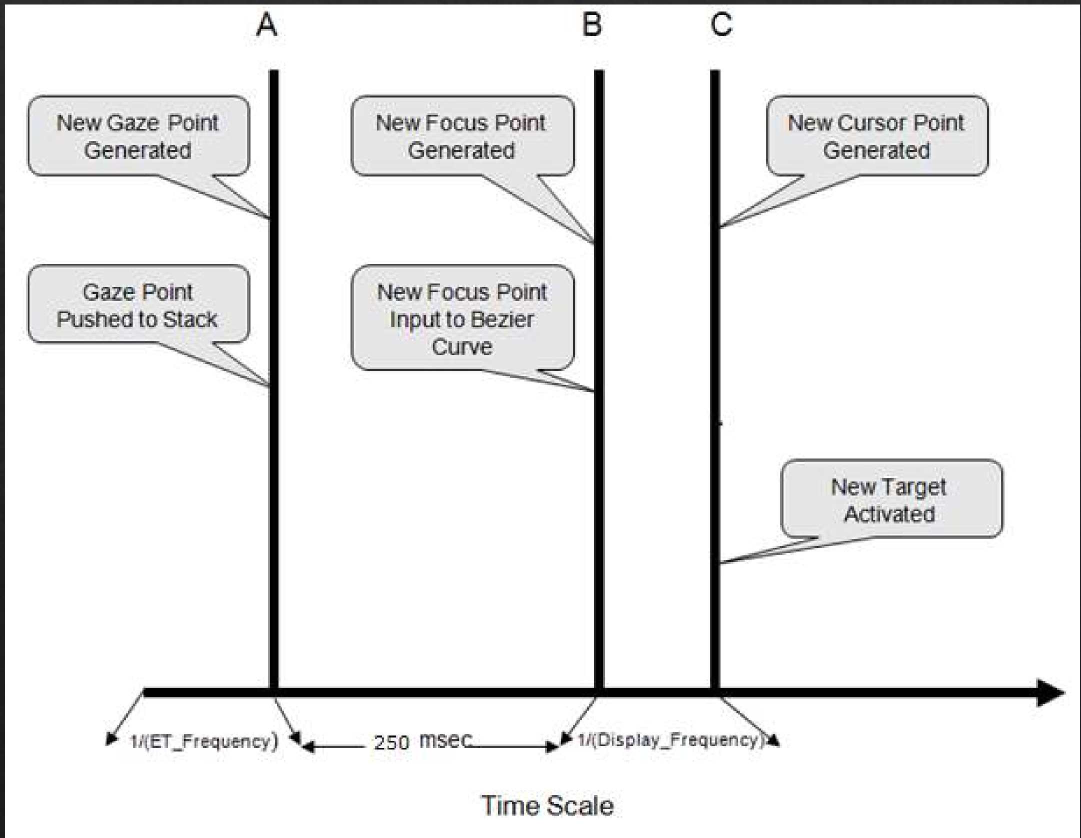
What is Eye Tracking & Gaze Control

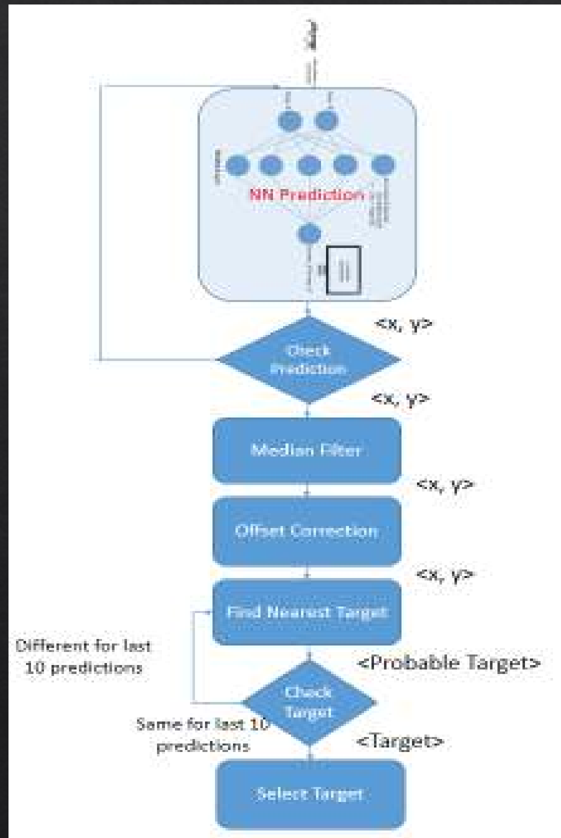


- **Eye tracking** is the process of measuring either the point of gaze (where one is looking) or the motion of an eye relative to the head. An eye tracker is a device for measuring eye positions and eye movement

- **Gaze control** is about effecting computer action by changing the direction of one's gaze (eye movement), blinking or dwelling on an object

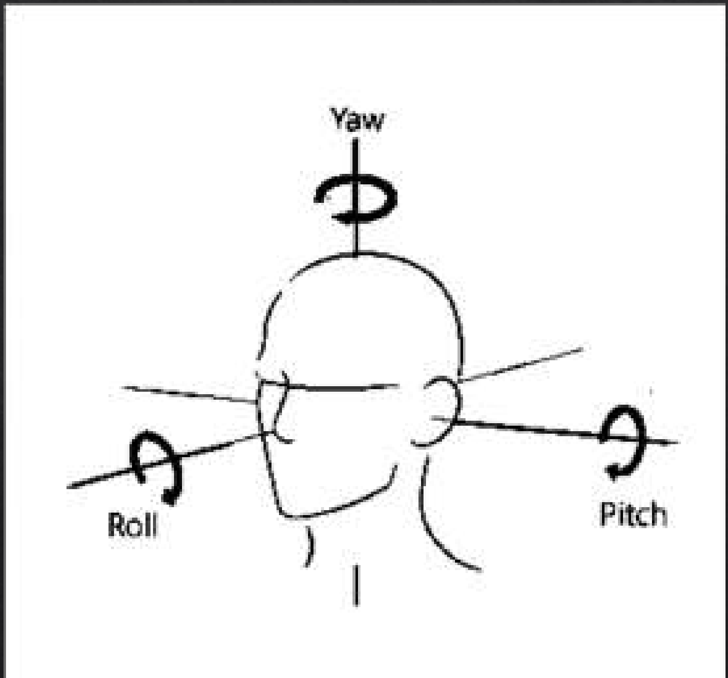
Gaze Tracker as Cursor Control Device





P. Biswas, Interactive Gaze Controlled Projected Display, Indian Patent Application No.: 201641037828

Combining Head and Eye Gaze Movement



- Gaze direction vectors from both eyes (*eyeL & eyeR)*, with their origins at their respective pupil centers are obtained from eye gaze tracker
- 9-axis IMU to measure yaw (α), pitch (β) and roll (Ƴ) of the user's head
- Initial head position is the reference co-ordinate axes and measured head orientation accordingly
- We performed intrinsic 3D transformation [2] for gaze direction vectors to obtain head compensated gaze vectors ($eyeL_{hc}$ & $eyeR_{hc}$)

3D Transformation

$$T_z(\alpha)=\begin{pmatrix}\cos\alpha & -\sin\alpha & 0\\ \sin\alpha & \cos\alpha & 0\\ 0 & 0 & 1\end{pmatrix}\qquad T_y(\beta)=\begin{pmatrix}\cos\beta & 0 & \sin\beta\\ 0 & 1 & 0\\ -\sin\beta & 0 & \cos\beta\end{pmatrix}\qquad T_x(\gamma)=\begin{pmatrix}1 & 0 & 0\\ 0 & \cos\gamma & -\sin\gamma\\ 0 & \sin\gamma & \cos\gamma\end{pmatrix}$$

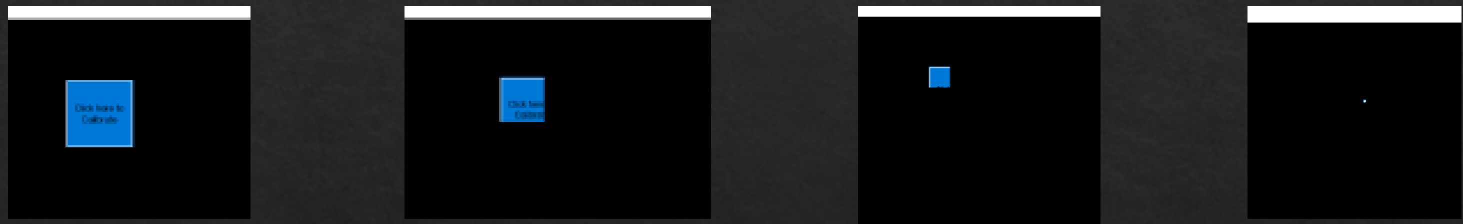
$$T=T_z(\alpha)T_y(\beta)T_x(\gamma)$$

$$eyeL_{hc}=TeyeL \qquad eyeR_{hc}=TeyeR$$

$$eye_{hc}=\left(eyeL_{hc}\ eyeR_{hc}\right)^T$$

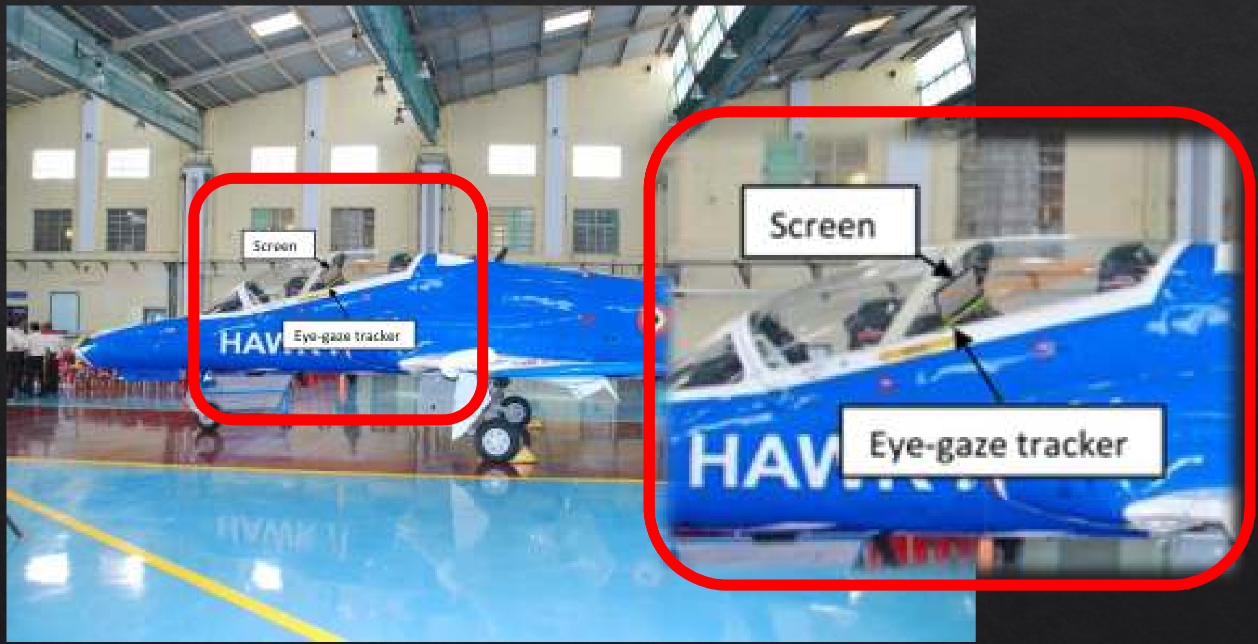
Calibration

- 9- Squares appear at designed positions on screen
- *Attentive Calibration*: User is asked to focus on each square ; The size of the square reduces in response to user's focus



- User can use either head or/and gaze to focus on squares; Hence a single calibration routine is enough to obtain head and gaze movements
- *eyehc* vectors are collected for each square position at it's minimum size
- The mapping function with *eyehc* as input and corresponding screen co-ordinates as the output is learnt by training a 2 hidden layer neural network
- Loss function: *Mean Squared Error*; Optimizer: *Adam*; Libraries: Tensorflow.NET and Keras.NET

At Hawk Trainer Aircraft



- Participants undertook 40 pointing and selection tasks seating at the rear cockpit
- Average target selection time was 1.35 sec (stdev 1.19secs)

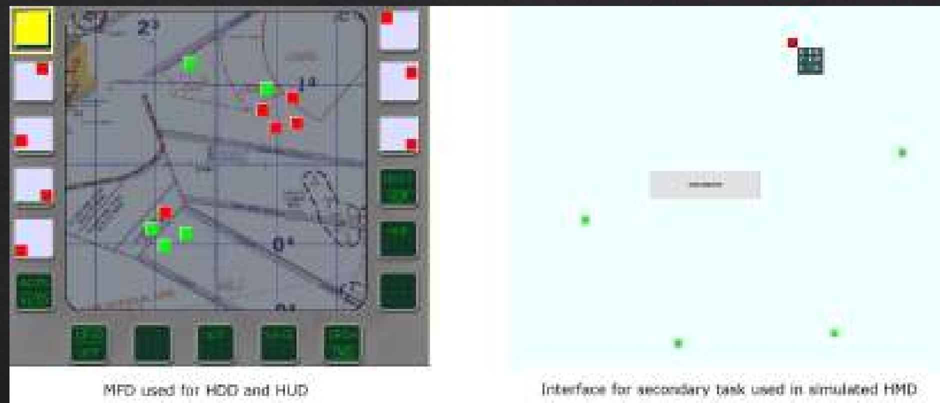
At High End Simulator

- Installed our gaze controlled CCD and MFD software at high-end Simulator in NAL
- Participants undertook 32 pointing and selection tasks seating at the rear cockpit
- Average target selection time was 2.4 secs (stdev 1.21secs)

Dual Task Study

Straight and Level Maneuver

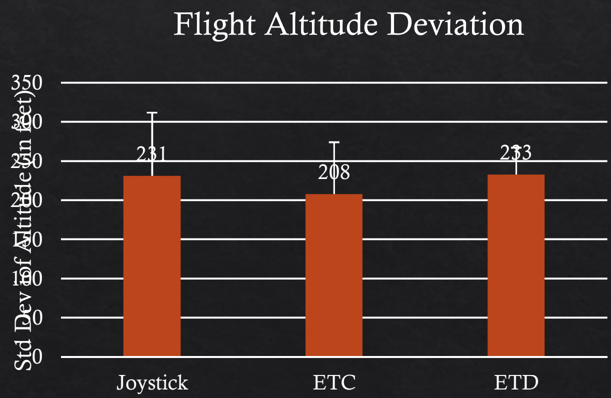
Auditory Cue

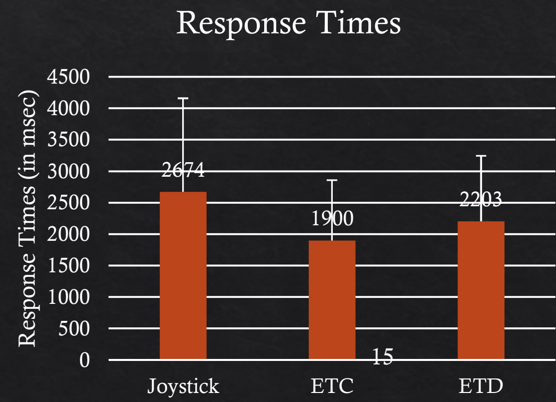


Pointing and Selection Tasks

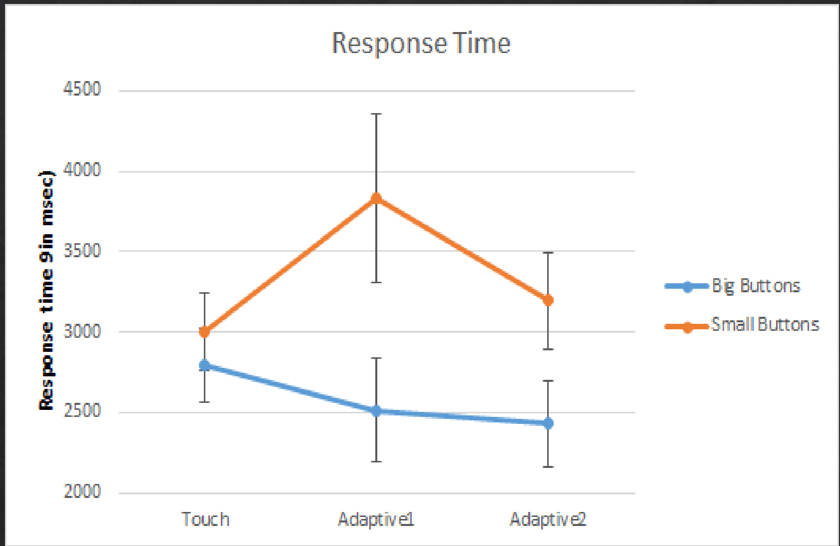
Results - HUD

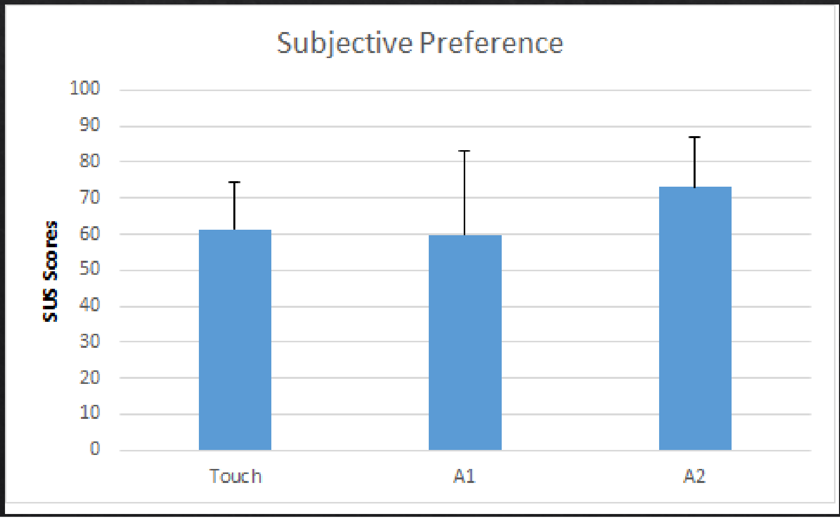
- Compared HOTAS Joystick with gaze controlled interface with pilot using clean (ETC) and dark (ETD) visors in aviation dual tasks
- Gaze controlled projected display improved flying performance and reduced pointing and selection times for secondary tasks

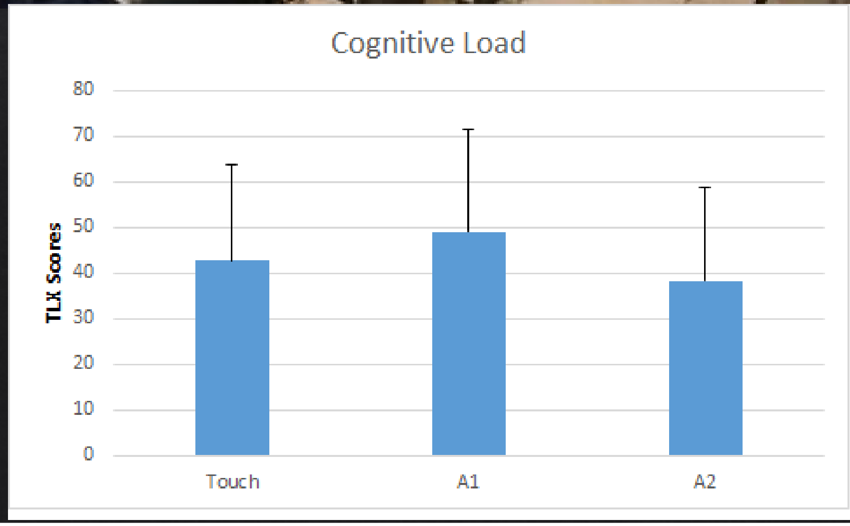




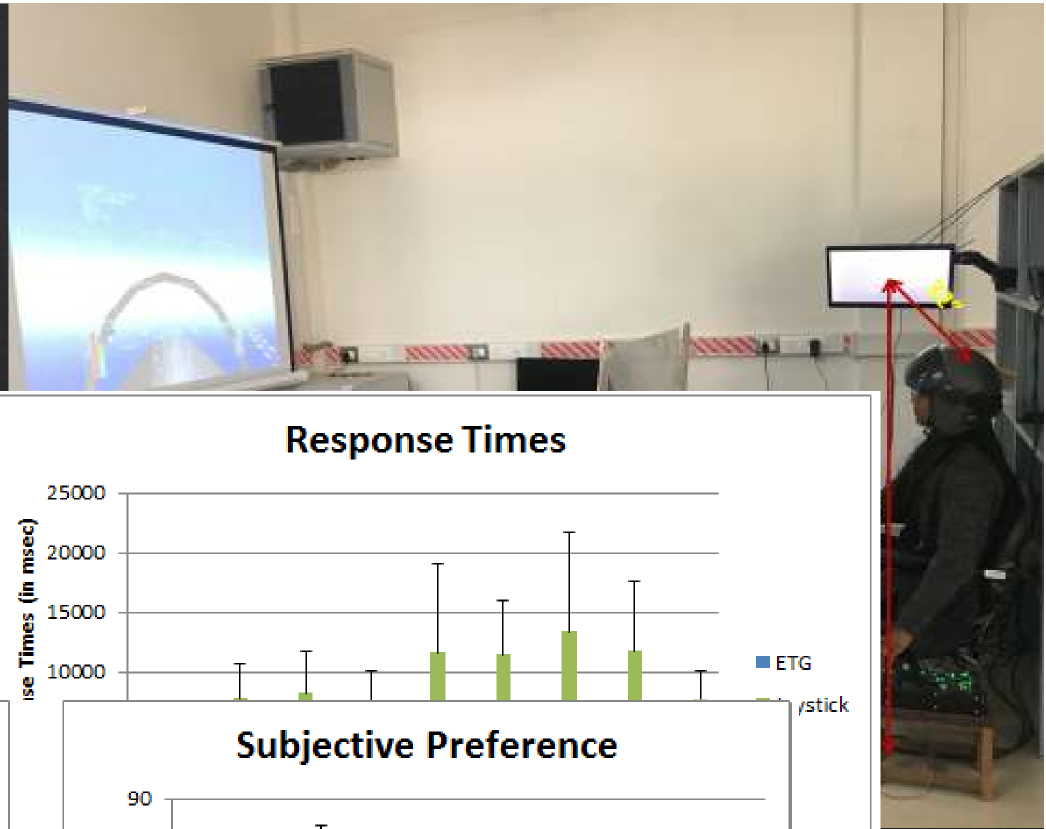
Results - HDD

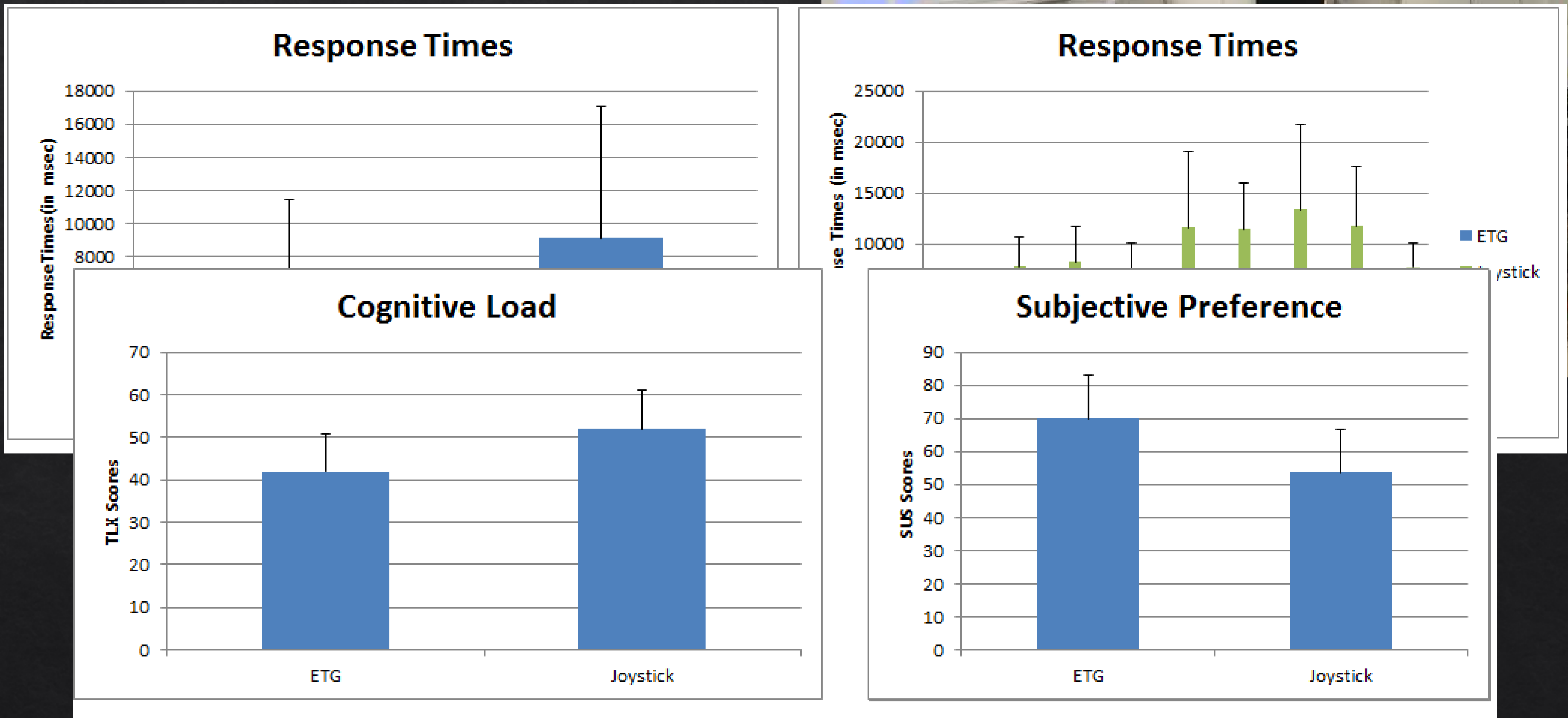

Response Time
Response time 9in msec)
4500
4000
3500
3000
2500
2000
Touch
Adaptive1
Adaptive2
Big Buttons
Small Buttons


Subjective Preference
SUS Scores
100
90
80
70
60
50
40
30
20
10
0
Touch
A1
A2


Cognitive Load
TLX Scores
80
70
60
50
40
30
20
10
0
Touch
A1
A2

Results – ETG with Simulated HMD



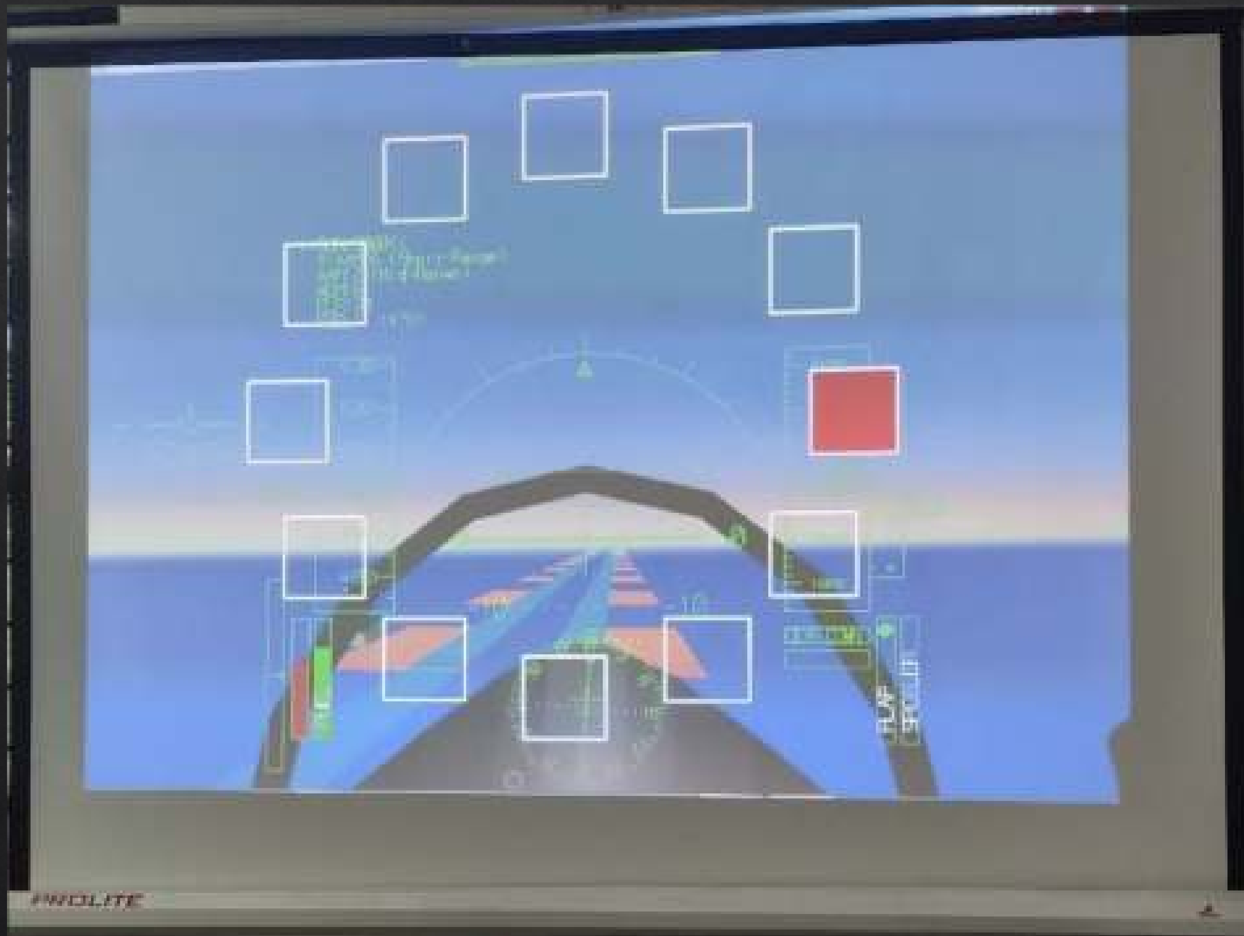


HMD with Head Movement

- We designed a pointing and selection task similar to ISO 9241
- *The Task*: Click a button at the center followed by clicking a red color target button.
- *Selection Time*: Time between the two clicks
- 3 Widths (W) for target button and 3 Distances between center and target buttons (D) → 9 Index of Difficulty (ID) cases.

$$ID = \log_2\left(\frac{D}{W}+1\right) \qquad TP = \frac{ID}{MT}$$

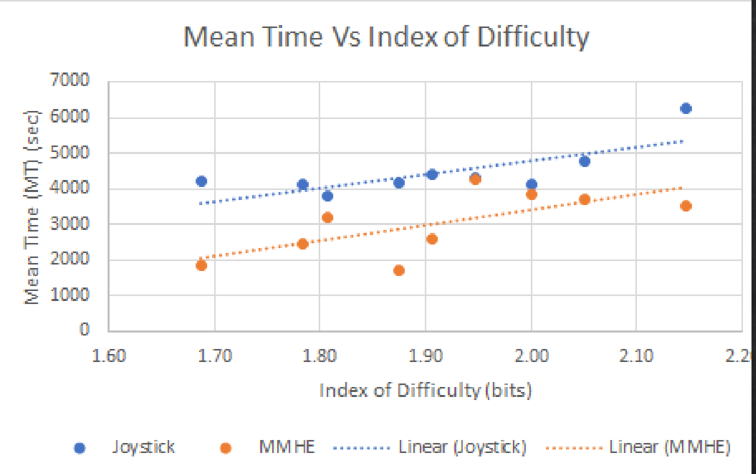
- The 3 target widths subtended a visual angle of 2.1°, 2.5° and 2.9°



User Study

- 8 Participants (7 male, 1 female) aged between 23 and 28 years (Mean = 25, SD=1.51)
- *Joystick Case*: Pointing and Selection using Trackball on Joystick
- *MMHE Case*: Pointing using head or/and eye gaze; Selection using trackball on Joystick
- Participants performed 2 clicks for each ID→ 18 clicks in each case
- Mean Time (MT): Average of selection times across all participants for a given ID
- NASA TLX for cognitive load & SUS questionnaire for subjective preference.

Results



Metric	Joystick	MMHE
Mean Time (MT) (ms)	4456 (731)	3017 (909)
Throughput (TP) (bits/sec)	0.434 (0.04)	0.686 (0.20)
TLX Score	45.63 (15.8)	37.92 (15.49)
SUS Score	64.68 (14.9)	73.44 (13.37)

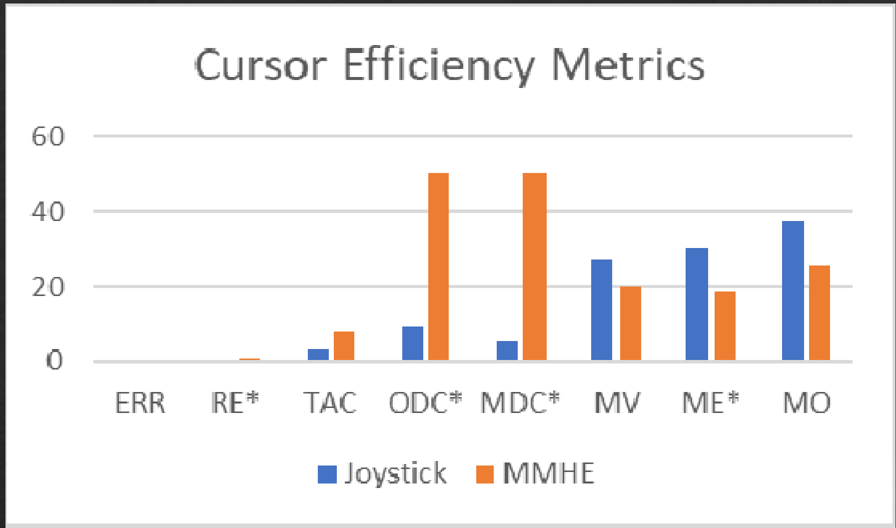
Metric	Joystick	MMHE
Deviation from path	486.8 (591)	375.2 (357.1)
Altitude Deviation	199.4 (46.4)	199.4 (39.7)
Average Flight Distance	56564	53313

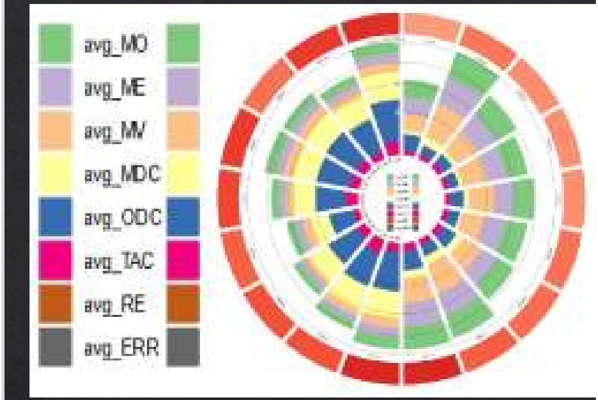
Results – Flying Performance Metrics

Metric	Joystick	MMHE
Deviation from path	486.8 (591)	375.2 (357.1)
Altitude Deviation	199.4 (46.4)	199.4 (39.7)
Average Flight Distance	56564	53313

- We compared participants flying performance while using both interaction modalities
- Participants had to fly longer to complete the task when joystick was used than MMHE.
- The deviation from central path is also higher while using joystick than MMHE.
- The altitude deviation was same in both interaction cases.

Results – Cursor Efficiency Metrics



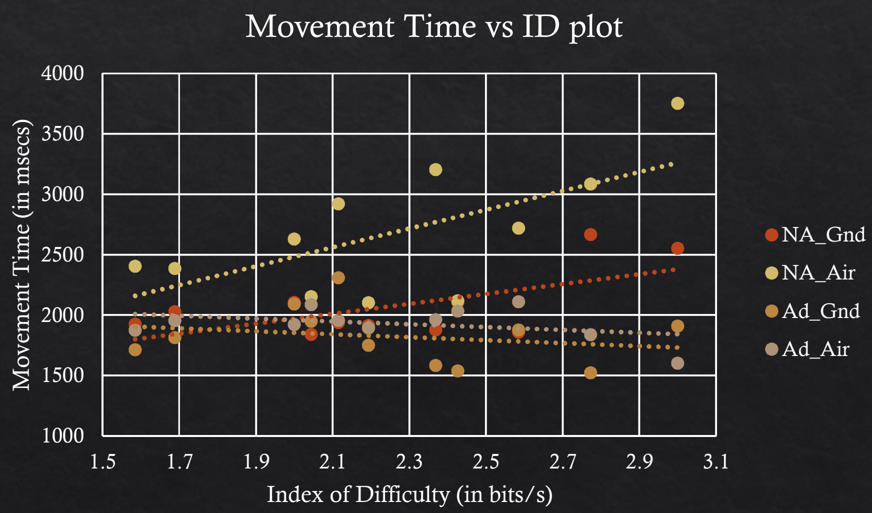


- While using MMHE, participants were assessing their flight control before clicking the target button;
- A significant higher ODC (t: 4.38, p=0.002, Cohen's d: 1.55), MDC (t: 4.73, p=0.001, Cohen's d: 1.68) and higher TAC in MMHE than in joystick can be explained by this observation
- MMHE has lower value in metrics that look at the variability of the movement (MV, MO) and it is significantly lower (t: -2.01, p=0.04, Cohen's d: -0.71) than Joystick in terms of movement error (ME)
- In Radial Stacked Bar chart, avg_MO, avg_ME and avg_MV for all the ID cases on left side (MMHE) is smaller than right side (Joystick) of the chart.

Results - OptiTrack & IMU Correlation

- Since the sampling rate of IMU and OptiTrack is different, we performed time sampling and computed the average value for 1 second interval.
- We computed correlation value between IMU and OptiTrack using these time average values.
- High correlation between IMU and OptiTrack for both yaw (0.85) and pitch (0.77) measurements
- Positive, but low correlation (0.4472) for roll measurements
- While using MMHE, participants performed offset correction using their head movements when targets appeared in *upper half* of the task region ---> A relatively lower correlation of pitch

IN FLIGHT STUDY



- Tested gaze controlled interface in Avro HS748 aircraft
- Study was undertaken during
  - Take off
  - Cruise
  - Landing phases of flight
- Pilots could undertake representative pointing and selection tasks in less than 2 secs on average using a nearest neighborhood algorithm

JeevithaShree DV, KPS Saluja, LRD Murthy and P. Biswas, (2018) Operating different displays in military fast jets using eye gaze tracker, Journal of Aviation Technology and Engineering 8(1), Purdue University Press


Gaze Controlled
Flight Simulator

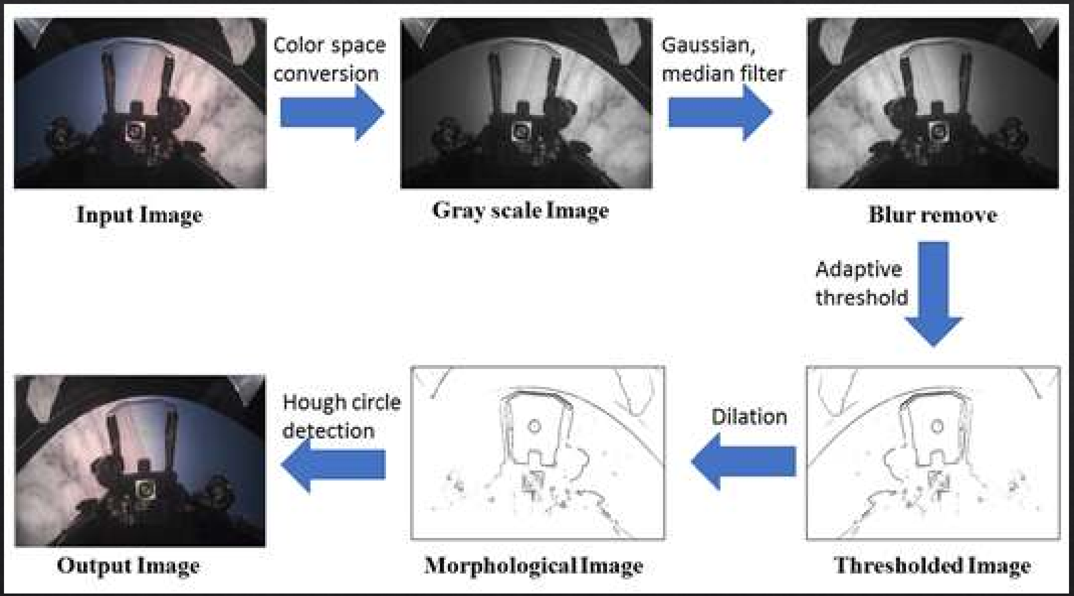
Flight Simulator at IISc

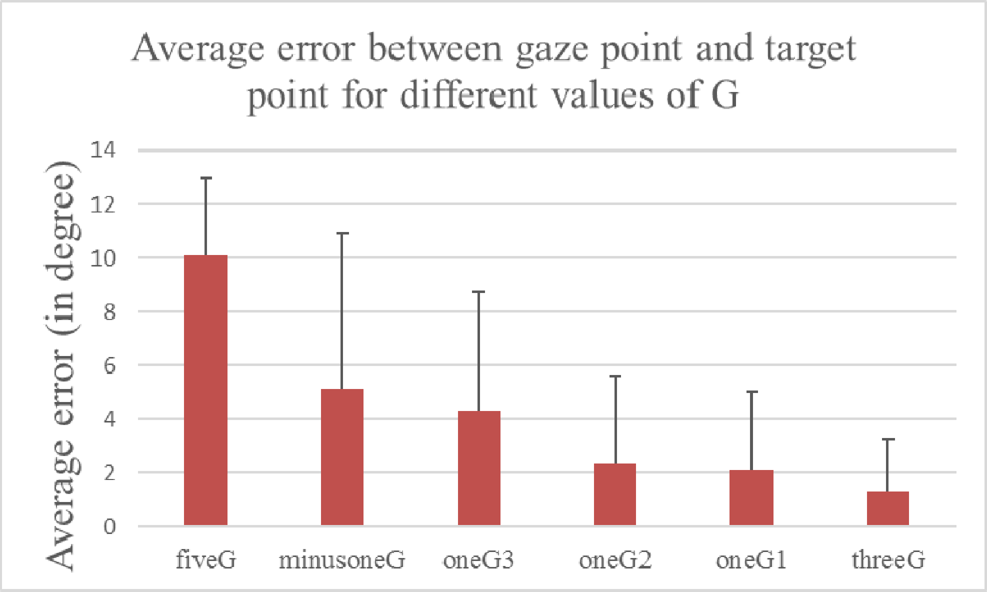
2019

AERO INDIA

The Runway to a Billion Opportunities

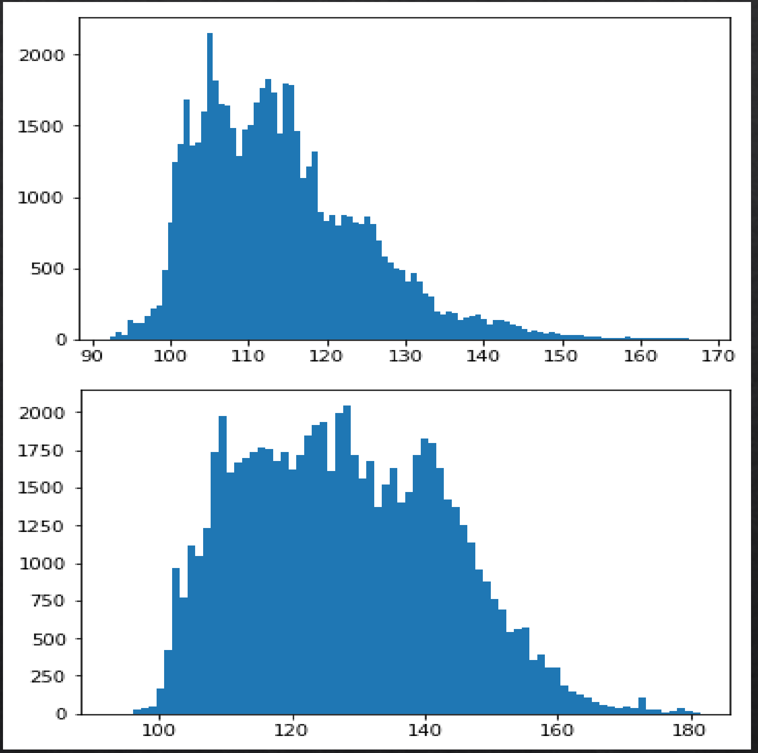
Accuracy of Eye Gaze Tracking



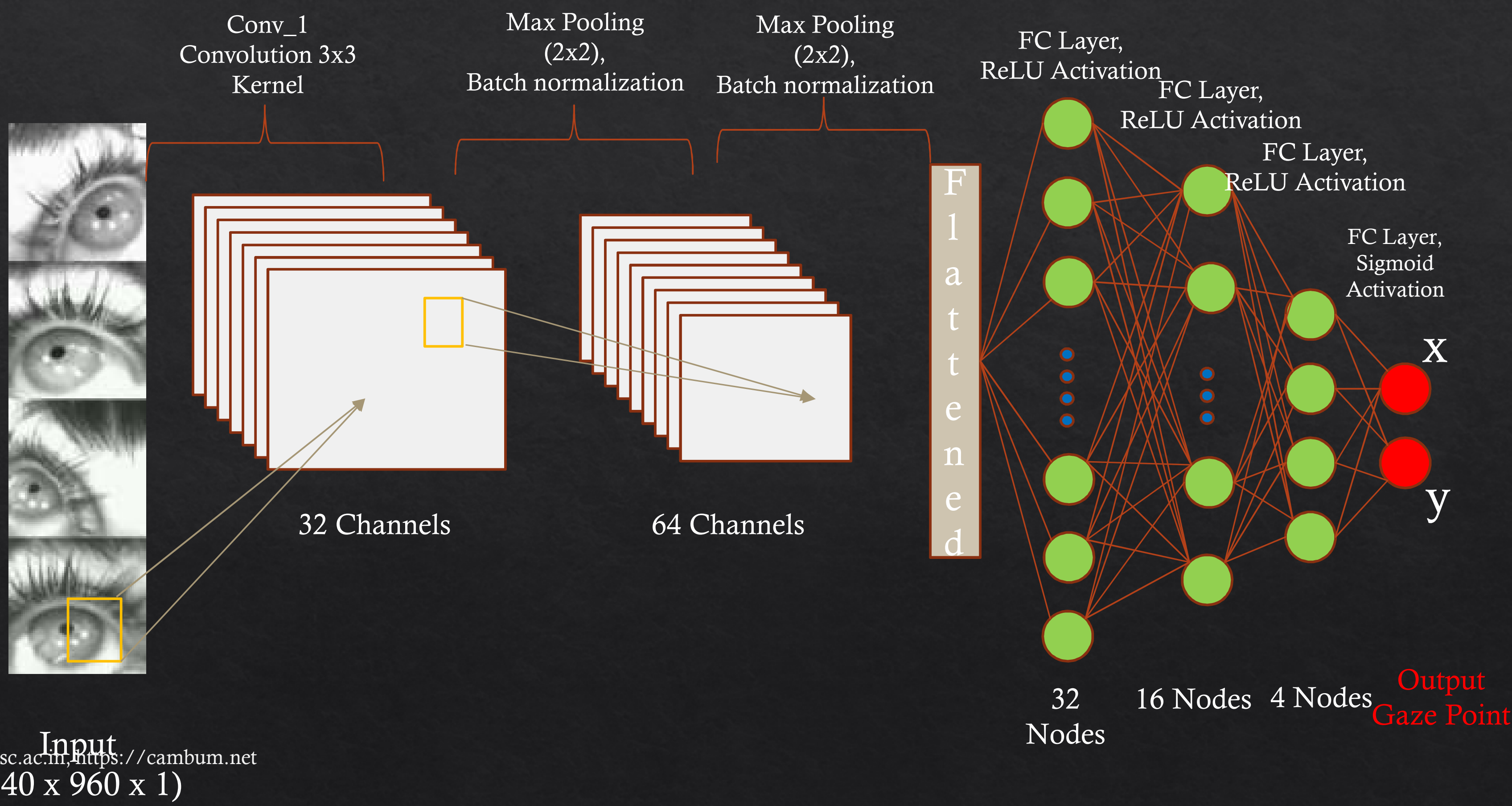


Gaze Recording Analysis

- Data - Two flights of duration of around 1 hour
- Tobii Pro Glasses recorded only 50% of gaze samples in both flights
- Failure Modes
  - Illumination (Average intensity of camera image)
  - Pilot looking beyond the tracking range
- Flight 1 – 93% of successful gaze detections have intensity < 131
- Eye image frames with intensity <131 failed to have detections when pilot looked beyond eye tracker tracking range (72° horizontal, 52° vertical)



CNN Architecture for End-to-End Gaze Estimation



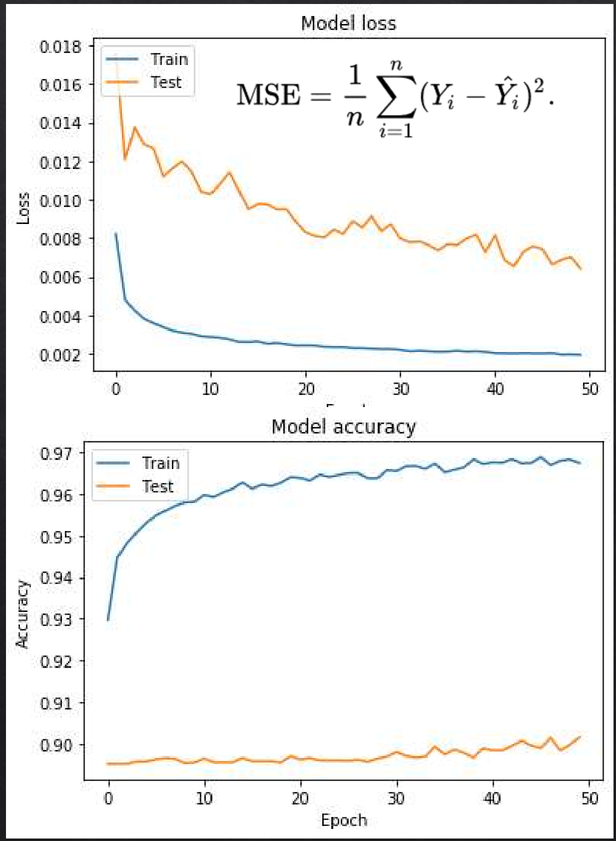
Dataset Creation

- 6 videos collected from Jaguar and Hawk – both pilot and trainer location
- Each video duration - ~1 hour
- Eye images from each video - ~1,50,000
- Useful eye images (40-60) % of total frames
- Baseline gaze points are from Tobii Pro
- A total of around 1 million images are available, with diverse
  - Illumination (Avg. pixels values of grayscale image: 30 – 240)
  - Pupil dilation (1.4 – 5.8mm)
  - Variable G -- Environment

Initial Results – Single Video Dataset

- Trained the proposed architecture for
  - Epochs : 50
  - Optimizer: SGD with Momentum
  - Loss Function : Mean Square Error
  - Training: 60K, Testing: 14K samples

- Results:
  - Accuracy - **Training-97% Testing:90%**
  - MSE- Training-0.002 Testing-0.007



Performance on Aircraft

Virtual and Mixed Reality

- Enhancement to Foveated Rendering to increase legibility
- Matching illumination level of live video with VR environment
- Investigating utility of VR as a training module for astronauts and pilots
- Integrating Computer Vision system with VR / MR environment
- Explain CNNs through visualization

Gaze Controlled VR Cockpit

Summary

- Eye gaze trackers can be used as a cursor control device
- Gaze controlled interface can statistically significantly reduce pointing and selection times compared to joystick based TDS and for bigger buttons compared to touchscreen
- Gaze control interface can be integrated to existing desktop flight simulator programs
- Existing screen mounted gaze trackers can track eyes of pilots for existing military fast jet platform (BAES Hawk Trainer)
- Pilots' can undertake pointing and selection tasks in less than 2 secs in different phases of flights
- Wearable gaze tracker can be configured to CCD for HMD

Cognitive Load Estimation

Related Work

Cognition from ocular parameters

- Psychological evidence of change in cognitive load reflected in Pupil dilation
- Redlich [Redlich 1908] and Westphal [Westphal 1907] found a relation between physical task demand and pupil dilation
- Micro saccades velocity also an evidence of change in cognitive load [Tokuda 2011]
- [Gavas 2017; Duchowski 2018] have used a metric to detect cognitive load by measuring frequency and power of pupil dilation

Cognition from other body parts

- Herat rate (skin response) [Healey 2011]
- Acoustic features of voice [Boril 2011]
- [Afzal 2009; Sezgin 2007] detected cognitive states by capturing affective states

Method

- Laboratory studies with N-back and arithmetic tests
- Simulation studies with flight simulator
- Correlation with ground truth in the form of EEG measurement
- Simulator study with pilots
- In-flight studies with air-to-ground dives and constant G manoeuvres

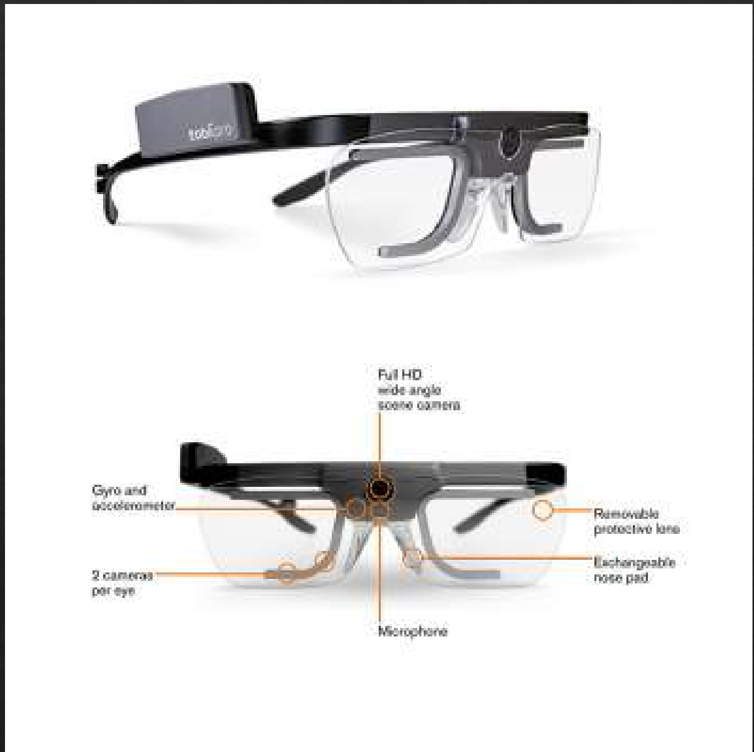
Method

- Fourier Transform (FFT) → Energy of single sided Frequency bins of Pupil Dilation
- Wavelet Transform (DWT and CWT) → Threshold the coefficient values and sum up (MCD) of Pupil Dilation
- Saccadic Intrusions (SI)→number of Saccadic Intrusions
- Saccades and Fixations→ No. of saccades vs no. of fixations

Hypothesis: Ocular parameters of pilots can estimate increase in cognitive load while performing secondary tasks

- 13 participants with designation ranging from Wg Cdr to Gr Capt. All participants were well versed with operating the flight simulator
- Desktop NAL Simulator at ASTE
- Tobii glasses 2 for recording eye gaze and pupil dilation

Apparatus



Existing Use Cases

- Dassault Aviation uses Tobii Glasses1(older model)
- French Army (air force, medical force = IRBA, ground force) using Tobii Glasses 2
- Nexter (tanks) - using Glasses1
- Thales (avionics)

Flight Simulation Study with Pilots

C1

Flying without any boundaries or operating any secondary tasks

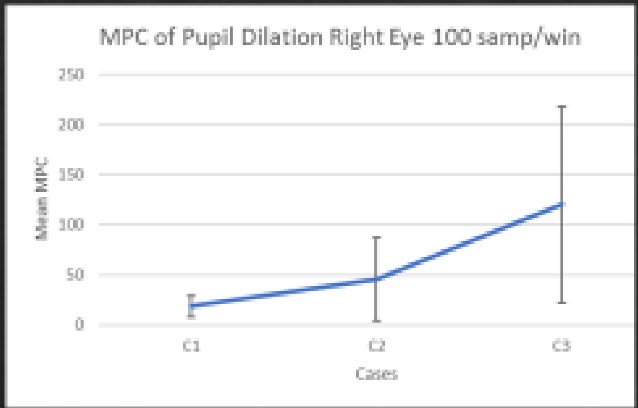
C2

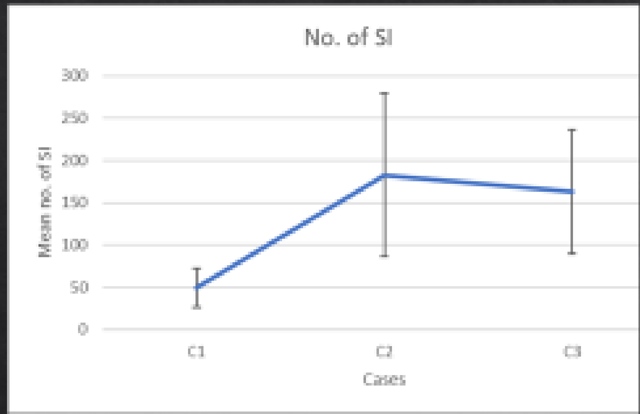
Flying within boundaries

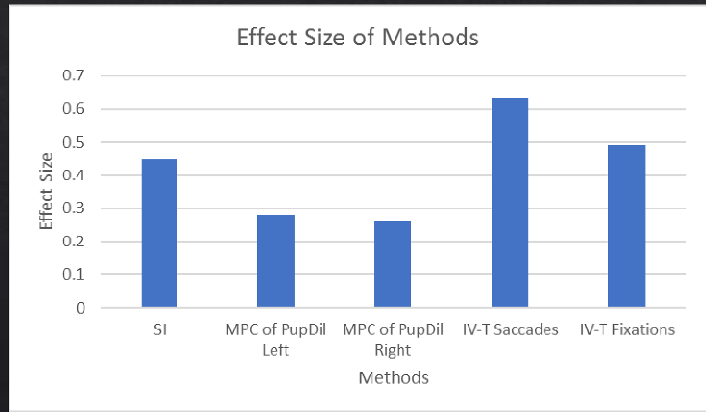
C3

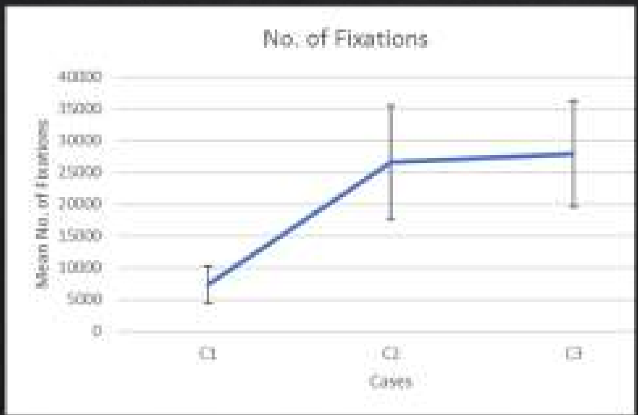
Flying within boundaries and perform the secondary task

Comparing Ocular Parameters

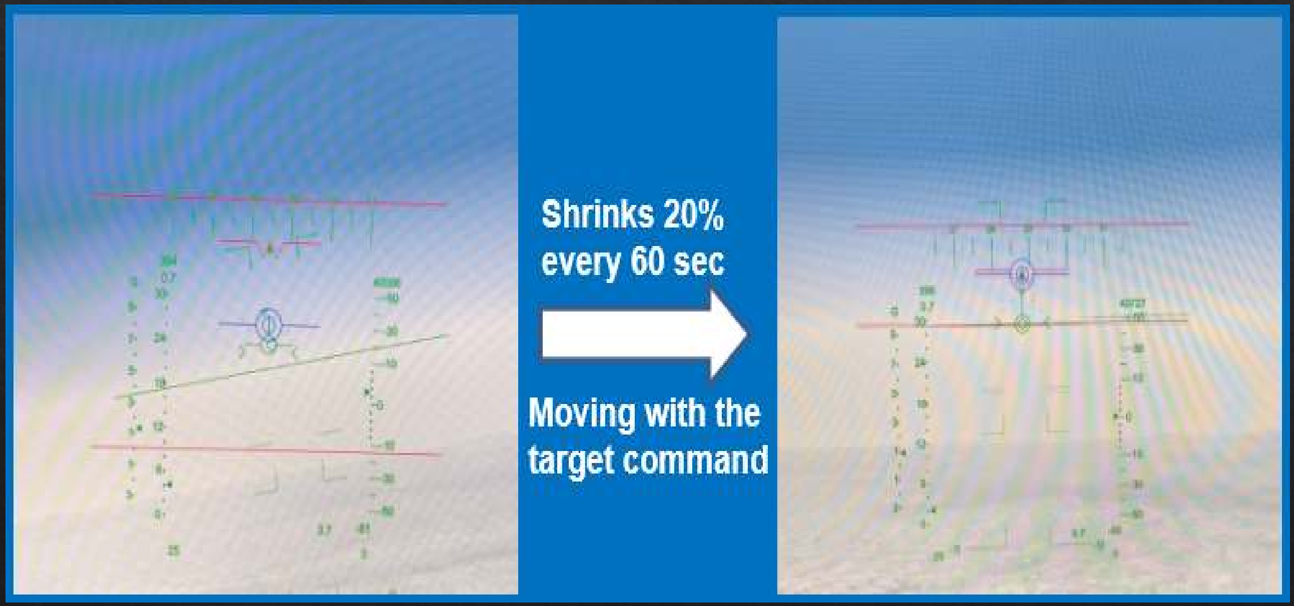


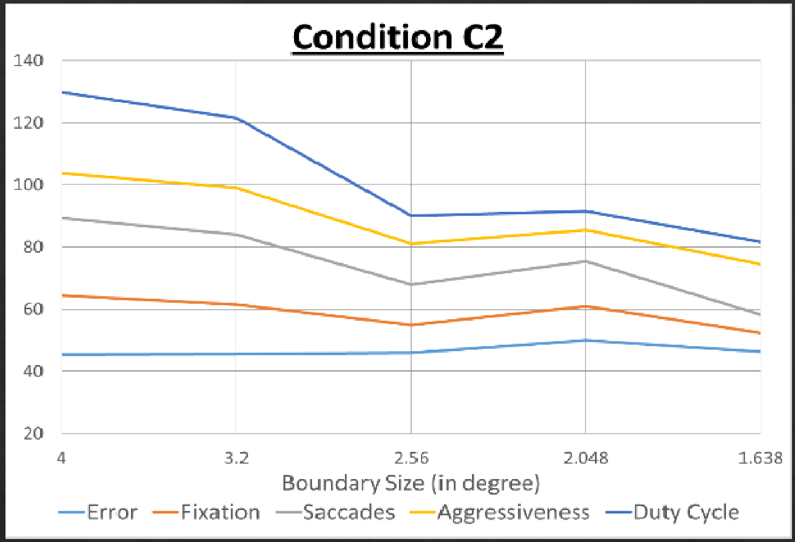


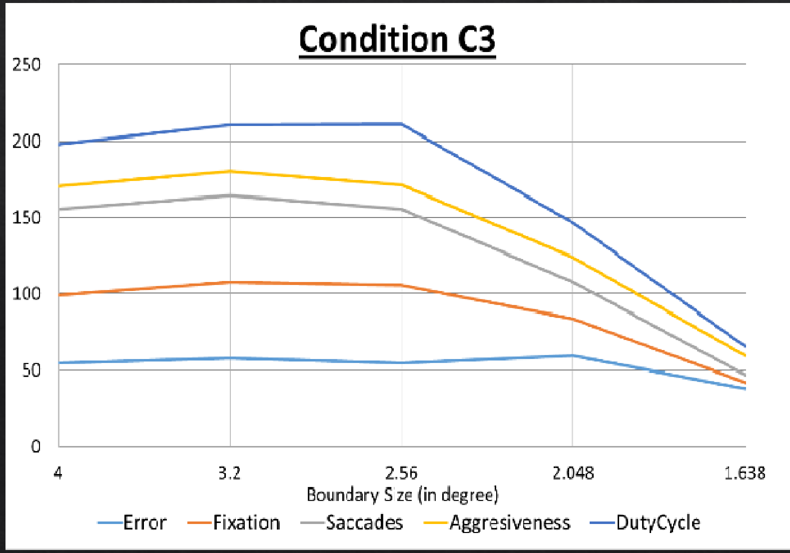




Within Condition Analysis



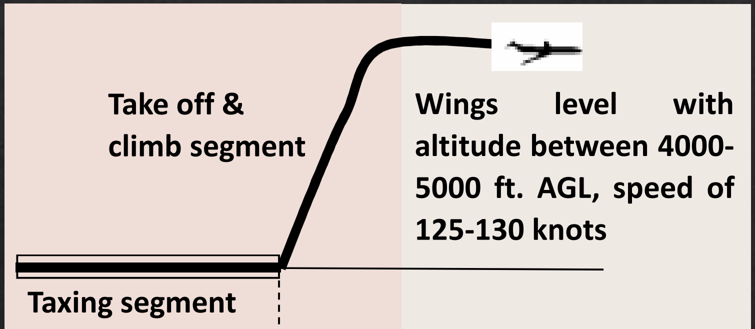




Comparison with EEG

Aim: To determine the correlation between physiological and performance-based metrics to estimate pilot's cognitive workload - a user study using flight simulator

Design: Take off Task scenario with increasing task difficulty levels (C1, C2, C3)



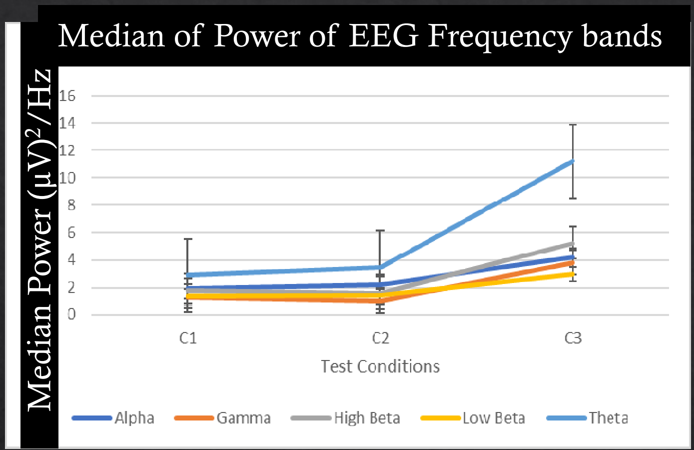
C1	C2	C3
Take off: Initial checks, apply full throttle, take off at 130 knots speed. Climb and continue with a level flight for 4 minutes.	Similar to C1 till level segment. Maintain altitude between 4000 to 5000ft above MSL for 4 minutes.	An additional secondary task of pointing and selection in an adjacent secondary head down touchscreen display along with the constraints discussed in C2.

NALSim flight simulator

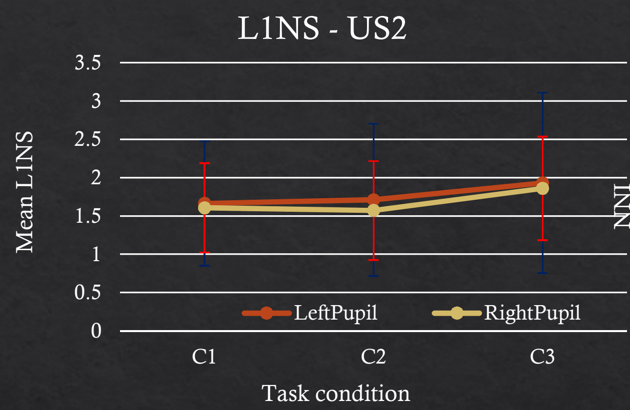
Tobii Eye gaze tracker

Emotiv Insight EEG tracker

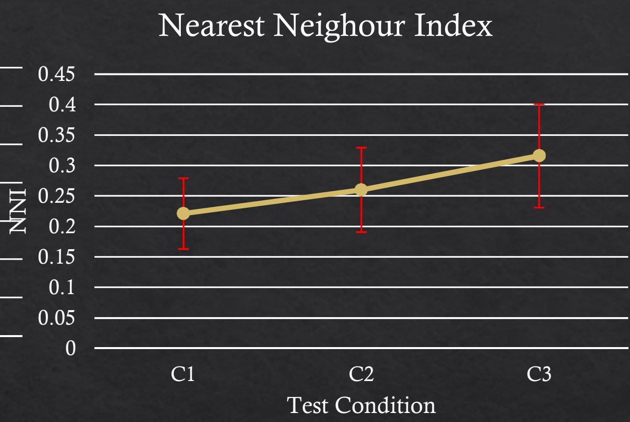
Results



EEG band power



Pupil dilation based ocular parameter



Gaze direction based ocular parameter

- ❖ Distribution pattern of gaze fixations are more random with increase in task difficulty.
- ❖ Pupil dilation based L1NS metric shows significant increase with secondary task.
- ❖ Low-beta and theta band powers of EEG data are sensitive to task difficulty.

Summary

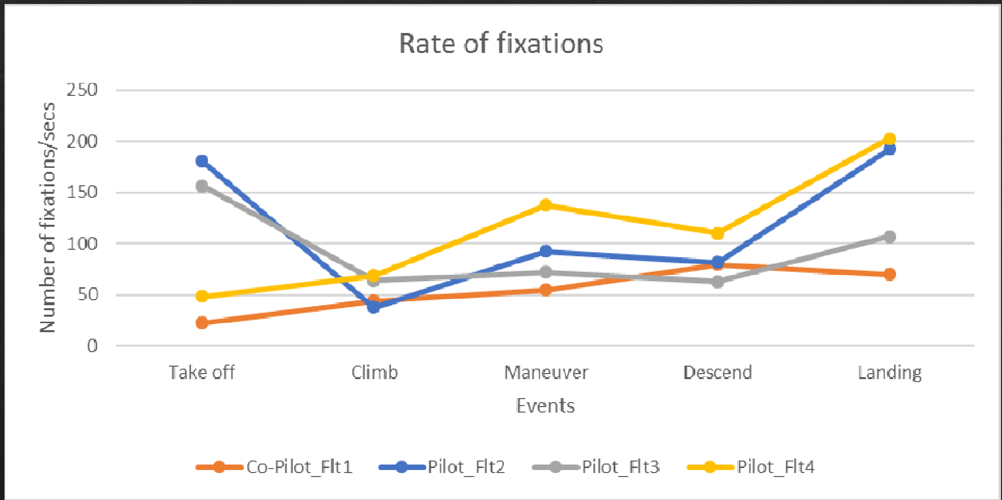
- Introducing secondary task causes significant increase in cognitive load.
- EEG band power and ocular parameter based physiological measures are indicators of pilot’s cognitive load.
- Above parameters exhibit significant positive correlation ($p<0.05$) among themselves.
- The study proposes a quantitative methodology for cognitive load estimation.

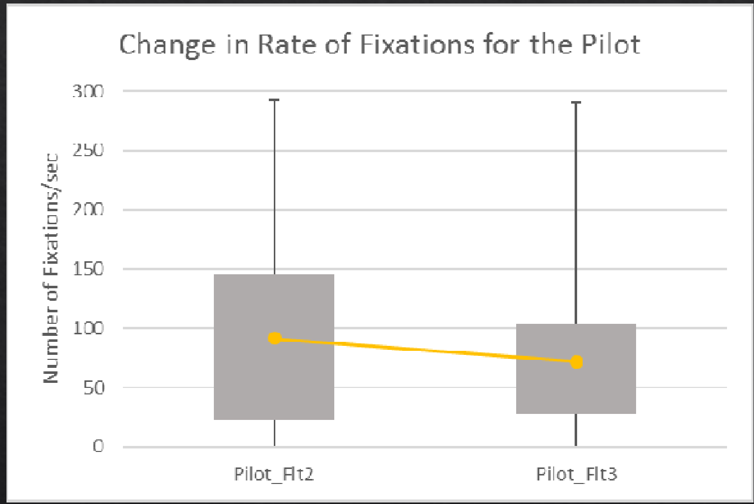
In – Flight Studies

BAES Hawk

SEPECAT Jaguar

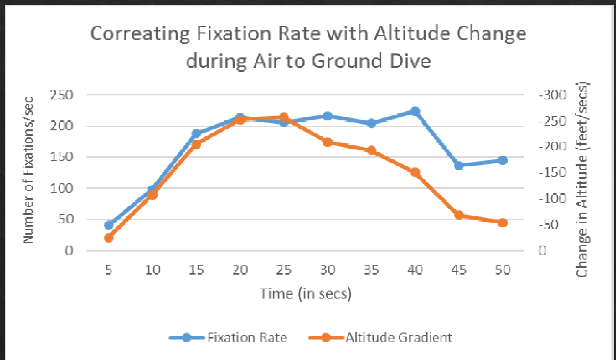
Flight Phase Analysis

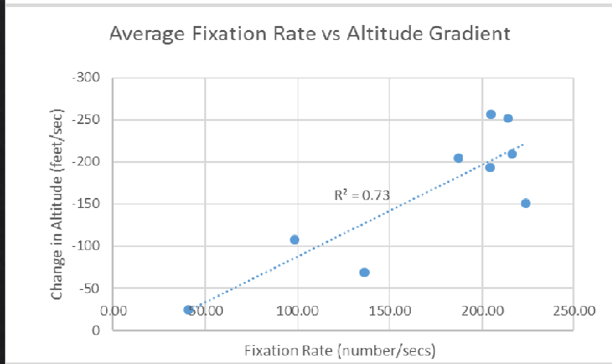




Air to Ground Dives

Results



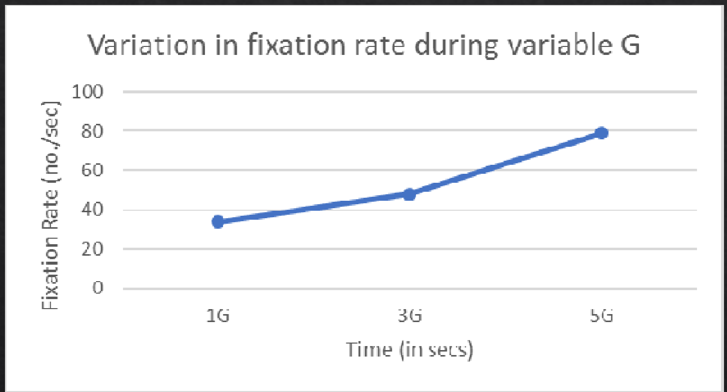


Video

Fixations

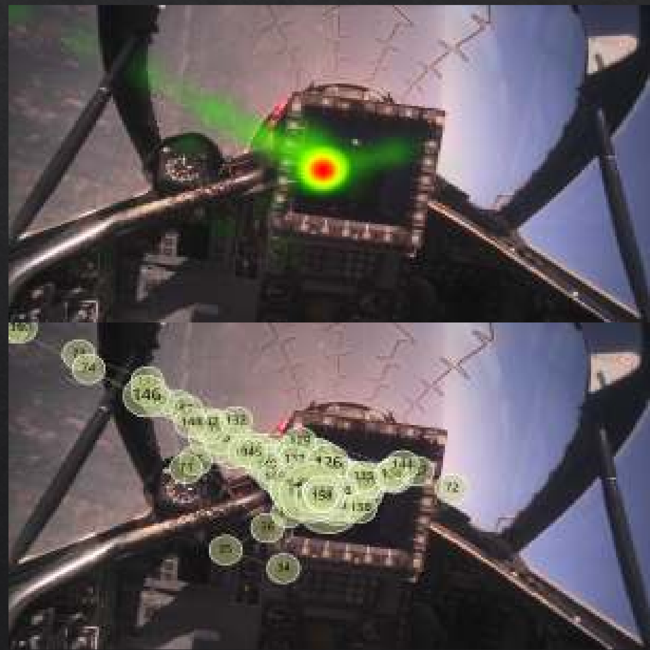
Constant G

Results



Video

Fixations



Conclusions

- Eye gaze trackers can reduce response time in operating various displays and automatically estimate cognitive load
- Preliminary tests on ground and air found promising results
- Rate of Fixations were higher in situations requiring higher pilot workload
- Eye gaze tracker can be used both as controller of display as well as for cognitive load estimation