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FITT'S LAW WITH EYE TRACKING ON A FLIGHT SIMULATOR COCKPIT

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Abstract

During the development of a flight control system that uses gaze as an alternative input method from the pilot, the human factors analysis is one of the most important processes. This gaze tracking system's architecture integrates three hardware elements that were not originally designed to operate with each other; the Tobii Pro Glasses 2, the HTC Vive Trackers, and the Aeronautics Institute of Technology' SIVOR flight simulator. This paper deals with an experiment that involves the visual search and acquisition of a target on a spherical screen, and the application of fitts's law to the eye tracking signal.

Keywords: Fitts's law, Human factors, Human-Machine Interface, Eye Tracking.

1. General Introduction

A prototype flight control system that uses gaze as an alternative input method from the pilot has been in development at the Aeronautics Institute of Technology[3], initial simulated flight testing has been carried out and during the operation of the system, some uncertainties have arisen regarding human factors. Being a human-machine interface, it is fundamental to understand the way that a user interacts with the system as well as some of the most common behaviors that are to be expected when using the system, two of those behaviors are search patterns and visual fixation on a target.

These characteristics can be measured by reducing the operation of the system to its most fundamental aspects, therefore, despite being a system intended for flight control assistance, the experiment that is the focus of this paper is a simple visual search task performed while the test participant is seated in the cockpit of a flight simulator with a surround screen that is normally used for representing the virtual world outside of the aircraft. In order to have a quantitative comparison between each test instance of search and fixate on a target, we applied Fitts's law to the collected data.

2. Experiment setup

2.1 Flight Simulator

This experiment was carried out at the *Simulador de Voo com Plataforma Robotica* (SIVOR) of the Aeronautics Institute of Technology (ITA) in Brazil, SIVOR is a full-motion flight simulator representing an Embraer Legacy 500, with some cockpit panels from other aircrafts from Embraer, the main purpose of SIVOR is to test its motion platform; an industrial robotic manipulator with seven degrees of freedom instead of the common Stewart platform. SIVOR is shown in figure 1.

Figure 1 – Composite image of SIVOR at the *Centro de Competência em Manufatura* (CCM), one of ITA's laboratories. image credit: ITA.

2.2 Gaze and head tracking system

The system used for this test had a Tobii Pro Glasses 2 wearable eye tracker as the source for the gaze vector of the participant, this vector is given in relation to the glasses' frame [1], therefore some form of head tracking is necessary to place the origin of this vector within the cockpit, this is accomplished using the HTC Trackers and Lighthouse base stations.
A single HTC Tracker is placed on the right side of the head of the pilot in the field of view of two lighthouse base stations [2]. The combination of this elements results in a gaze vector in relation to the cockpit's space, this vector is then used to locate a point of interception on the simulator's 180-degree field of view spherical screen, this interception point is considered the point of gaze of the pilot in the virtual simulation environment.
The intended use of this system is to experiment with gaze-assisted flight control and gaze-aware

human-machine interfaces on aircraft, for the purpose of this paper it is used solely as a means of determining the point that the person wearing the system is looking at on the spherical screen of the flight simulator. The hardware used in this system is shown in figure 2

Figure 2 – The Wearable hardware used in the proposed system, a Tobii Pro Glasses 2 headset with an attached HTC Tracker.

3. Fitts's law

Fitts's law establishes a relationship between the difficulty of pointing to a target and the spatial position and size of that target relative to the starting position of the pointer, it typically refers to cases like clicking on a button with a mouse cursor on a computer screen, where the distance travelled by the pointer to the button as well as the size of the button in pixels are considered in the equation for the Index of Difficulty.
In this case, the act of pointing is done using the human eyesight of the test participant, and the target size and distance from the initial point is measured in degrees to account for the spherical nature of a person's field of vision, as well as the fact that the screen were the target appears is a spherical screen. The equations used are as follows [4]:

$$ID = \log_2(\frac{2D}{W})$$

Where ID is the Index of Difficulty, D is the distance from the origin of the pointer (or the initial point of visual fixation, in the context of this experiment), and W is the size of the target.
For this experiment, both the distance to the target and its size are measured in degrees, the distance being the arc length in degrees from the initial point of fixation and the actual target position, while the target size is its apparent arc length in degrees from the point of view of the pilot.

$$IP = \frac{ID}{MT}$$

Where IP is the Index of performance, and MT is the mean time for acquiring the target at that Index of Difficulty. The index of difficulty can also be calculated by using the Shannon entropy formulation [5]:

$$ID = \log_2(\frac{D}{W} + 1)$$

4. Experiment procedure

The participant begins the experiment by receiving a briefing on the procedure and the goals of the experiment, then, the participant puts on the eye tracking and head tracking hardware and proceeds to enter in SIVOR's cockpit on the captain's seat (left-side seat). The system is then initialized, and the data collection begins.

The participant's task is simple: a target marker will appear in the screen and the participant must look at it steadily and press a button, this triggers a timer that will stop at a random interval between 2 and 10 seconds. When the timer stops, the target changes position and size, the participant must look for the new target as fast as possible, look at it, and press the button again for re-setting a new timer that will repeat the process during at least ten minutes. Data samples are continuously recorded from the system, this is used to determine a gaze vector of the participant in relation to the cockpit. Ideally, this gaze vector will point exactly towards the target marker, with any offset being considered a system error.

The participant will be encouraged to report if during the data collection period they were unable to maintain a fixed gaze towards the target, for example due to any sort of distraction or reflex that made them look elsewhere. Blinking is considered a natural and unavoidable behavior that must be accounted for by the system, therefore the user is permitted to blink naturally as necessary during all phases of the experiment. During data analysis it is then assumed that the participant's actual real gaze was steadily fixed on the target during the data collection time.

5. Results

A total of 9 participants performed the experiment, each had between 70 and 80 valid target acquisitions during the 10 minutes of testing.

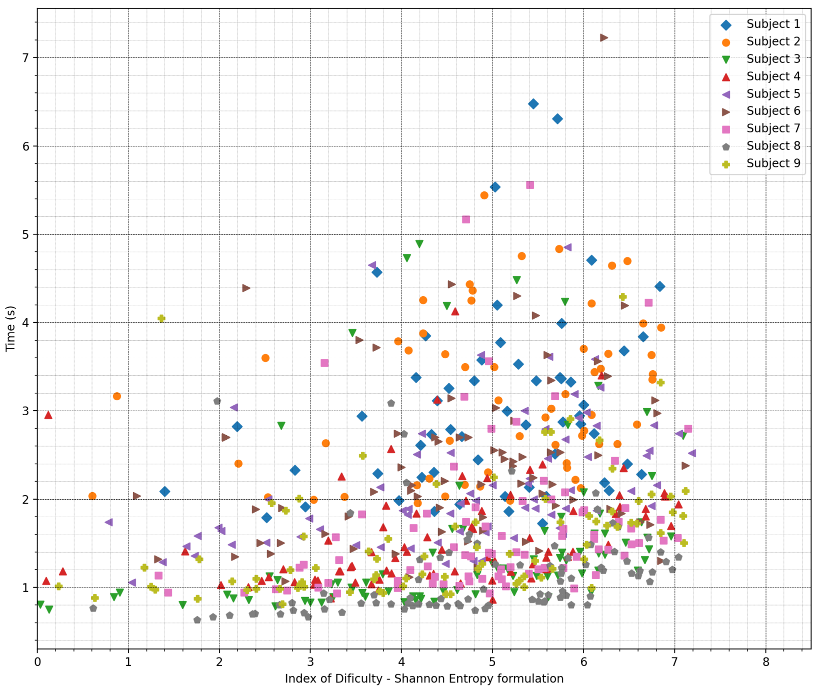

Figure 3 – Datapoints collected from all participants, Fitts's Law calculated using the Shannon information entropy formulation.

As can be seen from figure 6, most of the variations observed in the experiment comes between participants, instead of between index of difficulty.

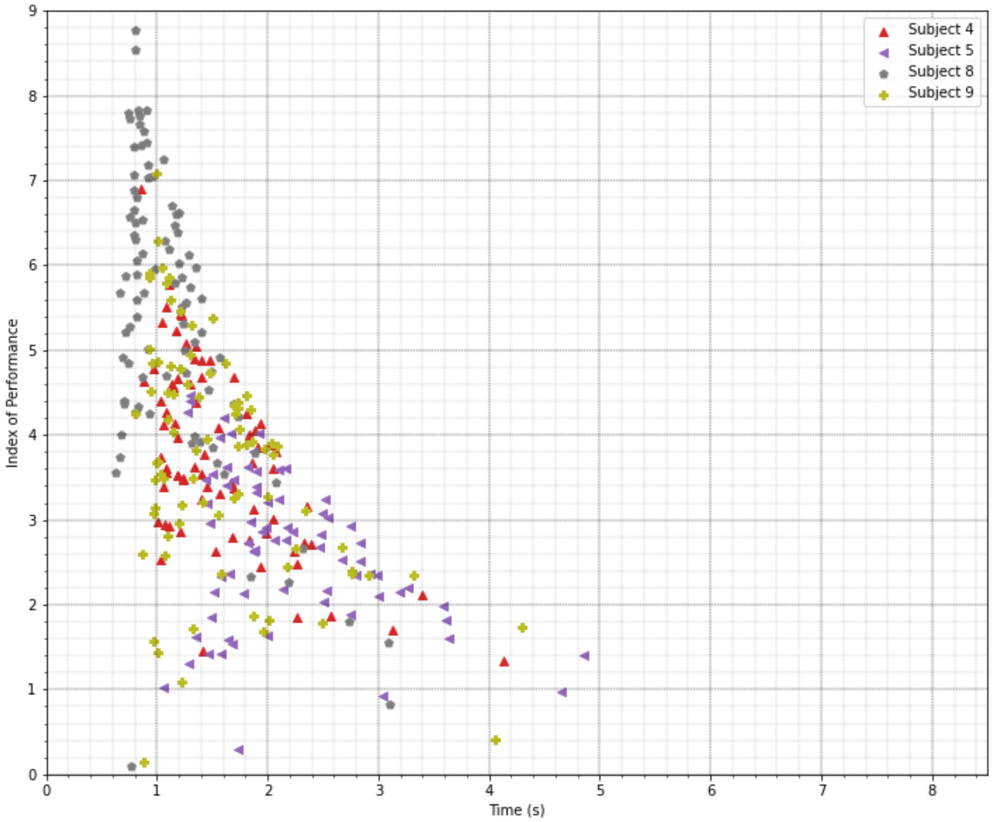

Figure 4 – Index of performance versus time for the best four participants.

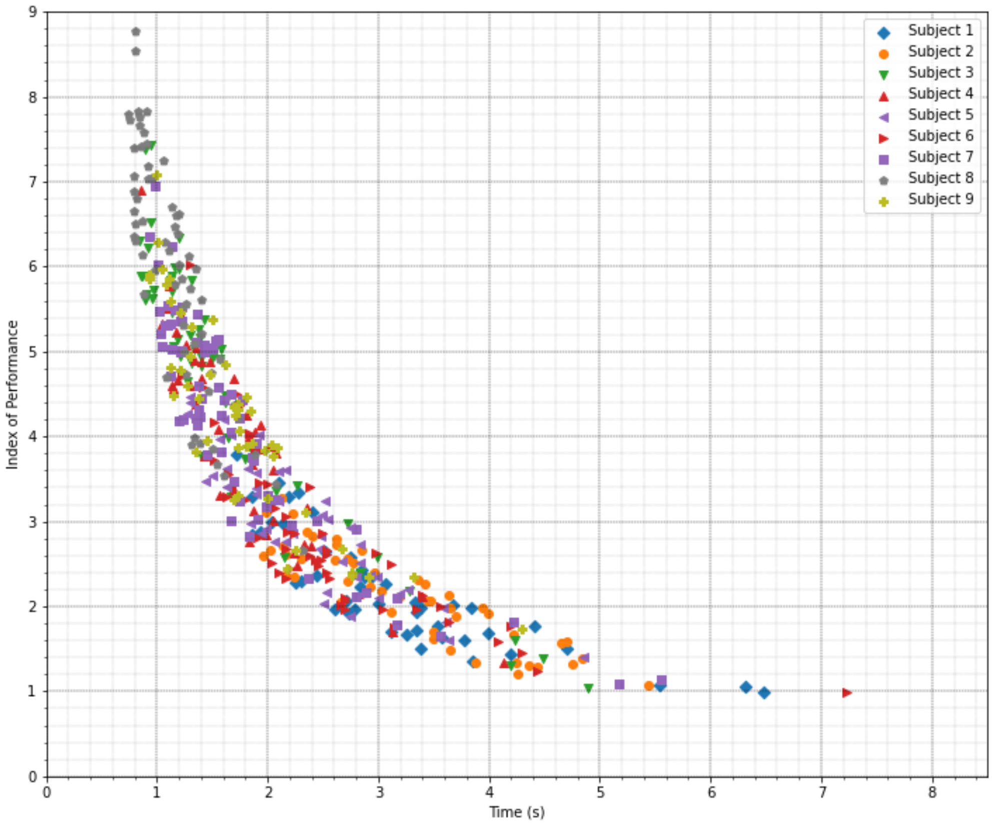

Figure 5 – Datapoints collected from all participants and index of difficulty over five, Index of performance versus time.

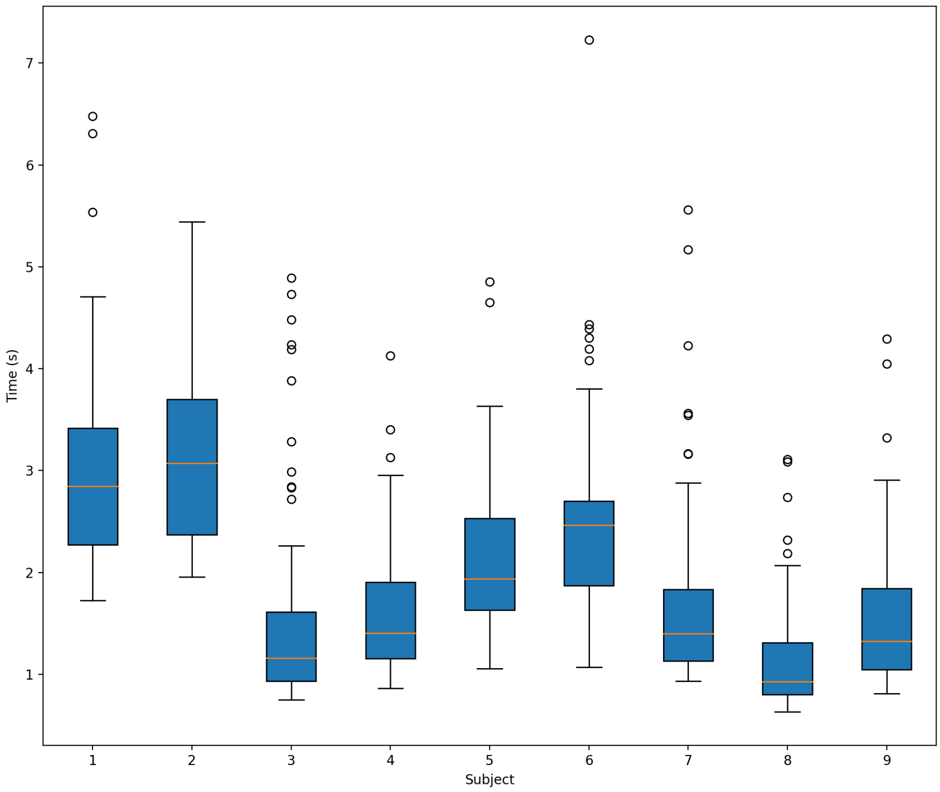

Figure 6 – Response time for all participants.

In some instances, the eye tracker appears to lose calibration references momentarily and recover them afterwards, resulting in a variable precision and accuracy reporting of the actual gaze vector, however the data can still be used to differentiate the segments during which the participant is performing a search pattern, and the segments where the gaze is being focused on a single point after the target has been found.

Figures 7, 8, and 9 show the pilot's gaze for a single target from the moment that the target appears until it moves to a new position. the figure to the left shows the actual gaze vector of the participant in green, the vertical axis represents the azimuth in relation to the simulator's nose (longitudinal axis), positive angles point towards the left of the cockpit while negative angles point towards the right.

In both this figure and the histogram that accompanies it, the red shaded area represents the angular size of the target; if the gaze signal is within the shaded area it represents that the gaze vector is intercepting the target position.

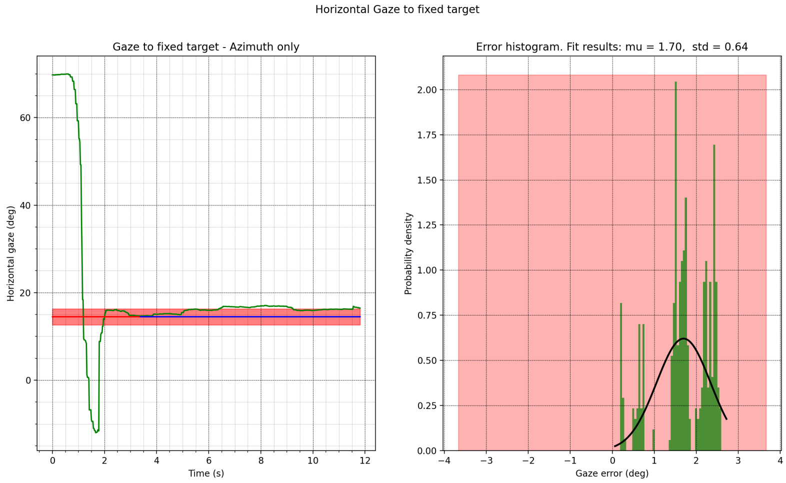

Figure 7 – Typical search pattern with typical tracking accuracy and precision.

The center line of the figure to the left represents the actual position of the center of the target, with its color changing from red to blue at the moment in time when the participant presses the button to indicate that the target has been acquired.
The histogram of all three figures contains a fitted normal distribution for comparison with the actual data, these histograms are centered on the target and contain the gaze angular error only after the participant has pressed the button to indicate that the target has been acquired, this is done to prevent data from the search phase to be included in the error estimation.

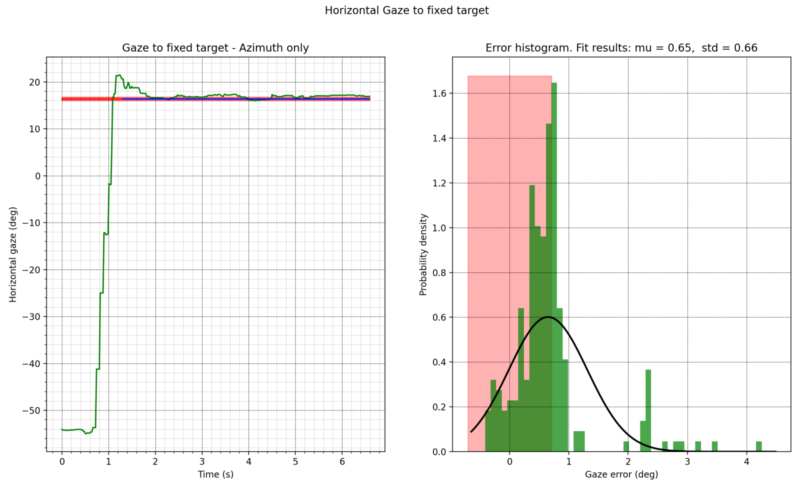

Figure 8 – Example of a quick acquisition from the right side of the cockpit (negative azimuth) to the left side of the cockpit.

Figure 9 shows a small target that appeared just behind the central window divider of the cockpit (a blind spot from the point of view of the participant), this caused the participant to search from the initial position looking to the left, to first look to the right, left, right again, and then realize that the target might be at a blind spot and finally find it, but it can also be seen that the eye tracker lost its calibration references during this instance, these calibration references were recovered in subsequent instances.
Figure 10 shows a histogram of the response times during the experiments for a single participant after outliers have been removed.

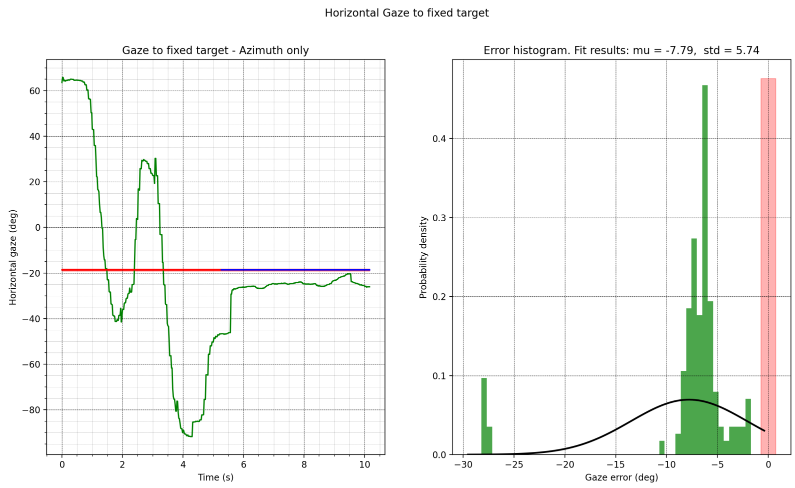

Figure 9 – Example of a long search pattern were the eye tracker has momentarily lost calibration.

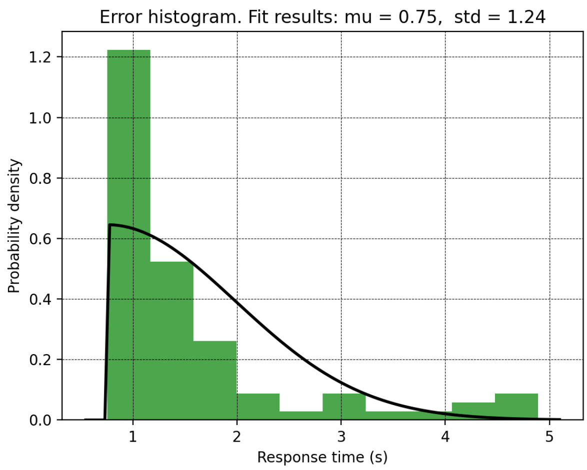

Figure 10 – Example of a response time histogram for a single participant with a half-normal distribution for comparison.

6. Conclusions

The experiment provided further insight into the user's interaction with the system, and allowed the observation of fitts's law applied to this scenario.

It can be observed that for the best half of the subjects, the index of performance is within about a factor of two (4-8 bits/sec). In the case of this experiment, an index of difficulty less than five results in the time delay due to reaction time of the person between the apparition of a new ball and the reaction of the person to begin looking for it being dominating in the calculation of the index of performance. only for indexes of difficulty larger than five a pattern emerges in the results.

7. Acknowledgements

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