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TARGETING SIMULATION FOR ASSESSMENT OF LAY ERROR UNDER VARYING CONDITIONS

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ABSTRACT

Lay error is a primary source of error in fire control, which is defined as "the gunner's inability to lay the sight crosshairs exactly on the center of the target." To evaluate the potential implementation of computer vision and artificial intelligence algorithms for improving gunners' performance or enabling autonomous targeting, it is crucial for the US Army to establish a benchmark of human performance as a reference point. In this study, we present preliminary results of a human subject study conducted to establish such a baseline. Using the Unreal Engine [1], we developed a photorealistic simulation environment with various targets. Fifteen individuals meeting the military applicant criteria in terms of age were assigned the task of aligning crosshairs on targets at multiple ranges and under different motion conditions. Each participant fired at 240 targets, resulting in a total of 3600 shots fired. We collected and analyzed data including lay error and time to fire. The initial analysis reveals that subjects demonstrated a significant number of outliers in lay error, and there was notable variation between subjects.

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Targeting Simulation for Assessment of Lay Error Under Varying Conditions

1. INTRODUCTION

Understanding the source of errors contributing to the inaccuracy and dispersion of weapon systems will improve warfighter performance. These errors

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include ammunition dispersion, gun dispersion, aerodynamics, and aiming errors, with aiming (lay) error representing one of the most significant [2, 3]. Lay error, which is directly contributed by the gunner, is defined as the gunner's inability to lay the sight crosshairs exactly on the center of the target [4]. Weaver detailed several factors that affect aiming error, including combat stress, training, position, and time to aim [5].

Notable research has been conducted to quantify aiming errors and other errors contributing to dispersion in order to improve soldiers' performance. Glumm et al. compared the lay error that resulted when gunners used two different styles of control Yoke [6]. Corriveau et al. evaluated the lay error between various firing positions (prone, kneeling, standing, and trenched) and ranges (between 100 m and 500 m). Using Monte-Carlo simulations, the probability of a hit was determined for each firing position and for three different ranges [7]. Both the experimental and simulation results are simultaneously presented to demonstrate the impact of the lay error on soldier performance. James et al. evaluated the performance of soldiers under the stress induced by competition [8]. It was found that the aiming error was greater in burst mode than in semi-automatic mode. Strohm studied the primary sources of delivery error for direct-fire ballistic projectiles [9]. The vibration of both the vehicle body and the weapon greatly affects the hit probability of gunshots fired from moving Ground Combat Vehicles (GCVs). Song et al. presented a relationship between road roughness and GCV speed when a predefined hit probability is required [10].

In this work, we present the preliminary results of a new study of the lay error of human subjects under varying levels of task and visual complexity. We seek to develop an accurate statistical model for lay error and determine the effects of varying conditions. We developed a realistic simulation environment in the Unreal gaming engine that features a variety of ground targets. A cohort of fifteen people that meet the criteria of military applicants was then tasked to run the simulation and align cross-hairs on targets at multiple ranges under different motion conditions. Lay error, time needed to aim, and other data were recorded under each condition. This data was analyzed as a whole and per individual to glean insights about cohort and individual performance. Initial analysis indicates that subjects exhibit a significant number of outliers in lay error and that variation between subjects was significant.

In summary, this work makes the following contributions:

- We present a realistic tank gunning simulation to analyze lay error under a variety of targets and conditions. We include discussion of the design of the simulation as well as the testing scenarios.
- We present initial results of lay error for 15 subjects taking a total of 3600 shots at four targets, at four distances, and under four moving conditions. To our knowledge, this is the first time a dataset of this type has been collected.
- We present initial key findings/deductions of our study and lay out plans for future analysis.

2. SIMULATION ENVIRONMENT

The simulation environment was built using the Unreal Engine. Figure 1 shows an image from the simulation environment, in which a reticle is near a tank target that is 2000m away. A red bar at the top indicates the time left to fire. Our simulation features four ground targets, four moving conditions, and four target distances. The four targets were based on those used in the Army *Training Ranges* circular [11]: a 2.3m$\times$2.3m square, a 2m$\times$2m trapezoid, a 7m$\times$3.6m trapezoid, and a detailed 3D tank of approximate 5.7m$\times$4m size. Targets were at distances of 500m, 1k, 2km, and 5km from the shooter. The movement conditions were static shooter/static target, moving shooter/static target, static shooter/moving target, and moving

Figure 1: View of the Unreal Engine and simulation environment.

Figure 2: The four targets in the simulated environment.

shooter/moving target. A timer was presented for 30 seconds to fire at four targets to compel speed in addition to accuracy. Only a single shot on each target was allowed, for which the shooting and environment data was saved.

The purpose of this study is to quantify lay error specifically. Therefore, we seek to reduce the time a subject spends searching for the target. For each target, the reticle is randomly placed in a neighborhood of the target, according to a uniform distribution. Locating targets in an important topic [12, 13, 14] but is outside the scope of this study.

An Xbox controller was used for controlling the simulation. We mimicked the button requirements of the Abrams gunner yoke by the following configuration: (1) Aiming with the right joystick; (2) The left lower trigger is a dead-man switch that must

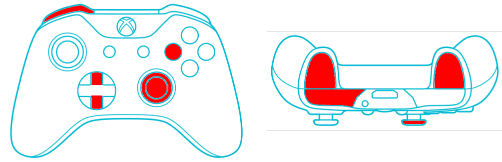

Figure 3: A front and top view of the Xbox controller with controls described above highlighted in red.

be pressed for any control to be accepted; (3) The left upper shoulder button turns on laser ranging and shot calibration; (4) The right lower trigger fires; (5) Up and down directional buttons optically zoom in and out the gunner's view; (6) The X button is used to move to the next target. Figure 3 shows an image of a Xbox controller from the top and front, with the controls highlighted.

All controller inputs, with the exception of the right joystick, register as binary switches. The right joystick angles map to the vertical and horizontal axes. While the raw inputs of these axes range linearly from -1 to 1, a nonlinear curve is applied to each axis when converting the inputs to turret motion. Let $x \in [1, 1]$ represent the normalized joystick input. The response curve is given by

$$f(x) = \begin{cases} (a(x-d))^n & x \geq d \\ 0 & d < x < d \\ -(-a(x+d))^n & x \leq d \end{cases} \tag{1}$$

where a is the sensitivity value, d is the dead-zone value, and n the exponent value. In the case of this simulation, the values $a = 0.95$, $d = 0.04$, and $n = 1.85$ were used for both the x-axis and y-axis. This curve is illustrated in Figure 4.

3. DATA COLLECTION

Trials were conducted on 15 human subjects at the University of Georgia. The participants were each introduced to the project via a review of the consent form, the study procedures, and the simulation workstation. After signing the consent forms, the subjects were asked basic demographic questions. Each subject first participated in an

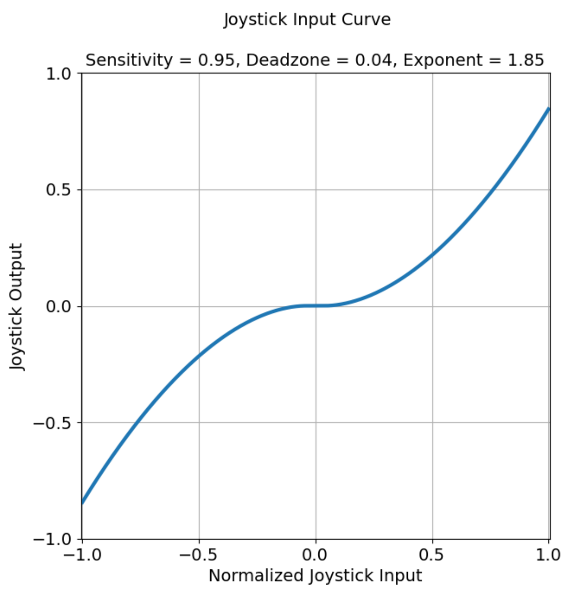

Figure 4: A graphical representation of the joystick input curve applied to both the x and y axis raw input values.

interactive tutorial to learn the task, user interface, and controls in a step-by-step manner. Performance was monitored during the practice target segment, and undesirable behaviors (e.g., not aiming for the center of the presented area, inaccurate range finding, prioritizing speed over accuracy) were addressed. Once the participant and researchers felt they were ready, the tutorial ended, and the data collection segment began.

Subjects targeted and fired at all four targets, at all four distances, and under all four moving conditions, with 80% of cases being the static-static condition and the remaining 20% of cases evenly divided between the three other motion scenarios. The simulation then saved screen captures of each shot for offline processing to compute the lay error. Each subject fired at 240 targets, giving a total of 3600 shots fired. Once the data collection finished, the subjects filled out a brief exit survey regarding their experience with the simulation and the control scheme. Compensation was provided to the subjects in the form of a $30 Amazon gift card.

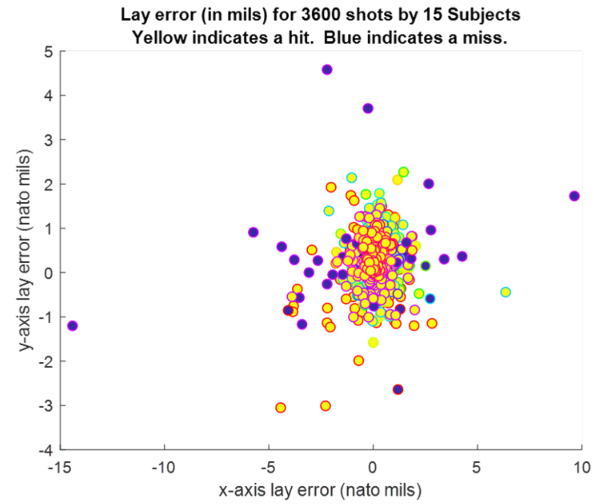

Figure 5: Lay Error in mils for 3600 shots by 15 subjects. Yellow indicates a hit and blue a miss.

4 DATA ANALYSIS

The first step in analyzing the collected data is to calculate the lay errors in the x and y directions in mils. To this end, the horizontal and vertical distances between the aim point and center point of the target are calculated in terms of the number of pixels, then converted to NATO mils. If the reticle was over any part of the target, the shot was recorded as a “hit”; otherwise, it was recorded as a “miss.” As this study focuses on lay error, no ballistics model was used in the determination of a hit, just if the reticle was on the target.

The scatter plot of lay errors for all 3600 shots is shown in Figure 5. This figure indicates whether the shot was a hit or a miss by filling the circle with yellow for a hit and blue for a miss. Figure 6 shows the lay error with respect to the distance at which the shot was taken. Notably, the lay error is larger for close shots, as the subject can get the reticle on the target to score a hit despite the lay error being large.

Scatter plots of error in meters for shots fired from all distances at the 2.3m$\times$2.3m square planar target and at the 3D tank target are shown in Figures 7 and 8, respectively. This was calculated by estimating where the shot would have crossed a plane through the center of the target and normal to the camera

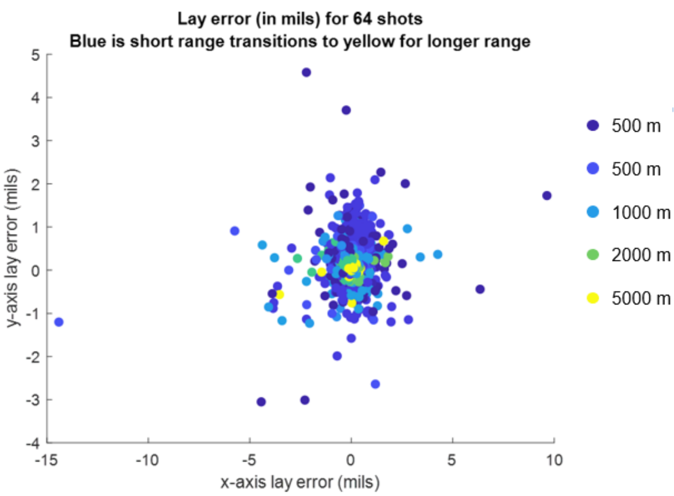

Figure 6: Lay Error in mils for 3600 shots. Dark blue indicates close range and transitions to light blue, green, and yellow as the distance increases.

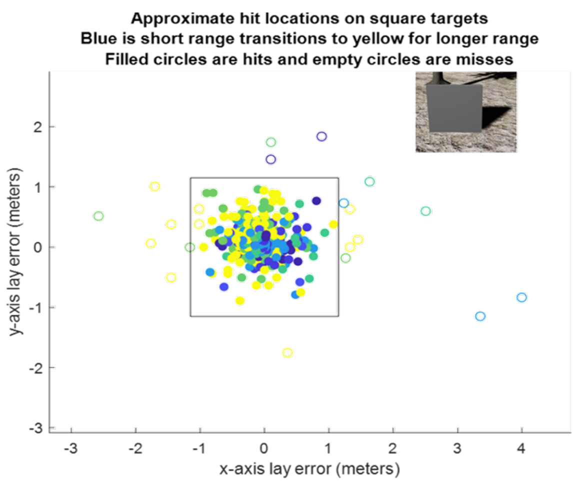

Figure 7: Scatter plots of error in meters with respect to the 2.3m×2.3m target. A bounding box indicates the approximate size of the target.

view. The color of each circle indicates the distance the shot was fired, with dark blue being close and transitioning to yellow for distant shots. The circle is filled if the shot was a hit and empty if it was a miss.

Histograms of lay error for 3600 shots by 15 subjects were generated. Figure 9 shows 2 1D histograms for x and y axis error, and Figure 10 presents the same data as a 2D histogram. From the histograms, we see very narrow peaks and flat tails

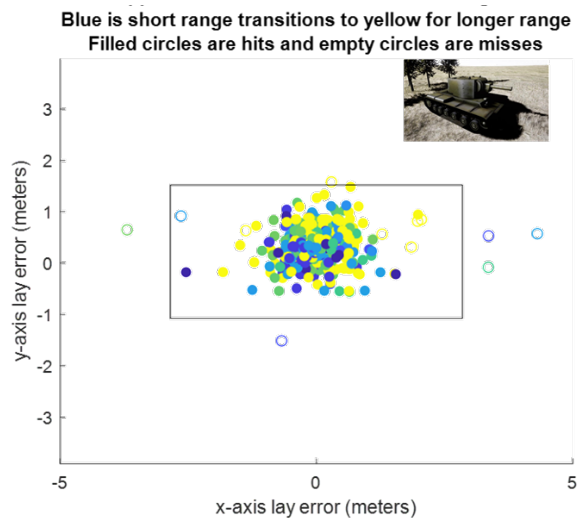

Figure 8: Scatter plots of error in meters with respect to the 3D tank target. A bounding box indicates the approximate size of the target.

from outliers.

Box plots for the x-axis and y-axis lay errors for all 3600 shots are shown in Figures 11 and 12. Note that the grey points indicate data that are more than 1.5× the distance from the first quartile to third quartile from the median, which are generally regarded as outliers. These plots indicate a large number of outliers, in the sense that many errors that were significantly far from the mean. Figure 13 shows a box plot for both the x and y-axis lay errors for all 15 subjects, with outliers removed to better show the medians and interquartile ranges. It can be seen that the distributions tend to be more positive for the y, indicating that subjects tend to "miss high."

We investigated the error as a function of the time a subject takes to fire, as seen in Figure 14. The four greatest errors and the six longest firing times were removed from the plot to improve readability. The vast majority of shots took less than 20 seconds (98.972%), and most had a total error (i.e., norm of the x and y error in meters) of less than 2 meters (98.917%). The mean Euclidean error for all shots is 0.15131 meters with a median of 0.15877 meters. While error is frequently low across all firing times, the *maximum* error and firing time shows a

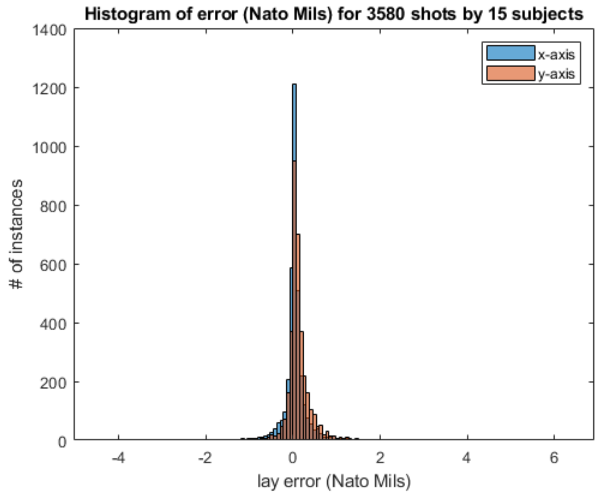

Figure 9: 1D Histogram of all shots fired. x-axis error is blue and y-axis error is orange. The inclusion of outlier results in the wide horizontal spread.

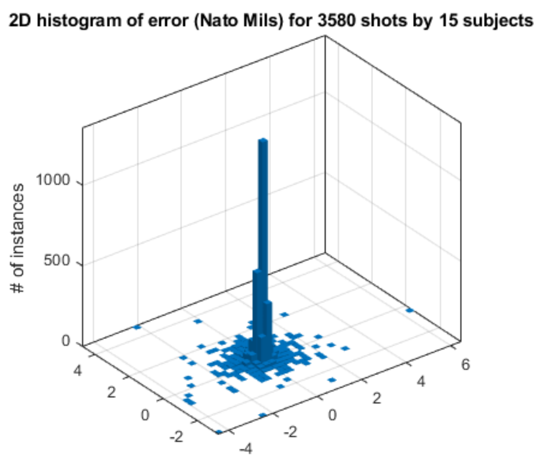

Figure 10: 2D Histogram of all shots fired.

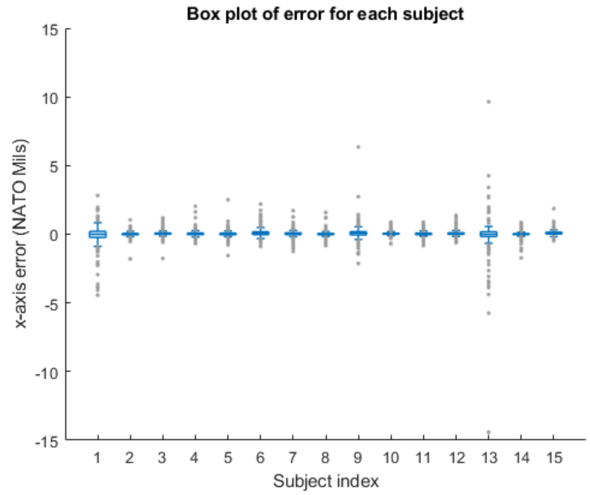

Figure 11: Box plot of x-axis lay errors for 15 subjects.

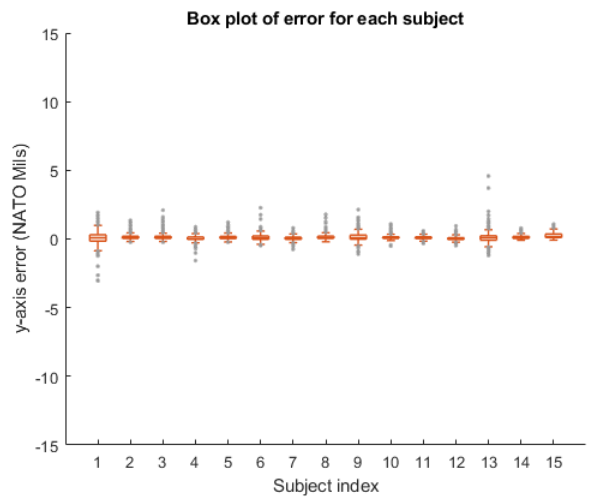

Figure 12: Box plot of y-axis lay errors for 15 subjects.

negative relationship; i.e., for longer aiming times, the maximum error seen at that time reduces.

In this preliminary data analysis, there are several notable elements. One is the presence of numerous significant outliers in the lay error data as seen in the histograms and box plots. Tests of normality using the Anderson-Darling and Lilliefors tests [15] were run with the collective 3600 data points and the individual sets of 240 data points for each subject. All tests indicate that the hypothesis that the data is from a normal distribution should be rejected, likely due to these large outliers. It is important to note that these are outliers in the sense that they are significantly far from the mean with respect to the standard deviation, but they are not necessarily outliers in the sense that they represent erroneous data. It may be the case that a typical proportion of shots have very large error. The fact that all subjects showed large outliers supports this supposition. Before additional subjects are tested, we will analyze data to ensure that large errors do not occur due to the structure of the simulation or testing scenario. We can then determine if outliers should be

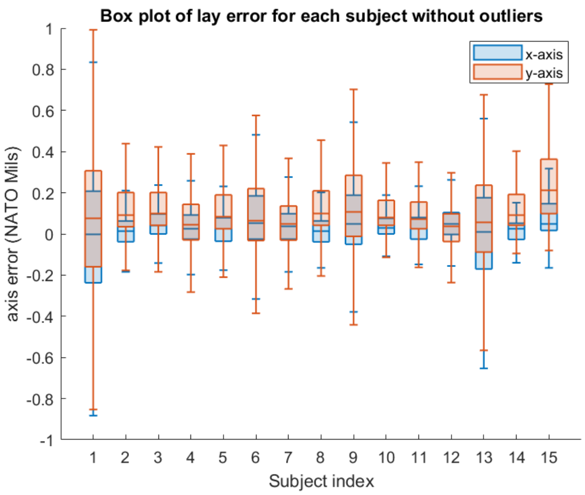

Figure 13: Box plot of x and y-axis lay errors for 15 subjects, with outliers removed for ease of reading.

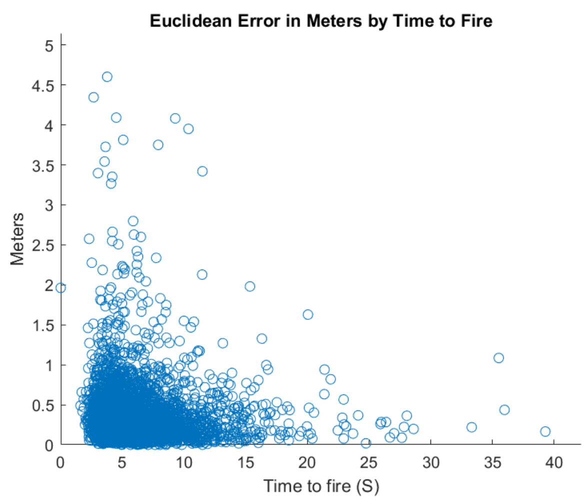

Figure 14: Euclidean error as a function of the time to fire.

removed or retained in the analysis.

A second interesting aspect of the data is the significant difference between subjects. We used Kruskal-Wallis nonparametric one-way analysis of variance (ANOVA) [16] to test whether data from each subject originated from the same distribution. Large chi-square values ($\chi^2 > 78$) lead us to reject that hypothesis. Similarly, two-sample Kolmogorov-Smirnov (KS) goodness-of-fit tests [17] were conducted for all pairwise combinations of subjects. Many pairwise KS tests indicate that we should reject the hypothesis that the pair of subjects have lay error from the same distribution.

5. CONCLUSIONS

In this paper, we presented an initial design of our study, test, and analysis of human subject trials for modeling and predicting the lay error of a tank gunner. Unreal Engine was used to develop a photorealistic simulation environment featuring a range of targets at different distances and moving conditions. Fifteen people were asked to align crosshairs on targets at multiple ranges and under various motion conditions using the simulation environment. Analysis of the lay error was conducted using the collected data.

We observed that each individual subject and the aggregate data show a significant number of lay error samples that are far from the mean, typically classified as outliers. If outliers are retained in the samples, the distribution of lay errors does not match a normal distribution. We also observe a significant difference in the lay errors between subjects.

These are initial results. We are collecting data from a total of 100 subjects, which may alter the observations of outliers and distributions. We are also extending the simulation to test the effects of additional conditions, such as weather effects and occlusions. Analysis will be extended to include analysis of variation between target types, distances, occlusions, etc. We will conduct regression analysis to predict lay error under varying conditions and factor analysis to determine categories of factors that influence lay error.

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