A Fitts' Law Evaluation of Video Game Controllers: Thumbstick, Touchpad and Gyrosensor

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Abstract
We present a pilot study evaluating three different game input methods offered by the Steam Controller: a thumb-based touchpad, thumbstick, and gyrosensor. In a Fitts' law pointing experiment, we compared these three input methods to the mouse, a commonly used baseline condition. The mouse had the best throughput at 4.73 bps, followed by the touchpad at 2.98 bps, then the gyrosensor at 2.85 bps, and finally the thumbstick at 2.39 bps. This indicates that the touchpad and gyrosensor are good alternatives to the traditional thumbstick, despite prevalence of the thumbstick on modern game controllers.

Author Keywords
Game controller evaluation; Fitts' law.

ACM Classification Keywords
H.5.2 [Information Interfaces and Presentation, (e.g., HCI)]: User Interfaces – Input devices and strategies. K.8.0 [Personal Computing]: General – Games

Introduction
Game console designers have long experimented with novel inputs when designing new game controllers. Modern controllers include numerous input options including touchpads, remote pointing, tilt control,

Figure 1. The *Steam Controller* used in our experiment.

triggers, back paddles, analog buttons, and even touchscreens. Despite this variety, most console games are still played using a combination of thumbsticks and buttons. Other inputs such as tilt are largely reserved for specific uses cases (e.g., mobile gaming) and are rarely used in console games, perhaps due to poor accuracy [6].

The performance potential of many of these input modalities are understudied. For example, thumb-controlled touchpads, such as that found on the HTC *Vive* controller or Valve's *Steam Controller* have yet to be formally evaluated. Many input modalities have not been looked at in tandem. For example, tilt-sensitive controllers support aiming with a thumbstick, while simultaneously using the gyro to control aim sensitivity [4]. Similar combinations of input modalities are likely also possible.

To assess the performance of thumb-controlled touchpads, we conducted a pilot study using the *Steam Controller*. The *Steam Controller* features two touchpads, a gyro sensor, a thumbstick, and two paddles on the back of the controller. See Figure 1. We compared the performance of the thumbstick, gyro, and touchpad in a point-selection task. Point-selection is critical not only in standard UIs, but in many game genres as well. Consider aiming at enemies in a first-person shooter, selecting and moving units in a strategy game, or clicking pieces in a puzzle game; all are point selection tasks.

Although using an actual game as an experimental testbed enhances external validity [12], point-selection is a highly-refined research area with well-established standards. Conforming to these standards offers a greater degree of experimental internal validity. Hence, our pilot study used a simple point selection task conforming to ISO 9241-9 [1]. Our aim was to study how effective the touchpad and gyro were as general pointing devices, especially in comparison to the more common thumbstick. The mouse was included as a baseline, as its performance is well-known from numerous pointing studies. This enables "calibration" of our results against other experiments.

Related Work

Input Modalities for Games

Tilt control has been studied as an input modality using Fitts' law [6, 12]. Mackenzie and Teather [6] conducted an experiment using a tablet to roll a simulated ball to the target. The results confirm throughput is low, but that tilt conforms to Fitts' law. Follow-up work revealed that a position-control mapping offered better performance with tilt than the more commonly used velocity-control mapping [12]. We expect similar results using the Steam Controller's gyro, but note that there are fundamental differences as it does not couple the display and input space like a tablet.

Alankus and Eren [4] used tilt to adjust thumbstick sensitivity, effectively applying a gain factor based on the orientation of the controller. The tilt-gain controller offered comparable performance to a standard game controller. Tilt was used exclusively as a secondary control to augment the primary thumbstick control.

Our work is closest to that of Natapov et al. [1, 2, 3], who evaluated several controllers in a series of studies. In their first study, they compared a thumbstick to a mouse and a remote pointing controller (a Wiimote) in a pointing task [1]. While the mouse had the best accuracy and throughput, the WiiMote offered comparable throughput, but the highest error rate. Subsequent work involved the development and evaluation of a trackball controller – a modified Xbox controller that replaced the second thumbstick with a small trackball [2]. In a Fitts' law pointing experiment, the trackball controller offered better throughput than the thumbstick controller, but the pointer path was less smooth than with a thumbstick. A follow-up study [3] using an actual FPS game (Call of Duty 4: Modern Warfare) had consistent results: the trackball controller outperformed the standard controller [3].

Pointing Device Evaluation

Similar to Natapov [1, 2], we employ Fitts' law in our evaluation. It has been previously shown that aiming in FPS games conforms to Fitts' law [8]. While lacking the external validity of testing in a "real" game [3], the results of pointing experiments are consistent with FPS performance. Hence, we deem this an appropriate evaluation protocol for a first pilot study. Future work will investigate performance in actual games. Fitts' law models the relationship between index of difficulty (*ID*) and movement time. *ID* is calculated as:

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

where *A* is target distance (amplitude), *W* is target size (width). We employ the ISO 9241-9 standard used by others in pointing device evaluation [1, 2, 6, 12]. The standard recommends throughput as a primary metric of performance. Throughput (TP) is computed as:

$$TP = \frac{\log_2\left(\frac{A_e}{W_e}+1\right)}{MT} \qquad (2)$$

where $$W_e = 4.133 \times SD_x \qquad (3)$$

A_e is the effective amplitude (average of cursor movement distances). W_e is the effective target width. This is adjusted post-experiment to fix the experiment error rate to 4%, facilitating comparison between studies with varying error rates. This accuracy adjustment is done by calculating SD_x as the standard deviation of over/under-shoots relative to the target centre, projected onto the task axis (line between subsequent targets). It is multiplied by 4.133, which corresponds to a z-score of ±2.066, or 96% of the values falling within a normal distribution (i.e., a 96% hit rate, or 4% error rate). The log term is thus referred to as the "effective" index of difficulty, and better reflects the task participants actually performed than standard *ID.* Dividing this by the average movement time for a condition yields throughput, and thus incorporates both speed (via *MT*) and accuracy (via W_e) into a single metric. Further discussion of the merits of this approach is available elsewhere [5].

Methodology

Participants

Our pilot study included 5 participants (3 male, 2 female, aged 21-30 years) recruited from the local community. Experience with input methods was assessed with a pre-experiment questionnaire. All were familiar with mouse input, mobile phone tilt control, and game controller thumbsticks. However, none had used a touchpad or gyro on a controller before.

Apparatus

The experiment was conducted on a laptop with a AMD A8-3500M quad core processor, a ATI Radeon HD 6620G GPU, and 6GB of RAM running Windows 10. A

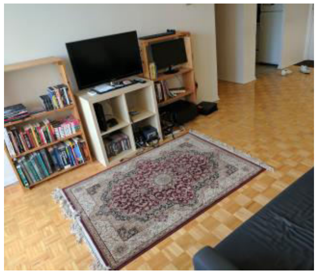

Figure 2: Living room setup for our experiment.

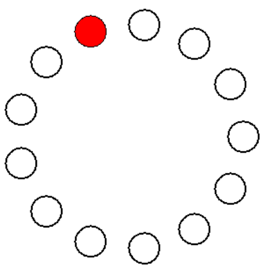

Figure 3: 2D Fitts' law pointing task

27 in. LG television was used as the display, for consistency with typical console gaming. We used Valve's *Steam Controller* since it included all required inputs in a single device: thumb-based touchpads, a thumbstick, and a gyro. See Figure 1. The study was conducted in a living room environment setup with participants seated on a couch. See Figure 2.

The controller touchpads, thumbstick, and gyro were configured to control the cursor. The top left and top right trigger buttons issued a left mouse button click event when pressed. The gyro input was mapped to operate like a steering wheel: when holding the control in front of them, rotating clockwise moved the cursor right, and counter-clockwise moved the cursor left. Tilting the top of the controller away moved the cursor down, while tilting the top of the controller towards the user moved the cursor up. Cursor sensitivity was consistent and pointer acceleration was disabled with all input methods.

We used MacKenzie's FittsTaskTwo software [7], which utilizes the ISO 9241-9 standard. The software presents a 2D pointing task with several circular targets arranged in a circle centered in the middle of the screen. See Figure 3. Targets vary in size and distance between each other. One target is highlighted red, indicating participants should click it. Upon clicking (regardless if participants hit or miss the target) the target on the opposite side of the circle becomes "active", becoming red. The software logs movement time, error rate, throughput, and motion trails.

Procedure

Upon arrival, participants completed a questionnaire on their familiarity with various pointing devices. They were then shown how to use the Steam Controller and software and were then given a 6 practice sequences of 13 targets with each input method, to get familiar with using the apparatus. Practice trials were not logged. Following the practice period, the actual experiment commenced. Participants were instructed to click the circles as fast as possible and as close as possible to the center. Following the experiment, participants were thanked for their time and debriefed.

Design

The experiment used a 4x2x3x5 within-subject design. The independent variables and their levels were:

input method: mouse, thumbstick, touchpad, gyro
target size: 20, 35 pixels
target distance: 128, 256, 512 pixels
block: 1, 2, 3, 4, 5

Input method ordering was counterbalanced via a Latin square. To produce a realistic range of task difficulties, we used six combinations of target size and distance seen above, yielding 6 *ID*s ranging between 2.21 and 4.7 bits. *ID* was presented in random order.

Participants completed 13 trials in each condition. In addition to generating more data, block allowed us to study performance changes over time (e.g., due to learning). In total participants completed 13 trials × 4 input methods × 5 blocks × 6 *ID*s = 1560 trials each, or 7,800 trials over all 5 participants.

There were 3 dependant variables: throughput (bps), error rate (%), and time (ms).

Results

Data were analyzed with repeated measures ANOVA. In Figures 4, 6, and 8 horizontal bars (●—●) indicate significant pair-wise differences, as determined in a Bonferroni-Dunn post hoc comparisons test ($p < .05$).

Throughput

Average throughput scores are seen in Figure 4, and throughput by block is shown in Figure 5. Repeated measures ANOVA revealed a significant main effect for input method ($F_{3,16} = 129.7$, $p < 0.0001$). The input method × block interaction effect was also significant ($F_{20,64} = 1.45$, $p < 0.5$).

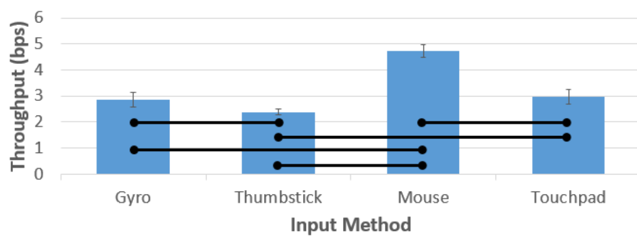

Figure 4. Throughput by input method. Error bars show ±1 SD. Black bars indicate pairwise significant differences.

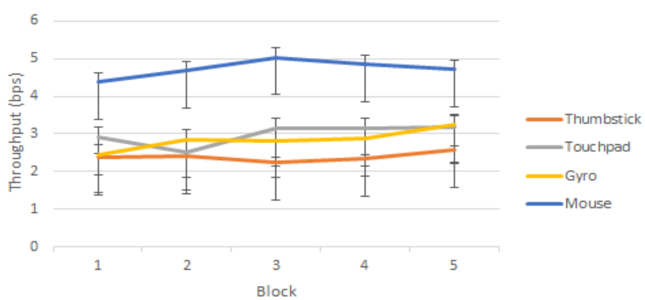

Figure 5: Throughput by block. Error bars show ±1 *SD*.

Error Rate

Average error rates are shown in Figure 5. The main effect for input method was significant ($F_{3,16} = 10.38$, $p < 0.005$). The input × block interaction effect was also significant ($F_{20,64} = 1.27$, $p < 0.5$).

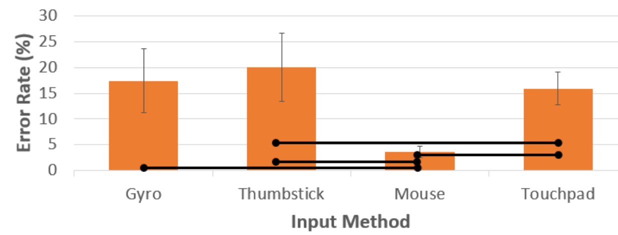

Figure 6. Error rate by input method. Error bars show ±1 *SD*. Black bars indicate pairwise significant differences.

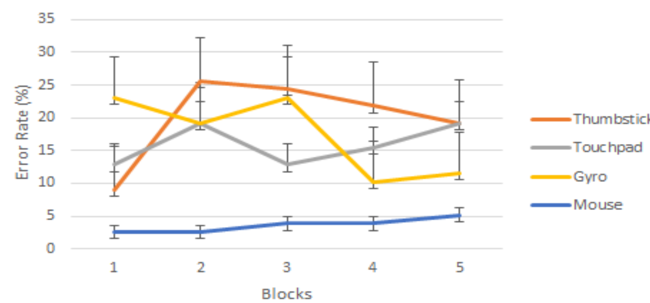

Figure 7: Error rate by block. Error bars show ±1 SD.

Movement Time

Average movement times are seen in Figure 8. The main effect for input method was significant ($F_{3,16} = 61.09$, $p < 0.0001$), as was the input method × block interaction effect ($F_{20,64} = 1.46$, $p < 0.5$). Movement time for each block are shown in Figure 9.

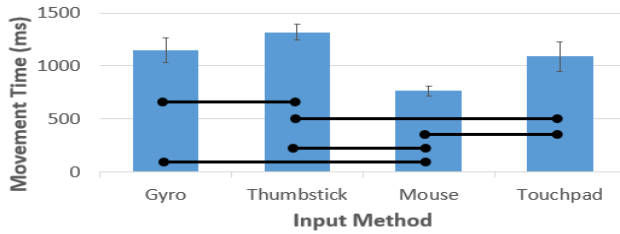

Figure 8. Movement time by input method. Error bars show ±1 *SD.* Black bars indicate pairwise significant differences.

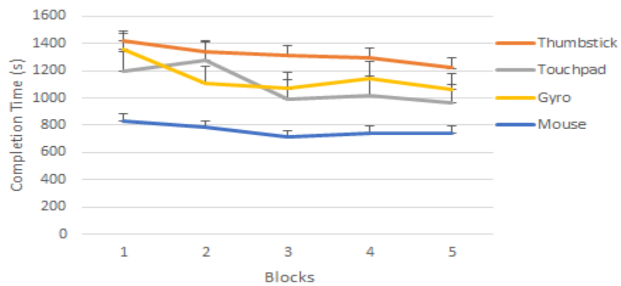

Figure 9: Movement time by block. Error bars show ±1 *SD.*

Discussion

As expected, mouse throughput was significantly higher than the other three input methods, but more importantly, consistent with previous studies enabling comparison of throughput scores. Surprisingly, the gyro performed roughly as well as the touchpad, contrary to our hypothesis. More surprisingly, the thumbstick performed worst overall, and yet still higher compared to results reported by Natapov et al. (2.39bps vs. 1.68bps) in a similar study [2]. This may be due to our participant pool largely consisting of regular gamers, or differences in the controller itself. Touchpad performance might have leveraged familiarity with the touchpad found on most modern laptops.

Unsurprisingly, the mouse had the lowest error rate. Error rates with the other three input methods varied considerably over block, as reflected in the significant interaction effect. The gyro exhibited the greatest improvement over the thumbstick. The touchpad had the second lowest rate of error after the mouse, again, likely due to participant familiarity. Compared to Natapov et al's [2], error rates were roughly twice as high (10.38% vs 5.81%). We believe this was due to the number of blocks: participants eventually became fatigued and distracted by the number of repetitions.

The mouse offered fastest movement time. It was surprising that the touchpad and gyro had around the same movement time; we had expected the gyro to fare worst. It exhibited the greatest improvement over time. The thumbstick offered the worst movement time overall, perhaps due to cursor speed or sensitivity.

Conclusion

We tested four different game input methods for their effectiveness in point selection: a mouse, a thumbstick, a touchpad, and a gyro. Results strongly favoured the mouse, but the gyro and touchpad throughput was about 20% higher than the thumbstick. This was surprising, as we expected that the thumbstick would perform better due to their ubiquity in controllers. This result is exciting given the novelty of touchpad-based controllers which opt to exclude a thumbstick altogether.

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