University of Glasgow | School of Computing Science

Honours Individual Project Dissertation

Modelling Mouse Movements For Machine Learning

Project Summary

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Introduction

Aims

This project first involved the design and implementation of a comprehensive test suite comprising of a diverse set of representative mouse pointing tasks that meet the following criteria:

- Produce data that follow the findings from established predictive models such as Fitts' and Steering laws.

- Produce data that help us understand the dynamics of mouse movements by examining aspects of motion such as movement time, pointer position, velocity, and acceleration.

- Obtain useful and reliable information about mouse interaction that can be used to improve machine learning models.

- Has parameterizable tests that can be modified to be used in future research of pointing tasks.

Participant trials were then conducted with this test suite, that captured mouse movements from 7 test subjects. The gathered data was then evaluated using an array of visualization techniques to highlight the most interesting aspects and behaviours derived from each test.

Motivations

Machine learning models aim to make mouse interaction more convenient by performing tasks like target and endpoint prediction. Before building the test suite, these models were studied to gain an understanding of the basic metrics and techniques necessary to implement and improve such models. Some models implement prediction based on learning some overall summary statistic like peak velocity, movement time or distance by abstracting the dynamics of the motion. This has seen success in a lot of cases with models being able to perform spacial and endpoint predictions, and through improvements in the underlying mathematical models, the predictions have gotten successively more accurate.

However, nowadays interaction with computers are getting more dynamic, and in addition to the target (or endpoint), the pointing process itself is just as important. As we bring interaction out of the computer into the real world, we have to design for and understand the dynamics of the interaction by taking into account the laws of physics and behaviour of the users. By creating an expansive and varied test suite, this project explores aspects of mouse motion dynamics and uncovers user behaviour in specific scenarios that has the potential to improve the accuracy of existing machine learning models in endpoint and motion prediction tasks.

Experiment

Data Collection

6 able-bodied participants and 1 disabled participant (mean age 29.42 years, std. dev. 11.58, 5 male, all normal or corrected to normal eyesight) took part in the experiment. All the participants were right-handed. The test suite was run and data captured on a 2017, 13-inch Macbook Pro, running on MacOS Catalina. The Apple wireless Magic Mouse 2 was used as the input pointing device. Each test was demonstrated first, and then the subject was asked to perform the task. This allowed for small breaks in between each test to prevent the participants from experiencing any form of strain or cramp in their hands. It also allowed to keep the instructions fresh in their memory since each test had a different set of requirements. A demonstration protocol was followed to provide the exact same instructions to every participant for the purpose of ensuring a controlled experiment.

Pointing Tests and Evaluation

Test #1

This test was a simple discrete pointing task using one target at a time (as shown in Figure 1). The simple nature of this test was used to dissect and explain each part of a mouse motion from the starting point to a target, as illustrated in Figure 2.

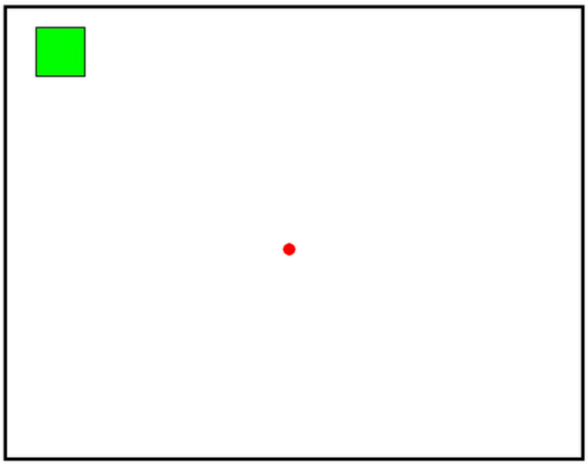


Figure 1: *Test #1 implementation. Comprises of a single green square target with the red dot as the starting point. Subjects were required to bring the cursor from the dot to the target, click on it, after which the cursor resets to the starting point and a new target appears.*

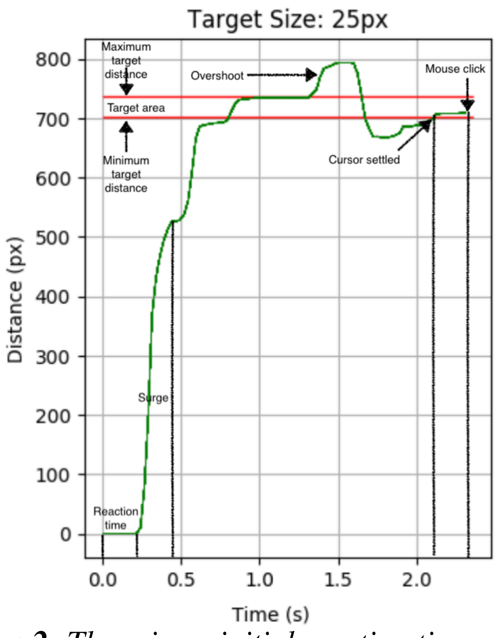
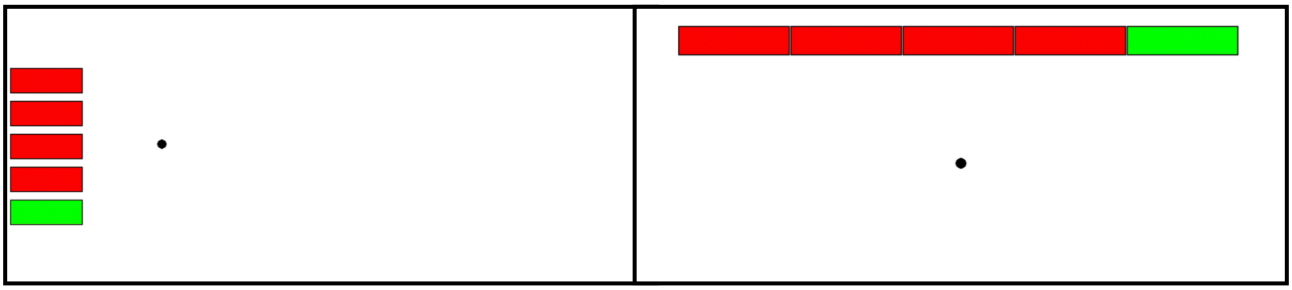


Figure 2: *There is an initial reaction time, after which the user moves the cursor towards the target in a ballistic manner, called the surge phase. There is then some overshooting and subsequent corrective oscillations towards the target area. Once the cursor is settled on the target, it rests for sometime before the user clicks the mouse.*

Test #2

This was another discrete pointing task, with multiple targets (1 main target to be clicked on and 4 distractor targets) laid out linearly, either horizontally or vertically to replicate the layout of linear interface elements, such as side menus and tabs (in a web browser, for example). Figure 3 shows the implementation of this test.



***(a)** Vertical linear layout.* ***(a)** Horizontal linear layout.*

***Figure 3:** Implementations of linear layout discrete pointing tasks. Green rectangle is the target to be clicked and the red ones are the distractor targets. The black dot along the middle of the targets, indicate the starting point. Subjects were required to click on the target as quickly and accurately as possible, after which another box becomes the target. After all 5 boxes are eventually targeted and clicked, the test is repeated with a new starting point further down the middle.*

This test revealed some interesting results. The users were instructed to click on the targets as quickly as possible. For any of the given 5 targets in either layouts, this meant moving the mouse in a straight line directly to the target, without crossing any of the distractor (red) targets. It was observed in the vertical layout of the test (Figure 3a), subjects crossed into the distractor targets more often from the closest starting point, going against the trivial assumption that as the distance reduces, pointing accuracy increases.

To explore this further, the cursor movements were plotted for the vertical layout. Figure 4 shows the plots for the cursor movement to the bottom-most and topmost targets from the closest starting position. It was observed that as the target to click is further away from the centre of the starting point, there are successively more crosses into the distractor targets. Subsequently, the most number of crosses into the distractors were observed for the bottom-most and topmost targets.

This phenomenon can be explained by the natural tendency of the human arm to follow a curved motion. This is because the motion of our wrists, describes an arc and not a straight line. And so, for short movements, the user may tend to only use their wrist and not lift their arms to drive the mouse, hence making it difficult to move the mouse in a straight line. The motion would then describe an arc, which in turn results in the cursor crossing into the distractor targets.

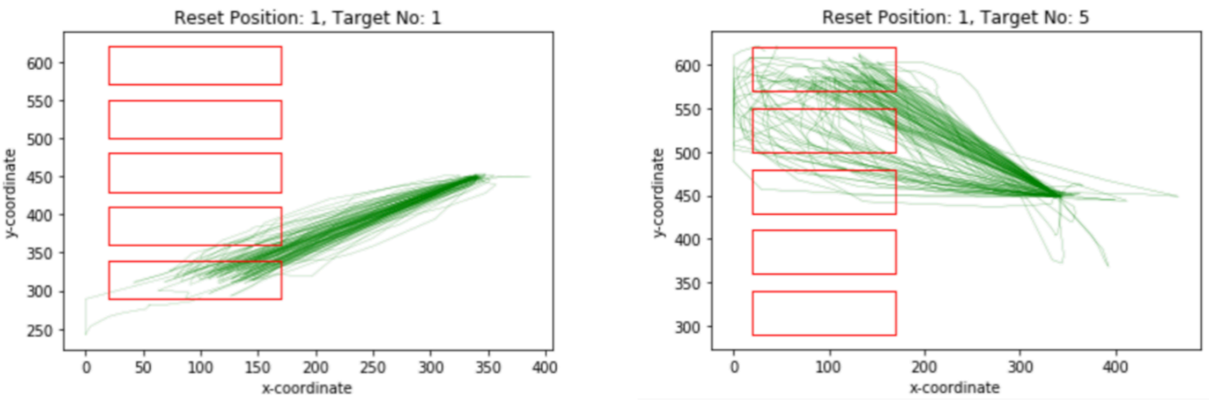


Figure 4: *Plots of cursor movement for all trials from the closest starting position to the bottom-most (Target No. 1) and topmost targets (Target No. 5). The most number of crosses into the distractors were observed for these targets. As the target gets further away from the centre, there were successively more crosses into the distractor targets.*

Test #3

This test was a continuous one-dimensional reciprocal tapping task (as illustrated in Figure 4).

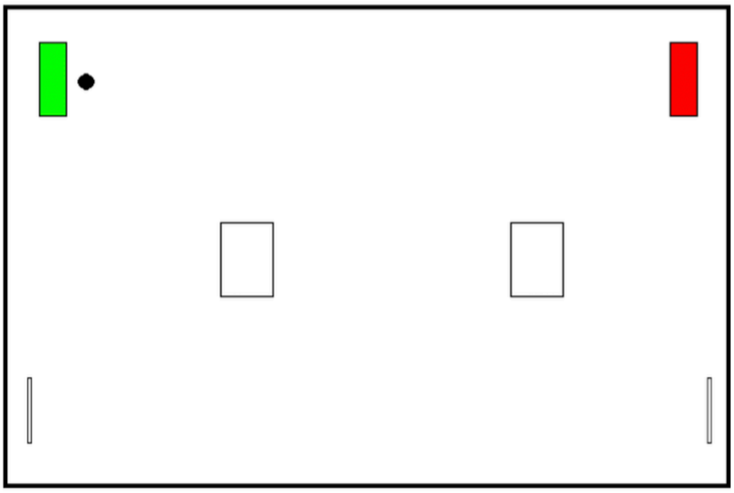


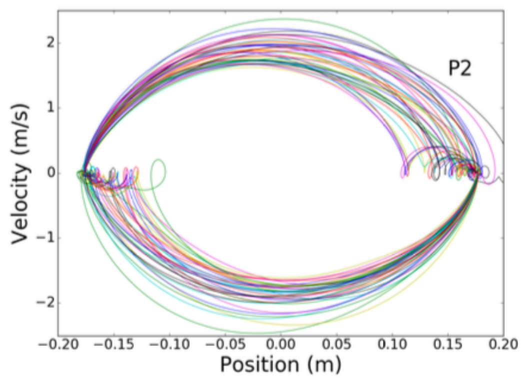
Figure 5: *One-dimensional reciprocal tapping task implementation. 3 pairs of bars, each pair with different target width and amplitude. Subjects were required to move the black circle using the mouse and click back-and-forth between the colored bars as many times as possible in the given amount of time. Moving to a bar and tapping is intended to be an abstraction of actions such as selecting icons.*

This test was used to examine the dynamics of cursor motion. Phase space and Hooke plots were used to do this. These plots were used to identify some motion patterns that indicated two types of strategies used by the subjects for target acquisition:

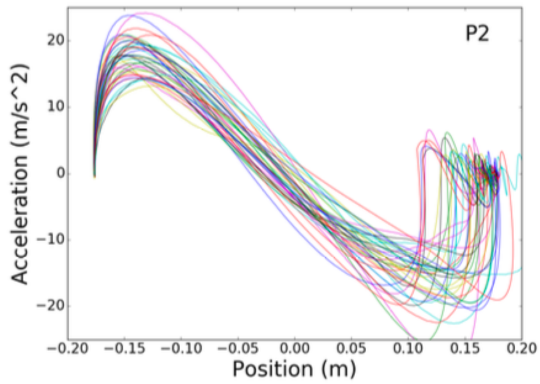
1. Some subjects used one big surge movement towards the target. This is usually accompanied by undershooting or overshooting, and there are further corrective movements to bring the

cursor to the target. This is called an open loop strategy. An example of a phase space and Hooke plot for the open loop strategy are shown in Figures 6a and 6b, respectively.

2. The other participants show flatter trajectories towards the target. This indicates that they are not executing the motion in a purely ballistic manner, but rather the motion is more controlled to try and land close to the target. This is called a closed loop strategy. An example of a phase space and Hooke plot for the closed loop strategy are shown in Figures 7a and 7b, respectively.

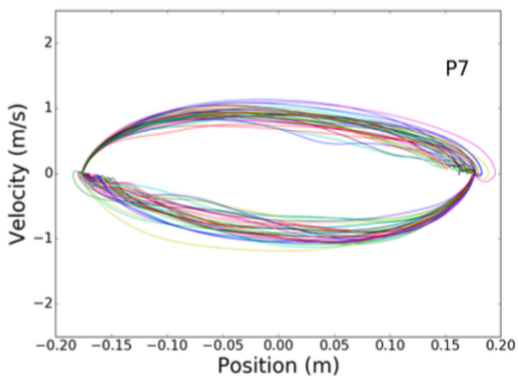


(a) *Phase space plot for an open loop strategy. Ballistic surge movements with a relatively symmetric acceleration and deceleration slope. Has high instances of undershooting and overshooting, followed by corrective oscillations.*

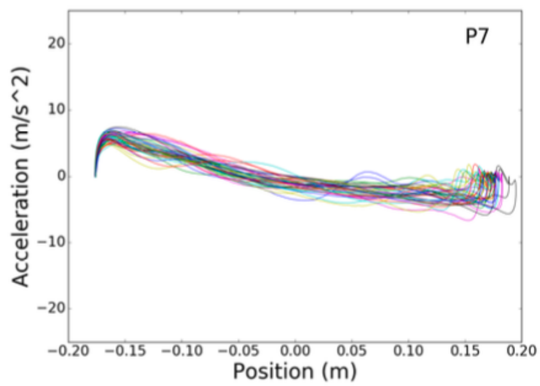


(b) *Hooke plot for an open loop strategy. Has a more symmetric N shape. Also has a high peak acceleration.*

Figure 6: *Open loop strategy employed by participant 2 for the bottom-most pair of bars (in Figure 5).*



(a) *Phase space plot for a closed loop strategy. Less ballistic surge. Has a less steep deceleration, indicating that the participants are moving in a more controlled manner to avoid overshooting. There is some undershooting, followed by corrective oscillations.*



(b) *Hooke plot for a closed loop strategy. The deceleration is less steep than the acceleration. Peak acceleration is not very high.*

Figure 7: *Closed loop strategy employed by participant 7 for the bottom-most pair of bars (in Figure 5).*

Test #4

By the Steering Law, it will take more time to move a cursor precisely through a narrow tunnel; and moving quickly will result in more accidental crossings of the tunnel borders. This test was a two-dimensional continuous reciprocal pointing task that tested this Steering Law effect, by having the subject attempt to move the cursor through a tunnel (as shown in Figure 8).

Figure 8: *Two-dimensional continuous pointing task. Green circle follows the cursor. The two lines indicate boundaries of a tunnel. Subjects were required to use the mouse to move the cursor back-and-forth between the two targets as many times possible while trying to stay inside the tunnel.*

There were 3 different tunnel widths and the Steering Law effect was observed as the time to move through the tunnel increased as the width of the tunnel decreased. It was also observed that participants who attempted to move quickly through narrow tunnels ended up crossing the tunnel boundaries many more times as opposed to the others who took their time to move through the tunnel is a more controlled manner.

Test #5

This was another tunnel task, comprising of multiple L-shaped 90-degree turns to emulate interaction with interface elements like cascading menus, like that illustrated in Figure 9. Figure 10 depicts how this interaction is emulated in the test suite. Figure 10a replicates the L-shape with longer horizontal tunnels and Figure 10b is a variation of the same with longer vertical tunnels. For both variations of the test, there were 3 different tunnel widths.

The cursor movements for these tests were plotted. Figure 11a, shows the cursor movement through tunnel shape 1 (Figure 10a) for all participant trials. The cursor mostly stays within the boundaries of the tunnel during the first three 90 degree turns. But towards the end of the movement, the participants tend to cut through the final turn of the top tunnel border in a straight diagonal line rather than move in a zig-zag to get to the target.

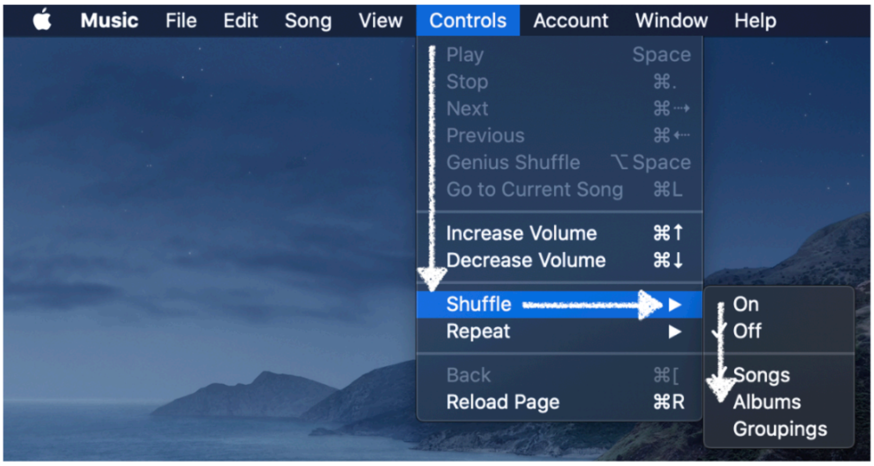
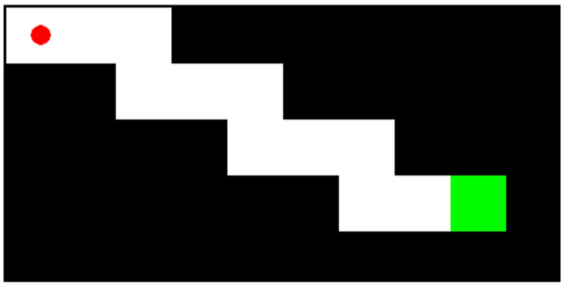
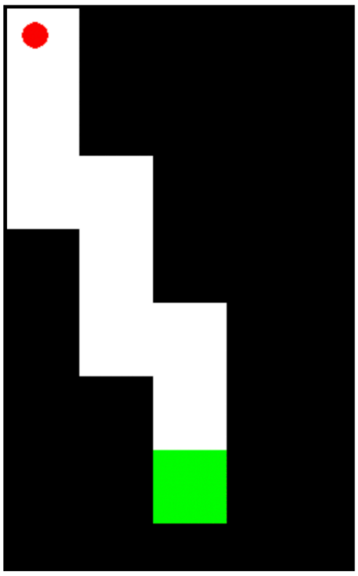


Figure 9: *Hierarchical menu structure in MacOS. Arrows indicate moving the mouse cursor through a series of linear path-steering tasks separated by 90-degree turns in an L-shaped sequence. The second step in this sequence involves the narrowest tunnel, which can be slow and difficult for users to move through without errors.*



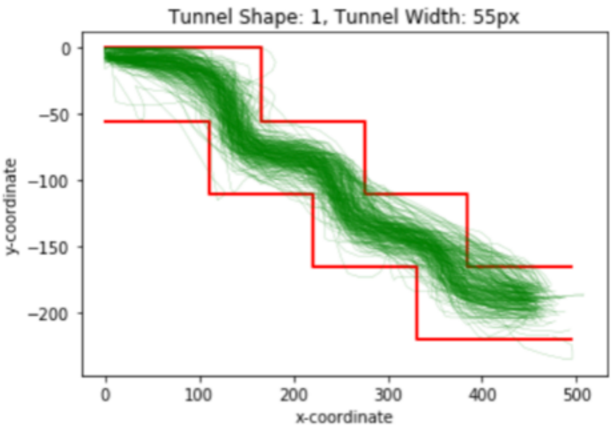
(b) *L-shape sequence with longer vertical tunnels.*



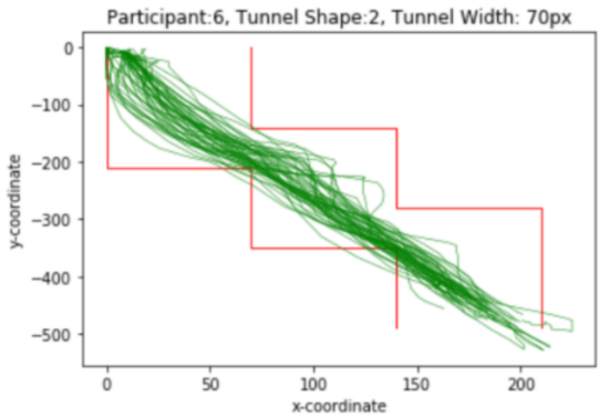
(a) *L-shape sequence with longer horizontal tunnels.*

Figure 10: *L-shape tunnel implementation in test suite. Red circle follows the cursor. Subjects were required to move the cursor as quickly as possible through the tunnels and click on the green square while always trying to keep a part of the red circle within the tunnel.*

In was also observed for tunnel shape 2 (Figure 10b), the participant with the most number of target hits employed an interesting strategy. From Figure 11b, it can be seen that the participant rarely followed the zig-zag path of the tunnel. Upon approaching the first 90-degree turn, the participant proceeded to move the cursor through the rest of the tunnel in a straight diagonal line through nearly all turns. Another interesting thing to note is that although this participant followed a straight path, there was a decreased number of boundary crossings, implying that if the tunnels are wide enough a user is likely to move in an optimal straight diagonal path through the tunnels.



*(**a**) Cursor movement through tunnel shape 1 for all participant trials. Cursor mostly stays within the boundaries of the tunnel during the first three 90 degree turn, but cuts through the final turn of the top border in a straight diagonal line to get to the target.*



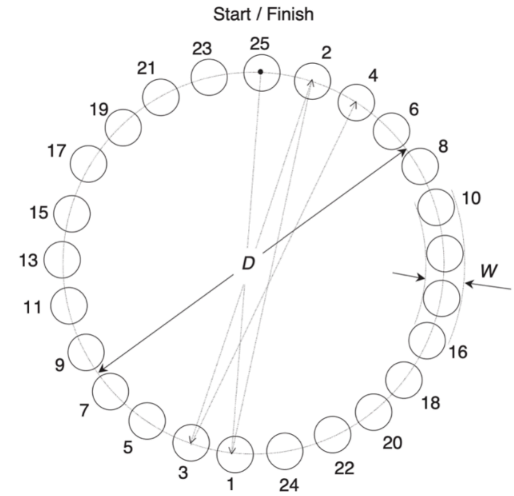
*(**b**) Cursor movement through tunnel shape 2 for participant 5. Cursor moves in a near straight line for all trials, but with a decreased number of boundary crossings indicating that for some of the trials, the participant may have gotten close to the optimal path (a straight diagonal line through the tunnel without crossing any of the boundaries).*

***Figure 11:** Plots of cursor movement through tunnels.*

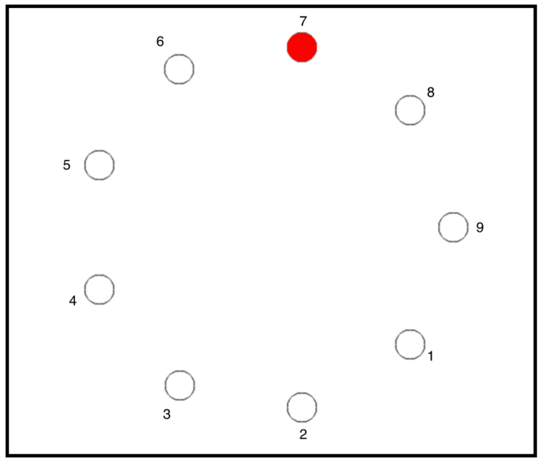
Test #6

The final test is derived from the multi-directional tapping task described in the ISO9241 standard, that is illustrated in Figure 11a. This test was repeated with 3 sets of amplitudes and target sizes.

Figure 12 shows the cursor movements for all participants for all trials when moving between targets 1 and 6 for all 3 variations. The red line indicates the ideal straight path between the centre of the two targets. The two circle-like shapes represent the targets themselves. For the smallest target size, the plots start and end very close to or on the red line, and near the centre of the targets. This is due the small target size, because of which the user is constrained by the target area and will click near the centre. As the target size gets larger, this behaviour deviates as the plots successively move away from the red line and the start and end of the motion gets further away from the centre of the targets. This is because as the target gets larger, the user has the freedom to click on a larger area to complete the motion. And so, they begin to click on the target at points further away from the centre.



(a) *Multidirectional tapping task described in ISO (2019) standard. The lines indicate the path followed using a pointing device, to alternating between targets clockwise around the circle. Path begins and ends in the top target.*



(b) *Multidirectional tapping task implementation in test suite. Subjects were required to use the mouse and move the cursor to click on the target, given by the red-circle that alternates and goes around in a clockwise direction. (Numbers indicate the target number (not target order) for later reference).*

Figure 11: *Multidirectional tapping task implementations*

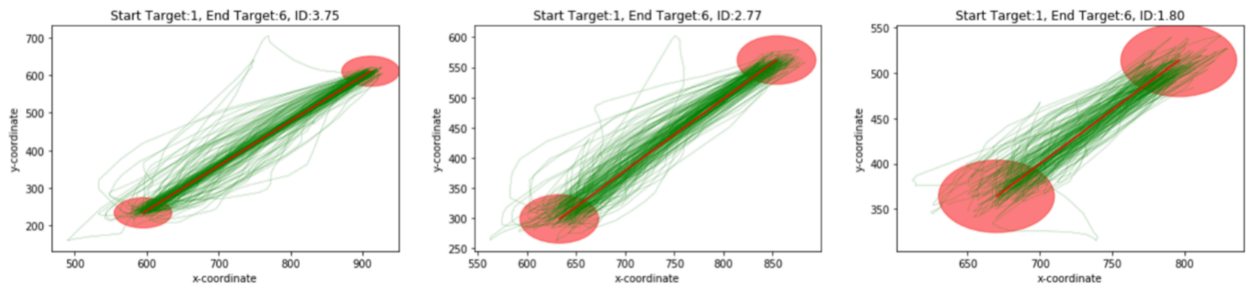


Figure 12: *Cursor movements for all participants for all trials when moving from target 1 to 6 for each target size. Lower circle is target 1 and upper circle is target 6. Red line indicates the ideal straight path between the centre of two targets. As the target size gets bigger, the plots successively start and end further away from the red line, indicating that the participants click further away from the target centre.*

Conclusion

Many of the behaviours observed from these tests have drastic implications when designing machine learning models for endpoint and motion dynamics prediction. For example in test #2, when it was observed that for certain trials, users were crossing through the distractors to get to the target for short distances, a machine learning model would need to be appropriately trained to adapt to such an anomaly to improve the accuracy and reliability of the model by not detecting the distractor as the endpoint. In the case of the tunnel tests (test #4 and #5), where users were crossing the tunnel boundaries to get to the target quicker, a model designed to predict endpoints in a menu system that comprised of moving through similar tunnels would need to be trained appropriately to adjust to the inaccuracies of the user but still be able to correctly predict their intent.

There is also the option of using this test suite with many different types of pointing apparatuses. For example, the results obtained by performing these tests using a touch pad or joystick would be much different than what was attained here. Conducting the experiments with an entirely different and more focused group of participants would also potentially yield different results. If the trials were conducted with people of old age or a group that suffers from hand tremors, the motion dynamics and behaviours would be much different. This data could then be used to train models to adapt to such users as well, thereby greatly increasing the ease and quality of interaction for them. Each test on its own can be analyzed in numerous different ways, and with more participant trials, this exact test-suite can be used to reveal much more interesting motion dynamics and user behaviours.