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MITRE Edge Table Pointing Device Evaluation

Introduction

The MITRE EdgeTable is software developed by MITRE's Edge team and RIT students (namely, Forrest Marvez and Lorin Peterson, among others, for use as an Interactive Tele-collaboration Multi-touch Table. The device was developed because MITRE collaborated using physical white-boards on tables with cameras pointed at them, each collaborator gathering around the table. This became a problem because one cannot remotely connect to a white-board, and when they networked the cameras to remote location because, the objects drawn or placed on one white board did not sync to the other whiteboard. Smart boards, because they synchronize the entire image much like a screen-sharing application, are not fast enough for telecollaboration and even lag out and perform badly when not networked.

The purpose of the Edge Table is to create an Interactive Tele-collaboration Multi-touch table that functions over the network, with a feature set defined for MITRE's collaborative users. Originally designed to be worked with a Kinect, the Kinect integration is not yet complete and users currently use non-multi-user devices such as mice, TUIOPad apps, Multi-touch screens and computers, and Mimio pens to use the Edge table. The software is a work in progress, but even if the Kinect integration is completed it is safe to assume that it won't be the final implementation as technology is always advancing, and a Microsoft Kinect or similar depth-tracking camera hardware may not always be readily available especially since this is going to be used "in the field" by the military and a physical table with a Kinect mounted on it may not be practical.

Question

The question we were trying to answer as part of this MITRE Edge Table pointing device evaluation is what would be the best device to use this software with. Several devices are available for the general consumer to point and click on a GUI interface such as the Edge table implements, and even more devices are available to the military, some of which we don't even know about. The most commonly available device is a mouse and keyboard, which comes with nearly every commercially available computer on the market that comes with accessories. Newer iMacs optionally come with an Apple Multi-touch trackpad. Smart phones and tablets have impressive market share, and there is an App that can control the Edge table available on both Android and iOS. Mimio pens are used by MITRE collaborators using current implementation of the Edge table. Wacom tablets (and other pen-based drawing tablets usually without screens) are used by designers and artists to draw on a screen, could they not also be used to draw on a whiteboard?

The Kinect Multi-touch table is not yet available or integrated with the table, but if it was, how would it stand up compared to existing devices? How many users could it support (where an existing whiteboard is only limited by its drawing area and the physical bodies of the users using it). Would there be a significant learning curve or awkwardness to be drawing with your finger, just like it is to play a first person shooter game with the Kinect using your fingers. Would it be accurate?

Direct-neural interfaces are not too far off from current technology, but they do not yet exist in a consumer-available form that can reliably control a GUI interface. If they were available, however, how effective would brain-tracking software be on a virtual whiteboard?

Methods

To evaluate the best pointing device to use the Edge table would be we were able to test a Dell Mouse, TUIOPad App on an iPad 2, and a Dell Multi-touch Computer. We were not able to test the Kinect Multi-touch Table because it is not yet working on a table with the Edge Table. We decided against an Apple Multi-touch Trackpad (it's not true multi-touch, it only recognizes

gestures), or a Wacom tablet (or similar pen-based tablet) because we had limited time to test participants and we wanted the test to last ten minutes or less. We were unable to test any direct neural interfaces as they do not yet readily exist in consumer available devices that interpret thoughts into computer-available actions but one wonders whether it would just become computer-mediated telepathy with such an implementation.

The order of devices was changed for each participant in a way that tested each of the possible combinations to ensure that the tasks did not become learned and that bias for the first item tested was accounted for. However, the order of the tasks was not changed. There was one subjective tasks and three objective tasks followed by a subjective user survey.

Each of the participants was read a script to ensure that our presentation of our evaluation was consistent.

Hello, and welcome to our pointing device evaluation test. Our intention is to determine which device is most accurate and comfortable.

Please wait while we prepare the software. We will do further setup via a remotely connected software. Please start when we say 'go'. We will count down from 3 each time.

Any Questions?

Then each of the participants was given more information about the evaluation as they proceeded. Once we set up the table (usually it was set up from the previous test) we described the order they would be testing the devices in and explained that we would take a screenshot of the Edge table and reset the software for the next task. Each task was only explained as they encountered it.

First you will write your name on the software outside of the testing area.

Then you will draw a straight line within these bounds.

Then draw a circle within these bounds.

Then draw a point within the bounds of every 2nd circle within this larger circle.

Due to software issues with the Dell Multi-touch monitor lagging out with a networked Edge table, we were unable to set up the tasks or screenshot the tasks remotely and had to briefly interrupt the user between tasks.

The first task, the "subjective symbolic data task" had each user write their own name and later the name "Forrest" in print (not cursive). This was to standardize the task as Forrest pointed out to us that each name would have different characters and lengths and may obscure our results. For all participants, time was divided by the number of characters to evenly measure people with different length names that was tested before this change, but this did not account for some letters taking more effort than others. Accuracy was determined by subjectively scoring

it on a scale of 1 to 3, with 1 being not legible and 3 being perfectly legible.

A handwritten name 'Josiah' in blue ink. The letters are clear and well-separated, with a horizontal line above the 'J'.

Figure 1 - Josiah writing his own name. This would be scored 3/3.

A handwritten name 'JARED' in black ink. The letters are heavily scribbled over with multiple overlapping lines, making them difficult to read.

Figure 2 - Jared writing his own name. This would be scored 2/3, ignoring the connected lines issue that the Edge Table had.

The next task they were given is the bar task. The object of this task was to draw a vertical line within the bounds of the blue boxes. Each box becomes gradually smaller, increasing the difficulty.

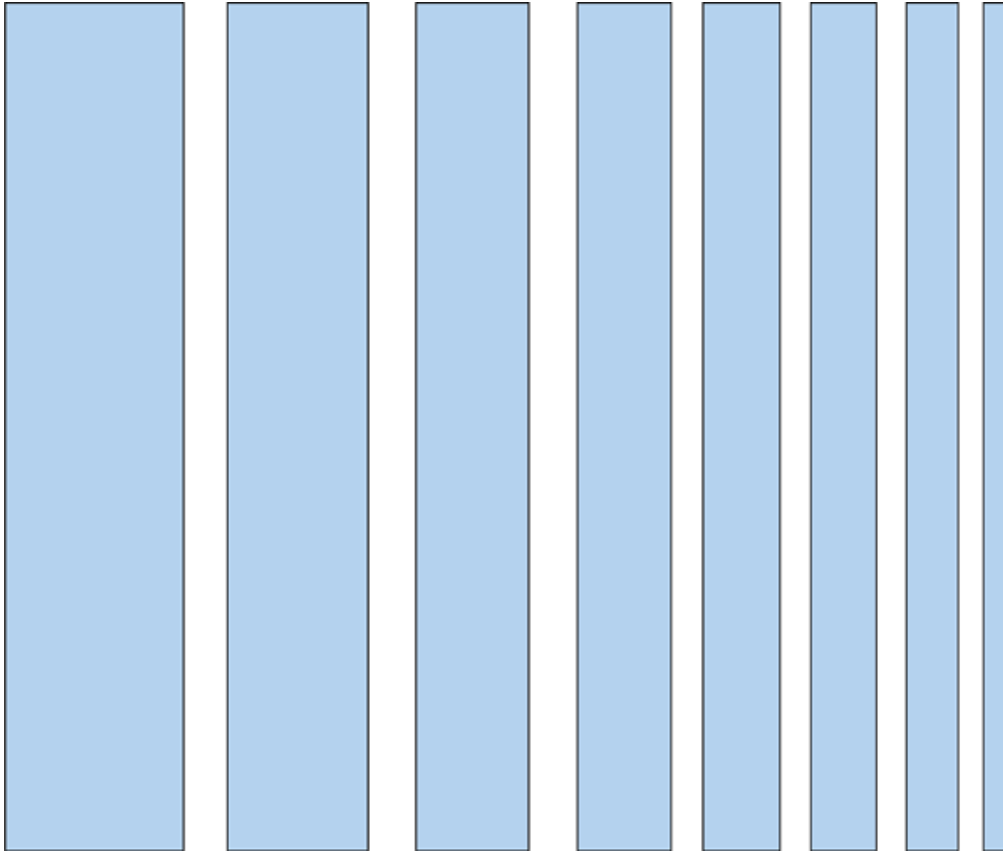


Figure 3a - The bar task

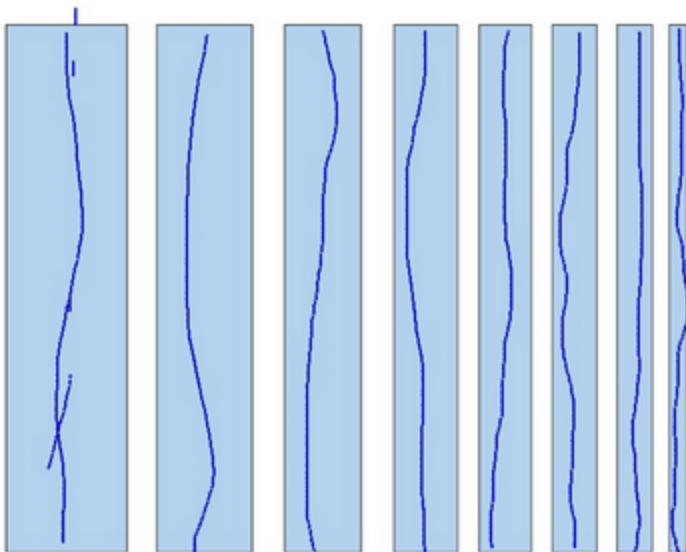


Figure 3b - A participant's bar task, completed with two errors.

The next task was to draw within the bounds of a blue circle.

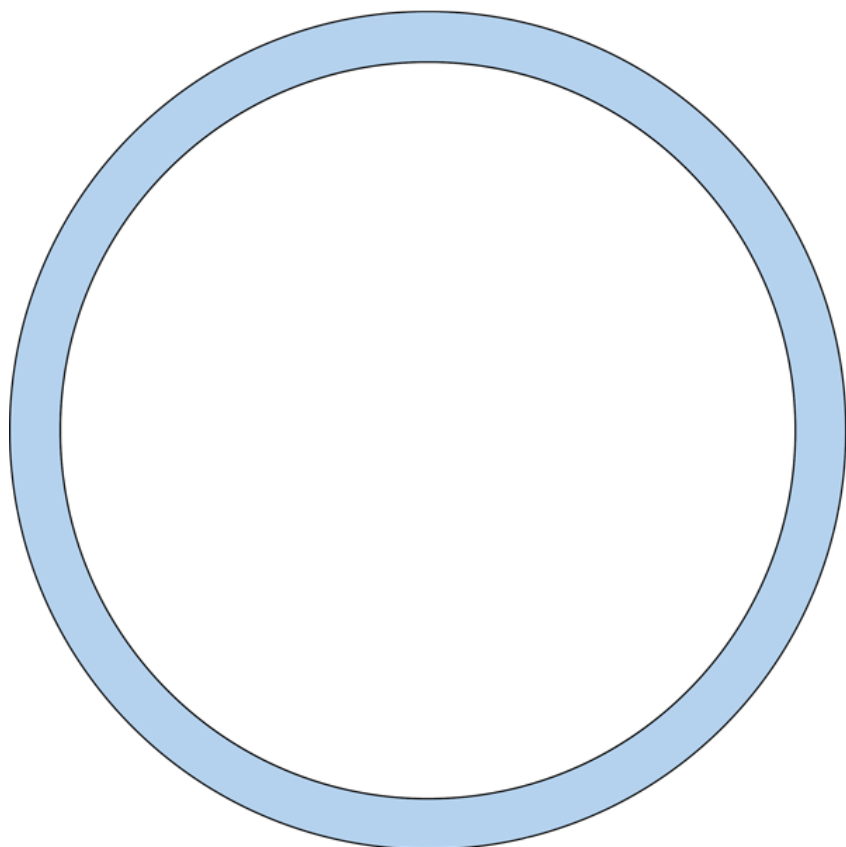


Figure 4A - The circle task

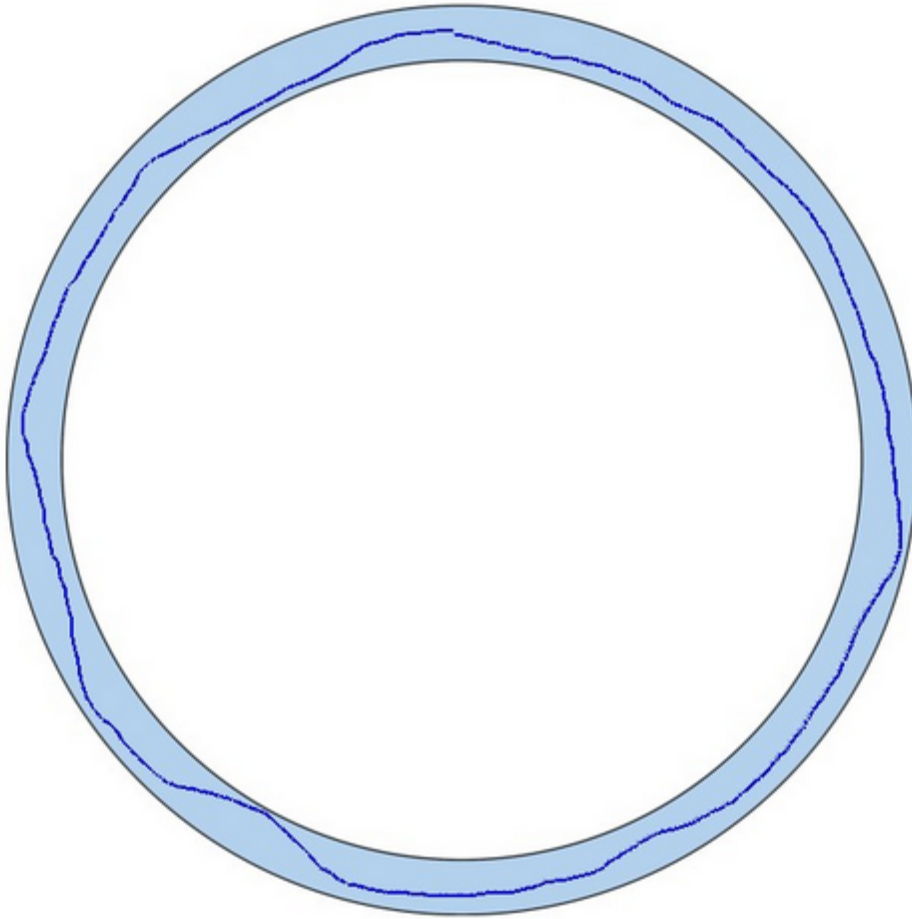


Figure 4B - A participant's circle task - completed with 0 errors.

The final task participants were given was to draw inside the bounds of every other white circle inside a larger blue circle. This was called the small circle task.

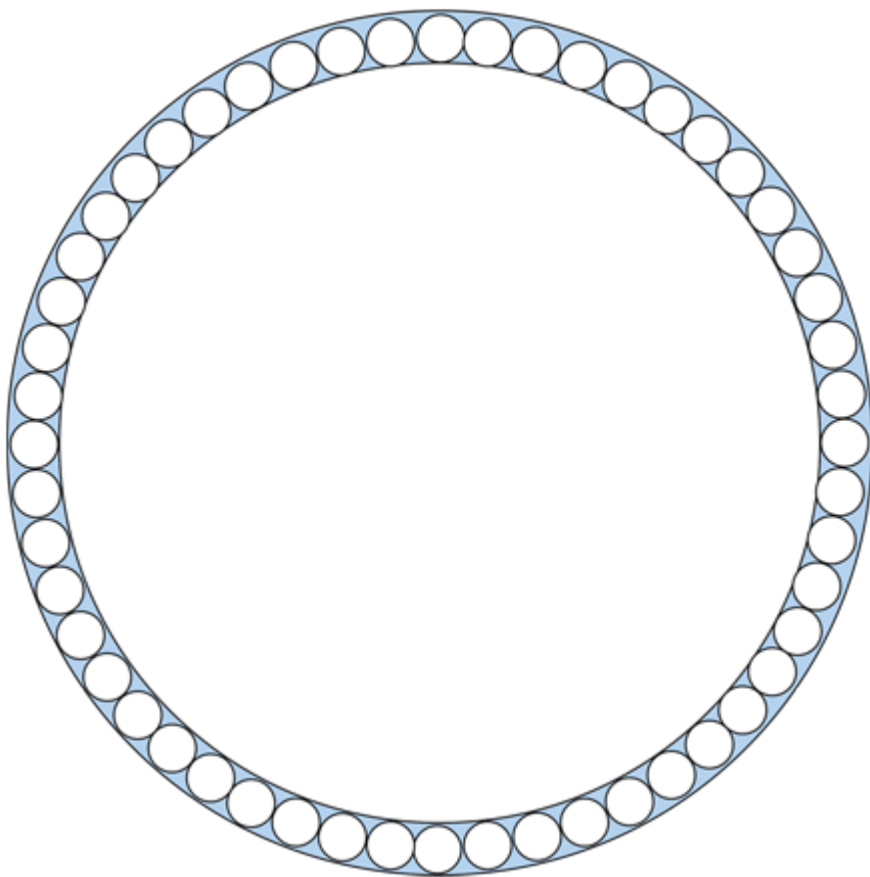


Figure 5A - The Small Circle Task.

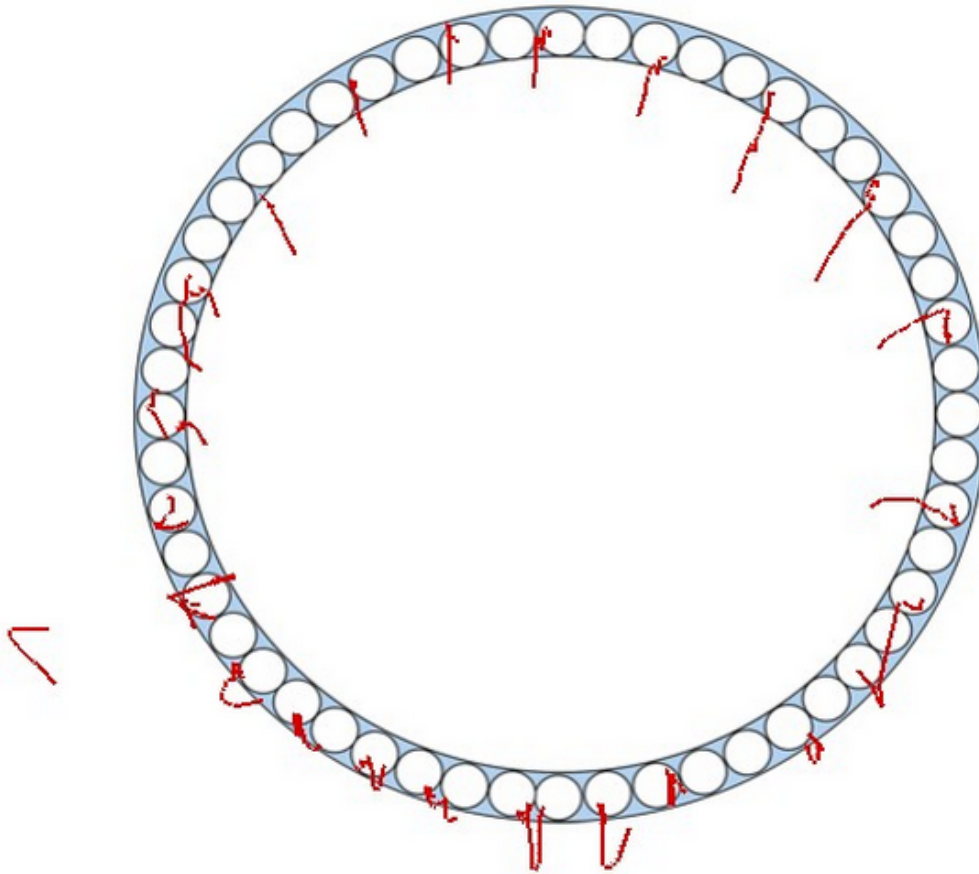


Figure 5B - A participant's circle task - the errors were too numerous to count and were counted as ten.

Participants were then each asked the following subjective questions:

1. "What device is the most comfortable?"
2. "What device is the easiest to use?"
3. "What device would you prefer to use for long periods of time?"
4. "What device is the most accurate and responsive?"

Results

We originally tested ten people, however, due to some issues with the test plan and the EdgeTable software itself, we had to completely throw out two of the results. We timed each task using the iPhone built in timer application and wrote each data point down in a Google document. We took screenshots to measure accuracy data at a later time, but we ended up forgetting to take several for two of the tests, so we ended up with eight data points for time data and six data points for accuracy data. Additionally, one person was tested with the older Edge Table software that had different TUIO functionality, one finger would move the cursor and two fingers would cause the EdgeTable to draw. This made it much easier to use, especially

the toolbars; however, the accuracy was diminished because the EdgeTable seemed to have trouble picking up which finger to use for drawing.

The time data shows that the fastest device is the Dell Multi-touch Computer. The mouse, however, did perform faster on the small circle task, but this was due to a software issue with either the computer or the EdgeTable that made it impossible to draw a point or tap with the computer, so users were forced to draw a small line instead -- we will discuss this issue more later.

The accuracy data shows that the most accurate device was the Dell mouse, despite its acceleration problems that some people complained about. The Multi-touch Computer closely followed it, mainly falling behind on the Small Circle task, again due to software issues that forced users to draw lines instead of points.

As you may recall, each participant was also asked four simple survey questions. They were asked what device was the most comfortable, what device was the easiest to use, what device they would prefer to use for long periods of time, and what device they thought was the most accurate and responsive. Overall, the mouse won in all four categories. Four people said it was the most comfortable, while only three people said the TUIOPad App on the iPad 2 was the most comfortable, and one person said the Multi-touch computer was the most comfortable. Four people said it was the easiest to use, while only one person said the TUIOPad app was and three people said they would prefer the Multi-touch computer for ease of use. Additionally, the mouse was also the preferred device for longer periods of time, with four people choosing the mouse, two people choosing the TUIOPad App, and two people choosing the Multi-touch Computer. Finally, six people chose the mouse as being the most accurate and responsive while only one person chose the TUIOPad App and one person chose the Multi-touch Computer.

Participants using the mouse took an average of 1.56 seconds per character on the subjective symbolic data task and had an average legibility score of 2.67 out of 3 points, being almost perfectly legible each time. They took an average of 27.16 seconds on the Vertical Bar task while making an average of 2.83 errors, and taking an average of 14.71 seconds on the Circle Task while making an average of 1.17 errors, and finally they took an average of 35.69 seconds on the Small Circle Task while making an average of 3.67 errors.

Using the Multi-touch Computer, participants took an average of 1.67 seconds on the subjective symbolic data task, but scored the worst legibility score -- granted, this was subjectively measured -- out of all three devices, an average of 1.67 out of 3. The participants, were however significantly faster, taking, on average, a mere 17.61 seconds on the vertical bar task while making an average of 2.33 errors, quickly executing the circle task in an average of 8.61 seconds while making an average of 1.17 errors, and finally performing the Small Circle task in an average of 42.46 seconds, still faster than the TUIOPad App but slower and less accurate than the mouse, making an average of 5.5 errors.

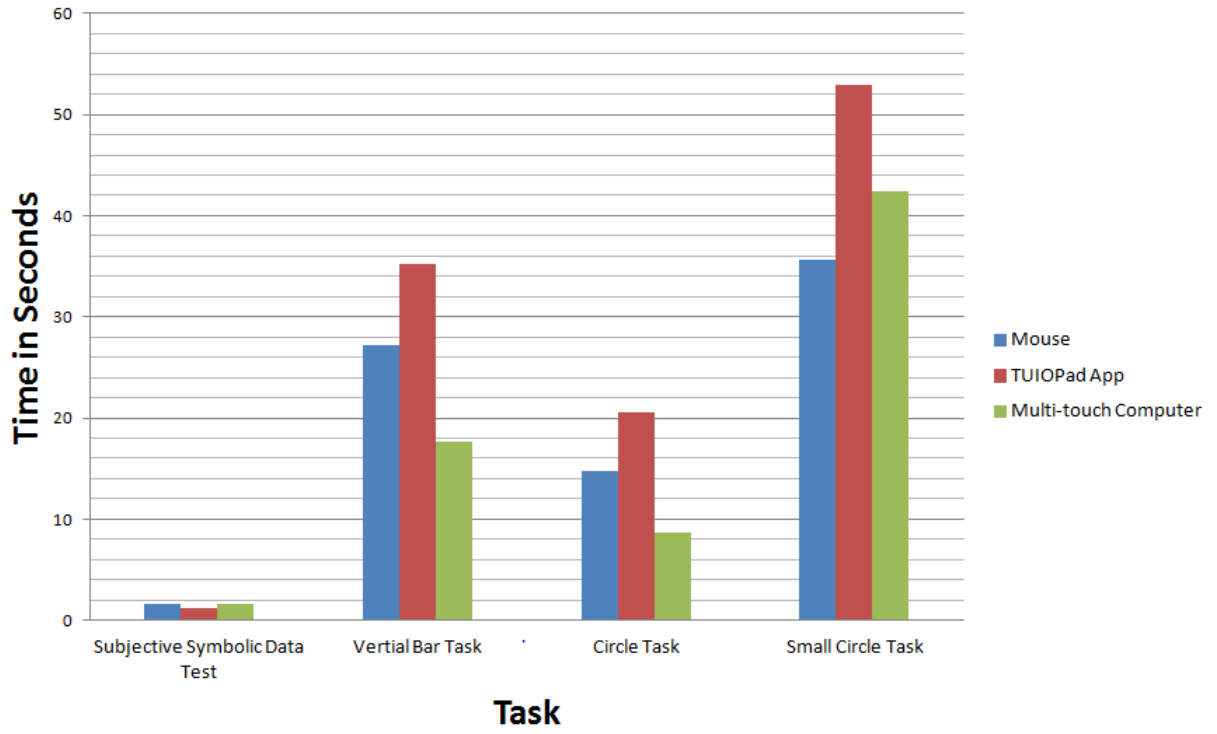
Using the TUIOPad App participants completed, on average, each of the tasks far slower and less accurately than each of the other devices. No one was definitively better with the TUIOPad App on a specific task than another device. The exception is the subjective symbolic data task, in which participants completed in an average of 1.18 seconds with an average legibility score of 2.5 out of 3 points in which they were faster than the mouse, but not more accurate. On average, participants took 35.26 seconds on the vertical bar task while making an average of 6 errors, took an average of 20.525 seconds on the circle task while making 2.33 errors, and finally took an average of 56.3 seconds on the small circle task and making an 7.83 errors on average.

It is to be noted that, using the TUIOPad App on the iPad 2 that many people made too many errors to count for the small circle task. It became impossible to tell what errors should be forgiven because they were positioning the cursor into a circle, what errors were caused by bugs in the software and what were “true” errors. Additionally, a few people were uncomfortable with the TUIOPad App and cheated on the small circle task by going in and out of each circle in a wave motion which made them faster but also technically less accurate.

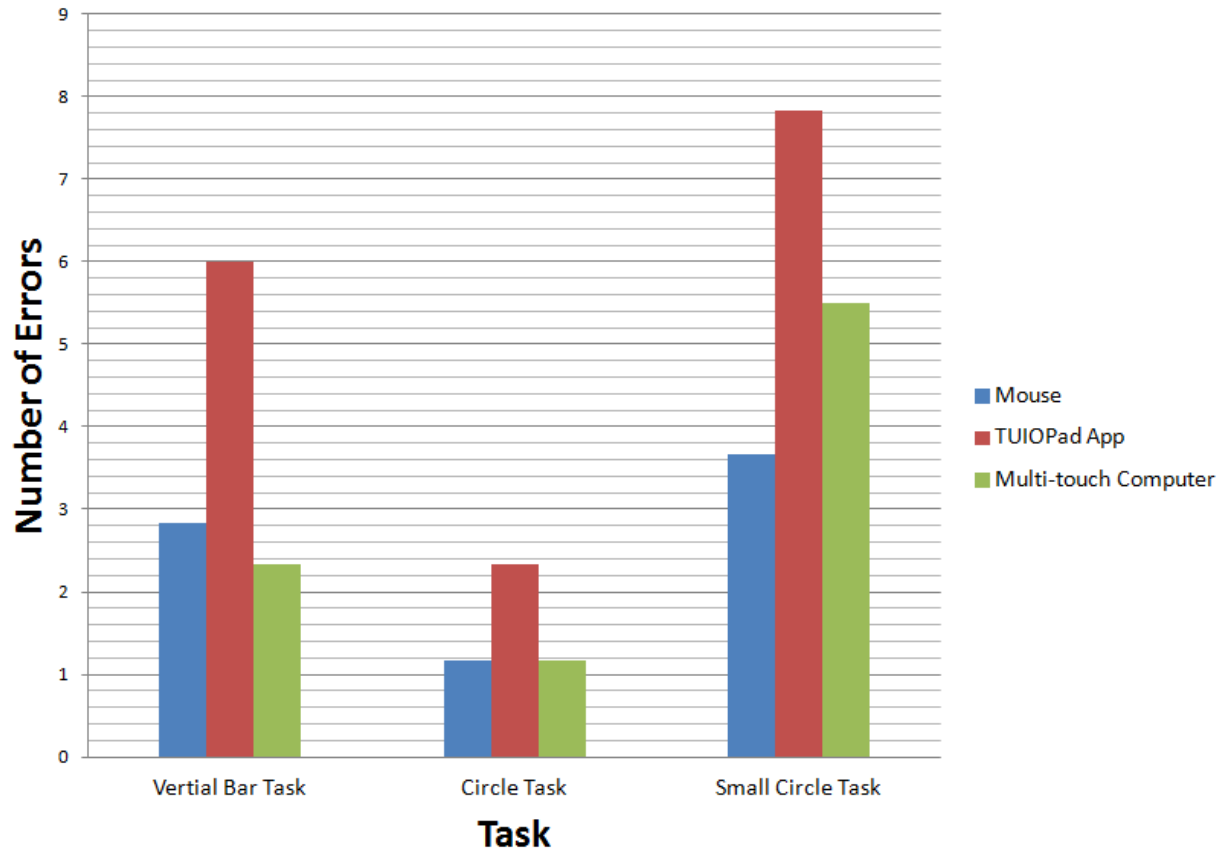
Overall, the best for the symbolic data, i.e., writing words, was the Mouse or the TUIOPad App. The Mouse was slightly more legible and the TUIOPad app was more accurate. The best for both the vertical line task as well as the circle task was the multi-touch computer, it was both the most accurate and the fastest. The mouse was both the most accurate and the fastest for the the small circle task. The fastest device was the multi-touch computer and the mouse was the most accurate device. The best overall is a cross between the mouse and the multi-touch computer, they each have their advantages.

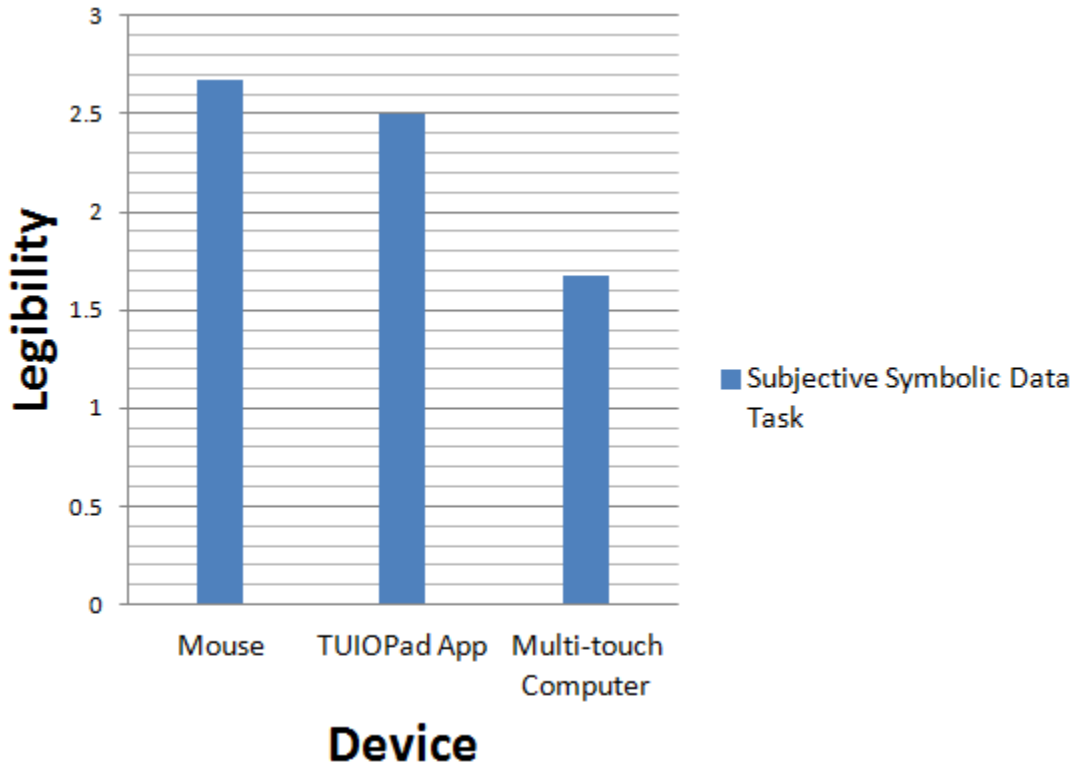
Overall, the TUIOPad app was the worst overall in terms of accuracy, speed and it's survey polling. This was probably due to three factors, one being “disassociated displays” as Forrest Marvez mentioned to me, as well as the fact that it is not a one-to-one ratio between the display and the Edge Table, and finally the iPad 2 does not have a hardware hover state, so it was impossible to the user to position the cursor without drawing.

Results - Time



Results - Accuracy





Conclusion

The technology we tested our devices on was a moving target for this experiment. The first three tests (we threw the first two out) used the old TUIO functionality that we discussed before. The first two also suffered from a crippling software issue that prevented library objects from syncing properly on the stage due to an issue with the newly implemented layers system. Additionally, it made it impossible to screen capture library objects, which we used for the the three objective tasks, and we did not realize this until after we attempted to analyze the screenshots to obtain accuracy data for the second participant. Luckily these two issues were fixed. However, TUIO functionality was changed to use one finger to draw on our third participant and all other participants, and while this made writing symbolic content (text) on the table more accurate, it made it impossible to position the cursor without first drawing, which caused the other tasks to be significantly more difficult. We chose to keep one of the datasets from the old TUIO functionality and average it in, but the rest were thrown out, mostly due to other issues like their screenshots not being saved and their time data not being recorded due to human error. Our testing was probably more effective at finding bugs and issues with the software rather than finding which devices would be optimal to use the software with.

Some of the problems and issues we experienced included Edge Table software issues: such as it not being truly ready for multi-touch devices, connecting line issue, and software not building or running issues; the former two were fixed after we finished testing, and the later one was human error (partially the fault of visual studio not getting the latest files correctly and partially the fault of forgetting to install Visual C++ 2008 runtime). Additionally, their was

significant lag on RIT's WiFi and the computer was too slow to be networked. We were originally planning to set up the tasks via a remotely connected Edge Table that would drag the library objects used for the tasks over. The Multi-touch Computer driver's or the Edge Table's handling of the Multi-touch computer (it's not certain which) could use improvement. Participants were forced to draw a line instead a of point on the small circle task and could not "tap" the toolbars. The small circle task was nearly impossible to use without a mouse and some people using the TUIOPad app did not perform optimally.

While the survey results showed the mouse as the best device overall, statistically speaking the multi-touch computer was the best overall in terms of accuracy and speed, despite the table issues. The mouse was still accurate (sometimes more than the Multi-touch computer on some tasks) and closely followed the multi-touch monitor. While the the multi-touch computer was also the fastest, it was still significantly difficult to "tap" the toolbar" or points on the Circle Task.

The TUIOPad App was fun, spiffy, exciting and awesome but also the most useless, inaccurate and time-consuming device. It was impossible to position the cursor without drawing, and it was impossible to use the toolbar. The screen did not show the status of the table, it was loosely coupled, or as Forrest would say "disassociated displays." It was also not a one-to-one positioning ratio. It was impossible to reach the far right side of the screen, so the tasks were designed in mind of that issue. Getting into the test zone for most the tests required an error, and we tried our best not to count these as errors.

It is indeed true that all of our test participants were more used to using the mouse, but that's true for most of the population. We were not able to test on young children that have not been exposed to human-computer input devices, but that might have changed our results. But if there is a learning curve over existing popular devices, perhaps it is better to stick with the trusted, time-tested device if the other devices are not a remarkable improvement. The keyboard and mouse are here to stay for the next ten years or perhaps more.

Discussion

Testing the different devices brought some interesting questions and concerns for future development.

One potential issue relates to the multi-touch computer. Assuming the inability point issue would be fixed by updated Edge table software or updated drivers from Dell, would it be usable for long periods of time? How long is the usual Edge table session? We didn't test it for long periods of time. It is likely that you would become fatigued using the monitor given that your arm is above or at your center of gravity, much more than say, a mouse.

Another issue is the large variety of computer mice and computer mouse settings available to the user. The mouse we tested (it came with the multi-touch computer) had a tad bit high acceleration according to our test subject's comments and complaints. Perhaps if each

user choose a mouse from a selection of mice or perhaps brought their own mouse, this would be mitigated.

The bugs we experienced were fixed or resolved. But what bugs or technical issues will there be in the future? How will these bugs affect future testing of usability, pointing device evaluation, or other testing of the Edge table software? For instance, one bug with the Edge table we had was it would sometimes connect lines drawn with the TUIOPad App together, making it difficult to judge errors versus buggy software

Additionally, the computer we used was unable to handle a networked Edge table. The table completely lagged out when we did do remotely controlled evaluations and it started to skew the test results because the display and TUIO input. Consequentially, we had to disconnect the Edge table from the remote table that we were using to control the tasks. How fast of a computer will it take to run the software? How fast and stable of a network connection will it require to effectively use an Edge table? Being military technology, will this be used "in the field" where equipment can be more limited in terms of network connectivity (and, perhaps, less computationally powerful since it has to meet Department of Defense specs for ruggedness)? And finally, will it be behind a Virtual Private Network (VPN), thus slowing down the connection because it has to be encrypted?

All in all, we hope that our research is useful for future development of the MITRE Edge Table.

Appendix:

Here is the raw data we collected for the tests:

We did not save our data from the first two tests. They were used to develop the test and they had too many technical issues to properly record data.

Participant #1:

Order: Mouse, Multitouch Monitor, TUIO Pad

Time (in seconds)

	Subjective Symbolic Task	Vertical Bar Task	Circle Task	Small Circle Task
Mouse	18.6 / 6 characters	35.2	9.3	33.4
Multitouch Monitor	11.6 / 6 characters	17.8	6.6	55.2
TUIO Pad (OLD Version)	6.3 / 6 characters	45.8	13.1	79

Accuracy

	Subjective Symbolic Task*	Vertical Bar Task (# Errors)	Circle Task (# Errors)	Small Circle Task (# Errors)
Mouse	3/3	1	0	0
Multitouch Monitor	2/3	0	0	2
TUIO Pad (OLD Version)	2/3	0	3	4

* Scale of 3, where 1 is completely illegible and 3 is perfectly legible

What device is the most comfortable? TUIO

What device is the easiest to use? TUIO

What device would you prefer to use for long periods? TUIO

What device is the most accurate and responsive? Touchscreen

Participant #2

Order: TUIO Pad, Mouse, Multitouch Monitor

Time (in seconds)

	Subjective Symbolic Task	Vertical Bar Task	Circle Task	Small Circle Task
TUIO Pad	7.1 / 5 characters	26.3	40	54.5
Mouse	11.1 / 5 characters	13.2	8.3	30
Multitouch Monitor	10.6 / 5 characters	10.6	9.3	59.6

Accuracy

	Subjective Symbolic Task*	Vertical Bar Task (# Errors)	Circle Task (# Errors)	Small Circle Task (# Errors)
Mouse	MISSING	MISSING	MISSING	MISSING
Multitouch Monitor	MISSING	MISSING	MISSING	MISSING
TUIO Pad	MISSING	MISSING	MISSING	MISSING

* Scale of 3, where 1 is completely illegible and 3 is perfectly legible

What device is the most comfortable? TUIO

What device is the easiest to use? Mouse

What device would you prefer to use for long periods? TUIO

What device is the most accurate and responsive? Mouse

Participant #3

Order: TUIO Pad, Multitouch Monitor, Mouse

Time (in seconds)

	Subjective Symbolic Task	Vertical Bar Task	Circle Task	Small Circle Task
Mouse	6.0 / 6 characters	33.7	7.0	34.8
TUIO Pad	7.0, 6 characters	19.5	19.1	46.9

Multitouch Monitor	9.7, 6 characters	25.7	11.7	35.3
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Accuracy

	Subjective Symbolic Task*	Vertical Bar Task (# Errors)	Circle Task (# Errors)	Small Circle Task (# Errors)
Mouse	3/3, 6 characters	0	0	0
TUIO Pad	2/3, 6 characters	10 errors	0 errors	3 errors
Multitouch Monitor	2/3, 6 characters	0	1	1

* Scale of 3, where 1 is completely illegible and 3 is perfectly legible

What device is the most comfortable? Mouse

What device is the easiest to use? Mouse

What device would you prefer to use for long periods? Mouse

What device is the most accurate and responsive? Mouse

Participant #4

Order: Multitouch Monitor, Mouse, TUIO Pad

Time (in seconds)

	Subjective Symbolic Task	Vertical Bar Task	Circle Task	Small Circle Task
Mouse	5.4, 7 characters	13.6	5.5	18.2
TUIO Pad	8.5	15.1	4.8	23.1
Multitouch Monitor	8.8	10.9	3.3	21.1

Accuracy

	Subjective Symbolic Task*	Vertical Bar Task (# Errors)	Circle Task (# Errors)	Small Circle Task (# Errors)
Mouse	2/3	3	2	10+
TUIO Pad	2/3	9	5	10+

Multitouch Monitor	3/3	0	1	3
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* Scale of 3, where 1 is completely illegible and 3 is perfectly legible

What device is the most comfortable? Tuio

What device is the easiest to use? Mouse

What device would you prefer to use for long periods? Mouse

What device is the most accurate and responsive? Mouse

Participant #5

Order: Multitouch Monitor, TUIO Pad, Mouse

Time (in seconds)

	Subjective Symbolic Task	Vertical Bar Task	Circle Task	Small Circle Task
Mouse	9.0, 7 characters	28.6	15.6	48.6
TUIO Pad	12.8	41.6	23.0	67.3
Multitouch Monitor	12.0	24.0	13.5	52.0

Accuracy

	Subjective Symbolic Task*	Vertical Bar Task (# Errors)	Circle Task (# Errors)	Small Circle Task (# Errors)
Mouse	MISSING	MISSING	MISSING	MISSING
TUIO Pad	MISSING	MISSING	MISSING	MISSING
Multitouch Monitor	MISSING	MISSING	MISSING	MISSING

* Scale of 3, where 1 is completely illegible and 3 is perfectly legible

What device is the most comfortable? Mouse

What device is the easiest to use? Screen

What device would you prefer to use for long periods? Screen if it gave me feedback on the cursor position

What device is the most accurate and responsive? Touch Pad

“You know where you’re your going to draw before your draw it”

“Getting into the zone required an error - don’t count the entry step when counting errors”

Participant #6

Order: Mouse, TUIO Pad, Multitouch Monitor

Time (in seconds)

	Subjective Symbolic Task	Vertical Bar Task	Circle Task	Small Circle Task
Mouse	12.9, 7 characters	39.8	16.4	37.8
TUIO Pad	5.9	56.0	28.7	58.1
Multitouch Monitor	11.6	14.8	7.2	52.8

Accuracy

	Subjective Symbolic Task*	Vertical Bar Task (# Errors)	Circle Task (# Errors)	Small Circle Task (# Errors)
Mouse	2/3	2	1	1
TUIO Pad	3/3	7	3	10+
Multitouch Monitor	1/3	4	1	10+

* Scale of 3, where 1 is completely illegible and 3 is perfectly legible

What device is the most comfortable? Mouse

What device is the easiest to use? Screen

What device would you prefer to use for long periods? Touchscreen

What device is the most accurate and responsive? Mouse

Participant #7

Order: Mouse, Multitouch Monitor, TUIO Pad

Time (in seconds)

	Subjective Symbolic Task	Vertical Bar Task	Circle Task	Small Circle Task
Mouse	7.7, 7 characters	25.5	11.0	24.6
TUIO Pad	4.8 Missing r's, 5	20.7	13.5	33.1

	characters			
Multitouch Monitor	6.4	9.4	5.7	26.1

Accuracy

	Subjective Symbolic Task*	Vertical Bar Task (# Errors)	Circle Task (# Errors)	Small Circle Task (# Errors)
Mouse	3/3	1	4	2
TUIO Pad	3/3	7	1	10+
Multitouch Monitor	1/3	10	3	10+

* Scale of 3, where 1 is completely illegible and 3 is perfectly legible

What device is the most comfortable? Touchscreen

What device is the easiest to use? Screen

What device would you prefer to use for long periods? Mouse

What device is the most accurate and responsive? Mouse

Participant #8

Order: TUIO Pad, Mouse, Multitouch Monitor,

Time (in seconds)

	Subjective Symbolic Task	Vertical Bar Task	Circle Task	Small Circle Task
Mouse	8.1, 7 characters	27.7	12.9	33.6
TUIO Pad	6.0 - 6 characters	57.1	22	61.4
Multitouch Monitor	15.1, 7 characters	27.7	11.6	37.6

Accuracy

	Subjective Symbolic Task*	Vertical Bar Task (# Errors)	Circle Task (# Errors)	Small Circle Task (# Errors)
Mouse	3/3	0	0	9

TUIO Pad	3/3	3	2	10+
Multitouch Monitor	1/3	0	1	7

* Scale of 3, where 1 is completely illegible and 3 is perfectly legible

What device is the most comfortable? Mouse

What device is the easiest to use? Mouse

What device would you prefer to use for long periods? Mouse

What device is the most accurate and responsive? Mouse