Multi-aspect Evaluation Method for Digital Pointing Devices

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Abstract: For decades the computer mouse has been used as the most common input device for laptops and computers alike. However for speeches a presentation remote with a laser pointer was used because they allowed the presenter more freedom. With the emergence of small and lightweight inertial sensors, a new type of presentation remotes becomes popular. These remotes use inertial sensors to move a digital pointer allowing presenters to show things on more than one screen or use enhancement methods like highlighting a region. Using inertial sensors however proves to be a difficult task and can lead to problems with the usability of such devices. When developing such systems, the designer faces the problem that no method for quantifying the usability of pointing devices based on inertial sensors is available. In the paper at hand, we propose an evaluation method consisting of three different tests to assess the manageability, speed and precision of digital pointing devices for a measurable comparison. Additionally, we conducted an evaluation to show that our tests reflect the subjective assessment from the users. Our quantitative test results showed a strong correlation to the qualitative subjective assessment from the users.

1 INTRODUCTION

The usage of Digital Pointing Devices (DPD) for presentations has many advantages compared to traditional devices like e.g. laser pointer. Especially when a presentation is shown on multiple screens simultaneously, the usage of a digital pointer has a huge benefit because the presenter can point on all screens at the same time and does not have to turn around to look at the screen to point at it. In addition it allows the presenter to utilize a number of digital enhancement methods during the presentation like highlighting a certain region of the presentation slides or doing annotations during the presentation. The usage of a DPD however is limited by the accuracy in sensing its movement. Additionally, the sensitivity and movement profile of the device have an influence on its usability. Ideally the usage of a digital pointing device should be as intuitive as using a laser pointer. The usability of such a DPD is the main objective in its design and needs a lot of attention and fine tuning during its development to be suitable for a wide user base.

In (MacKenzie and Jusoh, 2001) it is shown that these devices are often far away from the usability of a standard computer mouse and improvements need a lot of attention to bring them to the same level of usability. It is, however, not easy to determine the usability of such a device as there are multiple aspects that have to be considered at the same time. First of all the subjective assessment of the user about the performance is of great importance. Second, the DPD should allow the user to be able to precisely point at a target on the screen and also be able to quickly move between multiple targets to allow for a fluent presentation. However, no comprehensible and accurate evaluation method to assess the performance and usability of DPDs is available today.

This paper, proposes the multi-aspect evaluation method to asses and compare different DPD implementations. Our evaluation method consists of three separate tests that evaluate different aspects of the device: The first test evaluates the responsiveness, which we see as the ability to move the pointer directly between two objects on the screen. The second test evaluates how fast a user can move the pointer between objects on the screen. The third test evaluates how precise the pointer can be moved along lines or shapes. To evaluate our testing approaches, we conducted tests for four pointing devices with multiple participants and compared the measured results from the tests against each other and against the subjective assessment from the testers.

The remainder of paper is structured as follows: In Section 2, this paper discusses other publications dealing with the assessment of the usability of digital

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pointing devices in general. Afterwards in Section 3, we explain which criteria were used for the evaluation methods and describe the three tests which were developed to cover said criteria. In the following Section 4, an evaluation of the proposed methods is done using 160 measurements from multiple participants. Finally, Section 5 concludes this paper and gives a short outlook for future development.

2 RELATED WORK

In the past there have been many studies about the usability of digital Human Interface Devices (HIDs). The performance evaluation shown in (Batra et al., 1998) examines the usability of different built-in input devices for laptops, namely trackballs, stick points and touch pads. Said research tested three common tasks performed on a computer normally performed with a computer mouse and used the needed time, click errors and click accuracy. An assessment of the ergonomics of the used input devices was also conducted. The results however were meant to compare the usability of the devices and allow to compare subjective user experience with the measured results.

The International Organization for Standardization (ISO) released a norm to assess the usability of digital input device (ISO, 2007). However, as revealed in (Douglas et al., 1999) this standard does not allow a direct correlation between the measured performance and the user experience. To see how well such a pointing device will be accepted by potential users our approach seeks to create a direct correlation between measured performance and user experience.

Another work that seeks to examine the performance of input devices is (MacKenzie et al., 2001), which also derives multiple measurable aspects of the devices to evaluate their performance. The focus of this work however is on devices used for common office tasks on a computer and measures how fast and efficient certain tasks can be done. It does not consider the assessment of the users on how usable and comfortable the devices are.

3 TEST METHODS

For the evaluation of digital pointing devices, the first important step was to identify which properties can be used for an objective assessment and comparison. Three major properties were found:

Manageability. The manageability describes how well a device can be handled by the user to execute simple and common actions. For example how easy it is for a user to move from one place on the screen to another.

Responsiveness & Speed. The responsiveness and speed is a factor for how fast a user is able to conduct simple and common actions. In particular the responsiveness describes how fast or sluggish the device reacts to the user input and the speed describes how fast the user is able to move the pointer.

Precision & Stability. The precision and stability properties describe how well a user can conduct more complex actions. This can be for example highlighting a certain small object on the screen, write a note or move along a complex shape.

For the evaluation of the digital pointing devices, three tests were designed, where each evaluates one of the three properties mentioned above. The first test, called the 'Pointing Test' evaluates the manageability. In particular, it assesses how well a user can move the pointer from one place of the screen to another place. The second test evaluates the speed and responsiveness. It is measured how fast a user can move the pointer between different places on the screen. The last test evaluates the precision and stability of the pointing device. It measures how well a user can trace the shape of different objects with the help of the digital pointing device.

3.1 Pointing Test

The *Pointing Test* was designed to evaluate manageability of the pointing device. It tests how well the user is able to move directly between points on the screen. At the beginning, the user has to move the pointer to the first point on the screen. When the first point is reached, a second point appears after a short time to which the user has to move in a direct path. After reaching that point, the next point becomes visible and the user has to move to the new point. The user has to stay with the pointer in the current point for at least two seconds before the new point appears to evaluate that it is possible to reach a target point and also stay there. This procedure is repeated multiple times.

In the GUI the current point is drawn in blue while the point to move to is drawn in red. The test finishes after the user has traversed a number of points that was defined prior to the start of the test.

The score for the evaluation in the *Pointing Test* is calculated via the relation between optimal (minimal) distance between the points and the actually moved distance in pixels. A shorter distance traveled with the pointer results in a higher score. Equation 1 shows how the score for the traveled distance is calculated.

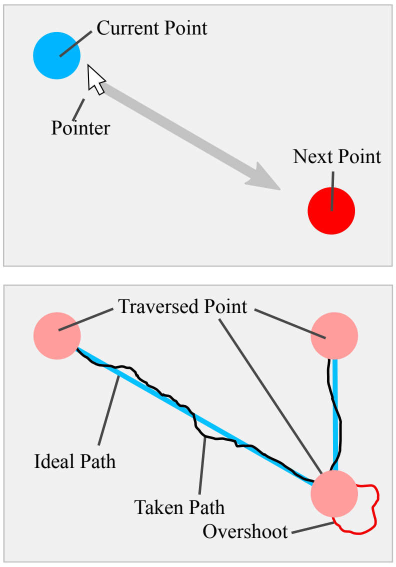

Figure 1: Top: Interface of *Pointing Test* and *Speed Test*. Bottom: Results from *Pointing Test* and *Speed Test*.

$$score_{dist} = \frac{\alpha_{dist} \cdot dist_{min} + (1-\alpha_{dist}) \cdot (dist_{min} - dist_{traveled})}{\alpha_{dist} * dist_{min}} \quad (1)$$

The score $score_{dist}$ for the distance is calculated as the ratio between the minimal distance $dist_{min}$ and the traveled distance $dist_{traveled}$. The difference between minimal distance and traveled distance is weighted by α_{dist} to allow for a suitable scaling of the score. Without the weighting the score would reach zero when the traveled distance is at least twice as long as the minimal distance. This scenario however is very unlikely and initial tests with multiple devices showed a way shorter traveled distance even for the worst devices. Based on the initial measurements with the test we chose an α_{dist} of 0.25, so the score will reach zero when the traveled distance is $33.\overline{3}\%$ higher than the minimal distance. Said factor was chosen empirically to allow for a better scaling of the score for the traveled distance.

In addition to the traveled distance, also an overshoot distance is used for the score to respect the fact that the user might move past the target point while trying to reach it. An overshoot can be seen at the bottom of Figure 1. The red line is the traveled path from the pointer after the user reached the target point but did not start to move to the next point. This so-called overshoot might happen if the device reacts too slow to the user input or is not well manageable. The score for the overshoot is calculated in Equation 2.

$$score_{overshoot} = \frac{dist_{min} - (\alpha_{overshoot} \cdot dist_{overshoot})}{dist_{min}} \quad (2)$$

A higher overshoot will result in a lower score as it shows that the device does not allow the user to stay in the reached location. The overshoot is calculated by the ratio between the minimal distance that can be traveled $dist_{min}$ and the traveled distance from the overshoot $dist_{overshoot}$ weighted by $\alpha_{overshoot}$. Based on initial tests, the factor $\alpha_{overshoot}$ is also set to 0.25 to allow for a better scaling of the range from the score because it is very unlikely that the overshoot distance ever reaches the actual distance the user has to travel.

We use the minimal distance for all scores as a factor to allow for a consistent evaluation across multiple screens with different resolutions. Using a fixed value for the evaluation would result in different results depending on the screen size and resolution as shown in (Oehl et al., 2007). Additionally the tests were conducted on a huge screen to reflect the common use case. The overall score $score_{pointing}$ for the *Pointing Test* is calculated by Equation 3.

$$score_{pointing} = score_{dist} \cdot score_{overshoot} \quad (3)$$

The values for $score_{dist}$ and $score_{overshoot}$ are clamped to not be below 0 before the calculation. A score higher than 1 should not be possible.

3.2 Speed Test

The composition of the *Speed Test* is similar to the composition of the *Pointing Test*. Again the user has to move to the first point and to all subsequent points like in the *Pointing Test*. However, the *Speed Test* evaluates how fast a user can move between multiple points using the digital pointing device. Therefore the test participants do not have to move in a direct line between the points but try to reach as many points possible in a given time frame.

The test only considers the time the user spends moving between the points on the screen and does not count the time the user stays at a point. This should prevent that the reaction time from the user influences the test result when the points are placed at random locations on the screen.

The score for the *Speed Test* is calculated by the relation between available time and reached points. The Equation for the score calculation can be seen in Equation 4.

$$score_{speed} = \frac{num_{points} \cdot \beta \cdot f_{distance}}{time} \quad (4)$$

The *time* is the overall time for the test in milliseconds. The factor β is used to weight the number of points against the time, so that it can be set how many points have to be reached per second to get the highest score. Based on initial test we chose a factor of $\beta = 500$ for two points per second. The factor $f_{distance}$ plays an important role for the repeatability and accuracy of the speed test. The speed test is designed that the points are placed at random locations on the screen to prevent a habituation effect of the tester. However, the random placement of the points causes the overall distance the tester has to travel to vary between each test. For example, in the first test all points are placed relatively close to each other and the tester manages to reach eight points. In the second test, the points are very far away from each other and the tester only reached four points and gets a worse score although the traveled distance might be actually bigger than in the first test. The $f_{distance}$ is a weighting factor used to incorporate the distance that is traveled and is calculated by Equation 5.

$$f_{distance} = \sqrt{\frac{dist_{traveled}}{num_{points} \cdot dist_{average}}} \tag{5}$$

The $dist_{average}$ is the average distance between all possible points on the screen and can be calculated at the beginning of the test. Using this factor the score is increased when the average distance traveled $dist_{traveled}$ between the points is longer than the expected average distance and decreased when the traveled distance is shorter. We chose to use the square root of the ratio from traveled and expected distance to consider the fact that a higher distance between points also allows the user to move the pointer faster. The number of reached points is num_{points}.

3.3 Precision Test

The purpose of the *Precision Test* is to evaluate the precision and stability of the digital pointing device. A precise movement is important to be able to point at small objects or interact with the content on the screen, like drawing a shape or highlighting an object.

For the *Precision Test* the tester has to move the pointer along the edge of multiple shapes to trace them. The difference between the drawn shape from the pointer and the real shape is used to calculate the score for the pointing device. The interface of the *Precision Test* can be seen in Figure 2.

For the *Precision Test* three shapes have to be traced with the pointer: The red and blue points are used as information for the user to show the progress and to ensure that the user really traces the shape.

Square. With the square it can be tested how well the pointing device allows a user to move precisely in vertical and horizontal directions.

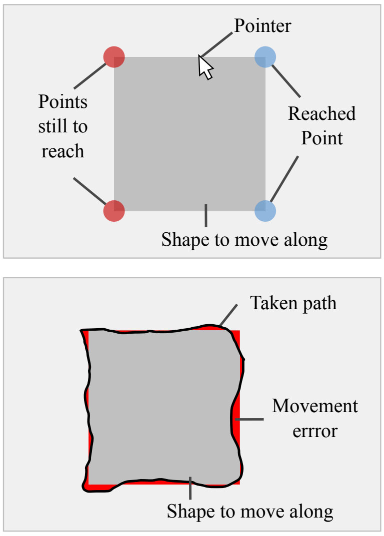

Figure 2: Interface of the *Precision Test* during the test. Bottom: Interface with the results. The red area is the movement error.

Triangle. The triangle is used to evaluate how well the pointing device allows a user to move diagonally between elements on the screen or draw diagonal lines.

Circle. With the circle the test can evaluate how well a user can move along curved edges or draw curved shapes.

With the three shapes different aspects and characteristics of the digital pointing device can be evaluated. The first part for the score of the *Precision Test* is calculated with the Equations 6 and 7.

$$dist_{avg} = \frac{\sum_{n=0}^{N} distanceShape_n}{N} \tag{6}$$

Here $distanceShape_n$ is the shortest distance between the n^{th} pointer position and the edge of the shape. N is the number of sample points captured during the test.

$$score_{shape} = 1 - \frac{\gamma \cdot dist_{avg}}{shapeCircumference} \tag{7}$$

The average distance between the shape and the traversed path it multiplied by the factor of γ to allow for a better scaling of the score $score_{shape}$ and was determined empirically to be 25. The circumference of the shapes is $shapeCircumference$.

In addition to the precision determined by the distance between the shape and the traversed path, it is also important to evaluate the stability of the pointer. Therefore a second score was added to the *Precision Test* which uses the sum of all angles of the traversed path to compare it with the optimal angle. For all shapes the optimal angle for a movement would be

360°. However an unstable pointer will have a much higher angle at the end because it moves up and down or left and right while being moved along the shape. This effect is illustrated in Figure 3 which shows two paths for a stable and for an unstable pointer including the angle change between each movement.

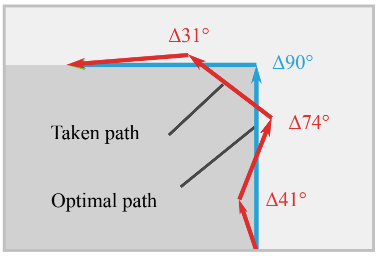

Figure 3: Traversed path of a stable pointer (blue) and exemplary path of an unstable pointer (red).

When summing up the delta angles from the blue path, the overall angle change of the path is 90°. For the red path the angle changes sum up to 146°. Thus a higher angle change indicates an unstable pointer. To not add huge errors for very small movements, where the pointer jumps between pixels adding angles of up to 180°, the movement angles are only calculated when the pointer moved a defined number of pixels away from the last location where the angle was calculated.

Using the angles, the second part of the score is calculated by Equation 8.

$$score_{angle} = 1 - \frac{1 - \frac{angle_{min}}{angle_{traversed}}}{2} \tag{8}$$

Here $angle_{min}$ is 360 divided by the number of calculated angles and $angle_{traversed}$ is the average of all angle deltas from the measurement. The overall score for the precision test is then calculated by Equation 9.

$$score_{precision} = score_{shape} \cdot score_{angle} \tag{9}$$

The total score $score_{precision}$ of this test is the product of the score for the shape and the score for the angles.

4 EVALUATION

For the evaluation of the proposed test methods we conducted tests with participants of different ages and sex on four devices. A huge diversity of the participants was important because it was shown in (Charness et al., 2004) that these factors have an not negligible influence on the results.

The devices used for the evaluation were:

- A computer mouse
- A commercially available pointing device
- A smartphone
- A prototype of a digital pointing device

The prototype consisted of a 1.5 x 3.0 cm sensor board rigidly attached to a ballpoint pen. The mouse was used with a mouse-pad on a flat table, the other pointing devices were used like a laser-pointer pointing at a 55” LCD monitor 3 meters away.

The computer mouse is used as a reference device because it is the most commonly used input device for computers (Atkinson, 2006) (Greenemeier, 2009).

To counteract a habituation effect when using the pointing devices, the sequence at which the test participants tested the devices was randomized. Overall, 160 measurements were made for all tests combined. After test conduction, the participants were asked for their subjective assessment of the pointing devices where they had to sort the devices from best to worst regarding their usability and handling.

4.1 Expected Results

To proof the reliability of the results from the proposed evaluation methods we expected that the results from the tests and the subjective assessment of the users show similar tendencies. Similar results would support the assumption that the ability to use the digital pointing device in a fast and precise manner would lead to a positive subjective assessment from the participants.

It was also expected that the results from the mouse would have the best results and therefore be the reference against which the other devices are compared, which was already shown by (MacKenzie et al., 2001). The mouse proofed to be one of the most precise pointing devices used in the last decades and nearly everyone uses a mouse on a regular basis when controlling a computer.

4.2 Pointing Test

The results from the *Pointing Test* are shown in Figure 4. The *Pointing Test* showed that the results from the mouse had the best overall score, directly followed by our prototype. The commercial product is placed on the third place. Moving the pointer with a smartphone showed the worst results.

The results indicate that the prototype has nearly the same performance as the mouse. The inferior behaviour of the smartphone was caused by a noticeable latency and some special characteristics that are pointed out in more detail in Section 4.4. The results still show that the minimal score reached from the

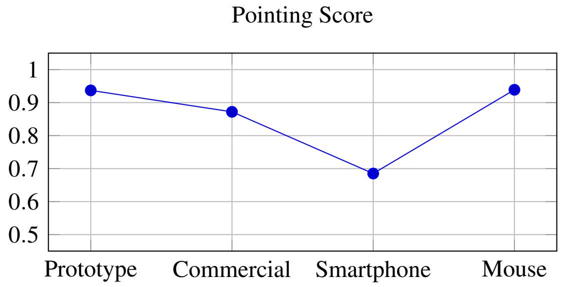

Figure 4: Score for the pointing test from the four tested devices.

smartphone was slightly below 0.7. Hence, all tested devices were still usable.

4.3 Speed Test

The results of the *Speed Test* show a similar order for the score from the tested devices. However it is clearly visible in Figure 5 that the results from the mouse are a lot better than the results from the other devices. A superiority of the mouse was expected for this test. First of all, all testers were already familiar with the usage of a computer mouse, secondly the movement needed to move the pointer with the mouse was different from the other tested devices which directly pointed at the screen to move the pointer. Last but not least, the mouse was the only device directly connected to the computer. The commercial pointer and the smartphone communicated wirelessly with the computer. The prototype was connected via an additional shuttle board. Therefore the latter three devices have a higher latency between device movement and pointer movement, which has an effect on the overall performance of said devices.

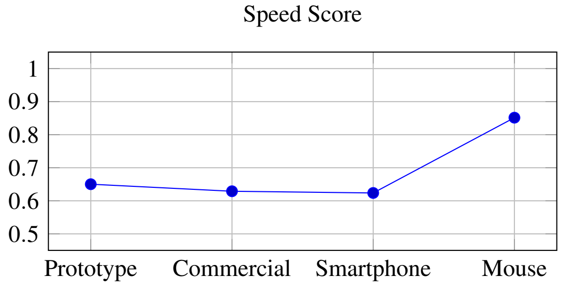

Figure 5: Score for the speed test from the four tested devices.

Similar to the *Pointing Test*, the prototype showed the second best results followed by the commercial product. The smartphone again had the worst results. However, the difference between the three devices is lower than in the *Pointing Test*. This is caused by the way the score is calculated to also incorporate the score from the mouse in a reasonable manner. Additionally the nature of the test using the number of reached points for the score causes a lower variance as it was possible to reach nearly the same number of points with all three pointing devices. It is possible that a longer duration of the test would yield better distinguishable results.

4.4 Precision Test

The score for the *Precision Test* consists of three subscores for the movements around the square, the triangle and the circle. The overall score of the *Precision Test* shows a different distribution for the usability of the devices, than the *Pointing Test* and the *Speed Test*, due to an anomaly in the test with the square shape. The sub-scores and the combined score can be seen in Figure 6.

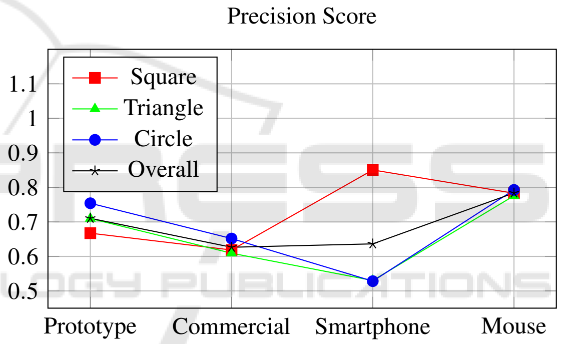

Figure 6: Score for the precision test from the four tested devices.

4.4.1 Square Shape

The scores from the evaluation with the square shape show different results than all other conducted tests. It can be seen in Figure 6 that the Smartphone has the best score in this part of the test despite being the worst for the two other shapes and the other tests. The second best score is from the Mouse, followed by the Prototype. The worst result was measured with the commercial product. While the score for the smartphone was the worst in all other tests it shows the best results for the *Precision Test* with the square shape. This anomaly is caused by the combination of three factors:

1. All edges of the square shape are either vertical or horizontal.
2. To reduce the influence of noise from the sensor-data, the application on the smartphone uses a

high threshold. All accelerations and angle-rates below that threshold are ignored.

3. The threshold is applied independently for each single axis on the smartphone.

When the user now moves the pointer along the shape of the square, the movement on one axis is low enough to be below the threshold and is filtered out causing the pointer to get 'locked' on one of the axis. Therefore the pointer can be moved in a perfect straight line which makes it a lot easier for the user to draw the square shape.

4.4.2 Triangle Shape and Circle Shape

The tests for the triangle shape and the circle shape showed similar results to the *Pointing Test* and the *Speed Test*. The mouse has the highest score, followed by the prototype and the commercial device. The results from the Smartphone are again the worst, which is not only caused by the overall bad accuracy of the used device. Additionally, the properties described in 4.4.1 make it impossible for the user to move along a diagonal line or curve because one of the movement axis very often gets 'locked' causing a sawtooth distortion of the actual movement.

4.4.3 Combined Score

The combined score from the *Precision Test* clearly shows the influence of the outlier measurement from the square shape causing the score from the smartphone to be higher than the score of the commercial pointing device. All other devices show a similar relation compared to the *Pointing Test* and *Speed Test*.

The distribution of the results shown in Figure 7 show a relatively constant performance from the Mouse and the commercial product. The prototype had worse results in some cases indicating a need for improvement. The results from the smartphone had the highest distribution indicating that it cannot be reliably used for the given use-case.

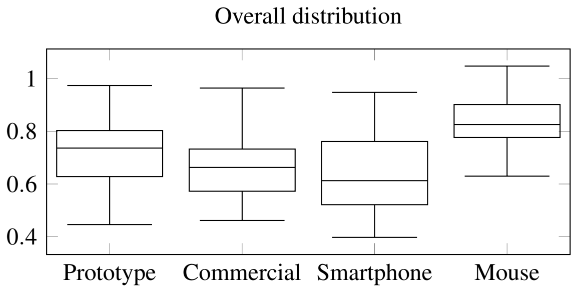

Figure 7: Distribution of the test results.

4.5 Overall Score

For the comparison of the test methods against the subjective user assessment, the average score for each device was calculated and normalized to be between 0 and 1. The resulting scores can be seen in Figure 8.

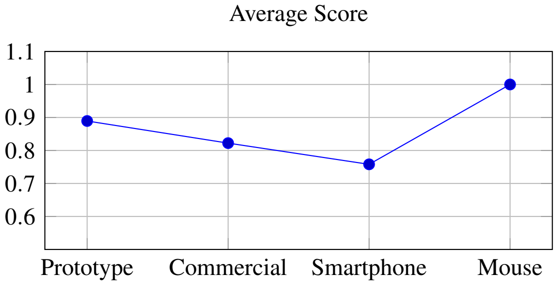

Figure 8: Normalized average score for the tested devices.

It can be seen that the outlier from the measurement of the *Precision Test* with the square shape did not have a huge influence on the average score.

Using other values for the scaling factors α, β and γ, the overall score will show a different scaling. However, changing these factors will not change the relative score between the devices. A change of α, β and γ also changes the influences of each single test in the overall score.

4.6 Subjective User Assessment

The subjective assessment of the usability of the tested devices allows us to determine if our developed evaluation methods can be used to make a qualitative comparison of the digital pointing devices in a reliable way that reflects the experience of the users.

For the subjective assessment the user had to put each device into an order from best to worst. The best device receives 3 points, the second one 2 , the third 1 and the last one 0 points. The results from the subjective assessment from the test participants can be seen in Figure 9.

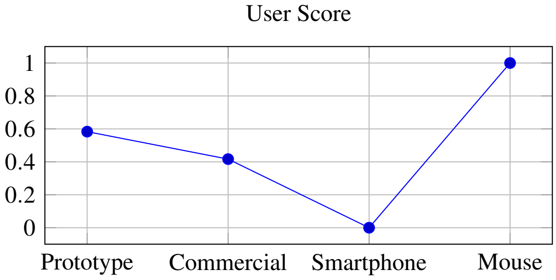

Figure 9: Normalized subjective usability assessment.

As expected, the mouse achieved the highest score and was rated to have the best usability from all test participants. The qualitative rating of all evaluated devices reflects the rating that was measured by the three test methods except for the square shape from the *Precision Test* due to the named factors from Section 4.4.1.

4.7 Comparison

The results from the subjective user assessment and the scores from the tests show a strong correlation, which suggests that the proposed test methods can be used to make a qualitative assessment of the usability of a digital pointing device. Apart from one exception all tests show the same order for the usability of the tested devices as the subjective user assessment.

However, the results show that the subjective user assessment has to be enhanced to allow for a quantitative evaluation with the developed testing methods. Therefore the user should not only create a ranking for the devices but also rate them between 0 and 10 for manageability, responsiveness and precision.

5 CONCLUSION

In this paper, we presented three test methods to evaluate the usability of digital pointing devices whose primary focus is on presentations. Each of the test methods evaluates one of the three identified properties of a digital pointing device that can indicate its usability, namely manageability, speed and precision. Each of the tests calculates a score to assess the tested devices. In the evaluation we showed that the assessments from the proposed tests were able to reflect the subjective assessment from test participants and therefore showed that the tests are able to compare and evaluate the devices in a qualitative way.

The formulas for the tests use many empirically determined factors that showed to give reasonable results during initial tests and were chosen in a way to cover the range of results expected to be reached by digital pointing devices primarily used for presentations. For a more precise assessment of the device properties, the determined factors will probably have to be adapted to result in scores that are more true to the subjective user assessments, which increases the reliability of the proposed testing methods.

The adaption of the empirically determined factors leads us to the outlook for further development. First of all the subjective user assessment has to be enhanced so that the device tester not only rank the tested devices from best to worst but also rate them on a scale from 0 to 10 for each of the three properties as well as for the overall usability. Based on the results from the subjective assessment the calculation of the score from the tests should be adapted to be as similar to the user rating as possible.

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