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Improving Mouse Controlling and Movement for People with Parkinson's Disease and Involuntary Tremor Using Adaptive Path Smoothing Technique via B-Spline

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Many input devices are available for interacting with computers, but the computer mouse is still the most popular device for interaction. People who suffer from involuntary tremor have difficulty using the mouse in the normal way. The target participants of this research were individuals who suffer from Parkinson's disease. Tremor in limbs makes accurate mouse movements impossible or difficult without any assistive technologies to help. This study explores a new assistive technique—adaptive path smoothing via B-spline (APSS)—to enhance mouse controlling based on user's tremor level and type. APSS uses *Mean* filtering and B-spline to provide a smoothed mouse trajectory. Seven participants who have unwanted tremor evaluated APSS. Results show that APSS is very promising and greatly increases their control of the computer mouse. Result of user acceptance test also shows that user perceived APSS as easy to use. They also believe it to be a useful tool and intend to use it once it is available. Future studies could explore the possibility of integrating APSS with one assistive pointing technique, such as the Bubble cursor or the Sticky target technique, to provide an all in one solution for motor disabled users.

Keywords: cursor control, Parkinson's disease, mouse trajectory, assistive technique, HCI, B-spline, break point

Introduction

Existing computer systems are designed mainly for able-bodied users. Therefore, those who have unwanted tremor, such as Parkinson's disease, have difficulty interacting with computers. Furthermore, direct effects of aging on computer interaction methods have been reported in human computer interaction (HCI) research (Keates & Trewin, 2005; Olwal, Feiner, & Heyman, 2008; Trewin & Pain, 1999). Using pointing input devices, such as computer mouse or trackball, for interacting with a computer requires precise finger control and hand movements, whereas Parkinson's users, due to their involuntary tremor, cannot provide this required control. A considerable amount of work is required in order to cancel these tremors. Most solutions try to filter the tremors to achieve real intended movements. Generally, the existing assistive solutions can be categorized into two main groups: software or hardware. For example, a device called a Wearable Orthosis for Tremor Assessment and Suppression (WOTAS; Pons, Rocon, Ruiz, & Moreno, 2007) was made to reduce tremors in a patient's upper limb. WOTAS is a robotic exoskeleton that applies dynamic internal force on the upper limb without any external help. However, hardware solutions are known to be costly and must be carried around by the user. On the other hand, a distinct advantage of the software version for assistive technologies is their accessibility and download-ability, meaning that the user can get them directly off the Internet or via e-mail without extra physical effort. IBM developed a mouse adapter for people with hand tremor in 2005 (Levine & Schappert, 2005). This hardware, which should be placed between the mouse and computer, costs US$100 (Bodine, 2005). In cases where disabled persons do not have enough income, the cost of assistive technology becomes a very important factor that will determine whether they will be able to acquire the tool or not. Another issue is the portability of the hardware. Even with advances in hardware technology, users are still required to carry the equipment, thus adding to the burden of an already handicapped person. This could also detrimentally affect self-confidence due to the constant need to awkwardly carry an additional hardware on just to use the computer.

For the past two decades, many studies have been carried out to address the inadequacy of existing HCI techniques for disabled people. There are many input devices for users to interact with a computer system. However, the computer mouse is still recognized as the most popular device for interaction (Hassan, 2009). A computer mouse has two functionalities: cursor movement on the computer screen and target pointing to activate or run it. As previous studies (Hurst, Mankoff, & Hudson, 2008;

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Keates & Trewin, 2005; Kim & Ryu, 2006) demonstrated, motor impaired users have difficulties fulfilling both these functionalities. To address pointing functionality, many assistive techniques, such as the Bubble cursor and the Sticky target technique, have been designed and developed by researchers to help disabled users in pointing tasks (Hyun, Richard, & Sharma, 2010; Shih, Cheng, Li, Shih, & Chiang, 2010; Shih, Shih, & Peng, 2011; Trewin, Keates, & Moffatt, 2006). These pointing techniques either try to make target sizes larger for the user or bring the target closer to the mouse cursor. To accomplish most computer tasks, users need to perform both mouse functionalities. In other words, the user must first reach the target and subsequently click on it. In some cases, a user can do without the first step (reaching the target) and just focus on the target-clicking step; for example, when the user uses a touchscreen computer, so that instead of relying on the cursor, he or she can just use a finger. However, in tasks such as drawing or painting, the cursor movement is considered the main task. Consequently, this article emphasizes on the first step (i.e., reaching the target rather than the clicking step). From the literature review, however, there are very few techniques and assistive technologies available for computer mouse (cursor) movement functionality to help disabled users (Barreto, Al-Masri, & Cremades, 2003).

One quite successful assistive technology for mouse controlling by motor impaired users is the SteadyMouse (Gottemoller, 2011). This software is free and can be downloaded from www.steadymouse.com. SteadyMouse processes incoming data using a Windows-based finite impulse response (FIR) filter that has different coefficients and order of magnitude for each position on the slider bar. These coefficients are designed in the low-pass style. By using this filter, unwanted "noise" is removed from the mouse data stream to deliver smoothed data to the operating system so as to accomplish intended action. After installing this software, the user can adjust the filtering level based on his or her needs. Tremor level can change due to different factors, such as stress or medication, so that each time, the user must adjust the software manually to get better results. If the software could adjust automatically to user tremor level, then the user could have better control of the computer mouse. Therefore, besides trajectory smoothing, a new technique should also try to address this issue.

For filtering noise or tremor, better results can be obtained if the noise is in a predictable and repetitive format. In other words, if tremor follows a predictable pattern, eliminating noise from intended path/signal can be easier and more effective, and the output path/signal will be smoother. Unfortunately, in most cases, the disabled person's tremor is not repetitive enough to be predictable. Both discussed assistive technologies require users to adjust the software/hardware manually every time, based on his or her feeling and need. Therefore, a better solution in the form of an automatic adaptive technique for eliminating unpredictable tremors is needed. The proposed new technique presented and discussed in this article can automatically adapt itself to the disabled person's tremor level. This adaptation leads to smoother mouse trajectories on the computer screen. Adaptive path smoothing via B-spline (APSS) technique, by providing smooth mouse trajectory, tries to make computers accessible for people with Parkinson's disease. The APSS technique processes the mouse data based on the user's tremor level. If the user already has a smooth mouse trajectory, the APSS will not affect his or her mouse trajectory. This can help the disabled person to use a shared computer. An important thing to note is that the function of APSS is not to recommend the best or shortest movement path to the target. APSS, instead, tries to smooth the mouse movement itself. It is a path independent technique as there are many paths that a user can select to reach the target.

Methods

Usually, mouse trajectories are dynamic and unpredictable, meaning that the user could move his or her mouse to any point on the screen and use different ways to reach the intended point. Hence, the coordinates of the path are not known. The dynamic nature of the mouse movement was strongly considered in the design phase of APSS. The operating system displays the mouse current position on the screen using the X and Y values. Hence the proposed technique should process and smoothen the data in X and Y coordinates. Briefly, the technique should act in real time, be adaptive, and be path independent at the same time.

Preliminary Stage

For exploratory stage sampling, two users diagnosed with Parkinson's disease suffering from involuntary tremors and two healthy users were selected. Both the Parkinson's users also participated in the final testing stage for APSS. All of them used the ordinary computer mouse to move the cursor on predefined paths. During the trial, they were asked to move the cursor on predefined paths (i.e., straight lines in both vertical and horizontal directions). Each person must repeat his or her task 10 times. Collected data from this step is then used to design the APSS technique. The healthy users finished the trial in one day, while the Parkinson's users finished the trial in one week. The study was limited in that the Parkinson's users, due to their age and tremor, got tired very easily. Parkinson's users were given the option to undergo the trial before or after taking their medicine. For some trial sessions one of the Parkinson's users took his medicine prior to testing. Comparing his before and after results, it was obvious that his performance in the trials was much better after taking his medicine (i.e., his detected break points were lesser than when he did not take his medicine). Analysis of results showed that disabled users had more break points in their mouse movements compared to normal users who had smoother mouse trajectory without any break points. These break points, also called *knots* (i.e., guide nodes about moving path), give vital information about a user's current mouse trajectory status; thus they should be detected and used in the smoothing process (Andersson & Kvernes, 2003). To detect break points in user's trajectory, real time break point detection (RBPD) method, which is a part of APSS technique, was used (Banihashem, Zin, Yatim, & Ibrahim, 2013). RBPD uses X and Y coordinate differences to detect break point. Participant's medical documents, furnished by the hospital, provide information about the kind of tremors they experience and their severity. Collected trajectory data from participants are analyzed and then categorized according to the number of detected break points per second. The results show that there is a relationship between tremor level and

Table 1. Mouse cursor movement patterns.

	X	Y
Stop	Not Changed	Not Changed
Right	Increased	Not Changed
Left	Decreased	Not Changed
Up	Not Changed	Decreased
Down	Not Changed	Increased
Up-left	Decreased	Decreased
Down-left	Decreased	Increased
Up-right	Increased	Decreased
Down-right	Increased	Increased

detected break points counts per second. Increased tremor causes more break points; detected break points for people with a higher level of tremor in one second are more than the average, which are more than 4 per second. If the person has median tremor, detected break points range between 2 and 4 and if tremor level is still in the primary stage, detected break points will be less than 2. This classification is correct for all cases in the current study. However, to define a more accurate classification, in future studies, it is good to investigate a larger sample of Parkinson's users to refine the classification of the number of detected break points per second and respective tremor level. A break point in mouse trajectory must satisfy two conditions. First, the cursor-moving vector has changed in the last 0.5 seconds. For example if it was moving to the right and then it suddenly moves up or down. To satisfy the next condition, the cursor should have enough position changes during the last 0.5 seconds. Based on X and Y changes, the cursor has only nine different directions in which it can move. All these possible situations are explained in Table 1.

After detecting the change in movement direction, Equation 1 is applied to find out whether the cursor has experienced sufficient location change or not.

$$|b_x - a_x| > m \, or \, |b_y - a_y| > m \quad (1)$$

where (a_x, a_y) *and* (b_x, b_y) are two-sampled points from the trajectory, which will be compared against each other to calculate the location change amount. In other words, this formula checks whether the cursor has had a location change in the past half second. Based on primary sampling, *m* is defined as {2, 3, 4, 7, and 10} pixels. For high-level tremors, m needs to have small values (i.e., 2, 3). The amount 4 is achieved when the user has medial level of tremor. For low-level tremors, values of 7–10 are enough. At the initializing stage, by default *m* is set at 4 for RBPD. Figure 1 illustrates the concept of *m*.

Automatic Adaptation Stage

The smoothing quality of APSS depends on the accuracy of break points detection in a user's trajectory. During the first few seconds—less than 5 seconds—of interaction for a particular user, all break points will be detected and calculated. This way, the number of detected break points will help to adjust the proper amount of *m* for the user. In other words, break point detection—a part of APSS—will adapt to the user based on his or her tremor level. This action will be continued/repeated the entire time that the user interacts with the computer. In cases where tremor levels change, the amount of *m* will be set to another amount for better detection of the break points. For example, if *m* was set to 2 (high level tremor) and the technique expects to detect more than 4 break points per second but incoming results show that detected break points are less than 4, so the system will need to readjust *m* for low level tremor.

Smoothing Stage

After the break-points detection step, two levels of filtering are used to smoothen the trajectory; all of these steps combined together is known as APSS. In the first level, filtering attempts to remove the main noise or unwanted movements from the path. In every movement, users with hand tremors will try to keep the mouse cursor on his or her intended path, but unwanted tremors always change the movement direction. At this point in time, the user attempts to suppress the tremors so his or her hand could control the cursor. This effort causes an obvious zigzag pattern in the cursor movements. To eliminate this zigzag pattern, a *Mean* filtering was used (Equation 2). The detected break points are then used as input for *Mean* filtering:

$$B_x = \frac{(a_x + b_x)}{2} \, and \, B_y = \frac{(a_y + b_y)}{2} \quad (2)$$

Mean filtering calculates mean of (a_x, a_y) and (b_x, b_y) points. These two points are coordinates of detected breakpoints in user's trajectory. By using *Mean* filtering, a new coordinate (B_x, B_y) can be calculated for mouse cursor location.

However using only *Mean* filtering does not sufficiently smoothen the trajectory and the cursor will jump sharply from one point to the next. This type of movement could potentially annoy users. To achieve smoother movement, another filtering method was applied to the output of this stage. A second level filtering attempts to make cursor movements smoother and keep it in a continuous trajectory. B-spline, with smoothing ability can automatically take care of this continuity (Wang, 2007). In various researches (Guilbert & Lin, 2005; Moray, 2004), B-spline was used for drawing smoother curves. Furthermore, in image processing, B-spline is often used for smoothing and filtering. To our knowledge, this is the first time B-spline has been used for smoothing mouse movements. The most commonly used form of B-spline is the uniform knot-vector form (Equation 3):

$$S_i(t) = \begin{bmatrix} t^3 & t^2 & t & 1 \end{bmatrix} \frac{1}{6} \begin{bmatrix} -1 & 3 & -3 & 1 \\ 3 & -6 & 3 & 0 \\ -3 & 0 & 3 & 0 \\ 1 & 4 & 1 & 0 \end{bmatrix} \begin{bmatrix} B_{i-1} \\ B_i \\ B_{i+1} \\ B_{i+2} \end{bmatrix} \quad (3)$$

A B-spline uniform knot-vector is used in second stage filtering to eliminate effect of tremor on user's trajectory. For sharp and unsmooth lines between cursor movements (points), B-spline makes a smooth curve between them. For B-spline *t* is time in seconds and is always less than 1 second in order to work with latest *B* points. All *B* points are the *Mean* break points that were calculated in the previous step. Figure 2 shows the overall smoothing process using APSS.

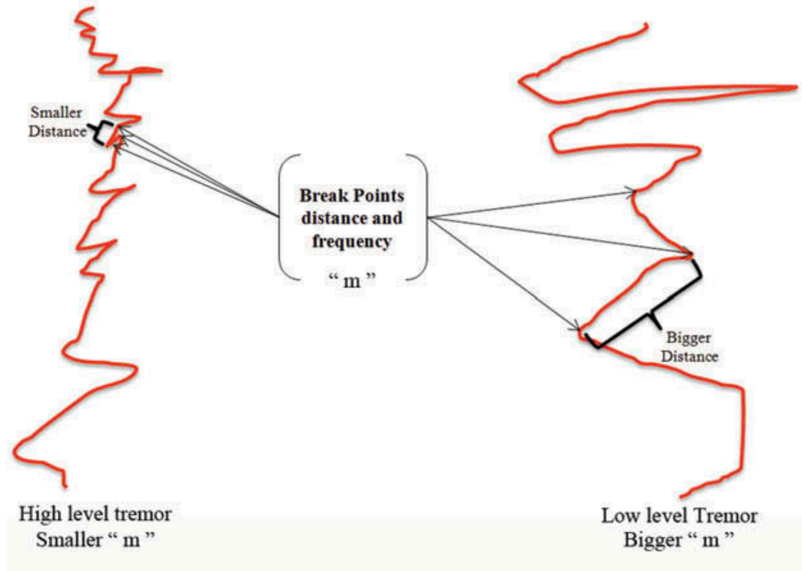


Fig. 1. Illustration the concept of *m*.

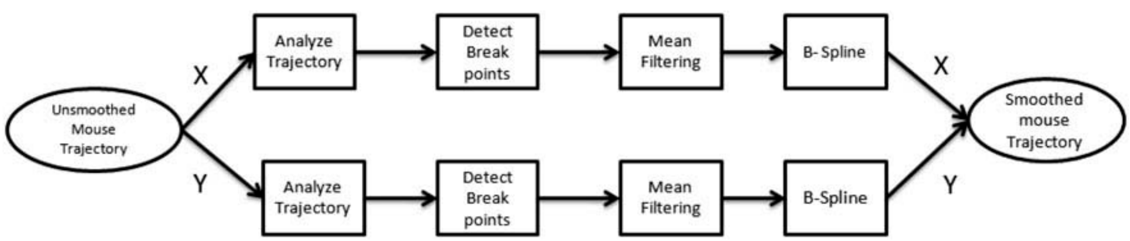


Fig. 2. Overall smoothing process in APSS has four main steps. This technique process X and Y coordinate separately. Needed steps for smoothing for both X and Y coordinates are the same. First of all if user has any mouse movements then his trajectory will be analyzed to detect breakpoints coordinates. Later on in first phase of smoothing, the *Mean* filtering technique will reduce unsmooth points in trajectory. In the last phase B-spline technique will smooth and deliver final trajectory.

Figure 3 shows the first step, which involves analysis of the mouse trajectory and break points detection. In the next step, the detected break point will be fed into the *Mean* filtering step to eliminate large noise disturbances from the trajectory. The final step recalculates the mean break points, which will then be passed to B-spline. Once all these steps are completed, a smoothed trajectory will be sent to the computer to be displayed on the computer screen.

Testing and Evaluation of APSS

A testing session was conducted for APSS to verify the effectiveness of this technique. After testing, each participant who has used APSS is required to answer a user acceptance test (UAT) questionnaire. For testing, the SteadyMouse technique was selected as the benchmark. This is because it is also an assistive technique that assists people with Parkinson’s disease to achieve smoother mouse trajectory. If testing results show that APSS does not work as well as SteadyMouse, then APSS is considered to have failed to achieve smoothing tasks but if the testing results show that APSS works better than SteadyMouse, then it can be deduced that APSS has made a significant improvement in smoothing techniques.

Participants

Due to the small population of people with Parkinson’s disease, some of whom have knowledge about computers, it was difficult to obtain a big number of participants in the testing phase. Another issue—as mentioned earlier—is health condition. Most people diagnosed with Parkinson’s disease get tired quickly during long periods of testing. To avoid this issue, each trial participant was given a 10-minute rest in between sessions. According to Lazar et al. (2009), 5–10 participants are acceptable for research focusing on disabled persons. In this study, seven patients from a teaching hospital with different tremor levels and gender participated in the APSS testing. Target participants were individuals who suffer from Parkinson’s disease. The testing was carried out at a local teaching hospital, where patients were constantly under a medical specialist’s supervision. To avoid learning effect in testing, each technique was randomly selected and then tested out by the participant. For example some of them started their trials with SteadyMouse while others started with APSS. The research was carried out after obtaining permission from the hospital’s ethics committee. Based on preliminary interview and testing, people with high and severe tremor were excluded from the trials since these patients could not keep the

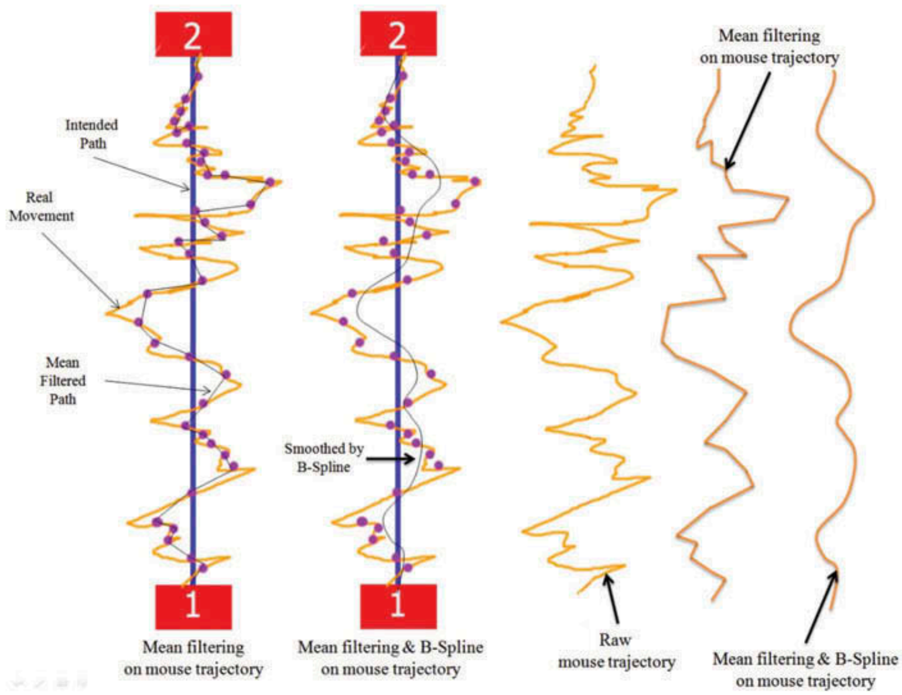


Fig. 3. Steps in smoothing mouse trajectory involve analysis of the mouse trajectory and break points detection. Then in the next step, the detected break point will be fed into the *Mean* filtering step to eliminate large noise disturbances from the trajectory. The final step recalculates the mean break points, which will then be passed to B-spline. Once all these steps are completed, a smoothed trajectory will be sent to the computer to be displayed on the computer screen.

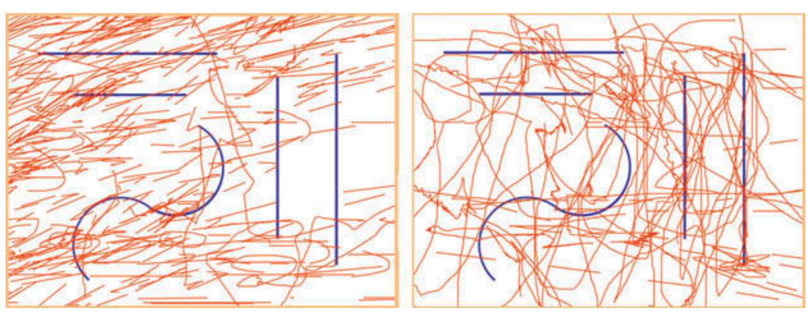


Fig. 4. Sampled data from participants with high level of tremor (without assistive technology).

mouse in their hand even for a short time due to the severity of their tremors. Figure 4 illustrates sampled data from participants with high level of tremor (without assistive technology).

Trajectory Record Software

In this study, software was developed for use in the testing stage. Main functionalities of the software are: (a) saving all participants bio-data, (b) saving used assistive software detail and condition in current testing, (c) recording participants' task completion time, and (d) recording all participants cursor trajectory coordinates (X, Y) for analysis.

Apparatus and Setting

Testing was conducted in the Patients Visiting Room at the hospital. The testing room was well-lit. For testing, a Toshiba Satellite A105-S4094 laptop (Irvine, CA), with specifications Processor Intel Core Duo 1.73 GHz, 2 GB RAM, 120 GB HDD and Operating System Windows 7, was used. A Microsoft Optical 100 mouse (Chicago, IL) was used as input device.

APSS Setting

APSS can automatically adapt to the patient's trajectory level and tremor, therefore, there was no need to manually change its filtering/smoothing power. Since the purpose of the current study is mouse trajectory smoothing and not pointing tasks, all buttons on the mouse were disabled during testing.

SteadyMouse Setting

As previously mentioned, participants were given some time before the testing session, to work with testing software and both assistive techniques. By default the anti tremor filtering level was set to *medium* for SteadyMouse. During pretesting interaction

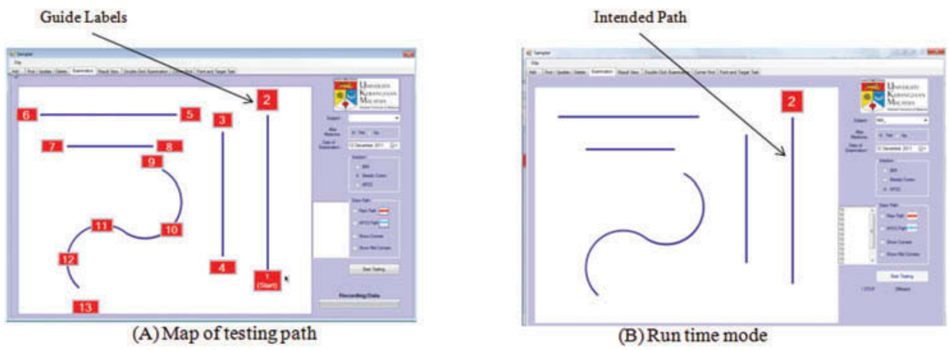


Fig. 5. Testing panel used in the study included thirteen guide labels (A) to guide user to move the cursor on the predefined path. The starting point is at label 1 and the ending point is at label 13. Only one label is shown to the user at any time during the experiment (B).

Fig. 6. Participants undergoing testing. Experimental setup and participants are displayed. The testing was carried out at the hospital in the Patients' Visiting Room.

time the participants had the chance to manually adjust the anti tremor level. The research assistant recorded the desired anti–tremor-level in the respective participant profile. Later—during testing—the participants would accomplish tasks based on their requested level of anti-tremor for SteadyMouse.

Experimental Setup

At testing session, participants were instructed to move the cursor on the blue lines of the testing panel. The first step of testing involved a 15-minute training, which includes briefing, instruction, demonstration, and trial of tasks for participants. All participants had at least a minimum knowledge of how to use a computer. During this 15-minute session, a research assistant instructed participants to move the mouse cursor on a predefined pattern, which consisted of one straight line and one half circle. Each participant was given an extra five minutes to repeat this activity. To ascertain the effect of APSS and SteadyMouse, participants were required to move the cursor on these predefined paths using both techniques. After this step they must attempt to move the cursor on a predefined path without any assistive techniques. Results from this step were not used for analysis. The full pattern—as indicated in Figure 5—was used for the real testing session. To avoid learning effect in testing, each assistive technique was randomly selected and then tested out by the participant. Some of participants started their trials with SteadyMouse while others started with APSS. A research assistant to assist participants in familiarizing themselves with the testing session explained all testing scenario. In some cases, the participant would stop the trials to ask questions about related issues. In such cases these participants must repeat the trial since stopping and asking questions can effect the task completion time. Each participant must undergo one full trial using both the SteadyMouse and APSS techniques. During testing, a message displayed on the screen informs the participant about which technique he or she is currently using. This helps the participant to answer UAT questions correctly, according to which technique he or she has used.

The reason behind the design of the testing panel was to include all possible mouse movement directions. These possible movement directions are up-down, bottom-up, right-left, left-right, clockwise turning, and counter-clockwise turning. To guide participants on the movement pattern, red colored arrows and numbers are displayed for them to follow the intended path. The guide numbers range from 1 to 13. Red arrows show movement directions to be followed by the participants. Figure 6 shows two participants undergoing testing.

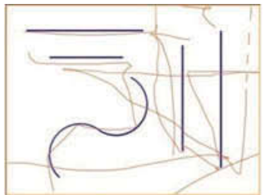
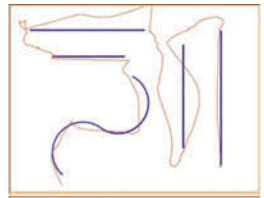
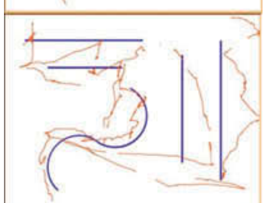
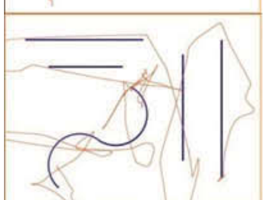
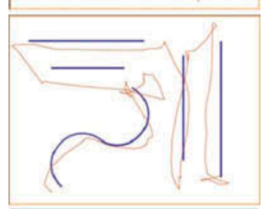
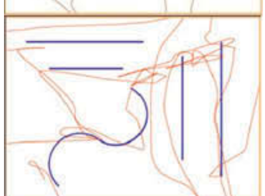
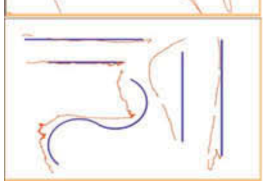
Results and Discussion

Experimental Results

Table 2 presents the results for each participant. The orange colored lines belong to the participant's mouse trajectory. The ideal result would be when all orange lines map exactly onto the respective blue lines.

Comparison of results for both SteadyMouse and APSS shows that overall, APSS performed better in smoothing mouse movements of participants compared to SteadyMouse.

Table 2. Results for both adaptive path smoothing via B-spline (APSS) and SteadyMouse.

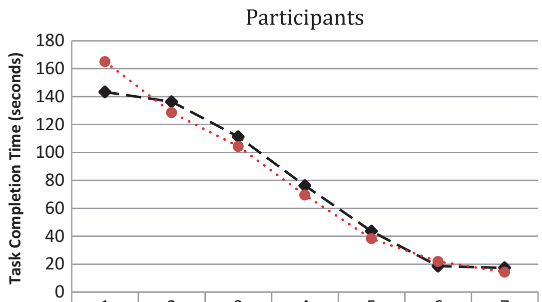
Participant	SteadyMouse	APSS
1		
2		
3		
4		
5		
6		
7		

Task Completion Time

Task completion times (TCT)—as outlined in Figure 7– were measured from the time the participant crossed the cursor at the start point until the moment he or crossed the end point. Comparing TCTs for both SteadyMouse and APSS, no significant difference was evident in task completion time for both techniques. Hence, even with similar TCT, APSS provides a smoother trajectory for users. From observation of participants' hand-eye coordination during the testing session, as they looked to the screen and simultaneously moved the mouse and the cursor responds and moves at the same time, it was found that there is no delay in functionality for both SteadyMouse and APSS.

UAT

The UAT Testing (Davis & Venkatesh, 2004) for APSS was carried out to evaluate participants' acceptance and usefulness



	1	2	3	4	5	6	7
APSS	143.3	136.3	111.2	76.2	43.6	18.6	17.4
SteadyMouse	165	128.5	104.3	69.5	38.3	21.9	14.3

Fig. 7. The x-axis is the Task completion times (TCT) using adaptive path smoothing via B-spline (APSS) and SteadyMouse. Participants had different TCT in comparison to each other. However, comparison between the two techniques shows similar TCT for each participant.

of the proposed technique. The goal of user acceptance testing is to evaluate the ease of use, usefulness, and user inclination, and to ensure correct technique functionality when applying the innovative idea in real life. The UAT reflects users' perceptions and opinions about the proposed APSS. The questionnaire is based on a 5-point Likert scale (Cuellar, Harris, & Jasso, 1980; Paull et al., 2009), with a range of 1 = *strongly disagree* to 5 = *strongly agree*. Based on the aim of this study, the UAT questionnaire was only concerned with the use of APSS and excluded the SteadyMouse technique. In other words, the UAT questionnaire were specifically designed to ascertain user acceptance of the APSS technique proposed in this study. The UAT questionnaire consisted of 12 questions. The first two questions ask users about the APSS ease of use. It is suggested that future studies include UATs for both APSS and SteadyMouse techniques and conduct an analysis of their UAT results comparison.

Ease of use

The APSS is an active enhancer for mouse smoothing and controlling. It runs in the background of the operating system, thus there is no need to teach users how to use it. The user only needs to know how to use the computer or the mouse itself. UAT results show that close to 86% of participants either agreed or strongly agreed that APSS is easy to use. The *Mean* for ease of use is 4.00, indicating that participants perceived APSS as easy to use.

Usefulness

Six questions were design to measure the usefulness of APSS to the user. The questions include statements such as: "Using APSS makes it easier to control the mouse cursor in a straight horizontal line" or "Using APSS can improve my computer interaction performance." The items in this part focused on usual mouse activities, such as turning and vertical and horizontal movements. Participants reported that they could perform mouse movements easier than before and with better precision in tasks. The results show that 70 % of participants either agreed or strongly agreed on the usefulness of APSS.

User inclination

In the third part of UAT, some questions were designed to determine whether participants would use APSS in the future; for example, "I intend to use APSS frequently to enhance my mouse movement skill" or "I intend to recommend my friends to use it when trying to interact with computers." Approximately 57% would recommend APSS to their disabled friends. Results indicate that APSS can address issues on mouse controlling and movement. After answering all the questions, participants are given the chance to give their comments or suggestions. One participant mentioned "how great would it be if this technique was provided by laptop manufactures as a default integrated service," while another said, "My laptop has voice command service but due to the quaver in my voice I cannot benefit from this service. Is it possible to 'attach' the APSS technique to that service to clarify my voice for the system?" It was later explained to the latter participant that data for computer mouse are in X and Y coordination's, while the data for voice is altogether different, and filtering and clarifying a voice requires other methods.

Conclusions

In this article, a new assistive technology for mouse controlling was described. Results of the testing show that APSS has a direct effect on unsmooth trajectory. Although participants had different levels of tremor, APSS successfully reduced the effect of these tremors and produced much smoother mouse trajectories. APSS takes advantage of B-spline to provide superior smoothing qualities; B-spline is a technique to draw smoother curves, which helps APSS deliver smoother results. APSS is a software-based solution designed to help motor impaired users with unwanted tremor to use their computers hassle-free. Unlike hardware assistive technologies, APSS is not physically dependent on any assistive hardware. APSS only deals with X and Y vectors provided by the operating system, and thus is not dependent on a specific pointing device but is, instead, suited to all. UAT results indicate that APSS successfully assists mouse cursor control and makes the task easier. It is easy to use, very useful and participants intend to use APSS in the future to improve their mouse controlling skills. Most importantly, when using APSS, a person does not need to do any modification or readjustment of the standard pointing devices. The APSS offers more accurate mouse controlling for motor impaired users who suffer from involuntary tremor. This accuracy is enhanced by its automatic adaptation ability to the user tremor level. As previously mentioned, the computer mouse functionalities are cursor movement on the computer screen and pointing targets to activate/fire/run them. Future proposed study can include the integration of APSS with one pointing assistive technique (Grossman & Balakrishnan, 2005; Shih, Shih, & Chiu, 2010) in order to provide motor disabled people with a comprehensive all in one solution. Additionally, the technique can be compared with users who do not use any computer assistive technology.

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