Design and Evaluation of a Computer-Actuated Mouse

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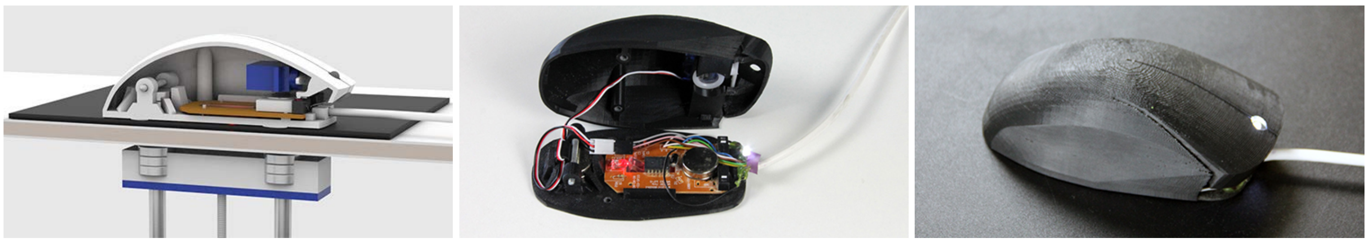

Figure 1. We present a computer-actuated mouse that allows to change its position and button states.

ABSTRACT
Although interaction with computing systems has become remarkably diverse in recent years, the computer mouse remained the primary pointing device for daily computer use. Being solely an input device, the classical mouse decouples input from output. In this paper, we propose to extend the mouse to a device that can be actuated by the user and the computer. We developed a mouse that allows its position and button state to be actuated. In a technical evaluation, we test the spatial resolution of our system and how effectively feedback is communicated to the user. In a subjective assessment, we explore users' reactions to four use cases including games and office applications, highlighting the potential of the device. Through a quantitative assessment, we investigate whether perceiving the movement of the mouse helps to learn gestures. Finally, we discuss how a mouse providing feedback can be used to build novel interaction techniques.

ACM Classification Keywords
H.5.2 Information Interfaces and Presentation (e.g. HCI): User Interfaces - Graphical user interfaces, Input devices and strategies, Haptic I/O

Author Keywords
mouse; pointing device; force feedback; actuated device.

INTRODUCTION
Despite today's proliferation of touch-sensitive surfaces, the computer mouse is still the most popular pointing device for stationary computers. Many technological innovations have contributed to this device's evolution, but English's and Engelbart's remained essentially the same since 1965: a tangible device that translates physical displacement into the movement of a pointer on the screen [11]. The addition of extra buttons and the scroll wheel, or the substitution of the ball by an optical sensor, indeed improved the usability of mice an an input device, although their use as *output* remained unexploited.

In contrast to direct input devices, such as the touchscreen, the mouse acts as an indirect pointing device. This provides advantages, such as allowing for finer granularity and more precise selection of targets, or *dragging* screen elements over the screen with ease.

The use of the mouse is easily learned by most users. However, steering through 3D environments or high-speed games that require fine-grained selections are highly challenging tasks that can be difficult to master. Complex workflows using software applications with a large variety of functions and options presented through a graphical user interface are hard to recognize, and users might profit from memorizing the set of movements to recall a particular action. In these scenarios, seeing how another user physically moves a mouse does not help much to understand how the user controls the interface.

We believe that the evolution of the mouse has not yet come to an end. Enhancing a mouse with physical actuation to provide additional feedback will enhance further its usability, enabling a bidirectional interaction between the user and the mouse. This novel kind of *dialogue* can open a channel for new ways of human-computer interaction. The possibility of the computer moving the mouse for the user enables several use case scenarios, such as tutorials to train users in specific software applications, remote assistance or rehabilitation of upper extremities.

In this paper, we present the concept, design and implementation of a computer-actuated mouse. We discuss use cases

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in which users can benefit from actuated mice and show how this technology can be user for learning skills that depend on movements. Further, we present the impressions of users about our design, and insights about the general concept of an actuated mouse.

RELATED WORK

As the large corpus of publications shows, the mouse has been a recurrent object of investigation. For the sake of brevity, we focus on previous work that discusses the usage of mice beyond the typical input modality and looks into different feedback possibilities. We also summarize previous work that examined the fundamentals of force feedback, which show the validity of this interaction method in similar contexts and makes a case for our design approach. At the end of this section we discuss how our concept builds upon prior contributions but differs from existing work.

Force Feedback

The use of *force* as means of feedback usually refers to controlling the physical movement of a device or a part of it. This can be used to convey different kinds of information. Roudaut et al. proposed a system capable of communicating digits and symbols using force feedback [14]. Their approach consists of a transparent sheet of plastic foil that is placed on top of a touchscreen. A set of motors can move the foil over the screen. When a finger touches the screen, the finger can be moved across the screen by moving the foil. The system enables to use the screen of the phone for haptic input and output. Their study shows how users are able to learn to perform and also recognize symbols of the Graphitti alphabet.

Noma et al. went beyond the representation of abstract symbols and proposed the use of force feedback for the spatial representation of virtual reality objects [12]. They built a robot arm, capable of being moved by the user, but also able to generate active or passive force. By means of an attached palmtop display, it allows to visualize virtual objects, and by manually repositioning the arm, observe them from different angles and distance, as in positioning a camera in space. The force feedback constrains the movement of the arm, not only adding solidity to the simulated objects, but also allowing to control its apparent hardness. This is achieved by braking (with a variable deceleration coefficient) the movements performed by the user, but only in the vectorial component perpendicular to the virtual object's surface. The device demonstrated to be not only capable of reaching a high accuracy in the spatial representation of objects, but also a fast learnability.

Further explorations of force feedback techniques involve the induction of gestures by muscle actuation. The use of hand poses, both as input and output method, was investigated by Lopes et al. [9], proposing thus a way of interaction completely independent from sight. Their concept is based on the *propioceptive* sense, the ability of perceiving the pose of the own body. Users' gestures are recognized with an accelerometer attached to the back of their hand, while the output is controlled with electrical muscle stimulation.

In the same line of work, the authors elaborated a method to communicate the dynamic use of objects by mimicking the hand movements corresponding to their use with electrical muscle stimulation [9]. Pfeiffer et al. compared vibrotactile feedback against EMS for free-hand interaction [13], showing that the later can be superior in many applications, in particular for interaction with virtual spatial constrains.

Haptic feedback has also been successfully used for training spatial motor skills, as shown by Feygin et al. [7]. They proposed a method based on *haptic guidance*, which consists on the physical guidance of the subject through the motions needed for a particular task. To measure the effects of force feedback, they used the Phantom from Sensable [1] to train the participants for tasks containing three dimensional movements, and compared their performance against control groups. The experiment revealed a better performance in the spatial aspect of the movements and a remarkably better performance in the temporal aspect.

In a related line of work, Yu and Brewster compared the Sensable Phantom with the Logitech WingMan force feedback mouse for representing graphical data [17]. Their contribution makes an argument for using multimodal technologies, since they showed how combining audio and haptic feedback enables visually impaired users to obtain information more effectively.

Augmented Mice

A body of work explores the use of mice as an output device. The advantage of adding haptic feedback to mice has been shown by Akamatsu et al. [2]. The authors compared tactile, auditory and visual feedback. They showed that providing haptic feedback when pointing to a target with a mouse, can reduce the task completion time. This was tested using an augmented mouse created by Akamatsu and Sato [3]. The device is able to provide tactile feedback to the user's index finger by moving a pin upwards through a hole on the mouse's left button. The mouse could also be slowed down while over a target by using electromagnets. This device was used later by Akamatsu and MacKenzie [1] to analyze movement characteristics, following MacKenzie's proposal to use Fitts' Law as a research and design tool in HCI [10]. The design principles derived from these contributions encourages the use of tactile feedback whenever its integration is possible.

A similar line of work was explored by Asai et al [4]. They proposed a system that enables users to *feel* bumps and slopes of a three-dimensional virtual surface when navigating it with a mouse. The mouse was attached to strings controlled by motors, which exert forces on the mouse, making the movement harder or easier on a given direction, and thus representing *uphill* and *downhill* movements.

The use of vibrotactile actuation was also used to transmit information in a non-visual way. Wiker et al. used a vibrotactile feedback on mice for blind access to computers [15]. Arrays of tractable pins were attached to mice and users were asked to explore unseen computer screens, using only the tactile feedback to detect the presence of graphic stimuli. The results showed that users are able of recognizing simple shapes. The

[1] Sensable Phantom products are now rebranded as Geomagic Touch: http://geomagic.com

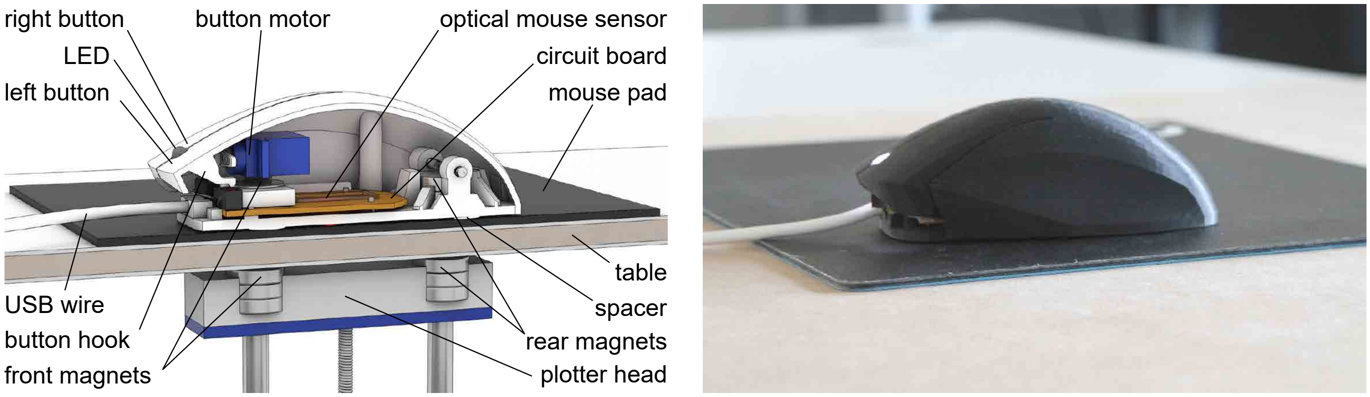

Figure 2. Rendered cross section (l.) and photo (r.) of the the 3D printed mouse. The mouse includes an optical mouse sensor, a motor for button actuation, two neodymium magnets at the front and two at the back. A LED is placed between both mouse buttons for external tracking. The robot head holds three magnets at the front, and three at the back.

authors also indicated the importance of the pixel-to-tractor resolution regarding the accuracy of the recognition, over the mere cutaneous stimulation.

This kind of mice was also explored by Yang et al. [16], using not only tactile information as output, but also thermal and force feedback. Their system simulates stiffness and roughness of virtual objects’ surfaces using a two-dimensional translation force feedback mechanism and a tactile display. Thermal feedback was controlled using a heat conducting plate and a water cooling system. The authors suggest that using vibration is more effective for displaying fine surfaces than static displacement.

Actuated mice have also been used in completely different settings. An example is the study approach taken by Bailly et al [5]. They actuated the position of computer components on a typical office desktop. Their system arranges computer peripherals autonomously on a desk to support ergonomy and collaboration in different scenarios. Focusing on arranging the computer monitor, keyboard, and mouse, they enhanced interactions between the user and the computer or other users. They proposed video-conferencing, setup’s physical configuration, workplace tiding, co-working and virtual spaces as scenarios in which their concept can be of advantage.

The use of force-feedback to control mouse movements was also investigated by Dennerlin et al [6]. They presented an actuated mouse, able to move within a very reduced surface, but capable of pulling the mouse towards its center, helping users navigate the cursor through narrow tunnels at higher paces.

Summary

Previous work approached the use of force feedback from multiple directions. It has been shown that force feedback can supports spatial representation of virtual reality environments [12], training for spatial-dependent tasks [7], and gestural interaction [9, 13, 14]. It shows that force feedback has the potential to support learning and the understanding of spatial representations. In addition, the computer mouse has been extended to provide different forms of haptic feedback and for different use cases [1, 2, 3, 16].

Overall, previous work showed the advantages of force feedback and also the potential of augmenting the mouse through additional feedback modalities. It is, however, unclear how to provide force feedback through a mouse that can be used in standard applications. Furthermore, it is not clear if users would accept a computer-actuated mouse, which use cases for such devices are promising and if the advantages shown for other force feedback devices can be transferred to computer mice.

CONCEPT AND SYSTEM IMPLEMENTATION

We propose a mouse that can be controlled by a computer, in addition to the traditional functionality it provides. Our concept enables the mouse to be steered over a desktop and its buttons to be actuated, both by the user or by the computer (see Figure 2). These enhancements are achieved by using magnets to control the position of the mouse and an electrical motor that actuates the buttons.

The presented system consists of three parts: (1) a force-feedback mouse with button-actuators; (2) a plotter, which controls the position of the mouse with the magnets from below the desktop; (3) and a controller, which consists of a software application running on the computer to control the mouse’s actuation with help of an optical tracking system. The following subsections describe these three parts in detail.

Force-Feedback Mouse

We built the mouse using parts of an off-the-shelf optical mouse, with dimensions of 131 mm (L)×44 mm (H)×70 mm (W), combined with the necessary additional components to enhance its functionality. To preserve the look-and-feel of a regular mouse, we designed and printed a mouse enclosure with the traditional form-factor, but still capable of fitting the additional components[2]. This enclosure was modeled using Autodesk 3ds Max 2016 and 3D-printed using a Stratasys Dimension Elite 3D printer.

The case consists of an upper and a lower part. The upper part is the hull of the mouse and the buttons. The hull and buttons were designed with a thickness of 1 mm, with a thinner profile

[2]CAD-files and documentation are freely available: https://github.com/valentin-schwind/crazymouse

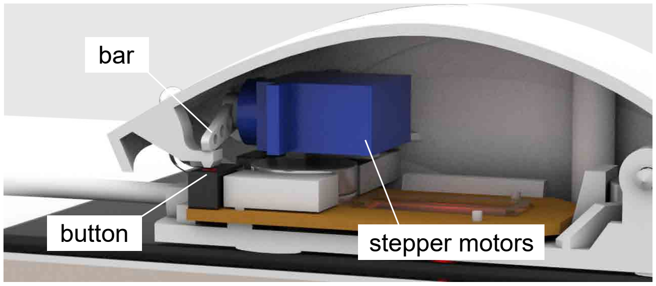

Figure 3. Close-up of the mouse interior. A stepper motor pulls down the button hook to actuate the buttons.

where the buttons are attached to the hull, thus allowing for the flexibility needed to easily move the buttons by pressing them. A hole between the buttons makes place for an LED, which is used for tracking the mouse position. Below the buttons, special fittings hold a servo motor, which controls the actuation of each button individually by rotating a bar that pulls them downwards. The design allows the user to actuate the buttons independently from the motor activity, but enables the mouse to click its buttons autonomously.

The lower part of the case was modelled with a thickness of 3 mm and holds the mouse circuit board. This board was obtained from a Basetech BN-S11 standard computer mouse and consists of an optical sensor, two press-buttons, and a controller that transmits the sensed input to the computer via USB. We power the additional LED using the 5 V channel that feeds the board. The lower part of the enclosure also contains two sets of magnets that allow the mouse to be steered by the system. Each set of magnets consists of two neodymium cylindrical pieces, each with a diameter of 20 mm, a height of 5 mm and a contact adhesive force of 58.9 N. We grouped the magnets in two piles to avoid unwanted rotational movements of the mouse. To fit the magnets securely and as close as possible to the desktop below the mouse, a hole was drilled through the circuit board, in an area were no components or conducting traces would be affected. The upper and lower parts are assembled and held together using two screws.

Figure 2 shows a cross section (left) and a photo (right) of the final mouse, the table, and the holder mounted to the plotter below the desk.

Plotter and Table

We use a commercially available plotter from Makeblock[3] to control the position of the mouse. Figure 5 depicts the plotter system from the bottom. The plotter is attached with screws to the bottom surface of a plate, keeping it hidden from the users. The plate consists of a medium-density fiberboard (MDF) with a thickness of 8 mm, a length of 800 mm and a width of 900 mm.

The mouse is moved through the robot head of the plotter. This head consists of two sets of three neodymium magnets, with the same properties as described above. Two stepper motors control the position of the head covering a working area of 310 mm×390 mm with a maximum speed of 50 mm per second. Each motor controls the position of the magnet along one of the axes with a granularity of less than one millimeter. An Arduino UNO controls both motors according to the incoming commands from the controller.

A third motor, in this case a through-type screw stepper motor, can move the head of the plotter along the Z axis, allowing to pull the magnets away from the table and thus enabling and disabling the automated control of the mouse’s position. This motor is controlled by a separate Arduino UNO, which also responds to commands from the controller.

Controller

The core functionality of the *Controller* software is control the position and button-clicks of the mouse. It can also record the user’s interaction with the mouse and to replay the recorded interaction again. The system is controlled by a standard computer running a C# application on Windows 10. The program constantly tracks the mouse position and directly controls both Arduino controllers of the positioning unit.

The position of the mouse is tracked in two different ways: (1) using the mouse input data and (2) using optical tracking with a camera. For this purpose, an USB digital video camera (UVC 2.0 FullHD) was attached to a tripod arm and placed 480 mm above the surface on which the mouse moves (see Figure 4 – left). Using OpenCV with the Emgu-wrapper[4] for C#, we remove camera distortion with a 9×6 chessboard calibration pattern (cf. the result in Figure 4 – middle). By removing the colors and reducing the camera’s exposure (see Figure 4 – right), the LED light of the mouse is tracked by the *SimpleBlobDetector* in OpenCV. The position is determined using the center of the detected blob. The combination of the two tracking methods allows to capture the absolute position of the mouse in addition to its input (relative position and button state). The placement of the LED between the buttons allows to keep it visible during normal use of the mouse, as long as the mouse is within the field of view of the camera.

TECHNICAL EVALUATION

We conducted a technical evaluation to explore the accuracy of the computer-actuated mouse and how well users can perceive the feedback provided by the mouse. In this experiment, the mouse communicated basic shapes to the user. We believe that the recognition of geometrical patterns is a fundamental trait of a force-feedback interface for this kind of devices. All bidimensional movements can be reduced to the combination of geometrical shapes; thus the ability of the system to present those in a way that users can recognize sets the baseline for more complex interactions.

We presented three different shapes in three different sizes and asked participants to recognize them. Furthermore, we determined the effect of a participant holding the mouse on the accuracy of the mouse’s movement by tracking the position of the mouse and comparing it with the traces the actuation should programmatically produce.

Participants

We recruited 12 participants (5 female and 7 male) for the study. The participants were between 22 and 44 years old

[3]Makeblock: http://makeblock.com

[4]EmguCV: http://www.emgu.com

Figure 4. Camera setup (l.), distortion removed camera view (m.), and mouse LED position detection pass (r.)

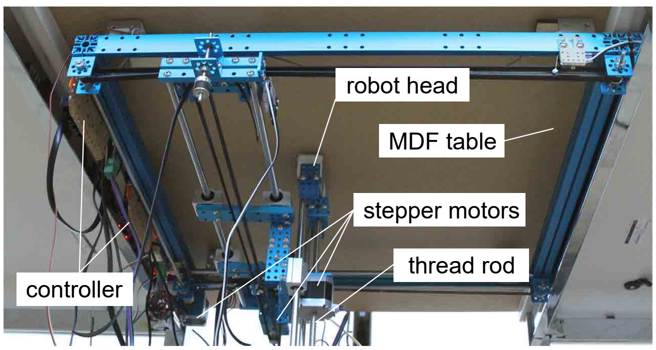

Figure 5. Bottom view on the table and plotter for magnetic mouse translation. A thread rod is used for adjusting the distance of the robot's head and the strength of magnetic attraction.

($M = 28.33$, $SD = 5.95$). All participants used their right hand to perceive the mouse's movement. They stated that they use mice on a daily basis. They all stated that they use mice for Internet browsing. All but one use mice for writing emails and using office applications. Ten participants use mice for software development. Half of the participants use mice for graphic design or 3D modeling activities and five use mice for gaming. All participants stated that they also use other pointing input devices, such as touchscreens, on a daily basis.

Method

The user study investigates to which extent participants can recognize shapes performed by the mouse. We presented squares, equilateral triangles, and circles to the participant. The shapes were performed in three different sizes, allowing to study the effect of the shape's size. To determine if the shapes' direction has an effect, we presented the shapes with eight equidistant angular offsets. Although the participants are aware beforehand of the shapes that they will perceive, thus priming their recognition towards these subset of geometrical shapes, the goal of this experiment is not to analyse if users can recognize shapes, but to assess the effecitivity of the system for conveying spatial information.

Participants had to state if they perceived a square, a triangle, or a circle after a shape was performed by the mouse, irrespective of the angle and size of the shape. For each presented shape, we determined if it has been recognized correctly or not. We tracked the position of the mouse to determine how closely the physical movement of the mouse follows the shapes. To assess the influence of the users' grip on the device we played all conditions once with participants' hands on the device and again without participants. As the optical sensor integrated into the computer-actuated mouse has drift, just as every optical mouse, we use the camera-based external tracking.

Study Setup

To only determine the effect caused by the mouse's physical movement, we shielded participants from visual and auditory stimuli produced by the system. Therefore, the area in which the mouse moves was covered with a box. A hole in the box allows the users to place their hands on the mouse without any hindrance. To avoid that participants get additional acoustic cues about the device's movement, we asked them to wear headphones and listen to music of their own choice. We ensured that the sound level was loud enough to disguise the sound produced by the motors moving the mouse, but always to safe levels for the participants' health. This way, participants could only perceive the movements of the mouse with their hand and were unable to extract further sensorial information. We recorded participants' response using a standard computer keyboard, with three keys labeled with the corresponding shapes.

Procedure

Each participant was seated on a chair placed in front of the box covering the mouse. A keyboard for user input was placed at the left of the box. The participants were asked to put their hand through the whole in the box and place it on the mouse, as they would do when using a regular mouse. When the participant was ready, the shapes were shown through the mouse. The application controls the mouse's movement, following the trace of a two-dimensional geometric shape.

Each shape was either a square, an equilateral triangle or a circle. Edge lengths of the squares were 200 mm (small), 300 mm (medium) and 400 mm (large). Edge lengths of the equilateral triangles were 265 mm (small), 398 mm (medium) and 531 mm (large). The diameters of the circles were 253 mm (small), 380 mm (medium) and 507 mm (large). Thus, the shapes had the following scaling; small 100%, medium 150%, and large 200%. Thereby, we ensured that different shapes with the same size had the same circumference. Shapes were performed with one out of eight angular offsets, separated by 45° intervals. This produces 72 possible combinations of

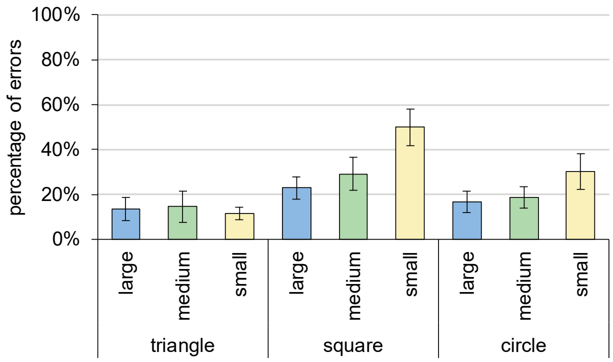

Figure 6. Estimated marginal means of errors in percentage with standard error for each size and shape combination.

shape, size, and angle. All conditions are randomized and performed sequentially by each participant.

After each shape was performed, the participant was asked to select one of the three possible shapes corresponding to the movements of the mouse. Participants entered the recognized shape by pressing the corresponding keyboard key, marked with the respective geometric shape. After one shape has been completed, the system re-centered the mouse and waited for the participant's input before continuing with the next shape. After completing all shapes, participants were asked to provide qualitative feedback using a questionnaire.

After the first six participants completed the experiment, an adapted version of the program was executed. It differs only in the fact that it is fully automated, skipping the user input and moving the mouse without a participant holding it. The timing and speed of the mouse were not modified, with the exception of an artificial pause between shapes to simulate the time needed by participants to input their answers. This program was executed 12 times, as often as participants took part in the study. After this phase, the last six participants used the unmodified version of the program to complete the study.

Results

Each of the 12 participants responded to the 72 possible shape, size, and angle combinations, producing a data set of 864 correct or incorrect answers. The very last answer from participant 3 was not automatically recorded due to a technical failure.

We used a repeated measures analysis of variance (ANOVA) to assess the effect of the angles on participants' ability to correctly recognize the shapes. Mauchly's test indicates that the assumption of sphericity has been violated ($p = .22$). Following Girden's (1992) recommendation, we used Huynh-Feldt correction (Mauchly's W = .477). No significant within-subject effects and no significant differences in the pairwise comparison between angles were found, allowing to aggregate the angles and reducing the subsequent analysis to two independent variables, namely shape and size. Thus, the results of the study are presented as error rate for each participant, for each combination of shape and size.

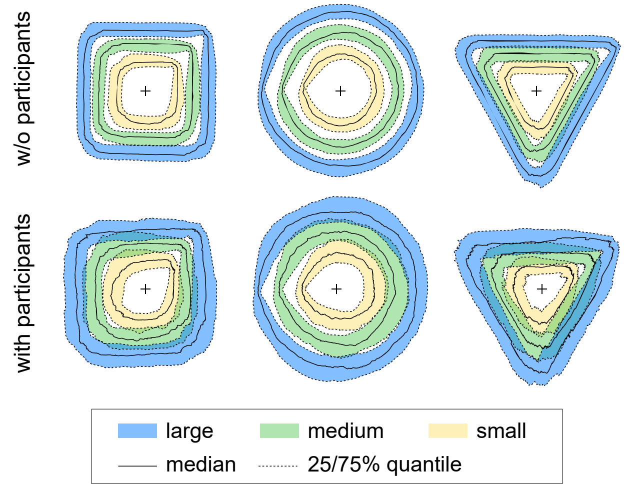

Figure 7. Median path performed by the mouse, with and without participants. Shape orientation of all shapes was normalized according to the shape center. Deviations in respect to medians are represented with quantliles.

Using a two-way repeated measures ANOVA, we determined the effect of shape and size on error rate. Mauchly's test indicated that the assumption of sphericity was not violated (all $p > .3$). We found a significant main effect for shape [$F(2,44) = 8.27, p = .002$] and for size [$F(2,44) = 13.49, p < .001$]. However, the ANOVA did not reveal a significant interaction effect [$F(4,44) = 4.690, p = .105$]. Bonferroni corrected post-hoc tests for shape ($Wilks'\lambda = 0.36$, $F(2,10) = 8.79$, $p = .006$) revealed significant differences ($p = .004$) between squares ($M = 2.72$, $SD = 2.08$) and triangles ($M = 1.06$, $SD = 1.41$), but no significant differences between circles ($M = 1.75$, $SD = 1.67$) and the other two conditions. For size [$Wilks'\lambda = 0.34$, $F(2,10) = 9.73$, $p = 0.005$], the the post-hoc tests revealed significant differences ($p = .002$) between large ($M = 1.42$, $SD = 1.36$) and small shapes ($M = 2.44$, $SD = 2.20$) and also ($p = .015$) between medium ($M = 1.67$, $SD = 1.79$) and small shapes. The error rate for each shape and each size are shown in Figure 6. Decreasing size appears to produce higher error rates.

To assess the influence of the participants' grip on the mouse we compared the tracked mouse movements of runs while hands held the mouse with the fully automated runs. Figure 7 shows how the different shapes and sizes were influenced by the hand grip of the participants. The 1st row in Figure 7 shows the tracked paths of the automated run. The 2nd row shows the tracked paths of the mouse while participants held their hand on the mouse. Through visual comparison of the medians and the 25/75% quantiles, we found that medium-size shapes overlap with both the small as well as large sizes at the three shapes when a participant's hand was on the mouse (cf. Figure 7 – bottom).

Discussion

We conducted a technical evaluation to investigate to which extent our design enabled participants to recognize shapes it performed. The mouse drew three different shapes, in three different sizes, at eight angular positions and we asked 12 participants to recognize them. Shapes have to be recognized by the participants. Through comparison of the recorded paths,

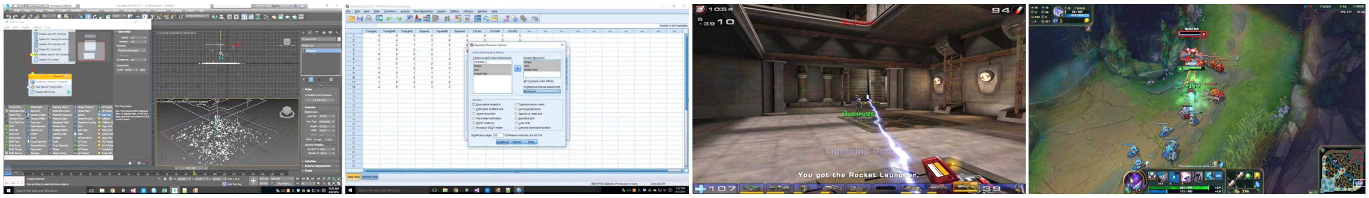

Figure 8. Screenshots of the evaluated scenarios: 3ds Max 2017, SPSS, Unreal Tournament 2004, and League of Legends

while participants held the mouse, and while the mouse automatically ran, we determined the accuracy of the device.

Results of the technical evaluation reveal that users were able to recognize most of the shapes, especially the larger ones. Increasing the shape size decrease the error rate. In contrast, changing the angle of the shapes had no significant effect on the errors made by the participants. We conclude that the mouse is able to replicate movements, which can be correctly recognized independently from the shape’s orientation.

Through plotting the camera tracked paths, we found how hand contact with the mouse reduces the accuracy of movements, which should be considered for future applications. Medium sized shapes overlapped with both small and large shapes. For use cases in which the shape size recognition is important, we suggest increasing the size ratio from 1:1.5:2 to 1:2:3, with small shapes having at least 200 mm width. Regarding this aspect, the main limitation of the design is the small, but perceivable, movement freedom allowed by the magnets. The length of the sides of the smaller shapes were in the same order of magnitude of this movement’s range. This hampered the clear perception of the movements by the users, leading to mistakes in the shape recognition. Stronger but smaller magnets could reduce the movement freedom. The results also suggest that users take angles, and not lines, as a cue to recognize shapes.

One of the limitations of the setup is the noise level of the device, which can be reduced by replacing the plotter with a different mechanism. The limitation of actuating only one button at a time can be easily addressed by adding a second stepper motor, or replace the current with a set of mechanical relays. This would also allow to add a scroll-wheel to the mouse.

Our system is not able to replicate the lift of the mouse from the desktop. The detection of this action can be implemented easily with a button or distance sensor on the bottom of the device, but performing the action itself requires a more complex approach. A similar feedback can be simulated to the user with mechanical relays, pushing the upper part of the case upwards and away from the lower part, which would still be fixed to the magnets beneath the desktop. Despite of the current limitations, the study shows that the system can convey spatial and gestural information to users.

QUALITATIVE AND QUANTITATIVE EVALUATION

In a second study, we investigate different application scenarios in which an actuated computer mouse can benefit the user. In particular, we propose four scenarios that comprehend real-life applications, and gather feedback about how the actuated mouse can support users for these applications. Additionally, we looked in depth into how an actuated mouse can support users in learning mouse gestures. Inspired by previous work [14], we asked the participants to learn the EdgeWrite alphabet using visual stimuli, tactile stimuli, and a combination of both. This allowed us to assess if the system can support learning activities using force-feedback.

Application Scenarios

We believe that force actuated mice can enrich many use cases by adding a new dimension to the existing ways of conveying information. In this particular study, the focus will be placed on activities related to learning or improving skills in computer related activities. It is possible to group these cases in the following categories:

Remote assistance

Even if current state-of-the-art software allows to remotely control pointers (e.g. TeamViewer, Chrome Remote Desktop), we believe that force feedback would assist novel users in an improved way, not only by showing the movements to be performed to reach a certain goal, but also to reinforce the impressions generated by adding a spatial and tactile stimulus.

Software tutorials

Similarly to remote assistance, tutorials can be enhanced by providing force feedback, making it more clear to users how certain actions in a computer environment can be performed. This can be specially useful in applications were the mouse movement does not reflect in the position of the pointer, but in the manipulation of computer generated objects, such as the rotation of 3D objects or the variation of a property of a CAD model (e.g. extruding a surface in Autodesk 3ds Max).

Gaming

Computer gaming is probably the area of application in which the skilled use of mice has the largest impact. Many video games require the user to perform several actions and movements with a high speed and a high precision. The precision and speed of these actions has a great impact for the advanced users, specially on a competitive level. Computer assisted movements and replays of matches and combats played by professional experts can likely improve the abilities of players in this kind of scenario.

Participants and Overview

We recruited 12 participants (6 male, 6 female) aged between 21 and 30 years ($M = 26.5$, $SD = 2.8$) through University mailing lists. All participants were right-handed. After the participants arrived in the lab, we first introduced the purpose of the study and ask them to sign an informed consent

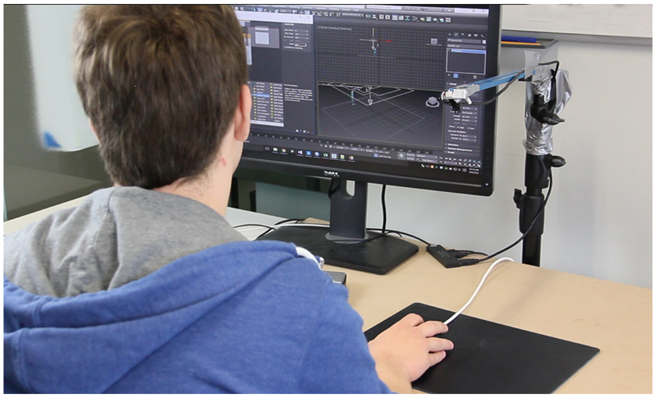

Figure 9. Participant at the 3ds Max-scenario.

form. We asked the participants how familiar they are with the four scenarios applications and the EdgeWrite alphabet on a Likert item from 0 (totally familiar) to 4 (not familiar at all). Participants reported to be familiar with League of Legends ($Md = 2$), SPSS ($Md = 1$), 3ds Max ($Md = 1$), and Unreal Tournament ($Md = 2$). None of the participants stated to be familiar with EdgeWrite ($Md = 0$).

Afterwards, we showed the four different scenarios to the participant which incorporate visual and haptic feedback. We assessed the user experience (UX) for each scenario and conducted semi-structured interviews. Finally, participants performed the EdgeWrite learning task and provided additional feedback on how they perceived the support provided by the mouse, using a Likert scale item.

Evaluating the Design as a Haptic Feedback Technology

To assess the validity of the presented concept as a tool for prodiving haptic feedback to users, we gather qualitative data about users' perception of the device, as well as quantitative data about the effectivenes of our design to be user as a teaching tool.

Qualitative measures were developed based on the scenario exploration: A set of recordings consisting of synchronized video and mouse movement which show software use in different use cases. These augmented video clips show activities which could be learned in an improved manner by adding the mouse force feedback to the visual stimuli. The clips prepared for this study intend to explore activities in which mice have typically an important role; namely 3D animating using Autodesk 3ds Max, creation of charts to display statistical data using SPSS, playing Unreal Tournament 2004, and playing League of Legends.

The recorded mouse activity was performed by skilled advanced users and pro-gamers. Video lengths ranges from 2:00 minutes to 3:29 minutes. Participants were shown these videos (in a compensated randomized order). To assess the subjective experience of the participants we used the user experience questionnaire (UEQ) [8] after each clip.

Quantitative measures were recorded in a learning task. The study was conducted in order to evaluate the effectiveness of the force actuated mouse in assisting learning. The study does not aim to evaluate if force feedback is a valid approach for learning, but to assess if the presented design serves as tool for learning. The subject to be learned is the EdgeWrite input method, because of its still limited presence despite its simplicity and its strong dependency on spatial movements. It consists of a set of one-finger, one-stroke movements between the four vertices of a square, including the diagonals. For the purpose of this study, a subset of the alphabet is selected, consisting of the main forms of the standard Latin alphabet.

Both parts of the experiment were run sequentially, presenting first the video clips to the users and afterwards the learning task. After both parts were finalised, participants took part in semi-structured interviews.

Procedure

The experiment consists in *teaching* participants the EdgeWrite input method. For this, the most commonly used Latin characters are split into three groups. Since there are 26 characters in the ISO basic Latin alphabet, eight characters are randomly assigned to each group, and two characters are randomly left out for each participant. Each group is assigned to one of the three possible conditions: *visual cues*, *force cues* and *mixed cues*. In the case of the visual cues, the participant will see a character of the group displayed on the monitor, and a simple scheme of the corresponding WriteEdge input shape. The starting point of the shape is marked with a dot. This information will be displayed for five seconds and then hidden. The user is then prompted to press space, before the next character is displayed. This process is repeated until all eight characters of the group are presented. In the mouse feedback condition, the character will be displayed, but not the corresponding schematic. Instead, the movement corresponding to the character will be performed once by the mouse. Finally, in the mixed learning condition, participants see the shape's scheme and also receive the force input of the mouse.

The order of the conditions is determined randomly, but compensated for the whole set of participants. After each of the character groups is shown, the participants perform a test to evaluate how many symbols they have learned. The characters learned in the current condition are displayed randomly, without any additional information. The participant perform the corresponding shape to each character with the mouse, while pressing the left button. When all parts of the experiment are finished, the participants are asked to fill a questionnaire.

In this study, the mouse is not covered but placed in a typical desktop setup, near a keyboard and in front of a computer monitor. The camera setup, as described in the previous section, is still used to provide external tracking. The whole procedure is explained to the participant. It is also explained to the participants, that the starting point of the displayed shapes is marked with a big dot. Before each condition is evaluated, the experiment's assistant tells the participant, which one is about to be evaluated. After the learning process is done, the participant starts the test. The participants' answer is recorded while pressing the left button of the mouse and all previous and later mouse movements are to be ignored in the evaluation. To proceed to the next question, the users are prompted to press the spacebar.

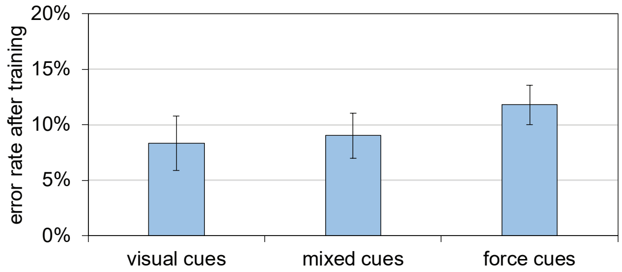

Figure 10. Error rate of EdgeWrite characters after training using the presented output modalities: visual, force, and mixed cue. Error bars show standard error.

Results

Scenario Presentation

The UEQ questionnaire contains 6 scales with 26-items: attractiveness, perspicuity, efficiency, dependability, stimulation, novelty. The results of the UEQ scales are depicted in Figure 11. We found a significant effect of the presented scenarios on efficiency [$F(3,33) = 5.482, p = .004$] and dependability [$F(3,33) = 4.459, p = .010$] on the UEQ dimensions. Further significant differences were not found between attractiveness, perspicuity, efficiency, and stimulation (all $p > .124$). Bonferroni corrected paired samples t-tests were used to make post hoc comparisons between the scenarios on efficiency and dependability. We found a significant difference between the League of Legends ($M = 4.458, SD = .745$) and 3ds max ($M = 5.375, SD = .944$) scenario for efficiency ($p = .019$). We also found a significant difference between the SPSS ($M = 5.583, SD = 1.094$) and the Unreal Tournament ($M = 4.354, SD = 1.231$) scenario for dependability ($p = .050$).

EdgeWrite Training

After repeating the EdgeWrite characters, we asked participants how much each rendering technique (force cues, visual cues, mixed cues) helped them to learn the presented set of characters. The results are depicted in Figure 12. A non-parametric Friedman test was conducted ($\chi^2 = 9.378$) and revealed a significant differences ($p = .009$) in the rating scores. Pairwise comparisons showed that there was a significant difference between the force cue ($M = 4.833, SD = 1.732$) and mixed cue ($M = 5.917, SD = 1.732$) condition ($p = .003$).Through visual inspection we compared the EdgeWrite symbols with the shapes drawn by each participants. A character, which was not drawn according to the EdgeWrite specification was considered as an error. Since this is unambiguosly measured by the order on which the corners of the shape are reached, there is no room for bias and thus we considered not necessary to automate the evaluation. The error rate after training the characters through visual cues, force cues, and mixed cues are depicted in Figure 12. A non-parametric Friedman test of differences among repeated measures of the amount of errors during the EdgeWrite task was conducted and rendered a χ^2 value of 2.513 which was not significant ($p = .285$).

Interviews

Participants were interviewed following a flexible structured. They were asked about what kind of applications other than the

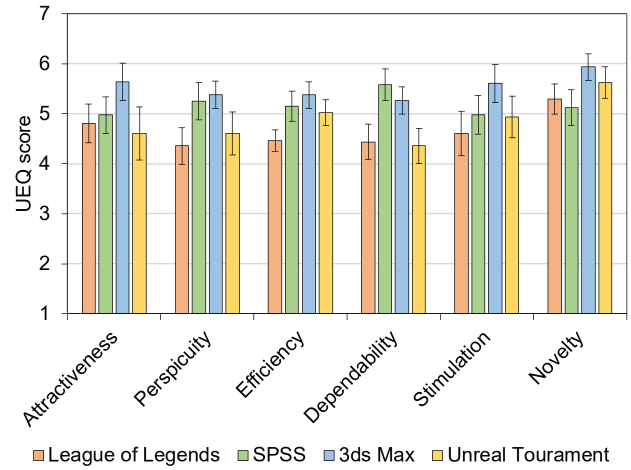

Figure 11. UEQ dimensions of the four presented scenarios (League of Legends, SPSS, 3ds Max, and Unreal Tournament) using the force feedback mouse.

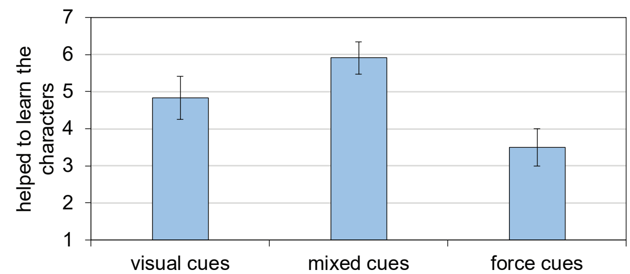

Figure 12. Perceived support for learning the EdgeWrite characters through displaying the symbols, mouse feedback and displaying the symbols, and mouse feedback only.

presented they could imagine would profit from an actuated mouse. They were asked about positive and negative aspects of the presented design, and asked for suggestions to improve the system. In the following subsections we present the most relevant insights gathered in these sessions, grouped by four general cathegories metioned above.

Suggested Applications: Several participants suggested use case scenarios related to teaching or learning: teaching games that require muscle memory, guiding novel users during their first experience with a new computer application, making tutorials more effective by reducing the effort of users looking for the position of a button or menu item on their screen, accesibility and remote assistance.

Interviewees also suggested using the actuated mouse to convey information such as "representing states by the mouse location" (sic), providing feedback about surface structures from 3D models or notification signaling.

Further suggested applications were: making users aware before confirmation, when deleting elements from the computer; helping users improve their posture when using a mouse; and a "mouse to hand" function, that recognizes a gesture of the users and positions the mouse automatically under the user's hand.

Positive Aspects: Users generally described the design as novel and *fun*. One participant praised the additional feedback other than vibration. Another one stated that the mouse felt natural and the movements smooth. One interviewee said that the “feedback is not too intrusive”, while another one stated satisfaction because “I don’t have to do anything if it moves on is own”.

Negative Aspects: Four participants express not feeling comfortable with a mouse moving their hand. One of them expressed disliking the feeling of not being in control. Another expressed concern about possible injuries caused by wrongly anticipating the mouse’s movements. One interviewee stated to find the “*staccato* movements”(sic) annoying. Three interviewees complained about the high speed of the movements. Two participants disliked loud noise of the device and other two expressed physical discomfort while holding the mouse.

Suggestions for Improvement: Participants suggested improving technical aspects of the device, such as smoothness of movements and loudness of the system. Three of them suggested adding more actuated buttons and an actuated scroll-wheel, for extra functionality. One interviewee suggested to use a smaller mouse.

Discussion

The qualitative assessment of the computer-actuated mouse revealed an overall positive feedback from the participants. Particularly, the results show that the computer-actuated mouse is efficient in scenarios in which tools were explained to users.

The computer-actuated mouse can have a higher impact in learning tasks when combined with other stimuli such as visual. Even though the quantitative results do not show a clear improvement in the learning of the EdgeWrite alphabet, the feedback provided by participants strongly indicates the viability and attractiveness of the computer-controlled mouse as a learning method. Since the aim of the learning task was not to validate the use of force feedback to learn EdgeWrite, but to assess the design as a tool for using force feedback in learning applications, the feedback provided by the users has stronger implications for our contribution than the quantitative results. While we did look into a simple example of using stroke-gestures, the results indicate that the computer-actuator mouse might also support more complex learning tasks (e.g., the tasks shown in the scenarios). This is also backed up by findings from the qualitative feedback.

Some participants pointed out that slower mouse movements could improve the comprehension of tasks. However, since the recording was replayed in real-time, this can easily adjusted by simply performing the task slower or reducing the playback speed post-hoc.

CONCLUSION

In this paper, we presented the design and evaluation of a computer-actuated mouse. We extend the mouse’s standard input capabilities with force feedback provided through the physical movement of the mouse and actuation of the mouse buttons. Through a technical evaluation, we investigate the spatial resolution of the device and show that users are able to distinguish different shapes.

In a study, we explored potential application scenarios for learning games and using applications. We found that participants especially appreciate serious applications and particularly complex 3D applications. In a quantitative assessment, we investigated the potential of the computer-actuated mouse to support the learning of mouse gestures. We found that participants value the feedback provided by the mouse compared to visual feedback.

The computer-actuated mouse is part of our research that aims to put humans and computers on par. The current mouse can only be used by the user to show things to the computer. We strive for devices that enable a smooth handover between the user and the computer on all levels of interaction. The computer-actuated mouse enables the computer to show things to the user not only visually but also through the physical input device.

Future work should explore further applications for computer-actuated mice. We are especially interested in using the device for users with special needs such as persons that are blind and stroke patients that could use the computer-actuated for relearning mouse handling. Furthermore, future work could tightly couple user and computer actuation. We envision, for example, to replace the snap function that today only affects the visual interface by a snap function that shifts the position of the mouse. The enabling of *clutching* and rotational movements can also add more functionality and further improve the overall user experience.

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