Titel/Title: An Interactive-Shoe For Surgeons: Hand-Free Interaction With Medical 2D Data

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An Interactive Shoe for Surgeons: Hand-Free Interaction with Medical 2D Data

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Abstract
During interventions, surgeons often need to review medical imaging data, e.g., CT scans. Usually, surgeons need to rely on an assistant to browse the images because of sterility requirements. Communication with a substitute operator is tedious and error-prone if the operator does not have an equal level of professional experience and might interrupt the workflow. We present a sensor-integrated shoe allowing surgeons to browse and manipulate 2D medical image data by foot movement. It is portable and wearable. The shoe uses an optical sensor taken from an off-the-shelf computer mouse for tracking the foot movements and an additional micro-switch to turn it on or off. We evaluated the performance of the shoe interface against a control condition with assistant together with eleven surgeons in an empirical user study. Our results provide first indications for the effectiveness of a shoe interface in this application area.

Author Keywords
Human-computer interaction; foot mouse; usability; 2D images.

ACM Classification Keywords
H.5.2 [Information interfaces and presentation (e.g., HCI)]: User Interfaces - input devices and strategies (e.g. mouse)

Figure 1: The inside of the shoe sole

Figure 2: The interactive shoe

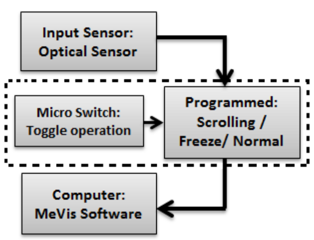

Figure 3: The general architecture of the interactive shoe prototype

Introduction

Modern surgical procedures are guided by a plethora of medical information. Digital data is the key for successful diagnosis and intervention planning. However, there exists an interaction gap when looking at input devices for pre-operative planning compared to the possibilities for intra-operative interaction [13]. In general, surgeons have access to innumerable amounts of digital data before a surgery to plan surgical interventions. Software tools support this planning by registering data from different sources [15]. During operation, access to these tools is severely limited. Often only a selection of images are defined beforehand and can then be browsed during operation by an assistant who goes through a complex 3D or 2D data set slice by slice acting on verbal instructions by the surgeon.

Communication with an assistant may become even more complicated when the assistant and the surgeon do not have an equal level of professional experience [10]. Graetzel et al. [11] illustrate a scene where an assistant follows the instructions of a surgeon and needs around seven minutes to click on the particular correct location on the screen. In such scenarios, it would be an improvement to provide the surgeon with a comfortable, precise, and sterile input device to manipulate and interact with visual data sets efficiently during surgery.

This paper presents a foot-based interaction device, an interactive shoe, which can be operated by surgeons to manipulate medical image data in a hygienic way.

Foot-based interaction is already used in some surgical procedures, e.g., dentists use foot pedals to control certain surgical instruments with their feet. The main advantages of using these systems are that the surgeons have direct control over many parameters of the surgical instruments, while their hands are free for the main surgical procedure. However, interacting with 2D images and manipulating them through this modality has not yet been fully explored [18, 12].

Related Work

During surgical procedures, surgeons usually need their hands to operate surgical instruments and tools. If they touch anything not completely sterile during and intervention, they have to re-clean and sterilize their hands. Therefore, hand-driven interaction using mouse, keyboard or touch-screen is often not feasible. In principle, this leaves voice, gesture or gaze interaction as potential options. While some studies show that speech recognition systems can be used under certain circumstances as input modality [2, 17], they are problematic if the Operation Room (OR) is too noisy. Other works have looked at hand gestures or gaze as input modalities [5, 8, 11, 9] but these input channels are also limited as they may conflict with the primary task of the surgeons if their hands are busy otherwise. The gaze is typically very hard to control without resorting to tedious methods like time-based thresholds for filtering unwanted interactions. Therefore, surgeons are often dependent on their assistants to navigate visual data indirectly during surgery.

While using the feet for human-machine interaction is well established in many areas, e.g., for driving vehicles or digital music controls, in human-computer interaction (HCI), foot interaction is still largely unexplored, even though it has been proposed already in the the early days of HCI [6, 7]. Some mediated sensing commercial products such as large trackballs [14], the Nintendo Wii Balance Board [16], or the BiliPro Foottime Foot-Mouse [1] have been developed but none are suitable to be employed in the OR. A different device, the so-called Shoe-Mouse, was designed foremost as a platform to collect data from foot movement [19] but a

Figure 4: The dummy box as used in the study

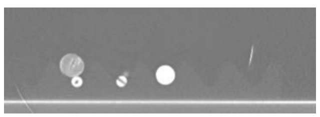

Figure 5: A screenshot of a 2D CT scan slice

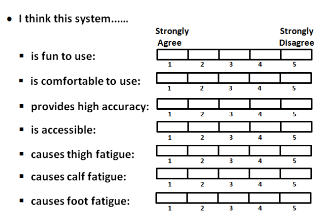

Figure 6: The likert-scale post task questionnaire

similar setup could also be tested in the context of surgery. Díaz et al. [4] developed a foot pedal that provides real-time feedback through the foot, for example, tactile warning cues to support the surgeon during robotic surgery. Velloso et al. [18] provided a survey and general characterization of foot-based interaction. They investigated the interaction possibilities of the lower limbs and found that foot-interfaces complement and assist the hands rather than replacing them. Additionally, they explored the possibilities of reassigning pointing devices from the hands to the feet and found that the mouse consistently performs better than other foot-based interfaces.

Interaction Design and Concept

Our goal was to design an interactive device that is self-controllable, less complex, comfortable as well as precise and by which surgeons can easily access the desired 2D image data, e.g., MRI or CT scans, during an operation. For this, the pose of the user (sitting, walking, and standing), the available input senses of the lower limbs (intrinsic, extrinsic, and mediated), and the degrees of freedom of movement of the three joints of the lower limbs (the ankle, the knee, and the hip) needed to be considered during the design phase [18]. Moreover, surgeons also suggested to incorporate functionality similar to the scroll-wheel of computer mice to interact with 2D CT images.

With these design considerations in mind, in this paper, we introduce an interactive shoe, a prototype of a shoe-based mouse based on the optical sensor system of an off-the-shelf computer mouse. We use the free scripting tool AutoHotkey[1] to map the shoe-mouse input to control commands for a medical image viewer. We used foam rubber to manufacture a special shoe sole to properly integrate the sensor in a safe and reliable way.

[1] https://autohotkey.com

The sole was shaped with a laser cutter, which allows for computer-aided construction and customization of the prototypes. Figure 1 shows the shoe sole and Figure 2 shows the complete interactive shoe. To protect the device from the bend of the toes and the pressure of the heel, we integrated the wireless computer mouse in the middle of the shoe sole. Additionally, we embedded a micro switch on the side of the sole to toggle the three states of the mouse: left-click, scrolling, “freeze”. Considering statistics about the average size of shoe of the German population (male and female), we constructed prototypes for the European/German shoe sizes 39, 42, 44, and 46. Using an off-the-shelf surgical sandal the sensor-integrated shoe sole is attached with a strong velcro-tape, which allows to safely attach and remove the sole.

Hardware and software design

The general architecture of the interactive shoe is shown in Figure 3. The prototype consists of three subsystems: (1) The interactive shoe with an optical sensor and micro-button as an input device, (2) a software application processing the input signal and controlling the functionalities (left-click, scrolling, freeze). The scrolling speed is correlated with the speed of moving the interactive shoe, and (3) a medical visualization software for displaying medical images, which is a custom-built application based on MeVisLab[2].

Experiment Design and Methodology

A use case-study was carried out to evaluate the performance of the interactive shoe. The focus of this study was to provide a proof-of-concept and investigate the principle feasibility of the approach. The study design was inspired

[2] MeVisLab is a framework for developing medical imaging applications and used in a number of commercial and research projects: https://www.mevislab.de

Method Setup

Method 1: The Interactive Shoe
The user stands in front of the table wearing the interactive shoe. The task is to remove the small wooden ball that is hidden beneath one of the big balls. The user sees the 2D computerized CT scan images, while scrolling up or down by dragging the interactive shoe on the floor to detect the hidden small ball in the images.
Possible actions with the interactive shoe:

- For scrolling up: move foot forward
- For scrolling down: move foot backward
- To activate the scrolling command: press the micro-button of the interactive shoe
- To freeze the screen: press the micro-button of the interactive shoe

Method 2: Assistant Control Computer Keyboard Method 2 has the same setting as method 1. In this case, the user stands in front of the table without wearing the interactive shoe. The same tasks are performed by verbally instructing a human assistant to scroll up or down the slices to see the desired image.

- For scrolling up: user says 'up'
- For scrolling down: user says 'down'
- To freeze the image: user says 'stop'

by clinical work flows and focused on the elemental task of browsing medical image data, which is relevant to clinical settings. We were interested in how well users could manipulate the visual representation while trying to reach a certain view on the data, and we wanted to compare the required effort within the limited acclimatization time.

Again, the experimental design was motivated by the surgeons' need for independent and efficient interaction with medical image data during interventions. Therefore, we designed a task that required users to select a 2D image (slice) from a CT scan data set using the aforementioned custom-build visualization software (a basic medical image viewer) and the interactive shoe.

To provide a repeatable and well-defined task and to generate a well-controlled CT data set and limit potential biases due to the different experience levels of participants, we designed and scanned a dummy box made of Styrofoam containing balls of different colors and materials, i.e., fluffy balls, wooden balls, and Styrofoam balls. During the case study, this dummy box was placed on the tabletop, and its surroundings were covered with a piece of green cloth as shown in Figure 4. The task of the users was to remove the small ball, which was hidden beneath one of the big balls by using the information of the CT scan data of the dummy box presented on a screen.

The study included two conditions that only differed in the way the CT data could be browsed: (Method 1) Using the interactive shoe and (Method 2) relying on an assistant to browse through the slices (Assistant Controlled Computer Keyboard; ACCK). The participants performed three repetitions for each condition using three different setups of the dummy box.

The concept behind this experimental task design is that surgeons mostly look for specific orientations and they try to match the orientation of the 2D image data as closely as possible to a desirable target orientation, e.g., matching the current orientation of the patient as closely as possible to help them to acquire an accurate mental model of the current situation to proceed with the intervention.

The study was conducted with eleven surgeons (10 male, 1 female; mean age 44.5 years) of two hospitals in Germany. Surgeons had between 5 and 30 years of experience. The participants had no known disorders. With the exception of one surgeon they had no prior experience with foot-based interfaces. While they were informed about the general procedure and task at the introduction (informed consent) they did not know the specific hypothesis underlying the experiment. All participants were right-footed as no left-footed participants volunteered for the study. Each participant signed a consent form and demographic information before the start of the experiment. As mentioned above, they had to perform the same tasks under two different conditions (within-subjects design). The order of conditions was pseudo-randomized by alternating the starting condition across participants and the three tasks were presented in random order for each condition.

The participants were allowed to have a short training period before starting each condition so they could familiarize themselves with the devices and the environment. Images were presented on a 32" monitor placed on an otherwise empty desk. A Lenovo Thinkpad T410 laptop was used to record user task completion times, activate the interactive shoe functionality, and run the visualization software. A video camera and a webcam were used for recording the user performance. The video camera captured facial expression and the webcam captured foot movements. The whole task performance was also recorded

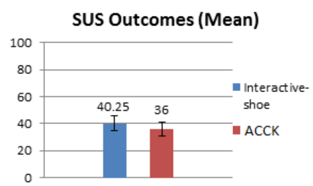

Figure 7: Mean ± SE SUS scores

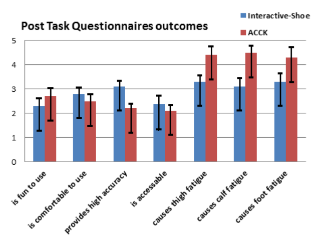

Figure 8: Results of the post task questionnaire (Mean ± SE)

	Interactive Shoe
CT scan 1	65.74
CT scan 2	41.5
CT scan 3	45.75
Mean	51.01

Table 1: Task completion times for the interactive shoe

	ACCK
CT scan 4	61.17
CT scan 5	41.2
CT scan 6	48.85
Mean	50.41

Table 2: Task completion times for ACCK

using the free screen capture video software Ice Cream Screen Recorder[3].

To measure general usability, we recorded task completion times and collected subjective feedback after each condition with the System Usability Scale (SUS) [3] and additional custom Likert-scale questions presented in Figure 6.

Results and Discussion

The SUS questionnaire outcomes are presented in Figure 7. The interactive shoe has scored 40.25 points on average and the ACCK average score is 36 points, i.e., in absolute scores the interactive shoe achieved a slightly higher usability rating by the participants in our experiment than the control condition.

The results of the average task completion times are presented in Tables 1 and 2, which indicate that both methods achieved comparable completion times during our experiment.

In terms of qualitative feedback, surgeons remarked that the proposed device is independent, easy to handle and quite comfortable to operate. This is in-line with the results of the post task questionnaire presented in Figure 8. They also stated that they would expect it to be more convenient during an actual operation because of being able to review the CT scan data more often. However, the participating surgeons also felt that scrolling using the prototype was too fast and hard to control. A paired t-test has been used to test for significant differences between the two groups. The result of the t-test for SUS ($F_{2,9}, p < 0.64$) revealed no significant difference as both conditions achieved comparable usability ratings.

The participants specifically appreciated the micro-switch outside the sole, which was also used to toggle activation to avoid accidental unintended inputs.

[3]https://icecreamapps.com/Screen-Recorder/

Conclusion and Future Work

In this paper, we presented a foot-based input device for intra-operative interaction with 2D image data while the surgeons' hands are occupied. The main motivation of the proposed device is to give surgeons a comfortable, precise and independent device. We conducted a user study with surgeons taking qualitative and quantitative measures for general usability. However, as the prototype is still in an early stage, our results provide only a first indication of the potential of foot-based interaction in the OR. In addition to general improvements of the prototype, e.g., smoother tracking and options to personalize the mappings and sensitivity of controls, we are working towards evaluating the device in a real-world setting inside the OR.

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