Prototyping a Chest-worn String-based Wearable Input Device

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Abstract

In this paper we describe a novel wearable interaction device that is based on the principle of a badge reel often found in corporate environments. Our prototype devices are composed of hardware components from an ordinary off-the-shelf game pad. Preliminary results of a user study, conducted in the first prototyping cycle, showed that the device concept allows for a more accurate and intuitive interaction than an ordinary game pad when performing navigation tasks in a three-dimensional information space. Furthermore, the study suggests that device operation requires minimal attention demands due to provided tactile feedback cues when maneuvering the retractable string. Finally, the paper discusses lessons learn from the first prototyping cycle and presents the modified device after the second prototyping cycle.

1. Introduction

Wearable computers should support their users during a primary task while the interaction with the wearable computer is only secondary. Such dual task situations call for interaction designs that require minimum effort to control the computer. Therefore, the design of interaction devices for the wearable computing paradigm is a challenging task that usually requires the device to be unobtrusive, robust, and easy to use in a dual task scenario without imposing significant attention demands [8].

Badge reels, attached to the belt, are very popular in corporate environments because they provide a small and intuitive to use mechanism to access, for example, an employee's personal RFID card frequently needed to pass security checks. The retractable string of a badge reel, which can be attached to arbitrary objects, provides an approach to move an object in a three dimensional (3D) but restricted space in front of the body. The force originated by the spool where the string is wounded up on, provides some tactile feedback that makes the interaction with the badge reel compelling without forcing users to spend much attention on the device itself.

Inspired by these badge reels we designed and prototyped a wearable input device that makes use of a retractable string to control various applications. The device is meant to be chest-worn on the users' body. The string can be pulled out of the device and moved in various directions in a spherical coordinate frame. Our two prototypes presented in this paper are composed of different hardware components from off-the-shelf game pads and special mechanics to combine a retractable string mechanism with the game pad hardware.

1.1. Outline

The remainder of the paper is structured as follows: Section 2 reviews related work to the envisioned interaction device. In section 3 we describe the interaction concept of the envisiond input device with a retractable string. While section 4 describes our first prototype device including a preliminary user study to gain first insight on interaction accuray and speed, section 5 discusses lessons learn from the first prototype and presents the modified device after the second prototyping cycle. Finally, section 6 concludes the paper and presents future work.

2. Related Work

Quite a lot work on managing user input in wearable computing with gesture input has been documented so far (e.g., [4],[7]). Here, distinct gestures are usually needed to execute application commands. In [10] an approach was shown that combined different gestures by using the chording principle to provide an approach for gesture-based text input. Similar approaches for wearable keyboards are known, too [5].

Little work has been documented on string-based interaction. Vickers [9] and Vectorix [3] both use strings to mechanically track objects. Rantanen et al. [6] intoduced the Yo-Yo user interface. Their user interface consists of a hand-held display connected with a retractable

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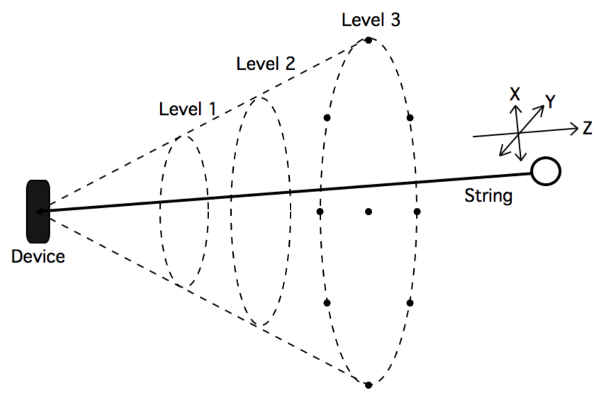


Figure 1. Cone-shaped interaction space with a retractable string.

string to the clothing of the user. The winding mechanism as well as an optical encoder are embedded into the clothing. With this setup users can change between different menus on a graphical user interface by moving the hand back and forth or squeezing the display to select a menu item. Due to the optical rotation encoder the device can only track positions in an one-dimensional space, i.e. the distance between the device and the winding mechanism.

Blasko et al. [2] presented a string-based interaction technique for dual-display mobile devices. Their device was wrist-worn and occupied both hands during interaction. The prototype uses optical 3D tracking technology, external to the spool enclosure, to track the string in a polar coordinate frame. Our functional prototypes neither requires sophisticated optical tracking techniques nor do they occupy both hands, but can still track the string position in a spherical coordinate frame.

3. Device Concept

Considering the principle of a badge reel with its retractable string, one can pull and move the string arbitrarily in space as long as the limit of the string length has not been reached. Once pulling force on the string is released the string is automatically retracted. In order to design an interaction device based on this principle, two limitations have to be taken into account. Firstly, there is a limit that belongs to the mechanical concept of a badge reel, i.e. the length of the string. According to the size of a standard badge reel the string length is limited to approximately 25 cm. Secondly, there is a certain limit for the mobility of the human arm and how it can be moved in front of the body when controlling a chest-mounted device.

These two limitations as well as the desired mounting position on the chest, were the major constraints for our input device design. Given a vertical mounting position, a retractable string of an input device would span a kind of cone-shaped space for interaction once being pulled out of the device in front of the body (cf. Figure 1). Since the cone-shaped space is basically due to the retractable string pulled away from the body, this space could be fragmented into different polar coordinate frames each assigned to a certain length the string is pulled out of the device. For example, for every 10 cm the string is pulled, a new virtual polar coordinate frame could be defined. The advantage of this fragmentation is that different mappings between the current position of the string in space and various operations to control an application could be defined.

Considering usability and ease of use of the new input method, there is likely a maximum number of different areas a string can be positioned on each polar coordinate frame to be reasonablely usable. Along with an increasing number of reachable areas the attention demands would be higher. According to this the motor skills for interaction will be difficult.

Although—in theory—there is almost no limit to the number of polar coordinate frames assigned to a certain distance the string is pulled out of the device and the number of different areas in one coordinate frame, we decided to use three different coordinate frames with nine different areas the string can be located in. This decision was confirmed by one of our pre-studies where subjects mentioned that with a given maximum length of 25 cm for the string they could easily manage to use three different coordinate frame but each additional was very difficult to use.

For our interaction concept, we designed our device prototypes so that every 8 cm the string is pulled out of the device a next level with a virtual polar coordinate frame is reached. Figure 1 depicts this approach. In summary, our interaction approach includes three levels. On each level we defined nine different areas, which we deemed to be easy to separate from each other by users. Hence, our interaction design allows for 27 (3 x 9) different actions to be triggered with the device.

4. First Prototype

For our first prototype we fragmented an off-the-shelf Saitek P880 game pad. The circuit board and both potentiometers were arranged in a plastic box with a dimension of 9x11 cm. Figure 2 shows this first prototype.

The first potentiometer was attached in the middle of the box on the left side. It is used to measure the position of the string within the two-dimensional polar coordinate frame. Thus, we utilize both axis of the potentiometer to determine the position by the values of the x- and y-axis. The second potentiometer on the bottom of the box was used to mea-

sure the distance the string is pulled out of the device. For this, only one axis of the potentiometer is used to measure the z-axis, i.e. the position in our cone-shaped space.
To measure the distance the string is pulled out, we had to design special mechanics that allowed us to drive the potentiometer dependent on the amount the string is pulled. Our mechanism guides the string in a zick-zack (yellow marker) style through the first potentiometer. Thus, pulling the string is recognized by the second potentiometer. The measurement gathered from the potentiometer allows to derive how far the string is currently pulled out of the device.
Finally, we attached at the very end of the string a ring that should make it easy to grab the string with the hand and eases its handling. The ring itself features a button that users can press to trigger an event, e.g., a selection. Getting access to the data provided by the game pads potentiometers and the button located on the ring, we used a special joystick library[1] available for Java. This library allowed us to open a joystick handler and to register for callbacks of our device.

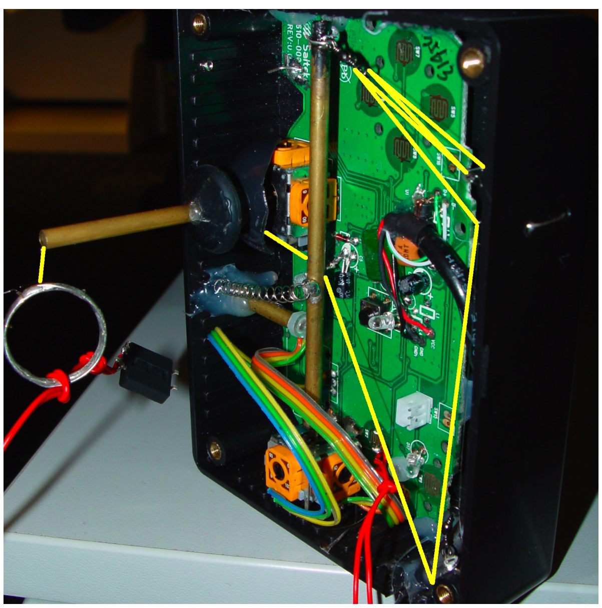


Figure 2. First prototype of the retractable string device with "zick-zack" mechanics.

4.1. Preliminary User Study

Our first preleminary user study compared our first prototype with an ordinary game pad. We assumed that by us-

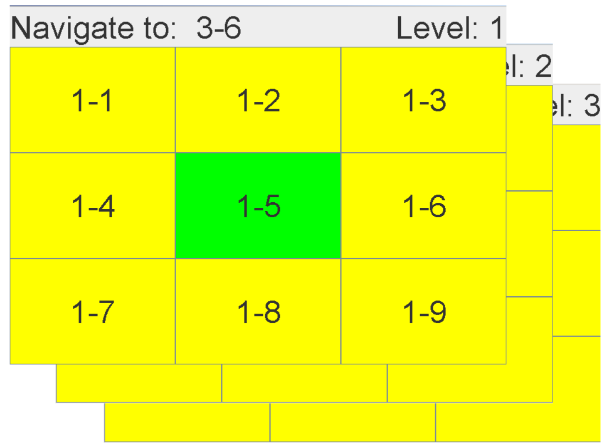


Figure 3. User interface representing the navigation task in 3D space.

ing the novel string-based device subjects will already accomplish given navigation tasks with higher accuracy compared to our baseline game pad, which was a Logitech Wingman Rumblepad.

4.1.1. Study Setup We tested ten users recruited from students of the local university and university unrelated people with an average age of 30.8 years. All subjects were screened not to be colorblind. The study uses a within-subject design with the input devices as the single independent variable. Users were divided into groups where the order of devices differed. Five subjects started with our base line game pad before they performed the studie's navigation task with our string-based prototype device. Subjects of the second group started the test with the string-based prototype and continued with the game pad.
Before running the actual experiment, subjects could experience both devices as well as how they are supposed to handle given navigation tasks for about 30 seconds. After this period we continued with the experiment where the number of given tasks users had to perform as well as their achieved error rate were recorded. The time for each device was limited to 5 minutes in which subjects were requested to do as much as possible tasks without neglecting accuracy. To include the mobility aspect of wearable applications, subjects were requested to stand in front of a TFT-Monitor that shows the navigation task.

4.1.2. Visual Interface We created a graphical user interface representing our navigation tasks. The interface was designed to allow interaction in a 3D information space. The user interface consisted of three different panels. Each panel, which represents a certain level of our interaction approach (cf. section 3), has nine buttons aligned in a grid similar to a mobile phone keypad. Each button features a unique

1 http://www.cybergarage.org/vr/device/joystick/java/

label consisting of the level number (1-3) where the button is located on, followed by the number of the button itself (1-9).
Figure 3 shows the graphical user interface. An indicator in the right top corner of the interface shows the current level the user is at. Also on top, but aligned to the left, the navigation tasks subjects are requested to navigate to are presented. A green color was chosen to visualize the current position of the cursor.
Pressing the button located on the ring of our string-based device selects the current button as the answer for the task. To answer a task with our game pad the right fire button was used. Once a button has been selected the system immediately generates a new navigation task. A new task is a randomized button label to be found on one of the three levels of the interface. For our string-based prototype the current level can be changed by pulling or releasing the string. For the game pad this is done with the right analog joystick.

4.2. Preliminary User Study Results

Although the conducted experiment was rather small in terms of time and number of subjects, the preliminary results confirm our hypothesis that subjects answered navigation tasks with higher accuracy with our prototype device than with the game pad.
The average number of accomplished tasks with a game pad was about 22% higher than with our string-based device. An ANOVA showed that this difference was significant (F= 10,61; p<0.004). From our post-hoc interviews we learned that all subjects mentioned that they felt more familiar with the game pad than with the new device, providing one possible reason why they accomplish more tasks with the game pad then with the novel device. Figure 4(a) shows the average accomplished tasks.
To verify our hypothesis that subjects answered navigation tasks more accuratly, we calculate a single factor ANOVA for our average error rate metric. It showed a strong significant (F=19,16; p<0,001) difference between both input devices. Subjects did two times more errors with the joy pad (11,31%) than with the string-based device (5,42%), supporting our hypothesis. Figure 4(b) shows the average error rate metrics.
These early results suggest that the interaction concept implemented by our first prototype likely offers a rather accurate but slow interaction. Since user interfaces for wearable computers are relatively simple in sturcture and design compared to desktop or mobile interfaces [11], this is not critical in general. The following section will, however, present a second prototype designed to improved limitations of the first prototype and to make interaction faster and compelling.

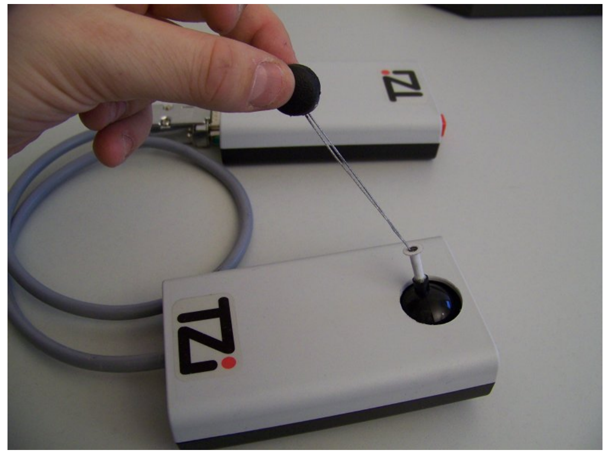


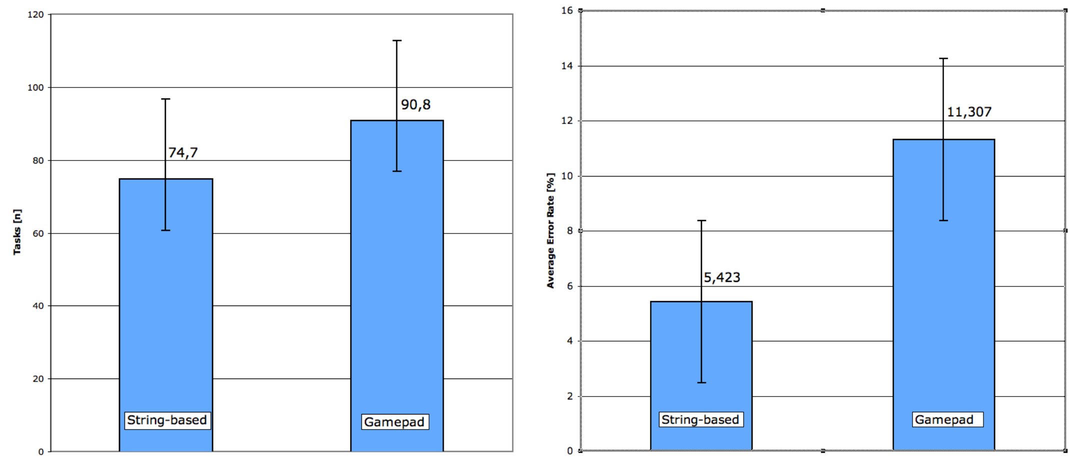
Figure 5. Second Prototype.

5. Second Prototype

5.1. Lessons learned

Studying the use of our first prototype, we identified some possible improvements to increase usability. Most imporvements that we derived from our user study to optimize usability are technical nature:

- **Trigger button at the end of the string**
  Our first prototype featured a trigger button attached to a metal ring at the very end of the retractable string. The button was connected with two seperate wires to the electronics of the device. Most users were distracted by this ring/button combination and reported problems grapping the string as well as pressing the button quickly. Some users even got stuck with there thumb in the ring.
- **Mobility when using the device**
  Another issue we discovered was the limited mobility of users when using the device during our experiments. The first prototype was not wireless but required a fixed USB cable connection with the computer. Since the device was meant to be connected to the personal wearable computer a user is carrying, this was not a mayor problem. However, a wireless version would reduce the overall number of cables needed by a wearable system, thereby increasing usability and reliability of the entire setup.
- **Weight of the device**
  The first prototype was integrated in a single box to be mounted onto the chest. From our observaitions during the experiments we could derive that users had problems with the weight of the box. The weight caused the box to move. Furthermore, users reported that the de-



(a) Average acomplished tasks.

(b) Average errors of answered navigation tasks.

Figure 4. Preliminary Results.

vice was uncomfortable to wear and difficult to mount on clothing users were wearing.

5.2. Technical Setup

The second protoype of our input device is shown in Figure 5. Like discussed above, we reduced the weight of chest-worn device by seperating the core electronics from the mechanincs of the winding mechanism. The second prototype consists of two different boxes connected with a Sub-D HD 15 pin cable to each other. The new second box is equiped with our core electronics, taken from a wireless Thrustmaster Run'N'Drive Wireless Rumble Force[2] gamepad, and a force feedback motor. The electronics of the new gamepad offer the possibility to implement a wireless communication (15 meter range) with the wearable system, helping us improving the users mobility during interaction and reducing the number of needed cables. Since wireless communication comes along with increased power consumption, we had to pay attention to battery life-time of our second prototype. The current battery life-time of our new device is approximatly about 120 hours with two 1.5V mignon cells. This long life-time is possible, because of a suspend mode that is used after two minutes of inactivity, i.e. no interaction. The device will automatically return from suspend mode and reconnects itself to the wearable system once a button is pressed or the string is pulled.

To let the user know the status of the input device, we integrated two LED's (cf. Figure 6). The yellow LED indicates the power status of the device. Once battery is low, the LED starts blinking. Then, either batteries have to be replaced within the next 30 minutes. or an external power suply has to be connected. The green LED on the right side of the device is used for the status of the wireless connection. Although wireless connection is usually automatically estabilished, we integrated another button to manually force pairing, e.g., to recover from connection failures.

Figure 6. Control Unit Status Indicators.

The chest-worn box contains the mechanics needed to implement our envisioned device concept. Similar to our first prototype we used one potentiometer to track movements of the string in the two-dimensional space. Figure 7 shows the new mechanics. In the upper part of the box we fixed the potentiometer. On top of it, the new trigger button can be seen that replaces the button/ring approach. A little button was integrate into a silicon mass to improve its grip so that it can be easily graped by users. Users no longer have to care about how they hold the button and the ring. By squeezing the silicon mass the button will be triggered. To connect this button to the electronics we used a special conductive yarn from Statex [1]. Two threads of this yarn are needed to drive the button. Figure 4(b) shows the new string composed from the conductive yarn. Both threads are attached to an ordinary badge reel, located on the right side in the chest-worn box (cf. Figure 7). The badge reel provides the

2 http://www.thrustmaster.com

winding mechanism to retract the threads. To recognize the length the string is pulled out of the device, we connected standard mouse wheel electronics to two button interfaces of the gamepad electronics. Finally, we integrated another small force feedback generator into the chest-box to be able to generate tactile feedback during interaction also at the users chest.

Figure 7. Second Prototype, chest box.

6. Conclusion and Future Work

We presented a novel string-based input device for 3D space navigation. Our prototypes were composed from off-the-shelf gamepads. A preliminary study showed that users could already achieve higher interaction accuracy with the first prototype of our input device than with a baseline standard game pad for our tested navigation tasks. Navigation was more accurate and intuitive compared to the conventional game pad but slower. In a second iteration the first prototype was improved based on our user study findings. The second prototype was especially designed towards better weight and mobility during interaction. Besides optimizing winding mechanics, conductive yarn was used to build the string. To increase user feedback options, force feedback generators were integrated in both modules. Finally, the second prototype features a wireless connection between the interaction device and the computer system.

Future work includes the enhancement of the prototypes usability by making use of, for example, the newly available feedback mechanisms during interaction. Furthermore, an in-depth user study for the second prototype with a larger number of participants is amonge the next steps. We also plan to extend our user study beyond navigation tasks by investigating the possibilty of text input with the device. While doing so, we like to compare our string-based input device with other wearable computing devices for text input like, e.g., the Twiddler [5] chording keyboard or the approach presented in [10].

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