

Evaluating of Wearable User Interfaces: How to Simulate a Primary Manual Task?

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Abstract. We introduce an apparatus capable of simulating real-world primary tasks typically encountered in wearable computing. The apparatus allows for controlled and reproducible primary task simulations in laboratory experiments while retaining the properties of wearable computers being used in mobile environments different from the desktop. The paper discusses the construction of the so-called HotWire apparatus including available software. The software helps to conduct user interface studies with the HotWire where the application domains' primary task is characterized by manual work. Moreover, we provide guidance on how the HotWire can be used by researchers for their own studies on wearable user interfaces and dual-task interaction design.

1 Introduction

Wearable computing typically expects users to accomplish two different tasks – a real-world primary task involving physical actions and mobility, and a secondary task of interacting with the wearable computer. Examples for such dual-task situations are airplane technicians accessing blueprints in a head-mounted display (HMD) while simultaneously working on the corresponding part of the aircraft or assembly workers receiving audio guidance while assembling parts of a car.

When conducting user interface evaluations of a wearable system for such scenarios, a major challenge is the simulation of typical real-world tasks under laboratory conditions [1]. Here, laboratory experiments are not only preferred due to an often limited access to industrial facilities or the real end-users of an application, but because they offer controllable and reproducible conditions [2, 3]. For instance, changing light conditions or randomly changing levels of environmental noise may significantly effect the outcomes of studies testing different input and output modalities if they appear without any control by the experiment leader. Another important aspect is the abstraction from real world tasks that are needed for a laboratory experiment. Previous studies [4, 5] demonstrated that by introducing more realistic wearable computing tasks many findings known from stationary and mobile computing can be confirmed, while at the same time new findings can be uncover. This suggests that there are inherent differences between wearable and stationary or mobile computing due to its specific kind of mobility and the physical primary tasks typically performed by users.

This paper introduces the so-called “HotWire” apparatus as well as its construction. It offers an approach to simulate primary manual tasks in a laboratory environment, while retaining the characteristic properties of wearable computing and their application domains.

2 Related Work

Research methods applied in the field of mobile human-computer interaction (HCI) are manifold [6]. However, for conducting studies for user interface evaluations, laboratory experiments are often chosen as they are highly replicable and facilitate good data collection under controlled conditions (e.g. [2, 3]). In [7], for example, McFarlane presents the first empirical study of all four known approaches to coordinate user interruption in HCI with multiple tasks. The study concerns how to interrupt users within the context of doing computer work without increasing their cognitive load. The method applied in the laboratory experiments was based on a simple computer game that requires constant user attention while being randomly interrupted by a color and shape matching task. As a continuation of McFarlane’s original interruption study for the scope of wearable computing, in [8, 5] a HMD was used to display the matching tasks to measure the effect on performance and preference. Although this work was able to relate HCI findings to wearable computing, the conducted experiments only used virtual primary tasks, which are uncommon in wearable computing. In [4, 1] it has been shown, however, that by introducing a real physical primary task instead of an virtual one, outcomes of experiments differ, suggesting that having a physical primary task that more realistically encodes the specific properties of wearable computer usage can uncover aspects that virtual tasks are not able to.

3 Properties of a Primary Task Simulator

For simulating primary tasks typically found in wearable computing applications, a reasonable approach is to abstract from a concrete physical tasks of an application domain in a way that the original properties of the task are retained. Once having found such an task abstraction, tasks can be carried out in a laboratory environment that is fully controllable throughout a user study. To approach such a system, we wanted in particular a system that fulfill at least the following requirements:

- **Real physical task abstraction**

Primary tasks in wearable computing are often of physical nature, i.e. tasks require users to work with their hands on real world objects while being mobile (e.g. assembly or maintenance tasks). A task abstraction has to simulate such activities and should demand some form of motor and kinesthetic effort to accomplish the task.

- **Easy to learn**

The system has to be easy to learn by users to reduce errors in the experiment data due to a misunderstanding of the experiment setup. The time to

make the user proficient and fully trained should be short enough to make a practice period just before the actual experiment sufficient, so that the user's performance will remain even throughout the study.

– **Adaptable to different simulations**

To allow the simulation of different primary tasks with different characteristics, the system has to be reconfigurable. In particular, the simulation of different body postures users would typically be engaged in their real world application domain should be possible and easy to model.

4 Construction of the HotWire Apparatus

The HotWire apparatus was designed to meet the requirements discussed above. It allows for simulating a real world physical task in a controlled laboratory environment and is easy to learn. The idea of the apparatus is inspired by a children's game used to train their motor skills and is known as "The hot wire". It consists of an intricately bent metallic wire mounted on a base plate, and a hand-held tool with a metallic ring. The idea of the game is that a person has to pass the ring from one end of the wire to the other without touching the wire.

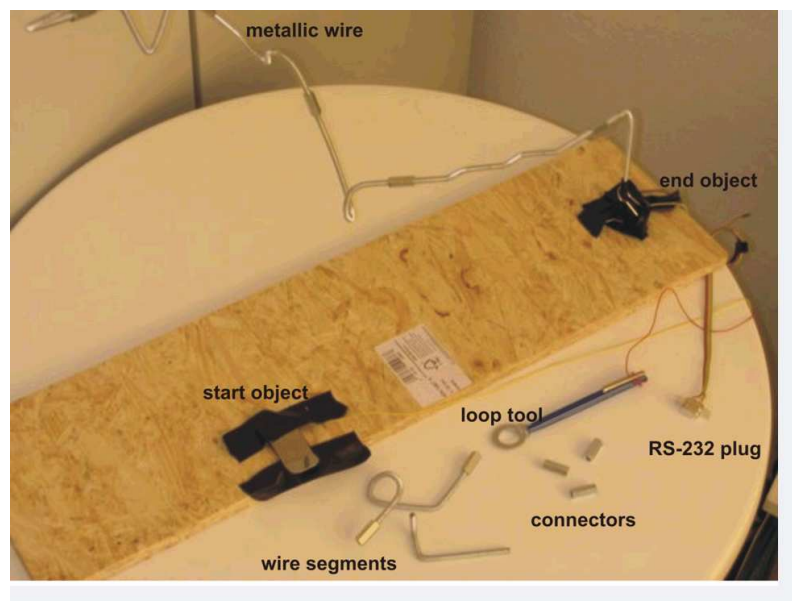


Fig. 1. First Prototype of the HotWire Primary Task Simulator

Figure 1 shows the very first prototype of the HotWire apparatus as well as all needed parts to build it. To start the task the user has to touch a special metallic

object attached to the base plate (start object). Then, the user has to pass the ring from the open end of the metallic wire to the other end that is attached to the base plate. At the very end of the wire the apparatus features another metallic object that indicates the end of the game when being touched (end object). The wire itself is constructed out of differently shaped smaller metallic segments. Each of the segments is connected via special screws to another segment and allows the difficulty or characteristic of the primary task to be varied by replacing or changing the sequence of connected segments.

4.1 Technical Setup of the Apparatus

The technical setup of the apparatus is relatively straight forward. For automatically measuring beginning, end, and errors being made during the task, i.e. the number of contacts between the metallic ring of the tool and the metallic wire, with a computer, we connected the start and stop indicator objects, the tool, and the metallic wire itself to a RS-232 serial connector.

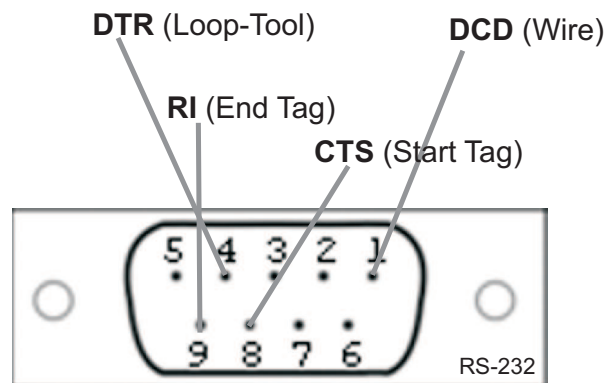


Fig. 2. Connection scheme to connect the HotWire to a serial RS-232 connector.

For detecting errors the carrier detect (DCD) pin of the RS-232 connector is connected to the metallic wire. The clear to send (CTS) pin is connected to the start object and the ring indicator (RI) pin to the stop object. Finally, the data terminal ready (DTR) pin is connected to the ring tool (see figure 2). Each time the ring tool touches one of the other components an electrical circuit is closed and can be detected by software listening on different state changes of the serial port connection. Note, that there is no additional power source needed to run the HotWire. The provided power of the serial RS-232 hardware interface is sufficient.

4.2 HotWire Monitoring Software

Special simulation software written in Java has been implemented to monitor user performance of the HotWire task and to support data collection during user studies is general.

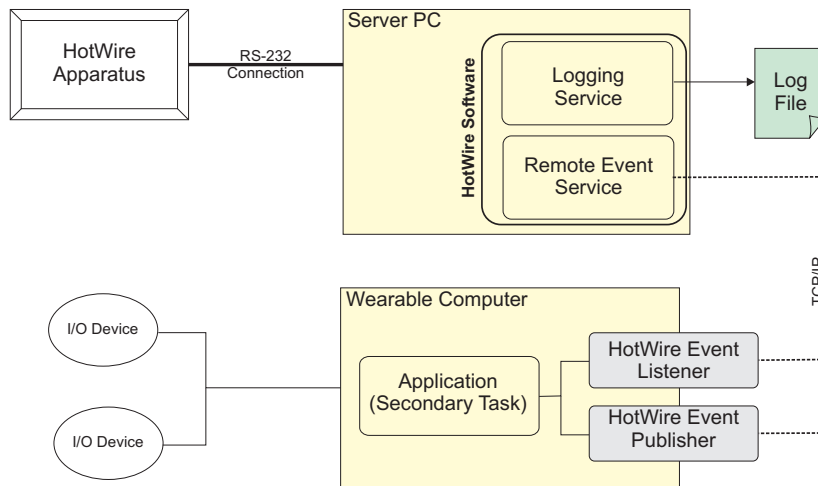


Fig. 3. Software

Figure 3 shows an example how the HotWire software can be integrated in an experiment setup. A stationary computer (Server PC) is connected to the HotWire apparatus and runs the HotWire software. The wearable application (Secondary Task) that should be evaluated within the user study is running on a separate wearable computer and features a network connection to the server. To communicate with the server the wearable application uses special handlers, provided by the HotWire software, to publish and listen for events.

The HotWire software consists of two main services that implement basic logging and remote event dispatching functionalities:

Logging Service The *logging service* records all data (coming from the HotWire apparatus) that is of value for a user study. For instance, the time needed by a user to complete the track or the number of wire contacts being made by the user. Besides logging HotWire events, the service also provides an API for logging custom events, e.g., coming from other software component; offering a mechanism to centralize all log messages of a user study. Because wearable computing applications are often composed of different distributed entities, the logging service is able to handle logging information from remote devices by utilizing an *Event Publisher* that is part of the *Remote Event*

Service. For easier post processing, all recorded data is written to one log file per user at the end of each session.

Remote Event Service As already mentioned, wearable applications are often distributed. The *Remote Event Service* provides an extensible plug-in architecture for arbitrary remote event dispatching. Other software components can access HotWire logging event data during runtime by using the *Event Subscribers*. For this, a publisher-subscriber design pattern has been implemented. If software components are running on the same system, direct function calls are used for event delivery. However, if components are distributed but connected through a network infrastructure, the remote event service also offers a plug-in for TCP/IP based event dispatching.

Note, that the developed software is currently available upon request from the authors and will be made available for download over the internet soon.

5 Modelling Primary Tasks with the HotWire

Although the HotWire apparatus has been designed to meet a broad range of different primary physical tasks, that involve to some extent manual work with the hands, the HotWire's metallic wire shape often needs to be changed to realistically model a certain real world task.

There are many methods that can be used to analyze application domains regarding characteristic user tasks that could effect the usability of an application or its interface. These include, for example, techniques like observation or work place studies (see e.g. [9, 10] for an overview). When conducting studies with the HotWire apparatus, the following properties of a physical manual task to be abstracted are important:

- **Visual Attention Demands**

Most manual task require some form of visual attention, i.e. vision is needed by humans to close the hand-eye coordination feedback loop to accomplish the task. Because visual attention is focused and cannot easily be divided on different task, humans can only actively change attention to a secondary task, which produces some load [11]. In industrial applications most primary task demand some kind of visual attention, for example, to assemble an engine. In theses situations, it is not always easy also accomplish a secondary task that requires technicians to draw attention away for the primary task.

- **Cognitive Demands**

Even though required cognitive demands of a task are strongly coupled to the individual human performing the task and its experiences with it, tasks can still be rated as being more cognitively demanding than other.

For example, a task requiring any kind of memory to be successfully accomplished is likely to be more demanding with respect to cognitive demands than a task that requires no or even every day knowledge to be accomplished.

– Locomotor System Demands

Locomotor system demands describe how physically demanding a certain task is. For example, some task require humans to bend down, crawl into narrow corridors, or simply continuously move over short distances. All these activities produce load on the locomotor system and can have an impact on the performance or general feasibility of a secondary computer task

5.1 Modifiable Parameters of the HotWire Apparatus

To model a certain primary manual task with the HotWire, there are three different parameters that can be changed: By modifying or replacing the *wire segments* used to build the metallic wire track, a wide range of characteristics can be modelled. Moreover, the used *diameter* of the wire and the ring of the tools can be varied as well.

Tasks that require visual attention and cognitive effort to accomplish can be modelled, for example, with wire segments that are intricately bent, i.e. where it is difficult to pass the ring over the wire without contacts. In particular, to model visual attention demands only, the track has to be modelled so that it is only difficult to pass the ring over the wire but not requires the user to think about a solution on how to move or hold the tool to pass that section. In the latter case, also cognitive demands would be raised.

Additionally, by changing the diameter of the tools ring, high or low visual attention demands can be modelled as well. Reducing or increasing the diameter of the ring for a given wire diameter, increases visual attention or reduces it respectively. In combination with an intricately bent wire segment the diameter of the ring can also be used to raise cognitive demands.

Tasks that force people to adopt different body postures to accomplish them can only be modelled by looking at the overall shape of the wire track. To model such tasks, the overall shape of the metallic wire track has to be analyzed. Here, however, the detailed forming of the wire strongly depends on the certain postures to model. For example, to model a HotWire track that should force users to knee down at a certain point, the wire has to be shaped in a way that it leaves the “standard level” towards a significantly lower level that can only be reached when users’ bend or knee down. The following section will elaborate more on a user study that was using the HotWire apparatus to give more examples in this direction.

5.2 Modelling Different Body Postures

The interruption user study conducted by Drugge et. al [4] used a configuration of the HotWire apparatus that, among other things, forced subjects to adopt different body postures typically found, for example, in maintenance or assembly domains. Figure 4 shows an example of three different postures that were observed during the study. To achieve this, the HotWire apparatus was mounted on a round table with a height of approximately 1.20 meters and a diameter of 1.0 meter. The metallic wire was bent in a way that subjects had to start the

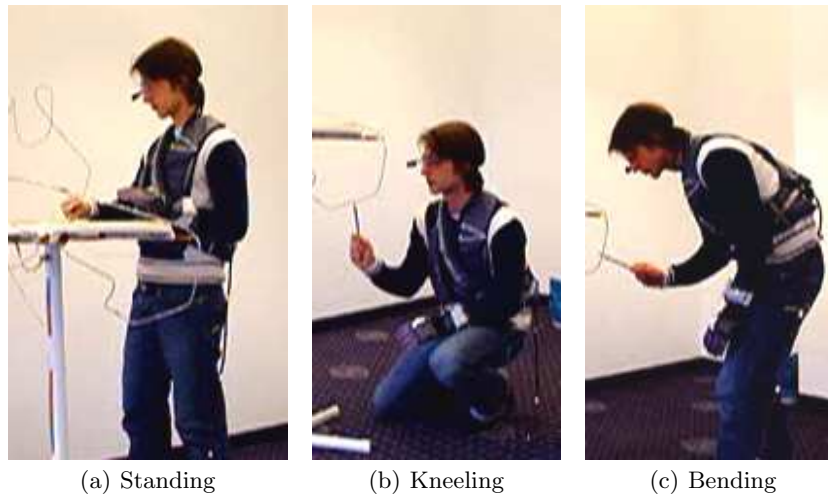


Fig. 4. Different body positions observed.

HotWire task underneath the table at a level of approximately 25 cm above the floor; forcing them right from the beginning to bend downwards to initially pass the ring of the tool over the wire. When continuing on the HotWire track the shape of the metallic wire forced subjects to slowly move around the table to reach the end of the wire track. While moving on, there were segments where subjects need to bend or even knee down to accomplish that section (see figures 4(c) and 4(b)). Finally, the track included sections with a higher difficulty to pass the loop tool without touching the wire compared to other sections (see figure 4(a)); simulating the aspect of changing subtask difficulties of a real work task that at some points requires increased visual attention. The total length of the metallic wire was around 4.0 meters.

While performing the HotWire a secondary task was interrupting subjects. It asked them to answer a matching task that was displayed in a head-mounted display (HMD) subjects were wearing (see figure 5). The matching tasks presented were adapted from work that McFarlane et. al [12, 7] did for studying interruptions in desktop computing environments. To answer these matching tasks subjects had to use intuitive left and right rotation gestures. For this, a wireless data glove device featuring a tilt sensor and different buttons was used [13]. The goal of the study was to evaluate different interruption methods as well as how much both tasks will interfere with each other in wearable computing applications. Although it was known beforehand that interference between tasks is deemed to be high if both task use the same cognitive capabilities (here, both involve the users hands), a previous preliminary user study within the wearIT@work project [14] with interviews and practical device tests with

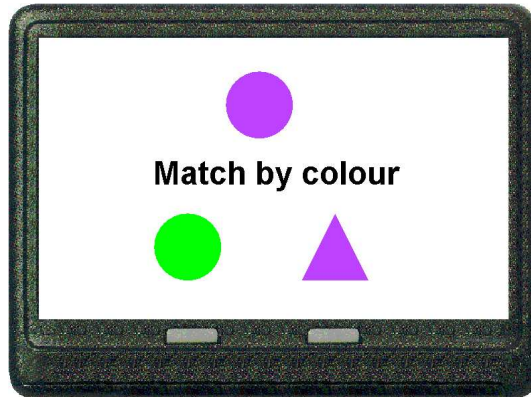


Fig. 5. Matching task presented in a HMD (adapted from [7])

aircraft maintainers, determined best acceptance for a data glove input device rather than for other tested devices such as trackball mice or speech interaction.

The results of the user study showed that by introducing the HotWire apparatus many findings from previous work [8, 5] could be validated while also new inherently different findings were uncovered; suggesting that the apparatus can be valuable for user interface research in wearable computing.

6 Conclusion

We have presented the construction of the HotWire experimental setup to evaluate user interfaces and user interaction for wearable computers as well as available software tools that can ease the technical experiment setup and post processing of collected experiment data. The HotWire provides the possibility to abstract a wide range of manual physical tasks by modifying up to three different parameters. It is easy to learn and able to retain the important properties of wearable computing such as mobility and dual task involvement in a laboratory environment. We discussed how the HotWire track can be modified to model different tasks with different levels of task difficulty, visual attention, and locomotor system demands. To illustrate how the HotWire can be applied in a user study, we reported on a previous experiment.

7 Future Work

Although the current technical setup has already been successfully used in different experiments, future work will concentrate on improving the available software tools. To provide users a maximum freedom in movement during the experiment we will investigate different possibilities that can make the ring tool wireless.

To allow a deeper analysis of occurred errors on the metallic wire track we are currently working on a mechanism to track the user's hand on the HotWire.

Despite these technical issues, we will conduct more interaction studies to investigate how wearable user interfaces have to be designed for optimizing a users' overall task performance in real world tasks. Here, we will also determine further to what extent the HotWire setup is an appropriate abstraction of typical primary tasks in wearable computing scenarios and how to model them.

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