HotWire: An Apparatus for Simulating Primary Tasks in Wearable Computing

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Abstract
In this paper we present a novel apparatus for simulating real world primary tasks typically found in wearable computing. Additionally, we report on a preliminary interruption study using the new apparatus in a laboratory experiment and compare its results with previous work to show its applicability for research in human-computer interaction for wearable computers.

Keywords
Wearable computing, primary task simulation, interruption study, HotWire experiment

ACM Classification Keywords
H.5.2 [**Information Interfaces and Presentation**]: User Interfaces—*Evaluation/methodology, Interaction styles, Input devices and strategies*; H.1.2 [**Models And Principles**]: User/Machine Systems

Introduction
Unlike in stationary computing where users concentrate mainly on one task to be performed with the computer, wearable computing typically expects users to accomplish two different tasks. A primary task involves real world physical actions whereas the secondary task is often dedicated to explicitly interacting with a wearable computer. As these two tasks often interfere, studying interruption aspects in wearable computing is of major interest in order to build wearable user

interfaces that support users during work with minimized cognitive load. However, as typical application domains of wearable computing, for example, maintenance [1] or healthcare [3] require “mission specific” interfaces rather than general purpose user interfaces, having a standard laboratory experiment setup for evaluating them at an early stage in the design process is beneficial. Thus, finding a way to simulate the varying primary tasks of wearable applications with a generic but adaptable physical simulation task can help to design appropriate interaction models and user interfaces for a range of application or task domains.

Following, we report on first results of the development of an apparatus able to simulate primary tasks of wearable computing applications. The apparatus is based on a children’s game usually used to train motor skills. For basic evaluation we conducted a preliminary experiment that focuses on the effects of interrupting the user while performing a real world primary task and compare the results with previous work.

Related Work

Research methods applied in the field of mobile human-computer interaction (HCI) are manifold [4]. However, for conducting interruption studies and user interface evaluations, laboratory experiments are often chosen as they are highly replicable and facilitate good data collection under controlled conditions (e.g. [5,9]).
In [7], 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 [2] a head-mounted display (HMD) was used to display the matching tasks. It was found that the scheduled approach gave the best performance, while using notifications came second although with shorter response time. As wearable computers are closely connected to the user, performance is not the only factor to be considered – the user’s preferences on interruption also need to be taken into account. In [8] it was found that audio notification appeared to give slightly better performance although users considered it more stressful, compared to visual signals that on the other hand were more distracting for the primary task.

Although the mentioned work was already able to relate HCI findings to wearable computing, the conducted laboratory experiments only use virtual primary tasks, which are uncommon in wearable computing.

Simulating a primary task

For simulating primary tasks typically found in wearable computing applications, we searched for a system that fulfills at least the following requirements:

- Real physical task abstraction: Primary tasks in wearable computing are often physical tasks, i.e. tasks that require users to work with their hands on real world objects while being mobile (e.g. assembly tasks). Thus, the system has to simulate such activities.
- 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 adaptable to simulate the demand of various user skills.

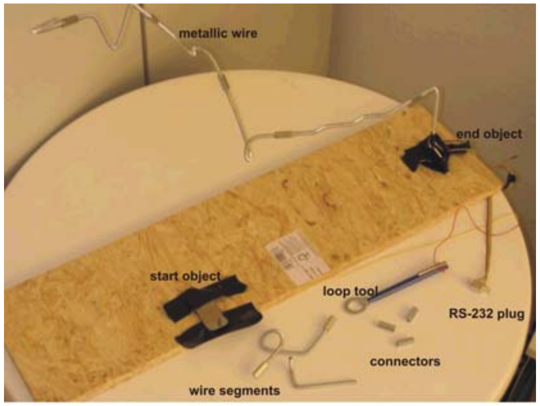

figure 1: First prototype of the HotWire.

Development of the "HotWire" apparatus

The apparatus we developed for simulating primary tasks that satisfies the requirements discussed above is based on a children's game called "The Hot Wire". It consists of a metallic wire bent in different shapes that is mounted on both ends to a base plate and a special tool with a grip and a metallic loop. The idea of the game is that children have to pass the loop from one end of the wire to the other end without touching the wire itself, which should train their motor skills. If the wire will be touched with the loop while being on the track an acoustic feedback indicates an error.

For our apparatus, shown in figure 1, we constructed the bent metallic wire out of different special shaped smaller segments each connected via special windings to another segment. This allows us to vary the difficulty or characteristic of the primary task by replacing or changing the sequence of connected segments. Unlike the original "Hot Wire" game, we mounted the metallic wire only on one side to a base plate which allows us an easier technical setup of the first prototype.

Technical setup

The technical setup of the first prototype is simple. To start the game the user has to touch a special metallic object attached to the base plate. Then, the user has to pass the loop from the open end of the metallic wire to the other end attached to the base plate which features at its very end another metallic object that indicates the end of the game when being touched. For automatically measuring beginning, end, and errors being made during the game, i.e. the number of contacts between the metallic loop of the tool and the metallic wire, we connected the start and stop indicator objects, the tool, and the metallic wire itself to a RS-232 serial connector. In particular, for detecting errors we connected the carrier detect (CD) pin to the metallic wire, the data set ready (DSR) pin to the start object, the ring indicator (RI) pin to the stop object, and the data terminal ready (DTR) pin to the loop tool. Through this, each time the tool touches one of the other components the electrical circuit will be closed and is detected by a program listening on the different state changes of the serial port connection.

Interruption study

The interruption study is based on McFarlane's original experiment in [7], designed to test how different approaches of interrupting the user will affect that person's cognitive workload. To make the experiment more applicable to wearable computing, the primary task in our study is represented by the HotWire game. The difference is that, just as in the real world, the primary task does not disappear into the background when the secondary task appears.

The secondary task consists of matching tasks presented in the user's HMD. Three figures are shown of random shapes and colors, and the user must match the figure on top with either the left or the right figure at the bottom of the display. A text instructs the user to match either by color or by shape, making the task always require some mental effort to answer correctly. New tasks will be created at random, and if the user is unable to handle them soon enough they will be added to a queue of pending tasks. The methods used for managing the interruptions are as follows:

- Immediate: The matching tasks are presented for the user in the instant they are created.
- Negotiated: When a matching task is created, the user is notified by either a visual or audible signal, and can then decide when to present the task and handle it.
- Scheduled: Matching tasks are created at random but presented for the user only at given time intervals.

The study uses a within subjects design with the method as independent variable – meaning that all subjects will test every method. To avoid bias and learning effects, they are divided into counterbalanced groups where the order of methods differs. The subjects get to practice the HotWire and matching tasks during the first half of the study, while the second half is the experiment during which data is collected.

Apparatus

A person using the apparatus is shown in figure 2. The matching tasks are presented in an SV-6 monocular HMD from MicroOptical with 640x480 pixels resolution and 18 bits color depth. Being non-transparent and relatively small, the HMD can be positioned so that it does not obscure the user's regular field of view, while remaining easily accessible via glances of the eye.

figure 2: A person using the HotWire setup

A data-glove is worn on the user's left hand serving as the interface to control the matching tasks. By tapping index finger and thumb together, an event is triggered in the program based on the position of the user's hand at the time. When the hand is held in a neutral position with the thumb up, the first matching task in the queue is presented to the user in the HMD. When the hand is turned to the left or to the right, the corresponding object is chosen in the matching task. For the negotiated methods, the user taps once to bring the new matching tasks up, and subsequently turns the hand to the left or right and taps to answer them. For the immediate method where matching tasks appear without notification, the user need only turn left or right and tap. Because of the novelty of the interface, feedback is required to let the user know that an action is handled. In general, any feedback will risk interfering with the experiment and notifications used, but in the current setup an audio signal is used as it was deemed to be the least invasive.

Pilot studies

A number of pilot studies were performed using the initial prototype of the HotWire game. The subjects, all right-handed, included the authors themselves as well as another member of the research group. This resulted in 12 sets of data from 3 different persons to analyze. The performance of the primary task was measured through the completion time of the track and the number of contacts with the wire. The secondary task was measured by the average age of a matching task, and the number of right and wrong answers. Although the pilot studies were not as rigorously done as would be required of a formal user study, some conclusions can still be drawn from these initial findings.

Preliminary results

The results concur with the findings in our earlier papers [8], indicating that the use of the HotWire as primary task is valid. For audio and visual negotiation, statistically significant ($p<0.05$) differences were found for the completion time ($p=0.005$) and average age of a matching task ($p=0.007$) where audio resulted in better performance. These findings are stronger than what was discovered in [2], suggesting that our new setup is better suited to uncover these differences.

Also in line with our assumption in [2], is that the immediate method would be preferable over negotiated when using a HMD. The results indicate that the user performs slightly better under immediate in all aspects except for completion time which is longer, although the findings were not statistically significant ($p>0.05$). Nevertheless, this challenges the general idea in HCI that negotiated is always better than immediate [8]; one of the peculiarities of HCI for wearable computing and its use for dual tasks is that an immediate method will be reduced to a variant of negotiated if the user can ignore it, thereby making it preferable by avoiding the need for explicit notification.

The requirement that the HotWire should be easy to learn was verified by looking at the completion time and number of wire contacts. For a user running the game 30 times in a row, the average time was 29 sec with a standard deviation of 5 sec. The trend was decreasing with 25% from 33 sec to 25 sec as the user would quickly learn the short track. No clear trend was found for the number of contacts which on average was 3.6 with a standard deviation of 2.2 after the user had initially learnt to hold and move the loop tool correctly.

The modular nature of the HotWire was demonstrated by replacing parts of the track and re-running the pilots with similarly reproducible results, yet with different average completion time and number of contacts based on how difficult the track was constructed. This indicates that the HotWire fulfills our requirement to be adaptable to different simulations.

Conclusion

We have presented the HotWire experimental setup for evaluating user interaction with wearable computers. It provides a physical task that is easy to learn and which can be configured for different levels of difficulty and track lengths. Results from an initial interruption study show that the data provided is valid, reproducible, and corresponds to findings from an earlier study that used a non-physical primary task. As stronger statistical significance was observed with this new setup, we conclude it is better for evaluating wearable interfaces than using non-physical tasks. In designing interaction, we deem it beneficial to have a laboratory experiment for early evaluation before starting on a full prototype, and we see the HotWire as promising for this purpose.

Future Work

Currently, we are working on a larger version of the HotWire that allows us to simulate higher user mobility, e.g. walking, and different body positions to complete the primary task. Although the current technical setup has been successfully used in experiments, future work will concentrate on building a wireless loop tool using Bluetooth to provide users a maximum freedom in movement. Once having a larger HotWire available, we will conduct more sophisticated interaction studies to investigate how wearable user interfaces have to be designed for optimizing users overall task performance in real world tasks. Here, we will also determine to what extent the HotWire setup is an appropriate abstraction of typical primary tasks in wearable computing scenarios.

Acknowledgements

This work has been partly funded by the European Commission through IST Project wearIT@work (No. IP 004216-2004) and also partly funded by the Centre for Distance-spanning Healthcare at Luleå University of Technology. We thank Dr. McFarlane for providing us with the source code to his original experiments and giving us permission to modify it for our wearable computing studies.

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