Design and Study of an Ambient Display Embedded in the Wardrobe

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Abstract
One of the opportunities of ubiquitous computing is to provide information in new ways in our everyday environments. In this paper we explore novel display opportunities in everyday situations with the design and study of the Hanger Display – a system for ambiently conveying information embedded in a wardrobe. We have built a working prototype of this display and explored it with users in a formative study. The results of the study show that this display is useful and appealing to people. Our experience creating and evaluating the Hanger Display also provided interesting insights for future work in embedding technology in everyday objects. In particular, we saw that such technology is beneficial because it provides information in places where it is useful, taking advantage of the established meaning of artifacts and places, and seamlessly supporting activities that occur in these places. In addition, we learned that such embodied interfaces could lead to new interaction possibilities, doing more than simply displaying peripheral information.

INTRODUCTION

Ubiquitous computing is often described as technology that is part of the world around us, enhancing everyday activities by bringing technology into the environment. Embedded technology is important to this vision, since it enables everyday objects to be augmented with digital functionality. Exploring technology embedded in everyday environments could improve human interaction with computers by making it more natural and less obtrusive to activities.

One type of information display typically situated in the physical environment is an ambient display, which attempts to convey information unobtrusively. Numerous ambient displays embedded in the environment have been designed and implemented. The ambientROOM [4] used ambient light, shadow, sound, airflow, and water flow to convey information (*e.g.,* remote activity of colleagues). Pinwheels [2] conveyed information (*e.g.,* network traffic) through physical movement and airflow control. The Digital Family Portrait [5] displayed information about loved ones through visual changes on a graphical picture frame.

Also, many projects have explored embedding technology in everyday objects. The Magic Medicine Cabinet [8] explored situated support for health needs. The Proactive Furniture Assembly project [1] placed sensors on IKEA furniture to aid consumers in assembling the furniture. The Strata Drawer [6] augmented dresser drawers so that remote loved ones could digitally explore their contents.

Despite these inspiring works, there is little understanding to guide design for ambient displays – or other technology – embedded in everyday environments. In this paper we explore novel display opportunities in everyday situations with the design and study of the Hanger Display, a system for peripherally conveying information that is embedded in the wardrobe (design sketch shown in Figure 1). We have built a working prototype and conducted a formative, in-lab user evaluation of the display. The results of the study show that this display is useful and appealing to people.

Our experience creating and evaluating the Hanger Display provided interesting insights for future work in embedding technology in everyday objects. One insight is that such technology is beneficial because it provides information in places where it is useful, taking advantage of the established meaning of artifacts and places, and seamlessly supporting activities that occur in these places. In addition, we learned that such embodied interfaces could lead to new interaction possibilities, doing more than simply displaying peripheral information.

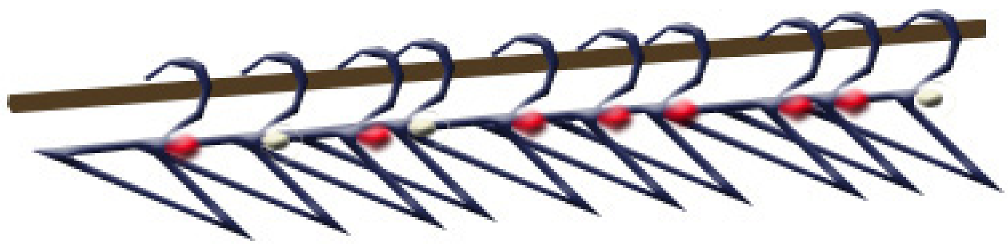

Figure 1: *Design Sketch of the Hanger Display*. This display is situated in a wardrobe, with a rod defining the display frame and hangers augmented with LEDs as display elements.

HANGER DISPLAY DESIGN

The Hanger Display is a generic system for portraying information relevant to the activities involving hangers. As shown in Figure 1, the Hanger Display consists of a row of hangers, each with a light emitting diode (LED) attached, placed on a rod in a wardrobe. The LEDs on the hangers are used to collectively display information. For example, the hanger display could portray a sense of the day's high temperature: given a 0 – 100° F range, if 7 of 10 hanger LEDs were lit this would represent 70° F. Alternatively, the hangers could portray remote presence: the occupancy of a room could be sensed as a proportion of its normal occupancy, and the corresponding proportion of hangers would be lit. Many other input sources could be mapped to the Hanger Display, though as we will discuss later in the paper, the most appropriate input sources appear to be those related to activities involving hangers.

The basic structure and behavior of this display is designed as follows:

- Rods are a core structural element in hanger systems 'in the real world.' We build on this by making the rod the framing element for our display.

- Hangers are augmented with LEDs, making them display elements. A hanger becomes part of a display when it is placed on a rod and ceases to be part of the display when it is removed.
- All hangers present on a rod at a given time collectively constitute the display.
- The display is dynamic: the number of display elements changes as hangers are inserted or removed.
- The display is generic: it can be used in conjunction with any type of input that can be mapped onto a changeable number of binary display elements.
- Multiple generic, collective display functions are possible, including relative quantities (proportions), trend indicators, and progress indicators.

Why portray information with hangers? Hangers are common objects in the home, naturally formed into collections. They are used in specific activities that could benefit from additional, easy to access information. Most people, confirmed by our evaluation participants, associate hangers with hanging and selecting clothes, morning rituals, and getting ready for the day. When performing these activities, people are interested in related information such as weather or their schedule to determine what to wear, amount of email as an indication of how much work there is to do, the type of day it is as indicated by news headlines, and traffic to give an indication of commute time. Our evaluation participants, many of whom were quite excited the opportunities the hangers posed as a generic interface device, suggested these as possible Hanger Display applications. The Hanger Display puts this activity-relevant information in a location where it will be useful. As a peripheral display, the hangers give people a *sense* of the information without requiring full attention. In this way, people get the information they want, where they want it, theoretically with little effort.

The natural affordances of hangers allow them to provide an easy to understand display. Hangers afford hanging. All participants in our evaluation assumed correctly from the beginning that placing a hanger on the rod meant it was part of the display and removing it meant it was not. When asked what they do with hangers, participants said they hang them on the rod, usually with clothes. This means there is a clear set of interactions that make sense. The state of a hanger as "part of the application" is easily determined by whether or not the hanger is hung on the rod. It is natural for hangers to be collocated together and they could provide additional information if augmented.

Of key importance for the Hanger Display is to preserve natural interaction with the hangers despite the information they collectively display. Think about how you use hangers: you may shift them on the rod, remove some to hang laundry or set out clothes for the day, replace hangers in different locations, and so on. These activities are not necessarily related to any information they may display. The Hanger Display was designed to seamlessly withstand changes caused by natural interaction. For example, a hanger can be removed from the rod and either put in a different location on the same rod or put on a new rod and it will be integrated into the rod's display.

The Hanger Display does not prescribe how information is mapped onto the variable collection of display elements. Instead it is flexible, allowing different display functions:

relative quantities, trend indicators, and progress indicators. First, as described in the temperature and remote presence examples, it can display a relative quantity by having a percentage of the hanger LEDs lit. A second display function is to show a trend. For example, with news headlines as an input source, the hangers could display what kind of day you might expect: somewhere between "good" and "bad," (*e.g.*, when all the hanger LEDs are on the news is very bad, and when none are on the news is very good, as indicated by certain keywords in the newspaper text). A third display function is to show progress or time. For example, the hanger LEDs could form a "progress bar" that indicates the amount of time until your laundry will be done washing (*i.e.*, when all the hanger LEDs are on, your laundry is done). Since we are focusing on peripheral displays here, we exclude possible interactive functions, though we address these at the end of the paper.

Design properties of the Hanger Display presented some interesting implementation challenges, including presenting information in a wardrobe, controlling multiple hanger LEDs, and supporting the dynamic configuration of hangers. We describe how we addressed these challenges in the next section on the implementation of the Hanger Display.

PROTOTYPE IMPLEMENTATION

We have implemented a working prototype of the Hanger Display based on the following set of components:

- hangers augmented with embedded hardware (an LED and a switch to control the LED);
- a rod augmented with a physical network medium to provide connectivity to the hangers;
- software to control the display system, *i.e.* determining which hangers are present on a rod and controlling communication in the system; and
- software mapping an input to the LED output of the Hanger Display, *i.e.* determining which hangers to turn on and sending commands to the hangers so the correct ones light up.

Figure 2 depicts the hardware components of the system. The rod has two strips of aluminum along its length that act as two wires, enabling its use as a network medium. One of the strips serves as ground and the other provides data and power transmission using the MicroLAN protocol [3]. MicroLAN is a low-bandwidth protocol also known as 1-Wire Bus, well suited for embedded components. In order to connect a hanger to this medium, we put two loops of wire around its hook so that separate contacts are made to the two aluminum strips on the rod. The balance of a hanger, with or without clothing, generally causes it to naturally fall into the correct place on the rod to make these contacts. (Our current prototype occasionally has problems with hangers not making contact: for example a hanger may shift backwards or forwards on the rod such that one of its wires is touching the gap between the aluminum strips. This is prototypical for issues that can only be addressed through iterative design and exposure to real use.) Note that this design overlays a pre-existing physical arrangement (a rod with hangers) with network connectivity, using common structures in our environments as network medium, using an idea originally developed in the Pin & Play project by Van Laerhoven *et al.* [7].

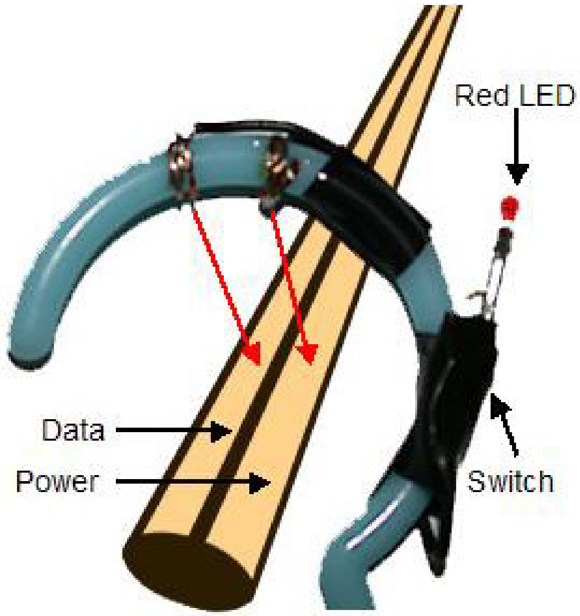

Figure 2: Augmented hanger and rod. Shows the two wires added to the hanger that contact the rod providing data and power to the LED and the switch (hidden under black tape).

The hardware on each hanger includes a switch, an LED, and a resistor. For the switch we use a 1-wire device that can be readily controlled over MicroLAN. The LED output is directly connected to the state of the switch, with the resistor included for brighter output. Note that the components are all very small and do not compromise the form-factor of the hangers in any significant way.

The Hanger Display application software is written in Java. Control of the display system is based on the MicroLAN protocol, which provides core functionality, such as detecting which hangers are present on the rod and addressing hangers in order to control each one's LED. To provide input to the display, the software parses data from web pages (*e.g.,* the predicted high temperature) or receives sensor data (*e.g.,* how many people are currently in a room, detected by proximity sensors). This data is then mapped onto the display depending on the number of display elements present. For our prototype, we implemented this software on a laptop, which communicates with the rod and MicroLAN via a serial gateway. However, the software could easily be ported onto an embedded device with wireless networking to make the Hanger Display system more self-contained.

APPLICATIONS

A Hanger Display application is made up of one rod and all the hangers on it. Each application has at least one input source. We chose three input sources to implement for the Hanger Display: temperature, barometric pressure, and remote presence. These input sources were selected based on the activities people associate with hangers. Again, most people associate hangers with hanging up and picking out clothes, morning rituals, and getting ready for work or the day. The temperature application shows the predicted high temperature, attempting to help people determine what to wear for the day. The barometric pressure application gives people a sense of whether or not it will rain. For example, if 90% of the hanger LEDs are lit then there is very good chance of rain and if none of the hanger LEDs are lit there is almost no chance of rain. This information helps people select appropriate clothing for the weather. The remote presence implementation gives an indication of how many people are in a room compared to its typical occupancy. For example, in an office typically inhabited by four people, 75% of the hangers would be lit if three people were in the office. When getting ready for work in the morning, people may be interested in knowing how many coworkers are already at the office.

For the user evaluation, both the temperature and barometric pressure applications parsed the weather.com web site for Lancaster, U.K. The hangers displayed the temperature as a proportion of the range from 0 to 30° C. So, if 4 out of the 8 hangers on the rod were lit, that indicated the temperature would be about 15° C. The hangers displayed barometric pressure as a percentage of the chance of rain. So, if 4 out of 8 hangers on the rod were lit, there would be about a 50% chance of rain. For the purposes of evaluating the prototype, we manually provided the remote occupancy input to the hangers.

With a working prototype and three applications, we presented the Hanger Display to users. The next section includes a description of the study and its results.

FORMATIVE USER STUDY

To evaluate the Hanger Display, we conducted a formative, in-lab user study with the three applications described in the previous section.

User Study Setup

In our lab, we set up a wardrobe as in Figure 3 with two rods: the top displaying the predicted high temperature and the bottom showing either barometric pressure or remote presence. Half the evaluation participants were presented with temperature and barometric pressure and half were presented with temperature and remote presence.

Seven researchers from other groups at the Lancaster Computing Department came to the lab for one individual evaluation session each with one of the authors. The participants' background in computing was felt to not be a significant influence for the evaluation since it was centered on domestic experience rather than work experience and computer knowledge. Participants were given a brief description of the applications and asked to explore and interact with the interface with no specific task.

An interview followed the interactive portion of the evaluation, in which the participants were asked for qualitative feedback on the interface. After the interview, the evaluation became an interactive brainstorm in which researcher and participant were collaboratively discussing the interface and future possibilities.


Figure 3: Wardrobe used in evaluation containing two Hanger Displays: top rod shows predicted high temperature (4 of 8 hangers are on, which indicates 15° C); bottom rod alternates between showing remote presence and barometric pressure (2 of 3 hangers are on, which, for the barometric pressure application, indicates a 75% chance of rain).

Results

All of the participants responded positively to the Hanger Display independent of the applications. They were all interested by the uniqueness of the display and the possibilities for new applications. Every user had ideas for other applications that they would find useful in their own homes. One of the most critical yet gratifying responses to the display was "Foxy interface. It really has potential. My thought is that the application is wrong." This confirms the appeal of the system and its success in inspiring and engaging users to develop their own application ideas.

While most users did not like the remote presence application, they varied on their acceptance of the two weather applications: two participants thought these applications were inappropriate for this type of display, two did not find the applications useful to themselves but thought they might be useful to other people, and three thought they were appropriate and useful.

Participants who thought the display was inappropriate for weather and remote presence had two reasons. First, for temperature, the hangers required more cognitive effort to get information that could be more accurately conveyed with another simple household device: the thermometer. Second, the physical, interactive hangers did not match well with the unverifiable, passive weather and presence information displayed. According to one participant, "such an embodied interface is not meant to display passive information. The embodied-ness becomes very valuable when the interaction has an effect." A better match for the hangers would be to provide feedback for interactions with the display and to provide more value to the user for their interaction. The first critique shows that the Hanger Display is best for displaying information for which you want to get a "general sense," not an accurate reading. An accurate reading requires too much cognitive effort to count hangers and figure out what percentage of LEDs are on, but a general sense of the information can be determined at a glance. For some participants, a general sense of the day's high temperature was acceptable, but for others it was not. The second critique questions the applicability of the hangers as a peripheral display, but leads us to consider future research in making the hangers into an interactive interface.

The other participants thought the display was appropriate and useful for weather information because it put the information in a place where it would be useful. They associated selecting clothes with the weather forecast and liked having that information conveniently placed where they selected clothes: "I like having information in the place where it is useful, so it is nice to get weather information when you are picking out clothes." This highlighted an important consideration for displays like the Hanger Display: information displayed with everyday objects should be appropriate to their use or the activities associated with them.

Two major usability issues were uncovered in the evaluation. First, some participants found it difficult to determine how many hangers were in the "off" state at a glance. Several suggested adding a second LED of a different color that, when lit, indicated the "off" state. Second, some participants had trouble quickly getting a sense of the proportion of LEDs that were lit. To help solve this problem, we could order the hangers such that they are lit from left to right like a bar chart (see Figure 4).

Figure 4: Mock-up version of the Hanger Display with LEDs lit in order from left to right.

The evaluation also pointed to the importance of preserving natural interaction with hangers, a lesson that is useful for future work in embedding technology in everyday objects. The Hanger Display was a prototype and had some problems with hangers making enough contact with the rod to get power. Despite this fact, most of the users thought it was important that the hangers could be moved around, added, and removed in order to preserve natural interaction: "I like that [the information is] there and it doesn't interfere with what the hangers do. It doesn't change the hangers so it's not demanding." About half the users questioned the usefulness of changing the hanger interface for any other reason. In particular, the participants who wanted more accurate readings from the hangers added hangers to the rod in order to gain precision. These participants disliked this interaction because it required too much work to gain only a few degrees of precision. As a peripheral display this is not an issue, since the hangers are only meant to give people a sense of the temperature rather than a very accurate reading. However, this critique is important to consider in future work that may add application-relevant interaction to the Hanger Display.

DISCUSSION AND FUTURE WORK

In this paper, we have attempted to address the challenge of finding new ways of integrating digital information into the context of everyday activities and environments. We explored embedding technology in everyday environments with the goal of improving human interaction with computers by making it more natural and less obtrusive to activities. Our user evaluation and our own experiences with the project have led to several insights related to this goal and into the potential of such technology.

The qualitative feedback from our evaluation speaks positively about the potential for this technology to improve human interaction with technology. In particular, the feedback indicated that embedding technology in everyday objects puts information where it is useful and can aid in an activity without interrupting it. All of the users thought of information related to hangers that they would find useful when picking out clothing or performing other tasks involving them. Aside from some problems with the prototype implementation (*e.g.,* hangers not always making a connection with the rod), the users asserted that the embedded technology did not interfere with natural interaction. Other objects could be augmented similarly to benefit activities associated with them. For example, a collection of CDs could be augmented to give you a sense of which CD you have listened to most recently and which you have not listened to in a long time. When you want pick out music, you may enjoy selecting a CD you have not listened to for a long time, information that would be readily available without you even reading the CD labels.

Building on this point, we believe that technology can do more than put information in a useful place and not interrupt an on-going activity: it should augment the *right* artifact(s) so that the digital information is now *physically embodied in the activity it supports*. It is interesting to have activity-relevant, digital information and interaction embodied in the artifacts one is already using. This is obviously different from the type of interaction one has with a desktop computer: desktop activity is dictated by the need to sit still in front of the computer screen, using a mouse and keyboard. It is less obvious but still quite different from interacting with a physical device in the environment that is not part of your natural activity. For example, reading the temperature from an LCD screen placed in your wardrobe is not the same as getting a sense of the temperature from your hangers. With the LCD screen, there is a disconnect between the activity of picking out clothes and the act of getting the temperature information. With the hangers, there is no disconnect: the hangers are part of the activity. While our evaluation does not tell us what impact this has on users, we believe this insight could be valuable to research in ubiquitous computing and we hope that future work will continue to explore the synergy between technology and human activity.

Related to this point is that embedded technology allows us to introduce technology in new and interesting places. Though a wardrobe is not typically a place one might expect to find a digital information display, it provides interesting opportunities for useful applications. The Hanger Display introduces technology into the wardrobe, an interesting and useful place for certain information. During the user evaluations, almost every user responded to the question of what they thought of the Hanger Display by saying, “Interesting… I like it. You could also display…” Users suggested many other everyday objects that could be augmented in a similar fashion: books, CDs, videos, food containers, cutlery, dishes, glasses, shoes, household decorations, files folders, and furniture.

Another related benefit is that such displays reduce the need for dedicated devices. Many people, including some of our evaluation participants pointed out that a dedicated device could more easily show the information displayed by the hangers. Namely, a thermometer could display temperature information. While a thermometer is more accurate and easier to read for an exact temperature, it is also a dedicated device showing only the current temperature. The hangers create a generic display that is already part of the wardrobe: there is no need to make room for an additional device. In addition to reducing the need for dedicated information devices in the wardrobe, the digital nature and generality of the Hanger Display makes it fundamentally different. For the temperature application, the hangers can show the predicted temperature for any location and any time, unlike a household thermometer, which can only show the current, local temperature. Also, the hangers are designed to give people a sense of the information they convey, not an exact reading. Therefore input should be selected such that an exact reading is not important to the user. These arguments apply to most other input sources as well.

The second main insight gained during this project was that, even though the current Hanger Display implementation only displays information peripherally, such an embodied interface could lead to new interaction possibilities. Evaluation participants showed a strong interest in the Hanger Display, both as a display for other input sources and as an interface for new types of interaction. “[The Hanger Display] is interesting because it can show any type of information you want.” Each user suggested several other input sources for the hangers and applications that involved greater interaction than the current peripheral display required. For example, the hangers could send messages to other people when moved, added, or removed from the rod. This could be useful in a clothing shop: hangers could indicate things like sale items or items to be moved by employees. By moving a certain clothing item to the “sale rack,” an employee could cause all hangers holding the same item to light up. Employees could quickly find and gather all of these items onto the sale rack, at which time the LEDs would turn off. The most exciting prospect for examples like these is that they point to new, creative, and useful applications of ubiquitous computing that support activities in the place where the activities occur. With further exploration, other collections of everyday objects forming displays could uncover new ways to provide the benefits of technology without sacrificing the ease and naturalness of everyday activities.

CONCLUSION

In this paper, we have presented an example of embedded technology, the Hanger Display, which attempts to provide information in the context of everyday activities and environments. We explored embedding technology in everyday environments with the goal of improving human interaction with computers by making it more natural and less obtrusive to activities. Our user evaluation and experiences with the project led to several insights related to this goal and to the potential of such technology. The evaluation emphasized the importance of selecting information to display with everyday objects that is appropriate to their use or the activities associated with them. In addition, the objects that are augmented should be carefully selected such that the embedded technology is embodied in the activity. This serves to put information where it is needed, requiring little effort from the user and reducing the need for dedicated devices. Finally, we discussed the potential for an embodied interface like the Hanger Display to lead to new interaction possibilities.

We believe that the type of display explored here demonstrates an informative, thought-provoking case study of embedded technology. We hope that the Hanger Display and other displays composed of everyday objects will provide researchers with creative fuel for introducing digital information and interaction in places where related activities occur.

REFERENCES

1. Antifakos, S., Michahelles, F., and Schiele, B. Proactive Instructions for Furniture Assembly. In *UbiComp '02*. 2002.
2. Dahley, A., Wisneski, C, and Ishii, H. Water Lamp and Pinwheels: Ambient Projection of Digital Information into Architectural. In *Proc. of CHI '98*, pp. 269-270. 1998.
3. Dallas Semiconductors. Overview of 1-Wire Technology and its Use. Application Note 1796, Dec 3, 2003.
4. Ishii, H., and B. Ullmer. Tangible bits: towards seamless interfaces between people, bits and atoms. In *Proc. of CHI '97*, pp. 234-241. 1997.
5. Mynatt, E.D., *et al*. "Digital family portraits: Providing peace of mind for extended family members." In *Proc. of CHI'01*, pp. 333-340. 2001.
6. Siio, I., Rowan, J., and Mynatt, E. Finding Objects in 'Strata Drawer.' In *Proc of CHI '03*. 2003.
7. Van Laerhoven, K., Schmidt, A., and Gellersen, H-W. Pin & Play: Networking Objects Through Pins. In *Proceedings of Ubicomp 2002*, pp. 219-229. 2002.
8. Wan, D. Magic Medicine Cabinet: A Situated Portal for Consumer Healthcare. In *Proc. of HUC '99*. 1999.