Wearable Computing

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Autism, Environmental Buffers, and Wearable Servers

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Ubiquitous computing systems often involve infrastructure placed either on the body or in the environment. Many issues help determine equipment's optimal placement (see the "Design Factors for Wearable and Environmental Applications" sidebar). We've developed a combined wearable and environmental infrastructure for CareLog, a prototype system for capturing and annotating the behavior of children with autism (CWA).

The infrastructure features a wearable Personal Server,[1] which stores each child's information, and environmental buffers—in this case Internet-isolated cameras that store audio and video streams for short intervals before removing them. If a caregiver wishes to annotate a behavior, the caregiver downloads images from these cameras to the child's Personal Server; otherwise, the images are irrevocably erased. CareLog demonstrates an interesting compromise between environmental and wearable infrastructures and takes advantages of some of the best attributes of each.

THE RESEARCH CHALLENGE

According to the Centers for Disease Control and Prevention, autism occurs in 1 out of 166 children.[2] Early behavioral intervention for CWA ages 2 to 6 can significantly improve language and social skills. Because every CWA is so different, caregivers create custom interventions for each individual, often after analyzing various data collected about the child. This practice is called evidence-based care.

Caregivers often struggle with analyzing data describing critical incidents because the lightweight tools that mobile caregivers carry don't supply data rich enough to describe the incident with sufficient detail for later analysis. Furthermore, tools designed for rich data collection don't scale well to the unstructured, mobile activities involved in childcare.

The research challenge is to enable caregivers to collect rich records in natural environments without significantly disrupting themselves or the people around them.

The research challenge, then, is to enable caregivers to collect rich records in natural environments without significantly disrupting them or the people around them. Caregivers need the ability to gather large quantities of data throughout a child's everyday life. Even more importantly, they need the ability to access the data they and others gather immediately after it's recorded and far into the future.

Caregivers can rarely count on having a network available to them. Although they might one day have ubiquitous network access, the current infrastructure available to impoverished school systems, at least in America, coupled with a child's inherent tendency to spend time outdoors and in other network-poor places, makes relying on network availability infeasible at this time.

CARELOG: OUR SOLUTION

Given these factors, we chose to develop a lightweight tool for caregiver note-taking, named CareLog, which doesn't require network access to gather and share data among caregivers. Instead, a pocket-sized, wireless Personal Server (see Figure 1), holds a database with the child's information and acts as a wireless application server for CareLog. The child can leave the Personal Server in a pocket or backpack nearby.

Caregivers record behavioral data about a child through customized forms

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DESIGN FACTORS FOR WEARABLE AND ENVIRONMENTAL APPLICATIONS

Many issues help determine the optimal placement for ubiquitous computing infrastructure, whether on the body, in the environment, or both.

Privacy: How can data gathered best be protected against unwanted disclosure? For example, medical data might best be kept in a user's bracelet.

Data accessibility: Who will be the primary user of the data—the mobile user or a group of collaborators? A busy academic should always have access to the most up-to-date copy of her schedule, yet a nurse will probably be the primary user of the sensor data from his patients in a hospital.

Sensing: Is it better to place the sensors on the body or in the environment? Blood pressure is difficult to sense from the environment, but the use of a particular object, such as a door, is much easier to sense by augmenting the object.

Cost: What will the equipment cost? The cost of augmenting a small environment, such as a meeting room, is relatively low and can have important benefits. Yet, providing projector displays everywhere in an office building is prohibitively expensive.

Comfort and wearability: Can the user tolerate wearing the appropriate equipment? Children might remove or damage on-body medical sensors, but many adults carry sophisticated computers in the form of mobile phones.

Immediate usefulness for user: With wearables, unless the equipment is perceived as immediately useful to the user or is embedded in devices that are already useful to the user, the equipment will likely be discarded. Blood glucose levels are of continual interest to a diabetic, but for most of the population, only occasional checks at the doctor's office are necessary.

Power: How will power be delivered to the equipment? Batteries provide the greatest limitation to the size and weight of current wearables, but wiring sensors into an office's electrical system or constantly replacing batteries can be an onerous maintenance cost.

Interface: Is the interface best implemented on the body or in the environment? For example, a display in the environment is much easier to share with a colleague during a meeting but a head-up display provides a better means to keep private notes. —*Thad Starner*

loaded to any nearby device such as a classroom desktop computer using its wireless connection to the Personal Server. The forms let caregivers collect discrete data through checklists and qualitative data through handwritten or typed notes. They can then access the data through local wireless connectivity to the Personal Server from whatever device is nearby, convenient, and appropriate (see Figure 2).

Caregivers' feedback

Although this application met criteria requiring a lightweight and easy-to-use design that's mobile and ubiquitous, caregivers requested richer data for detailed assessment of observed patterns in learning and behavior. Caregivers specifically requested additional rich data gathered from an observer's standpoint, such as video, as well as data an observer might have difficulty in gathering, such as temperature or humidity level. Because we want to gather data about a particular child at all times, the obvious choice for collection might be to place capture devices on either a caregiver or the child.

We explored wearable cameras and microphones in the Walden prototype[3] and found that caregivers wearing recording devices worked for certain situations but generally interfered with everyday instructional and caregiving activities. Also, kids in general aren't always the most cooperative and tend to remove or break instrumentation placed on them, but children with autism are an even more difficult case. Caregivers can't explain to a child who is not self-aware why he or she might want to wear a particular set of sensors.

We leave as an open research question to the community the exploration of ways to build and package sensors that CWA and their caregivers want and

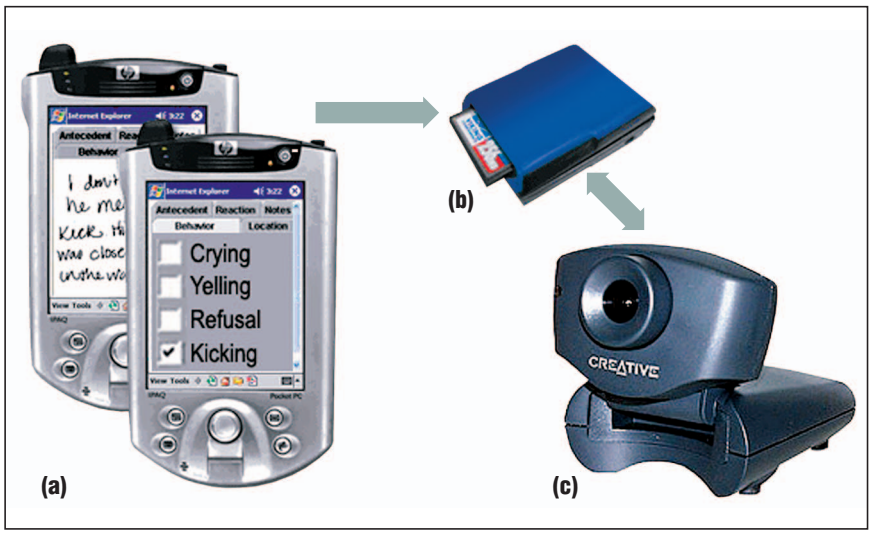

Figure 1. Caregivers take notes on (a) handheld devices using a database-driven customized CareLog application that's downloaded from (b) the child's Personal Server. CareLog uses Bluetooth to discover local experience buffers—in this case, (c) Internet-isolated cameras—and request information from them.

WEARABLE COMPUTING

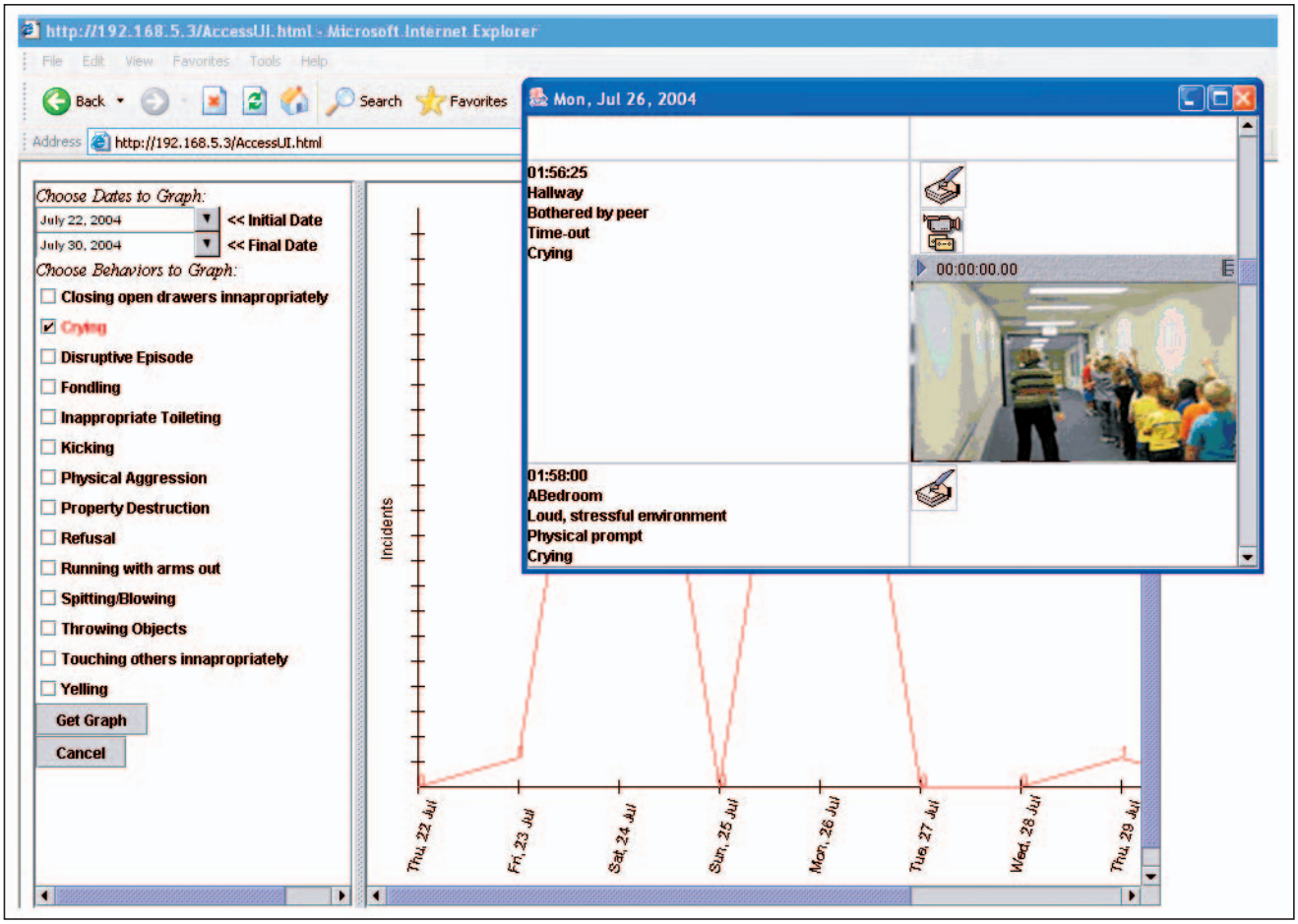

Figure 2. Caregivers access a child's behavioral trends as well as the details of a particular incident through CareLog.

can wear; instead, we explore use of sensors and rich-data capture devices such as video cameras embedded in the environment to gather the required data.

Adding experience buffers

We supplemented CareLog with the ability to quickly grab rich data from the environment in the form of *experience buffers*, a collection of environmental capture services that provide buffers of rich data such as video or sensor streams. (See the "Generalized Uses for Experience Buffers" sidebar for other possible applications.) Like the familiar TiVo buffer, these services save data for a brief period of time, erasing content after that time is up. If users explicitly request saving during that window, they can archive information from the buffers.

When a caregiver notes an incident, the system automatically logs the manually entered information as well as the date, time, caregiver, and note-taking device. The Personal Server then uses wireless inquiries to search the environment for buffer services. When the Personal Server locates those services, it connects to them and makes a request to archive some amount of data. If no buffers are available, such as when the child is outside, CareLog doesn't acquire additional information.

By combining features that define wearable and ubiquitous computing systems, we developed a tool that leverages the best of both worlds. The first compromise involved how and when rich data archiving occurred. A solution that involved automatically saving rich data constantly would have provoked a number of issues about surveillance, privacy, and control. On the other hand, relying on people to predict an event of interest and to equip themselves for recording that event often doesn't work. Anyone who has ever wished a camera were handy when a child did something for the first time can attest to that.

The second compromise involved using wearable devices to access environmental services. A fully wearable solution would have been physically unwieldy for either the child or the caregiver. A fully environmental solution would have required caregivers to be in the room with the capture services or rely on a network to access the data. These compromises have been pivotal in getting caregivers to want to use

GENERALIZED USES FOR EXPERIENCE BUFFERS

We've begun to envision how an experience-buffers architecture, which allows wearable devices to gather data from embedded services, might be generalized to other domains. Here we discuss some of those ideas in hopes that other researchers begin to add to the exploration of these hybrid solutions.

Other chronic care domains

Caregivers of elderly people often complain that by the time they become aware that something is wrong with their loved one, they don't know enough details about what happened. This is a particular problem with Alzheimer's patients who might not be able to tell a caregiver what happened even soon after it occurred. Imagine instead that the elder could simply push a wearable button to ask for help, triggering data from the environment five minutes prior to the button push to be sent to the caregiver. The caregiver could then quickly diagnose the problem (for example, that the patient fell), formulate a solution, and bring the right supplies for assistance.

Precious memories

How many parents have wished they had the camera on when baby took his first step? A household filled with experience buffers would let a parent simply grab the mobile phone and hit save after the event. The buffers would send the data down to the phone even minutes after the event. Parents could also use such recordings to populate a baby calendar application that educators and specialists could review to assess the child's development.

Impromptu meetings

Often the most important discussions happen when someone wanders into your office or when you're standing in the hallway. Without recording full time in those spaces, it's difficult to capture the important details. However, recording full time in public and semipublic spaces raises serious surveillance concerns. Experience buffers would enable participants in an impromptu meeting to save the data from that space to their mobile devices in a manner that balances these concerns.

Meeting and classrooms

Much research has been done on using automated capture technologies in meeting and classroom spaces. Often, however, people only care about accessing content they've already seen. In this case, a large scale service might be overkill. Instead, a buffered architecture would allow people who are present at a meeting or lecture to grab the content they've just experienced and save it to their personal archive, avoiding the overhead of searching through combined public archives.

CareLog. CareLog's use of the experience buffers is a testament to the power of compromise between the ubiquitous computing and wearable computing worlds as well as between the power of technology and the appropriateness of its use in daily life. P

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UPCOMING EVENTS

International Conference on Pervasive Computing (Pervasive 2005)
8–13 May 2005, Munich, Germany; www.pervasive.ifi.lmu.de

International Conference on Mobile Systems, Applications, and Services (MobiSys 2005)
6–8 June 2005, Seattle, Washington; www.usenix.org/events/mobisys05

International Conference on Mobile Computing and Networking (Mobicom 2005)
28 Aug.–2 Sep. 2005, Cologne, Germany; www.sigmobile.org/mobicom/2005

International Conference on Ubiquitous Computing (Ubicomp 2005)
11–14 Sep. 2005, Tokyo, Japan; www.ubicomp.org/ubicomp2005

IEEE International Symposium on Wearable Computers (ISWC 2005)
18–21 Oct. 2005, Osaka, Japan; www.iswc.net