A Context-Specific Electronic Design and Prototyping Course

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Abstract

This paper describes a context-specific electronic design and prototyping approach in an innovative project course at Carnegie Mellon. We built a sensing and notification wearable computing platform, called eWatch, for context-aware computing. eWatch senses user activities and provides them with urgent notifications. An accelerometer and microphone provide inputs to a model of user interruptibility levels. A vibration motor for tactile feedback and two ultra bright LEDs for visual feedback provide user notification through different vibration patterns and colors. User studies identified appropriate notification schemes for mobile and office settings. Bluetooth communication connects the eWatch to a PDA or desktop computer for sensor data analysis and notification.

1. Introduction

This paper presents a dual purpose, sensing and notification platform for context-aware wearable systems, developed in an innovative course on rapid prototyping of computer systems at Carnegie Mellon, as defined in [1, 2]. The course has created a novel generation of wearable computer systems for an industry partner every semester over the last twelve years. It deals with all four aspects of project development: the application, the artifact, the computer-aided design environment, and the physical prototyping facilities. During the Spring 2004 class, we designed and built eWatch, an electronic watch that senses user activities and provides urgent notifications. The design was driven by a series of user tests exploring human interruptibility and notification mechanisms. eWatch employs an accelerometer, a light and temperature sensor, as well as a microphone to sense user activities. In addition, user calendar data from a PDA are input to a model to estimate user interruptibility levels. eWatch communicates with a PDA using Bluetooth. A vibration motor and two ultra bright LEDs provide notification to the user through vibration patterns and colors. User studies identified appropriate notification schemes for mobile and office settings. Based on user context, the system uses incoming email priority levels to determine whether and how to notify the user. eWatch integrates with traditional social practices, using handshakes to exchange contact information.

eWatch was designed to provide a rich set of input and output modalities that are easily explored in a pervasive computing environment without any on-board computational restrictions. This introduces new capabilities, as the previous work [3] focused on the engineering challenges in building such a miniaturized device. These new capabilities and the context-specific approach itself represent an important advancement in electronic design and prototyping.

2. System architecture

Since eWatch was designed to be a wearable testbed with off-board computational facilities, little on-board processing is required. It utilizes a Bluetooth connection to a computer that can analyze the sensor data and appropriately activate the different eWatch actuators up to 15 meters away. The eWatch and its package are shown in Figure 1.

The eWatch architecture consists of three major components: the main controller board, the Bluetooth module and the host computer. The main controller board communicates over RS232 to the Bluetooth module which in turn connects to the host computer. The eWatch architecture can be seen in Figure 2. Note that the Bluetooth module and the main board are physically separated into two printed circuit boards. The main controller board shown in Figure 3 for eWatch is responsible for all sensor integration as well as controlling the LCD display and actuators. The main processor on the eWatch is an 8Mhz PIC18F2320 with 512B RAM, 4096B program RAM and 256B EEPROM.

Figure 1. eWatch

eWatch collects user state information from a light sensor, temperature sensor, microphone, and dual axis accelerometer. The temperature sensor is pressed against the user's skin and is sensitive to .1ºC changes. The microphone data is used to detect the loudness of ambient sound. To minimize size and power, the microphone uses a MAX4061 amplifier with a variable gain set to 1000. Acceleration is sensed using an ADXL202 MEMS accelerometer that measure two axis with +/-2g of range. Three buttons are placed around the outside of the board to emulate a standard digital watch. Sensor data is packaged and transmitted over Bluetooth to the host computer 20 times per second.

eWatch supports both tactile and visual output. The tactile output is generated by a small vibration motor. By mixing different durations, intensities and pauses, the eWatch can generate a vast variety of patterns. Two ultra bright LEDs could also be alternated and individually modulated yielding a similar level of variety. Images and time are sent from the main processor to the LCD controller using a custom bus. The LCD controller has an additional red and green LED that can control the screen backlight.

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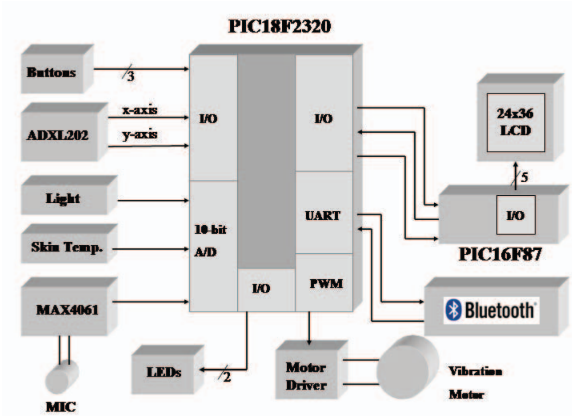

Figure 2. Hardware architecture

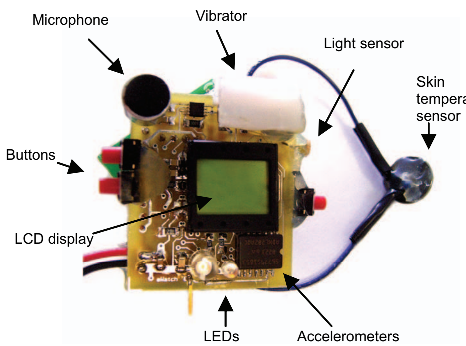

Figure 3. eWatch controller board

Table 1. Notification patterns used in user study

#	Visual	Tactile
1	None	Gradually increasing intensity & frequency
2	None	Single medium intensity
3	None	Long medium intensity, pause Long light intensity, pause Long heavy intensity
4	None	Three long medium intensity, steady frequency
5	Red, steady frequency	None
6	Blue, steady frequency	None
7	alternating Red & Blue	None
8	Fading Red	None
9	Fading Blue	None
10	Red, pause Blue, pause Blue, pause Red	Long medium intensity, pause Short medium intensity, pause Short medium intensity, pause Long medium intensity
11	None	Gradually increase intensity, steady frequency
12	None	Single short low intensity
13	None	Single short high intensity
14	None	Three medium low intensity, steady frequency

The main board, the Bluetooth module and a 7.2 volt lithium polymer battery are housed in a stereo lithography packaging. The device on average consumes 0.5 watts and lasts nearly 8 hours. The controller board is 33mm by 45mm and the final system weighs 85 grams without the battery.

3. Experiments

The current eWatch prototype is equipped with a blue and red LED light and a vibrating motor. A user study was conducted on the various combinations of notification modalities. The LEDs and vibrating motor were tested on three parameters: intensity, duration, and pattern. After each notification, the participant is acknowledges the pattern by pressing a button on the watch. The time between the end of the notification pattern and the time to when the eWatch button is pressed is the "response time." Based on the subject's response time, we aimed to determine which notification pattern is most effective.

We performed a preliminary study involving five participants. We chose a few patterns to send to users while they conversed. The two lessons we learned are that we need to make signals distinguishable in two or more parameters, and that we should pause between different intensities.

Based on this new information, we ran a complete study using 11 participants. Three participants engaged in oral conversation. Eight participants engaged in a computer-related task. In this iteration of the study, we systematically chose 14 notification patterns to send to the participant's watch. The patterns are listed in Table 1. Each pattern had a total duration of 10 seconds. Measuring the response time (in seconds), we obtained the results in Figure 4.

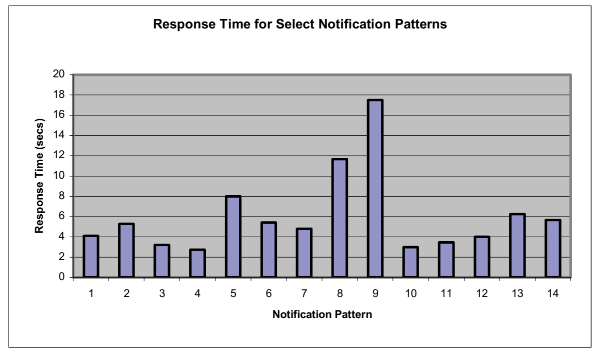

Figure 4. Response Time for User Study Notification Patterns

Pattern #4 (three long medium vibrating intensities) had the shortest response time of all tactile notification patterns. The alternating red and blue LED pattern provided the fastest response times among the visual notification patterns.

4. Conclusions

This paper presented a dual purpose, sensing and notification platform, for context aware wearable systems. In particular, we address activity sensing and notification mechanisms. eWatch senses user activities and notifies them when important emails have arrived. The system combines an interruptibility measure and email priority level, user calendar data from a PDA to decide how and when to notify the user. Our user studies explore effective notification mechanisms and their results have been presented. We are planning to run more field tests of the eWatch to continue testing our notification and input sensing capabilities.

5. Acknowledgements

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