Linux Watch: Hardware Platform for Wearable Computing Research

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Abstract. The Linux Watch is a wearable information access device that is worn on the wrist. It is an ARM7-based low-power Linux system with short-range wireless communications and a multi-modal (voice and image) user interface with a watch shape and is used as a hardware platform for wearable computing research. The Hands-free Mobile System is a kind of speech-oriented client-server system using the Linux Watch. The Linux Watch acts as a front-end user interface device but appears to have all the functions and intelligence of the server including voice-recognition and synthetic speech capability via its multi-modal user interface. This paper describes The Linux Watch hardware platform and the concept of the Hands-free Mobile System.

1. Introduction

For the practical use of wearable computers, it is important that end-users feel comfortable wearing them. Wristwatches have been used and accepted by many people for a long time. They have the advantage of always being there and instantly viewable with a flick of the wrist without taking it out of a pocket or bag.

We focused on this ergonomic advantage and have prototyped a wearable computer, called the Linux Watch, in this form factor as a hardware platform for wearable computing research in areas such as user interfaces [1], high resolution displays [2], system software, wireless communications, and power management.

We chose the Linux operating system for the watch, because it is suitable for a research platform with high programmability. Linux makes it very easy for many researchers to start developing programs on this new platform, because there is a lot of source code and a wide variety of software tools available.

The screen size of a wristwatch is relatively limited because of its small size overall and the requirements for elegance fashion do not allow many buttons on the device. Voice can be used as an additional user interface method to supplement image information and virtual buttons [3][4] and users find it very satisfactory when it is well integrated into a multi-modal user interface with images [5]. The extra audio information can effectively compensate for the limited display size. But it is quite difficult for the Linux Watch to recognize and synthesize human voices by itself, given its available processor power and power consumption at present. We suggested using the capabilities of another machine nearby or somewhere on the network via

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wireless communications to compensate for its computing limitations. In other words, we recommend load balancing using wireless communications between the Linux Watch and a server on a network.

In the following sections we introduce the system hardware and the Hands-free Mobile System concept.

2. Hardware of the Linux Watch

We made the hardware design modular to allow the use of various shells. The Linux Watch system has two types of shells now as shown in Figure 1. One is smaller and fancier and is called the "basic shell", and the other, intended to be more functional with an accessory card, called the "enhanced shell".

Fig. 1. Linux Watch Shells (Left: Basic Shell, Right: Enhanced Shell)

The Linux Watch uses an ARM7 core system LSI as its MPU. A touch panel and a roller wheel are employed as the primary input devices. A tilt switch is used to detect arm motions for gesture input. The enhanced shell has an accessory bay for various additional functions. A Bluetooth card and a RF-modem card are now available, along with PCM audio functions including a speaker and a microphone for a multi-modal (voice and image) user interface. As a display device, a self emitting organic LED display (OLED) with VGA resolution or a 96 x 120 pixels B/W LCD display is used. A rechargeable lithium-polymer was selected to resolve the problem of supplying peak current in a small form factor, though its capacity is smaller than the primary battery. Table 1 summrizes the specifications.

The main circuit card was designed using the off-the-shelf parts, but using the state-of-the-art packaging technology called Surface Luminar Grcuit (SLC). It is packaged in a small stamp sized board, only 35.3 x 27.5 x 3.0 mm as shown in Figure 2. Accessory cards are connected to the main board using an ultra low-profile elastomer connection method.

Table 1. System Specifications

Size / Weight	56 (W) x 48 (L) x 12 (T) mm, 44 g
CPU	ARM7 core (18 – 74 MHz)
Memory	DRAM 8MB / Flash ROM 8MB
Display	VGA OLED (740 dpi) / 96 x 120 LCD
Communication	IrDA v1.2, RS232C (Cradle), Bluetooth (Accessory card), RF modem (Accessory card)
Input Device	Touch Panel, Roller Wheel, Tilt Switch
Power Source	Li-Polymer Battery
OS / Window System	Linux 2.2.1 / X11R6.4
Bluetooth Protocol Stack	IBM BlueDrekar

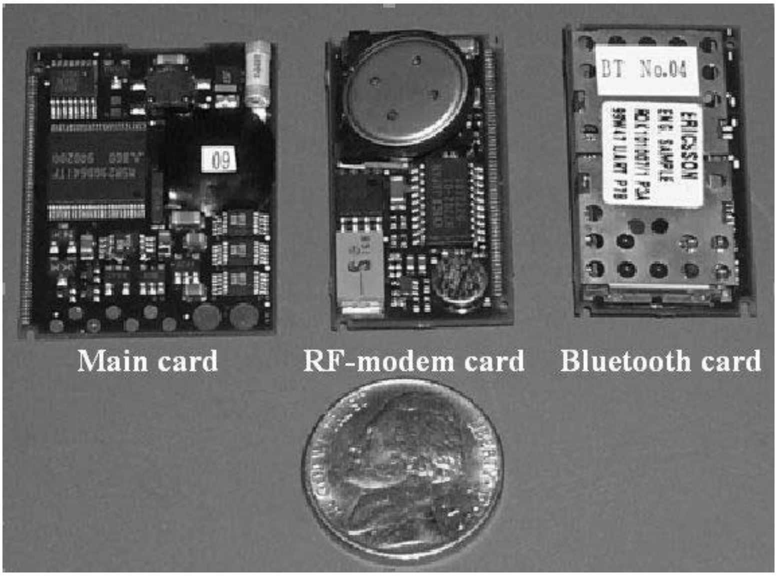

Fig. 2. Linux Watch Main Card and Accessory Cards

The interface between the accessory card and the main card is designed to support various additional functions using the interfaces of a Compact Flash (CF) and a Serial Peripheral Interface (SPI), as well as a Universal Asynchronous Receiver Transmitter (UART) and Pulse Code Modulation (PCM), which is actually used for the Bluetooth card and the RF-modem card. For example, a Peripheral Interface Controller (PIC) controlling sensors on an accessory card can be easily interfaced with the main card through the SPI.

The Linux Watch system is designed based on the modular concept shown in Figure 3. The basic device, which is composed of the main card and Linux, is very small to easily fit in larger devices, and can be used as a pervasive computing platform in the future.

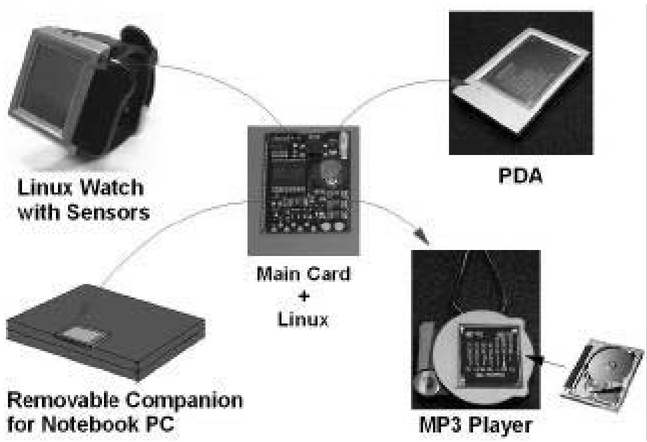

Fig. 3. Modular Concept: Design Variety for other form factors

3. Hands-free Mobile System

3.1. Hands-Free Mobile System Concept

The Hands-free Mobile System is a kind of speech-oriented client-server system based on short-range wireless communications as shown in Figure 4.

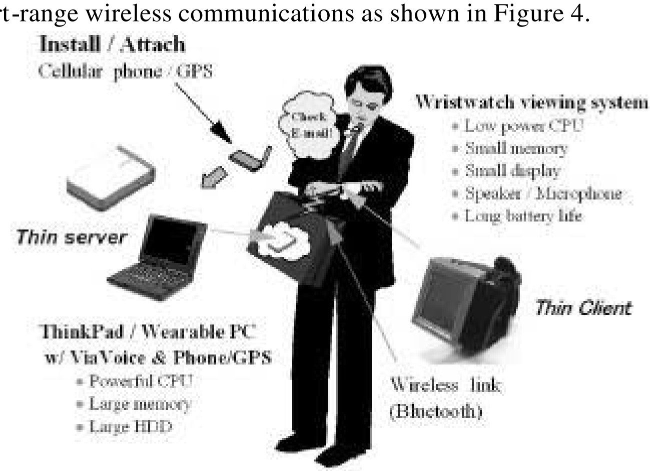

Fig. 4. Hands-free Mobile System Concept

This concept is based on a thin server and a wristwatch type thin client. The thin server has capabilities of handling voice, short-range wireless communications, and some application programs. We think the Linux Watch can be the thin client and a

ThinkPad or a wearable PC prototyped by IBM can act as the thin server. The thin client is a low power device for long battery life and has capabilities for short range wireless communications and to support a multi-modal (voice and image) user interface. In this system, a thin client transfers voice or user input to the thin server. The thin server receives this data and replies with an image or voice data sent to the thin client using wireless communications. Data processing should be handled, especially voice recognition and speech synthesis, in the thin server or in some cases the thin server can act as a relay to a more powerful remote system using long-range wireless communications.

Relying mostly on the computing power of the thin server, the thin client needs to have little more than I/O capabilities. Its form factor and the battery life become the important design constraints, rather than its computing power. When the thin client is a simple I/O system, developers can concentrate their application program development on the thin server side.

The short range wireless communications sytem will not be expected to connect every time and the thin client should have a cache mechanism for the information from the thin server and have some processing power, not only I/O capabilities. The progress of technology will lead the voice recognition with low power consumption even on a wristwatch type computer. Distributing various functions between the thin server and client will be an important design tradeoff. However, we think the Hands-free Mobile System concept system can be the first step for exploring how to get contextual information at the point of need in a ubiquitous computing world using the Linux Watch.

At the next stage, when short-range wireless communications such as Bluetooth becomes commonplace, it will be possible for information to be obtained from various hosts --ThinkPads, desktop PCs, or even devices like household appliances and the Linux Watch can be a general purpose browser or a controller.

3.2. Experiment Using Prototypes

We have prototyped an experimental system using a Linux Watch, including an RF modem card and a wearable PC produced by IBM to experiment with this concept as shown in Figure 5. Since the RF modem card cannot handle voice data to the wearable PC, a bone conduction microphone with an earphone is used for providing the voice input and output.

Fig. 5. Experimental System

Using this system, we studied the usability of personal information management applications such as a scheduler, mailer, car navigator, and a cellular telephone. All these applications are executed in the wearable PC and the Linux Watch acted only as an I/O device to transmit the user input from the touch panel and the roller wheel and to receive the image data from the PC with the assistance of voice-activated functions using the bone conduction microphone and voice the earphone.

We sometimes had difficulty in verifying whether the voice-activated functions worked correctly or not. We adopted a dialogue-based operation method to increase the tolerance for mistakes in voice recognition in the noisy environment. For example, when a user wanted to execute mailer application, he or she said "Mailer" and then the system would answer "Mailer" and change the image to the mailer for the verification by the user.

3.3. Feasibility Study Using Bluetooth

Bluetooth is expected to spread rapidly and widely in small gadgets like the Linux Watch and cellular phones and even to PCs and we anticipate good interoperability among them. This will be a good fit for our hands-free mobile system concept, because it can communicate not only text and binary data but also voice information. We used a bone conduction microphone in the above experimental system, but we believe we will be able to eliminate it when using a Bluetooth-based voice link.

Once the Bluetooth environment matures, any third generation cellular phone system (IMT-2000) might act as a relay device, and any computer connected to the Internet can act as a host for such a system. The Linux Watch will seem to have intelligence and many functions with the assistance of these powerful background computers.

We have prototyped another system in which we could control a presentation package made with PowerPoint and Freelance on a laptop PC from the Linux Watch via Bluetooth like a remote control. Using this prototype system, we verified that we can control presentations easily without standing near the laptop PC.

We tried a feasibility study of voice commands via a voice link using Bluetooth with this sytem and we succeeded in achieving the recognition in a quiet laboratory. However, it was still impractical in noisy real world environments.

4. Conclusions and Future Work

We are prototyping a Linux Watch as a research platform which has a capability of short-range wireless communications and multi-modal user interfaces. The Hands-free Mobile System concept has been tested and the usability of the prototype using a multi-modal user interface on the Linux Watch was verified.

As the next stage of this research, we will continue to study the multi-modal user interface using the Bluetooth-based voice link and would like to study other sensors for recognition of the user's context and for a new user interface. Other research areas will be involved such as developing suitable applications for such the Hands-free Mobile System, balancing functions between the thin server and client, and studying the power-consumption and local-function tradeoffs for the Linux Watch itself.

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