A Ubiquitous Fashionable Computer with an Intuitive Interface $i - throw$

Seung-Ho Lim, Hyun-Jin Choi, Ki-Woong Park
Jong-Woon Yoo and Kyu-Ho Park
Computer Engineering Research Laboratory
Department of Electrical Engineering and Computer Science
Korea Advanced Institute of Science and Technology
{shlim, hjchoi, kwpark, jwyoo}@core.kaist.ac.kr, kpark@ee.kaist.ac.kr

Abstract

The ubiquitous fashionable computer(UFC), introduced in this paper, is a wearable computer that exploits ubiquitous computing environment. In the ubiquitous environment, wearable computing systems integrate various types of devices, like communication interfaces and user interfaces to get services in any time and any where and facilitate the computing system without any burdensomeness. In addition, the external design should be aesthetic and comfortable to success its popularity and let more people use for their real lives. We present the design approach and philosophy of our wearable computing system that is wearable, aesthetic, and intuitive. The main features are like this. It supports the interoperability of various communication interfaces between WLAN, Bluetooth, and Zigbee devices. Novel user interfaces, called $i - throw$, is developed and integrated with the UFC system to help the intuitive use of it. Our UFC with $i - throw$ can control ubiquitous environment using intuitive hand motion. It is realized and tested with real testbed environment that has various network interfaces, sensor nodes and ubiquitous components, and also applications are implemented and presented.

1. Introduction

In recent years, wearable computing and ubiquitous computing system environment has realized due to the rapid progress of computing and communication technology. Wearable computing system can be broadly defined as mobile electronic devices that can be unobtrusively embedded as part of garment or accessory [2]. Unlike conventional mobile devices, it always active and running without user's attention and gives services to user with the support of ubiquitous environment. In the ubiquitous environment, we get necessary information in anytime and anywhere without any constraint, using the wearable computer.

In wearable computer, the design of new paradigm has concentrated on the problems that arises when user has to put up with considerable inconvenience carrying around devices [3][4][5][6]. The success of wearable computer will heavily rely on good wearability, usability, aesthetic appearance, and social acceptance. In addition, not merely considering about these uncomfortable carrying issues, the reflection about the exploit of ubiquitous computing environment should be done. The emerging wearable ubiquitous computer have various communication interfaces, such as WLAN, Bluetooth, and Zigbee communication to support various ubiquitous network environments. WLAN has already spread in many areas and widely used for network connectivity. It can support high data rate. Bluetooth is somewhat less used than which is expected for its high power consumption, however, lots of user interface devices are developed commercially. Zigbee has lower data rates, lower power consumption than others, so it can be used small sensor network devices and personal area network. In the ubiquitous environment, the user who wear the wearable computer can access internet using WLAN and identify his email, while hearing music using Bluetooth headphone. At the same time, he can get the location based service within the indoor location using Zigbee sensor networks. However, when various communication interfaces are integrated and used in one convergence device, these heterogeneous communication interfaces may interfere each other because generally these are operated in 2.4GHz ISM band. Therefore, the wearable computer might not operate well for these interference problems. To solve these problem, coexistence and interoperability algorithm should be designed with appropriate sterategies.

In addition to that, a novel user interfaces should be considered to allow users to access and utilize the system without any uncomfortable interference. The uncomfortable interface means that users should get training its function with burdensome input or output devices using wearable keyboard and mouse. This is called Human Computer

Interaction concept. In wearable computing, it is desired to develop comfortable and user friendly input devices for wearable computing. A novel user interface is required to be simple, easy and intuitive by recognizing human friendly gestures, activities, or senses. Intuitive interface can be described as the mechanism of controlling devices in a ubiquitous environment by human friendly gestures which everyone can easily accept and recognize. Human voice, eyes, and hand gesture are good means to realize input devices as user interfaces in wearable computer.

In this paper, we present the design approach and the philosophy of our wearable computing system that is wearable, aesthetic, and intuitive. The main features are as follows. It supports the coexistence and interoperability of various communication interfaces between WLAN, Bluetooth, and Zigbee devices that can be operated freely in any ubiquitous system environment. This can be done using dynamic channel allocation mechanism between communication devices that operates in the same ISM band. In addition, in our wearable computer system, novel user interfaces are developed and integrated with the UFC to help the intuitive use of it. One representive interface is what we call $i - throw$, which means intuitive throw devices. this input device can recognize human's hand gestures and direction, and control ubiquitous devices with the gestures. Our wearable computer is called Ubiquitous Fashionable Computer to advance the wearable computer, by representing the characteristics that is wearable, aesthetic and intuitive. Our UFC system is realized and tested with real testbed environment that has various network interfaces, sensor nodes and ubiquitous components, and also many applications are implemented and presented.

The remainder of this paper is organized as follows. Section 2 describes the related work concerning about wearable computing system. In Section 3, we explain the features of designed UFC wearable computer and ubiquitous environment. The intuitive user interface, $i - throw$, is explained in Section 4. Section 5 illustrates application in our UFC system, and Section 6 presents the conclusion.

2. Related Work

Wearable computing systems are already become one of the main research area. some of the currently available wearable computers include PDA based systems relying on industrial standard architecture concepts. MITthril[7] is one of these examples that integrated computation, sensing, networking into cloths and all devices are connected using body bus which is single-cable hardwired connection. These systems based on standard PC or PDA based solutions just made a conventional embedded devices as a wearable form, so do not reach high degree of wearability and usability.

Wearable systems based on custom design include low end special purpose appliances such as watchs[10] and garments[11]. IBM's Linux Watch[10] packed a fair amount of hardware into wristwatch size and showed the model of a wearable computer form. With this small watch form and communication interface with Bluetooth and Irda, it supports short-range communication applications. However, it has lack of other communication interfaces and user interfaces. Therefore, it should be considered what kind of service can be supported with its limited interfaces. These low end custom designs are bound to their specific task due to lack of system specification and interfaces.

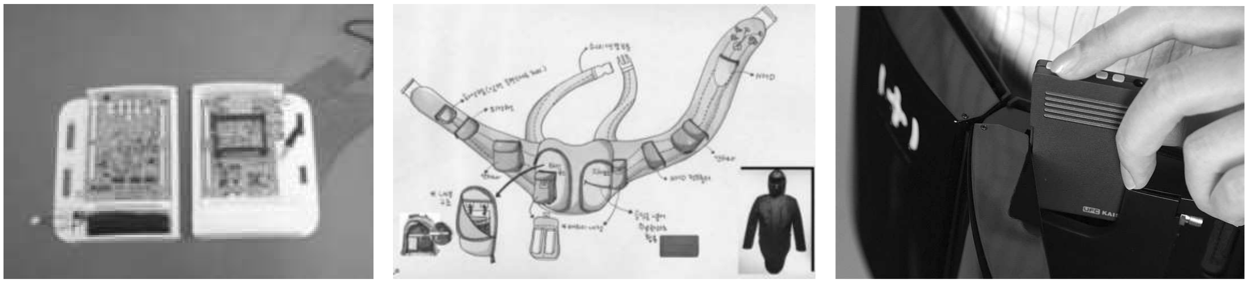
The custom multiple purpose systems have developed providing more functionality and flexibility. WearARM[8], QBIC[2], and Xybernaut wearable computer system[9] are wearable computer systems that is designed with custom multiple purpose. These are integrated into shoulder, belt, and waist, respectively. These systems establish a compromise between high and low end in providing processing performance and a wearable system design. QBIC shows a case that address ergonomic aspects as well as providing sufficient connectivity and computational performance in hardware level. However, these systems should consider ubiquitous environment to realize real necessity of wearable platform in any time and any where. It means that wearable system should be realized for supporting various ubiquitous systems environment without any interferences and disturbances, not merely support of its connectivity to devices. Also, intuitive user interface should be applied to these system to support the comfortable use of it.

3. UFC System Architecture

The UFC system consists of portable wearable computer with various communication interfaces and user interfaces, and ubiquitous environment. The basic design concept of UFC wearable computer is modularity and extensibility.

3.1. UFC Platform

Our UFC consists of several module parts: main module including CPU and Memory, communication module including various communication interfaces, and user interface modules with I/O interfaces. In the main module, the core of the UFC system is an ARM based Intel XScale processor: the PXA270. Main features of this processor include clock scaling and dynamic voltage scaling up to 624MHz. With this, power management of wearable computer can prolong the life time of the platform. Main memory of UFC is 256MB, which is relatively large capacity for a mobile devices. However, with this large capacity, we can support a wide range of services such as audio and video transmission, and java virtual machine based middleware



(a) UFC PCB board Design with Internal Hard Case

(b) UFC External Design Sketch of Soft Case

(c) Wearing the UFC with Zigbee Enabled Tiny Terminal

Figure 1. UFC Platform Design and Implementation. UFC give high performance computing environment with various communication interfaces and user interfaces

Table 1. UFC Platform Specifications

Modules	Specifications	
Main Module	CPU	XScale PXA270 624MHz
	Memory	Mobile SDRAM 256MB
	I/O Interfaces	RS232, USB 1.1/2.0, Mini-PCI and PCMCIA
Communicatnon Module	WLAN	IEEE 802.11 a/b/g
	Bluetooth	IEEE 802.15.1
	Zigbee	IEEE 802.15.4
User Interface Module	i-Throw	Intuitive Input Device using hand motion
	Audio In/Out	2 Ch Microphone for Voice Command / Earphone
	Video In/Out	Camera / VGA with HMD
Software Part	Operating System	Embedded Linux 2.6.9
	VM	Java Native Interface
	Middleware	OSGI Specification

services. Main specification of UFC platform is described in Table 1, and the implemented UFC platform is shown in Figure 1.

In communication modules, major theme is to implement coexistence and multimodal communication among WLAN, Bluetooth, and Zigbee RF communication. WLAN is used for network services such as internet, ftp, and e-mail, and Bluetooth is for wireless headset, mouse, and keyboard. The Zigbee is adapted for the location based service(LBS), which can be operated with ubiquitous sensor network systems. There are several studies on the interference and coexistence problems among communication devices that use the 2.4GHz ISM band. Up to now, many coexistence models were presented in terms of WLAN and others. In case of the interference between WLAN and Bluetooth, various problems were discussed in [16]. However, the coexistence problems between WLAN and Zigbee are not widely addressed yet. The study about coexistence problems between WLAN and Zigbee are very important because Zigbee has goo features so it is expected to be widely applied in various communication environment, such as wireless sensor networks, persornal area networks, body area networks. To miminize the interference between communication devices, we have dsigned and implemented the dynamic channel allocation algorithm in device driver and application layers that use communication interface devices. For that, we investigate the frame error rate(FER) for each communication device, and dynamically allocate the appropriate channel of Zigbee devices considering the channel status. The algorithm is as follows. At the initial status, we set a channel to the Zigbee device and thresdhold value of FER, and allocate a variable for counting the number of exceeding a given thresdhold FER. The FER of the device is measured in every observation window. If FER of current observation window is exceed the threshold FER that is set in initial status, we count it. When the count number, that represents frequency

(a) Zigbee Enabled Tiny Ternimal PCB board

(b) Apperance of Zigbee Enabled Tiny Terminal with Case

(c) Wearing of Stand Alone Zigbee Enabled Tiny Terminal

Figure 2. Tiny Terminal can support limited stand alone LBS, also dock to UFC Wearable Computer to present more LBS using Zigbee communication

of increasing FER, is over the limited value, which means the device has influenced by other devices. In that case, we change the channel of the device to other bandwidth for lowering the FER value. By doing this, Zigbee devices can operate properly without channel disturbance.

In addition to these modules, UFC supports high performance I/O interfaces including mini-PCI and USB 2.0 to support high performance devices connection. An VGA interface is integrated to connect with head mounted devices for system monitoring, camera interface is used for video input. For audio part, 2-ch microphone input is used for voice command interface. For the appearance of UFC, it is generally thought that the value of a wearable computer is largely determined by how easily and effectively it allows users to perform the tasks in everyday. Therefore, the success of wearable computer relies on not only wearability, but also the aesthetic appearance and social acceptance. We tried to find the solution to fulfill the requirements by repeating the prototyping bodystorming progresses. We defined the target users as young university students and drew design concepts by analyzing their activities in everyday life and fashion trend. The design appearance is shown in Figure 1(b) and Figure 1(c). Basic type of UFC is belt and backpack.

Operating system running on UFC is GNU/embedded linux with kernel 2.6. Linux 2.6 with ARM processor shows more deemed feasible performance in real time embedded system than lower versions. Efficient middleware platform is implemented with UFC to provide various helpful services with low overhead and power. The middleware interface can be implemented with standard Jave execution environment called Java Native Interface(JNI)[12]. Useful functions which are covered by middleware include context management, service discovery, and local file sharing.

Especially, Zigbee interface device is designed and implemented for limited stand alone LBS with its battery, because Zigbee offers battery life of up to several years for common small batteries. Main control processor of it is Atmega128 8-bit microcontroller which is sufficient to process the Zigbee communication and controlling. Chipcon's CC2420 Zigbee module is used in implementation for Zigbee communication, which gives low power consumption [15]. Audio codec chip is included for audio services, such as voice announcement and music play entertainment. The stand alone Zigbee device, which we call Tiny Terminal, is shown in Figure 2. Users can wear it like a type of necklace with its small size and light weight, and get the limited services such as LBS like location notification and entrance check. While running for stand alone using its low power microcontroller, Tiny Terminal can support high performance LBS by docking to XScale Based UFC platform and presenting Zigbee communication, as shown in FIgure 1(c).

3.2. UFC Ubiquitous Environment

The interoperability of mobile devices in ubiquitous environment is an important issues because various network environments are deployed. The wireless sensor network based on IEEE 802.15.4[13] is one of the possible technologies to provide the location sensing and mobility to mobile users. Figure 3 describes the architecture of UFC ubiquitous environment. The sensor nodes are installed in a regular manner for location sensing of users, and three types of servers are installed for the management : location management, network management, and application management.

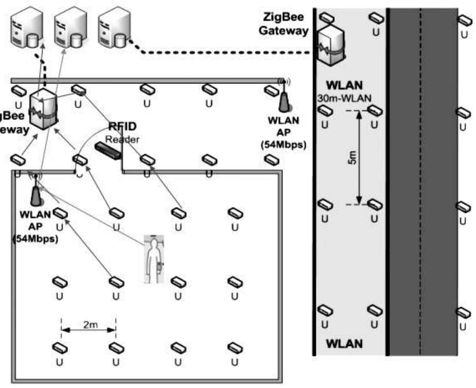


Figure 3. UFC Ubiquitous Environment for IEEE 802.15.4 based Wireless Sensor Network and IEEE 802.11.a/b/g Wireless Local Area Network System

The connection between servers and users could be done via multi-hop sensor nodes for low speed data transmission, and WLAN access pointer for high speed data transmission, respectively. The MAC layer of sensor node is implemented as Zigbee which supports IEEE 802.15.4. Zigbee network. For the location sensing, the Sensor node broadcasts beacons periodically, which uses 2.4GHz as a physical channel. The user who wear UFC wearable computer receives beacon signals from the Zigbee communication interface. When the user receives multiple beacons from the multiple sensor nodes, the users who has received the beacons can identify his location by calculating each Received Signal Strength Indicator(RSSI) value from each sensor node. For high speed data transmission service such as file transfer and multimedia services, UFC wearable computer can transmit or receive via WLAN network using WLAN access pointer, which also use 2.4GHz as a physical channel. Because all the network interfaces use 2.4GHz ISM band for their physical channel, these heterogeneous communication interfaces may interfere each other. These coexistence issues were described in previous subsection.

4. Intuitive User Interfaces, $i - throw$

In this section,we describe our user interface module. Suppose that a user who wear a wearable computer tries to transfer the files to other systems or to other users. Users should open a appropriate programs, type destination address, select files to be transferred, and finally transfer the files. Is may feel uncomfortable for these complex processes. In case of file transfer, we can use simple intuitive action like 'throwing a ball' to 'throw' to other systems or users. Another case can be described of listening to music.

Table 2. Intuitive Actions that can be serviced by $i - throw$ user interface

Intuitive Motions	Command Description
Throwing a ball	File Transfer
Turning Left/Right a dial	Intensity Control
Waving a hand	Scroll Up/Down
Wiping a blackboard	Erase

Users may often hears music with his wearable computer while he is moving. When he was listening music while walking, his friend came up to him and asked about the music. Then, he decided to transfer the music by throwing gesture toward other person as if the music file were a ball. Similarly, lots of services can be presented using simple intuitive actions of human. Table 2 describes some of these intuitive actions that is performed by human's hand action.

To realize the human action as input device for our UFC wearable computer, we have developed a tiny user interface called $i - throw$. The $i - throw$ is a new interface device which is worn on the back of the human hand. It operates with UFC to transfer files or control messages with intuitive hand gestures. It is composed of three major components. For the motion estimation, three-axis accelerometer is used to recognize user's hand motion, and three-axis magneto-resistive sensor is used to find direction that user's hand points. G-range is measured by accelerometer with its range from -4g to 4g, and magnetic filed are measured by magneto-resistive sensor. A Atmega128 micro controller is used for the control of these two sensor chips and the connectivity with UFC wearable computer that is connected using RS-232. Its internal ADC interfaces convert analog sensor output to digital by sampling with rate 288KHz. It's implemented device is shown in Figure 4. It is packed with small sized package and can be attached in the back of hand.

4.1 Recognition of Hand Motion

The recognition of hand motion is done with the estimation of hand's acceleration values and some special features which are stored in. For example, some values over 2g can be a special feature for throwing. It is uncommon that people move hand over 2g in usual life. When acceleration values exceeds over 2g for a short while, we can recognize that he got the gesture like throwing a ball with his hand. Some motion such as 'turning a dial' may need to know when a user try to stop the control like reducing or raising the volume. In this case, the acceleration is repeated twice and direction is altered twice. With these pre-defined threshold values for each action which is stored in $i - throw$ device, $i - throw$ can recognize a user's hand motion, transfer its

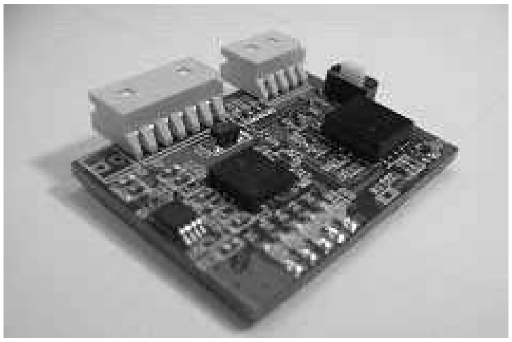


Figure 4. Intuitive User Interface called $i - throw$. It is equipped with an accelerometer for the recognition of hand gesture, and a magneto-resistive sensor to identiry the direction

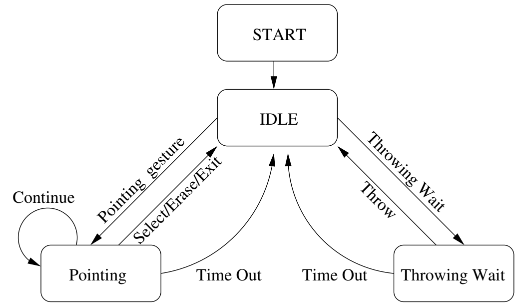


Figure 5. The State Machine of Motion Recognition Algorithm in $i - throw$

command to UFC wearable computer, and present the services.

the gesture recognition algorithm is basically a state machine, as shown in Figure 5. In the state machine, if a user turns on $i - throw$, it initializes the hardware and goes to the $IDLE$ state. While the user takes natural gestures, $i - throw$ stays in this state. The throwing gesture command consists of two parts: throwing wait part and throwing gesture part. If the user holds up his hand and stops for the time duration TS, $i - throw$ then supposes that the user is going to take throwing gesture soon. So it moves from the $IDLE$ state to the $Throwing\,Wait$ state and waits for the user's throwing gesture. If the throwing gesture is detected, $i - throw$ prepares a data packet which includes the information about the recognized gesture command, throwing, and sends it to the UFC. If the throwing gesture is not detected for the time duration TT in the Throw wait state, $i - throw$ generates a time out event and returns to the $IDLE$ state. In case of other gesture commands except throwing, each consists of the pointing part and the gesture part. $i - throw$ changes its state from the $IDLE$ to the $Pointing$ if the pointing part is detected. If any of the command gesture is detected in the $Pointing$ state, $i - throw$ prepares a data packet and sends it to the UFC. According to the kind of actions, $i - throw$ returns to the $IDLE$ state or remains in the $Pointing$ state. If it remains in the $Pointing$ state, the user can make another gesture command immediately without pointing. Therefore, the gestures such as the volume up/down or scroll up/down command can be taken sequentially with shot intervals.

The recognition algorithm could become simple and light enough to run in a micro-controller, such as ATmeaga128L, by extracting the minimum set of needed gestures and using threshold-based simple features. The microcontroller in $i - throw$ processes all the accelerometer's output and reports only the results of gesture recognition to UFC in the form of data packets. So the data traffic amount between $i - throw$ and the UFC could be reduced significantly. This reduction in traffic amount gives room for improving $i - throw$ as the wireless device using Zigbee.

4.2 Target Detection

The orientation of $i - throw$ can be obtained by combining the accelerometer and magnetic sensor outputs. Although we need only the accelerations of gravity while calculating the orientation, accelerations due to the hand movement are also included in the sensor outputs. Therefore, to get an exact orientation, outputs should be captured while $i - throw$ is motionless. For this, each gesture command has a motionless part to indicate the beginning of the command. So the orientation can be calculated exactly by using the outputs captured during that motionless part. Another problems is that because the orientation calculating contains some complex processes, such as getting the Euler angle rotation matrix or manipulating trigonometric functions, it is hard for a microcontroller to handle these works with its limited arithmetic instructions. We moved the role of orientation calculating from the microcontroller to the UFC. However, since the orientation information is needed only when a gesture command is taken, $i - throw$ generate a data packet that contains the magnetic field information only when a gesture command is detected. To find out the target, not only the orientation but also the position information is required, which is from the UFC ubiquitous environment that can trace the user's position based on the RSSIs of Zigbee sensors The location server has a virtual 2D map of the UFC ubiquitous environment. By managing a virtual map and varying the area of scan region with feedbacks, the overall target detection accuracy can be improved. Using these orientation value of $i - throw$ and targe position information of ubiquitous environment, target dectection can be performed properly.

4.3 Another intuitive interface, human voice

Human voice may be a good user interface for wearable computer. Voice recognition has been implemented in many mobile system to recognize voice command. Phone call dialing is a good example. In the wearable ubiquitous system, noise robustness is required for the comfortable use of it. In UFC, two microphones is used as its audio input devices for the robustness against noise, one for noise recognition and one for speech detection. The recognition process is as follows. Observing the waveforms which are received at each time, speech detector always checks whether they are potential speech or not. When an utterance is detected, feature extractor extracts high-dimensional features. Finally, we get to obtain a recognized word through calculating the probability of input waveform. The recognized speech consists of a string of characters. This string of characters is transferred to the sound console driver in the kernel, which is responsible to transmit the string to keyboard input strokes. Those key input stokes will be considered as if someone strokes keyboards.

5. Applications

The UFC can give very easy and intuitive high performance computing services with various communication interfaces and various intuitive user interfaces. Typical applications among many ubiquitous environment systems are indoor navigation, location tracking, and location based services. These include entrance checking with authentication of libraries or lecture rooms, navigation of guest users, and intuitive control of ubiquitous system devices. If one want to get the limited LBS such as entrance checking or libraries of lecture rooms, he can do it just using Zigbee enabled Tiny Terminal. While, the full UFC platform can perform the high performance service, for example, the intuitive message exchange between users or between user and ubiquitous environment.

To explain the UFC feasibility, we have implemented UFC demonstrative applications which are based on ubiquitous environment. Figure 6 describes the implemented ubiquitous computing environment. In the ubiquitous environment, Zigbee sensor networks are setup for location sensing of users and WLAN is for data transferring. Many ubiquitous test bed devices are deployed such as DVD player, sound system, Light, and so on. These have their own Zigbee sensor node, so the location server keeps tracks the locations of not only users who wearing the UFC, but

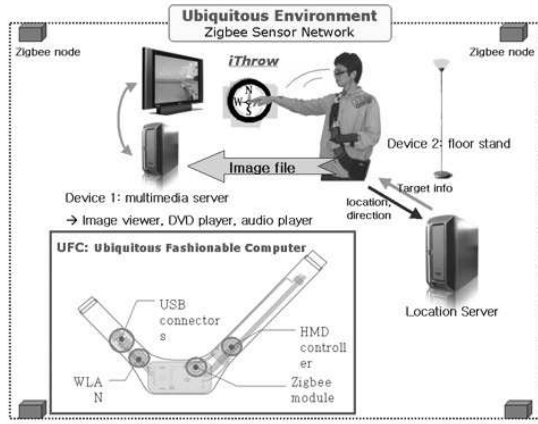


Figure 6. UFC system including UFC wearable computer and ubiquitous environment, and Intuitive control and message passing Application with $i - throw$

also these ubiquitous test bed devices. Zigbee based location server can also transfer small control signal to these devices using Zigbee communication network protocol.

When the user who wearing UFC enters in the room, the location server identifies his location using the Zigbee communication interface and keeps track of his mobility. If two persons are in the room, the location server can discriminate the location of each person. In that circumstance, if one person, A, want to transfer his information or some messages to other person, B, A can send it just by making a gesture that is similar to throwing motion to the direction of B's location. The throwing motion is detected by user interface, $i - throw$. and it recognize the A's throwing motion and notifies UFC that he wants to transfer something to the direction that directed by his hand. This command is caught by UFC, then UFC tries to identify the B's location from the location server and makes network connection. The UFC now tries to transfer the information message via networks. This easy communication method using intuitive user interface, $i - throw$, would activate the discussion environment and easy data transfer between members for ubiquitous conference room or lecture room.

Also, the UFC can facilitate the ubiquitous devices by controlling intuitively. In the ubiquitous environment described above, UFC can control the ubiquitous devices intuitively by hand gestures. When user who are listening to the music using uncomfortable headset are entering the ubiquitous environment room, he might want to listen to the music more powerful sound system, without any stopping the music. In that case, he can listen to music seamlessly by throwing his music to ubiquitous sound system. The throwing motion is detected by $i - throw$, and the similar mechanism is happened as described above. Likewise, UFC can control all the ubiquitous environment devices with its pre-defined control mechanism based on $i - throw$'s hand motion, such as volume up/down and fast forward/rewind, which are described in Table 2.

6. Conclusion

The ubiquitous fashionable computer(UFC), introduced in this paper, is a wearable computer that exploits ubiquitous computing environment. The success of wearable computer will heavily rely on good wearability, usability, aesthetic appearance, and social acceptance. Therefore, the external design of it should be aesthetic and comfortable to success its popularity and let more people use for their real lives. In addition, not merely considering about these uncomfortable carrying issues, the reflection the exploit of ubiquitous computing environment should be done. In the ubiquitous environment, wearable computing systems integrate various types of devices like communication interfaces to get services in any time and any where, and user interfaces to facilitate the computing system without any burdensomeness.

In this paper, we present the design approach and the philosophy of our wearable computing system that is wearable, aesthetic, and intuitive. The main features are as follows. It supports the coexistence and interoperability of various communication interfaces between WLAN, Bluetooth, and Zigbee devices that can be operated freely in any ubiquitous system environment. This can be done using dynamic channel allocation mechanism between communication devices that operates same ISM band. In addition, novel user interfaces are developed and integrated with the UFC to help the intuitive use of it in our wearable computer system. One representive interface is what we call $i - throw$, which means intuitive input devices. This input device can recognize human's hand gestures and direction, and control ubiquitous devices with the gestures. Our wearable computer is called Ubiquitous Fashionable Computer to advance the wearable computer, by representing the characteristics that is wearable, aesthetic and intuitive. Our UFC system is realized and tested with real testbed environment that has various network interfaces, sensor nodes and ubiquitous components, and also many applications are implemented and presented.

References

[1] Kyu-Ho Park, Jong-Woon Yoo, Ki-Woong Park, Seung-Ho Lim, Ju-Pyung Lee and Hyun-Jin Choi, "A Ubiquitous Intuitive Interaction with a Wearable Computer", *4th IEEE International conference on Pervasive Computer and Communications*, Mar. 2006.

[2] Oliver Amft, Michael Lauffer, Stijn Ossevoort, "Degisn of the QBIC wearable computing platform", *15th IEEE International Conference on Application-Specific Systems, Architectures and Processors*, Sep. 2004, pp. 398-410.

[3] S. Mann, "Wearable computing as means for personal empowerment.", *In Proc. 3rd Int. Conf. on Wearable Computing*, May 1998.

[4] A. Pentland, "Wearable intelligence", *Scientific American*, 276(1es1), Nov. 1998.

[5] T. Starner, "The challenges of wearable computing: Part 1.", *IEEE Micro*, July 2001.

[6] M. Weiser, "The computer for the 21st century.", *Scientific American*, 265(3):66-75, Sept. 1991.

[7] R. Devaul, M. Sung, J. Gips, A. pentland, "MITthril 2003: Applications and Architecture" *In Proc. of 7th Int. Symposium on Wearable Computers*, 2003.

[8] U. Anliker, and et al, "The WearARM: modular, high performance, low power computing platform Designed for Integration into Everyday Clothing", *In Proc. of 5th Int. Symposium on Wearable Computers*, 2001.

[9] Xybernaut Corp., Xybernaut wearable systems. Mobile Assistant wearable computer, www.xybernaut.com

[10] C. Narayanaswami et al., "IBM's Linux Watch: The Challenge of Miniaturization", *IEEE Computer*, vol. 35, no. 1, pp. 33-41, Jan 2002.

[11] J. Rantanen et al., "Smart clothing prototype for the arctic environment", *Personal and Ubiquitous Computing*, 2002.

[12] Sheng Liang, The Java Native Interface: Programmer's Guide and Specification, *Addison Wesley*, 1999.

[13] IEEE Standard 802, part 15.4, Wireless Medium Access Control(MAC) and Physical Layer(PHY) Specifications for Low Rate Wireless Personal Area Networks(WPANs), 2003.

[14] Su Min Kim et al, "Experiments on Interference and Coexistence between Zigbee and WLAN Devices Operating in the 2.4GHz ISM Band", *International Conference on Next Generation PC*, Nov, 2005.

[15] CC2420 Datasheet 2.4GHz IEEE 802.15.4 Zigbee-ready RF Transceiver, Chipcon, 2004.

[16] IEEE802.15.2 Specification, Coexistence of Wireless Personal Area Networks with Wireless Devices Operating in Unlicensed Frequency Bands, Aug. 28, 2003.