(4) Fulltime-Wear Interface Technology —Information 'As We Think'—

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In essence, a wearable device is not simply a small computer, but rather an interface mechanism that can be worn full-time and is available for immediate use as needed while we go about our daily lives. Here we present examples of interface devices that are designed for full-time wear.

1. The Computer as a Brain Enhancement Device

Computers were originally designed as machines for performing calculations, but now they have also come to serve as an indispensable link between persons and also between people and the information-world. The computer allows people around the world to interact via the Web and e-mail and to access the virtually unlimited knowledge that exists on the network. It can thus be regarded as a machine that enhances man's knowledge and ability to communicate ('brain enhancement').

If we regard the computer as a brain enhancement device, we would naturally want to be able to use it at any time and any place as we go about our daily lives, rather than being restricted to certain times and places. Originally considered to be a very difficult problem, this scenario, too, is gradually being realized through the penetration of the personal computer into ordinary homes and the proliferation of the cell phone (itself a kind of small computer) that can connect to the Internet. The difficulty of accessing information in daily life has already largely been put to rest. We could also say that 'any time, anywhere', a phrase which has long been used to express a goal of the future information society, has also been achieved for the most part.

However, the ability to obtain information as soon as the need for it occurs to us (immediacy) is important to the goal of handling information on the same level as our own memory or thinking. Dr. Thad Starner, a leading researcher on wearable computers, has proposed the 'two-second rule,' which suggests that the inability to obtain information when it is wanted within two seconds will result in many lost opportunities, so such delayed information is not useful for supporting daily life activities. Early portable devices were designed to be carried, as the term suggests. No matter how small and powerful such devices are made, they cannot be available to use as soon as the thought of using them occurs if they must be carried in a pocket or purse, because the device must first be taken out from where it is stored. One solution to that problem is to have the device worn on the body full-time as one goes about one's daily life. The term 'wearable' is often used to refer to an advancement of 'portable', but an important element is the ensuring of immediacy, in addition to improvement in portability through miniaturization.

Past research on wearable devices has emphasized the making of a computer (processing device) that can be worn on the body. In a world where continuous connection to a network is commonplace, however, the need for a computer (information processing mechanism) to be worn on each person's body fades. In such a world, the computation and memory functions can be positioned on the network side, where great processing power is available and there are no strict limits on size or power consumption. In that case, what must ultimately be 'wearable' is only the 'interface' for conveying the user's intentions to the network and displaying the results from the network to the user. We therefore believe that the essence of 'wearable' is not 'a computer that can be worn on the body', but rather 'an interface mechanism that can be worn on the body'. Nevertheless, conventional research has gone no further than simple miniaturization of existing interface devices such as buttons and displays.

The usability of the central processing unit (CPU), memory, and other such processing mechanisms does not deteriorate as a result of miniaturization. However, the usability of interface mechanisms, which are operated by direct human contact, is degraded by poorly considered miniaturization. (For example, the tiny buttons on wrist-watch-type calculators are very difficult to operate.) We believe that the approach of miniaturizing interface mechanisms that were designed for use on the desk top creates problems for both usability and wearability. We believe that interface mechanisms must be designed anew and specifically for devices that must be wearable full-time, such as 'brain enhancement' devices.

We are conducting research and development on interface mechanisms that satisfy the conditions listed below; we refer to such a mechanism as a Fulltime-Wear interface. A Fulltime-Wear device is more than simply 'wearable' (meaning worn on the body): it is a device that can be worn on the body and is available for use at all times.

① Wearability ··· Does not interfere with daily activities even if worn full-time.

② Usability ··· Rapid input and output is possible without disturbing the flow of the user's thought.

③ Immediacy ··· Can be used immediately after the desire to use it arises.

In the following Chapters, various interface mechanisms that are suitable for Fulltime-Wear devices are described and some implementation examples are presented.

2. Fulltime-Wear Interfaces

Some examples of interfaces that are suitable for Fulltime-Wear are listed in **Table 1**. The following subsections concern methods for implementing Fulltime-Wear Interfaces for various input/output media, such as text, voice, and images.

2.1 Input Mechanisms

(1) Keyboard-Type Text and Command Input Mechanisms

The conventional keyboards that are operated by pressing buttons with the fingers must have key tops that are at least 14.5 mm wide for comfortable typing [1], so it is difficult to achieve miniaturization without decreasing usability. On the other hand, if we think of a keyboard as a mechanism for input by moving the fingers, the need for buttons arranged in an array disappears. Furthermore, because it is not necessary to press down precisely at particular places, accurate input is possible even under unstable circumstances, such as while walking. The glove-type input mechanism is a well-known means for this kind of input [2], but gloves hinder our everyday activities by covering the fingertips and other sensitive parts of the hand that are important to the sense of touch. Methods that do not involve covering the hands include the detection of the myoelectric signals from the muscles with electrodes placed at the wrists to measure the angles of finger joint bending [3] and the placement of acceleration sensors on the fingertips or at the bases of the fingers [4]. Although

Table 1 Examples of Fulltime-Wear Interfaces

INPUT	Keyboard	An array of key switches is difficult to use in a Fulltime-Wear environment →Direct detection of finger movements • Detection of tapping impact by accelerometer (FingeRing/UbiButton) • Detection of finger bending angles from myoelectric signals (CyberFinger) • Detection of finger bending angles by optical fiber (DataGlove) • Use of ultrasonic or light reflection
	Pen Input	Requires a pad (Difficult to achieve both wearability and usability) →Padless operation • Combination of pen-shaped 3D locator and translucent HMD
	Speech-to-Text Interface	Difficult to use in the presence of others (nuisance) →Reduction of the need to speak loudly by improved feedback of own voice (FingerWhisper) →Inferring utterances from changes in mouth shape (lip reading) • Lip reading by recognition of images from a small camera • Use of myoelectric signals from mouth muscles.
	Visual Input	Post-processing is heavy, but the device itself has good wearability
OUTPUT	Audio Output	High simultaneity (can be used while performing other tasks) →Fulltime-Wear because of ultra-small earphone • Feedback by text-to-speech conversion
	Visual Output	Low simultaneity (hazardous because visual field is obstructed or reduced) →Use only when necessary • HMD is optimal for miniaturization of high-resolution, wide view-angle screens
	Other Sensory Channels	Touch, pain, temperature, and itchiness →For special purposes (evoking caution, etc.)

*The red letters indicate examples that are introduced in this paper.

these input methods are in principle capable of the same input operations as are possible with a full keyboard, current sensor sensitivity and signal analysis capability are insufficient to allow the detection of small movements of the fingertips during typing. Therefore, such operation cannot yet be achieved in practice. On the other hand, the same kind of acceleration sensors can also be used to detect the impact of the fingertips during typing [5], [6]. That method is capable of detecting very small typing movements without covering the fingertips. An example of an input interface implemented by this method is presented in the next section. A different approach would be to print key switches on clothing or something else that has a large surface that can be used.

(2) Pointing Mechanisms

The mouse, a typical pointing device used with personal computers, requires space for operation and so is not suitable for Fulltime-Wear systems. The trackball, another computer pointing device, does not require much space but it is difficult to use small trackballs for fine pointing. Stick-type pointing mechanisms, on the other hand, retain usability even in confined spaces [7], so they are easily to wear. Moreover, single-hand operation can be achieved by attaching a flat, multi-axis pressure sensor to a fingernail or the side of a finger. Again, another approach is to attach a pointing pad to the clothing or body surface as suggested for keyboard input.

(3) Pen Input Mechanisms

The pen input method can be used to input text or simple drawings and does not require training. One advantage of this method is 'direct operation', or the ability to draw or write in the original size wherever one wants to. However, direct operation requires a relatively large drawing and display device. One might imagine, for example, a virtual input pad method that combines a small pen input interface with a head-mounted display (HMD) system, detection of relative position would make it possible to use the palm of one's hand or any handy surface as an input pad. Furthermore, detection of fingertip motion by means of acceleration sensors in rings worn on the finger or attached to the fingernail could even eliminate the need for the pen.

(4) Voice Input

The input of text and commands by means of voice recognition is fast and requires no training. This method is also suitable for Fulltime-Wear systems because only a small microphone is required. However, the appearance of talking to oneself in public is not socially accepted yet. Voice input by earphone-microphone may be useful sometime in the future if such behavior becomes acceptable, but, until such a time, a socially acceptable method is needed. One example is a wristwatch-type handset that implements a telephone-like operation style, as described in the next section. Other approaches include mime input methods that do not involve the actual production of sounds. Such method involves inferring of what a person is saying from mouth movements detected from myoelectric signals by electrodes placed around the mouth [8]; another is 'lip reading' from images of the mouth captured by a miniature camera [9].

(5) Visual Input

An interface for visual command-input by recognition of mouth movements and facial expressions can be used without disturbing those around us. However, the image capturing device must be placed a certain distance away from the body, which decreases wearability. On the other hand, recognizing one's surrounding images acquired by a camera worn on the body, is very implementable since it does not suffer from positional and optical restrictions. For example, character recognition of text that appears in signboards and other objects in images of the user's surroundings [10] can be used to surmise the user's location. Also, face recognition technology could be used to identify other persons in a conversation so that the user's memory could be supplemented by retrieving information about those persons from a database.

2.2 Output Mechanisms

(1) Image Display

With conventional display panels, it is difficult to achieve both wearability and usability (easy-to-read characters and speedy browsing) at the same time. This problem can be solved by using a Head-Mounted Display (HMD), which can present a wide view-angle with a small display panel. Furthermore, miniaturization to the size of a bean is possible for devices that project images directly onto the retina [11]. On the other hand, methods that employ flexible display panels attached to clothing are also effective. However, systems that provide constant visual feedback are disadvantageous in terms of safety. Visual output should be turned on explicitly with a switch for use only when needed.

(2) Audio Output

A small wireless earphone has excellent wearability. Furthermore, sound can be used to convey information without interfering with other actions (i.e., it has the quality of simultaneity), so it is suitable as an output mechanism in a Fulltime-Wear environment. On the downside, it is difficult to convey information rapidly with text-to-speech conversion, so methods of data compression such as text summarization and conversion to symbol form using sound icons may be used together with methods of increasing the data presented by means of three-dimensional sound fields.

(3) Touch, Pain, Temperature, and Other Senses

Output methods of these kinds have a higher degree of simultaneity than the sound does, and they do not have disturbing effects on the user's surroundings. On the downside, however, they are not suitable for conveying a large amount of information.

In any case, it is difficult to cope with all circumstances with a single output mechanism. We expect that multiple media will be used in combination, as in the process described below.

① The arrival of information is announced by tactile means such as vibration.

② A short audio summary of the information is given with earphone.

③ Details are displayed when a visual display device is turned on.

2.3 Aware'less'

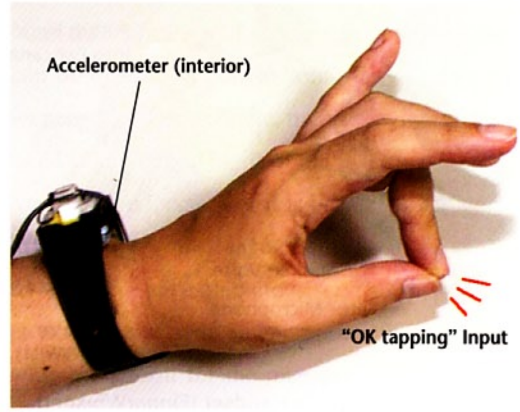
The quality of being used unnoticed by other people around the user is also important for a Fulltime-Wear Interface. We use the term "awareless" to refer to that quality. In a face-to-face conversation, for example, smooth communication would be difficult if the other person seemed to you to be using a head-mounted display to search for information about you. A way of obtaining information while maintaining eye contact, direction of gaze, and focus will probably be required.

3. Implementation Examples of Fulltime-Wear Interfaces

Here, we describe an input mechanism that employs the impact of finger tapping as in typing, and an audio mechanism that employs the conduction of sound by bones as examples of implemented Fulltime-Wear Interfaces.

3.1 Fulltime-Wear Command Input Interface

UbiButton [6] is a Fulltime-Wear command input interface. It uses a single one-axis accelerometer attached to the wrist to detect the impact of fingertips tapping in a typing-like motion. The timing of the tapping can be used to distinguish among a set of from 10 to 30 commands in a manner similar to Morse code. (Unlike ordinary Morse code, however, the command code always ends with a long element.) The small sensor can be installed inside a wristwatch, allowing the user to go about daily activities while wearing it. The input operation can be done on any surface, such as a desk, a purse or one's lap, so it is not necessary to select a keyboard and the immediacy required of a Fulltime-Wear Interface is achieved. Even when there is no tapping surface at hand, input can be accomplished by lightly touching fingers together ("OK tapping"). In particular, when UbiButton is installed in a wristwatch, true one-handed operation is possible in which the wristwatch can be controlled only by the hand on which it is worn. Furthermore, if UbiButton is incorporated into eyeglasses or earphones, devices can be operated without the need to press small buttons by simply tapping lightly near the device with a fingertip. Future development will aim for further miniaturization of sensors by using micromachining technology and increased expressive power by discriminating the tapping force and the tapping finger. The UbiButton sensor and the "OK tapping" operation style are shown in **Photo 1**.



(Input by "OK tapping" operation is possible, even while walking)

Photo 1 Fulltime-Wear Command Input Mechanism (UbiButton)

3.2 Fulltime-Wear Keyboard

The number of commands that are able to be expressed can be increased by putting a sensor such as UbiButton on each finger to identify which finger is being used. One example of this approach is the FingeRing [5], a mechanism in which a ring-like accelerometer (one axis) is worn on each finger. Because the fingertips are not covered, as they are with glove-type keyboard input devices, this mechanism has less adverse effect on daily activities. As with UbiButton, it is not necessary to find a typing surface, so this interface can be used anywhere. Commands are expressed as combinations of finger strokes. From 30 to 50 commands or characters can be input relatively quickly (200 characters per minute for a skilled person) by using a combination of 'simultaneous tapping,' in which multiple fingers are tapped at the same time, and 'sequential tapping,' in which fingers are tapped with intervals. The FingeRing sensor is shown in **Photo 2**. Further technological advances for this Fulltime-Wear command and text input device may lead to a "virtual keyboard" that enables the same kind of input operation as does an ordinary full keyboard, but with nothing more than a device worn on the wrist like a wristwatch.

Photo 2 Fulltime-Wear Text Input Mechanism (FingeRing)

3.3 Handset Mechanism Worn on the Wrist

"FingerWhisper" is a communication handset designed to be worn on the wrist as a Fulltime-Wear Interface [12]. It is used by inserting the index finger or middle finger of the hand on which it is worn into the ear-canal. The received voice signal is converted to vibrations by an actuator (electro-mechanical transducer) in the wrist unit, and the vibrations are conveyed to the fingertip and then to the ear (with bone-conduction). The user's speech is captured by a microphone in the wrist unit. (When the user's finger is in the ear for listening, the wrist is naturally closed to the mouth). Using bone conduction of sound allows miniaturization while still maintaining an effective distance between the microphone and 'speaker' (i.e., the distance between wrist and fingertip). Thus miniaturization is achieved without loss of usability. The bone conduction method also allows listening in a noisy environment without turning up the volume (an improvement of 13 dB compared with a conventional handset in the case of surrounding noise of 90 dB). It also allows the user to speak in a softer voice (improvement of 6 dB under the same circumstances). Worn on the wrist, FingerWhisper is difficult to distinguish from an ordinary wristwatch, so it does not give the impression to others that the user is 'wearing a strange device' as conventional wearable devices. The user of this device appears to others, to be using a telephone that has a small handset rather than talking to himself, as happens when one is using an earphone-microphone device. This feature may also be effective for use in voice operation of a computer. Combined use of FingerWhisper and UbiButton makes hook and dialing operations possible, improving operability. FingerWhisper is expected to serve as a bridge to the future era of Fulltime-Wear devices by reducing the resistance to "life with wearable machines." The appearance and structural

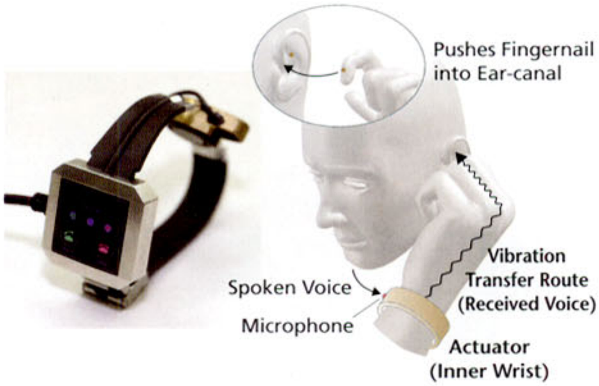


Figure 1 Wristworn Handset (FingerWhisper)

diagram of the prototype are shown in **Figure 1**.

4. Conclusion

We have described Fulltime-Wear Interfaces that can serve as operating mechanisms for the next generation of portable information devices. We also presented examples of their implementation. The devices described here are only examples; we expect that other novel mechanisms will appear as the research on Fulltime-Wear Interfaces expands.

The goal of regarding portable information devices as thinking support systems is to make use of the obtained information on the same level as one's own memory and thinking. Although the immediacy provided by Fulltime-Wear Interfaces is high, there is still the gap of 'operating a machine to obtain information' that separates the use of such devices and one's own thinking. If it were possible to tap directly into the signals that are transmitted by the nerves of our bodies, however, it would be possible to access information on the same level as our own thinking, without using our hands (mainpulators) or our eyes and ears (sensors). Even though there have been attempts in the past to develop interfaces that employ electrodes placed on the surface of the skin [13], the volume of information that can be transferred through such interfaces is small and a practical input speed has not yet been achieved. DoCoMo has targeted the establishment of techniques for measuring and analyzing neural magnetic fields, which have high temporal and spatial resolution, for application to interfaces. The results of that work will be useful for nerve signal analysis as well as being applicable to interfaces that employ neural magnetic fields directly. Nerve signal analysis will be essential to the implementation of 'implants', which will be the next step after Fulltime-Wear devices. In that future, the link will be direct between humans and information will be a direct one.

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