

# Whisper: A Wristwatch Style Wearable Handset

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## ABSTRACT

“Whisper” is a new wrist-worn handset, which is used by inserting the fingertip into the ear canal. A received signal is conveyed from a wrist-mounted actuator to the ear canal via the hand and a finger by bone conduction. The user’s voice is captured by a microphone mounted on the inside of the wrist. All components of Whisper can be mounted on the wrist, and usability does not decrease if the size of components is miniaturized. So, both wearability and usability can be achieved together. The way Whisper is operated is similar to that of an ordinary telephone handset. Thus, onlookers may not look upon Whisper’s operation as “talking to oneself”, even if the associated PDA is controlled by voice commands. Whisper is especially effective in a noisy environment. Signals received via bone conduction can be heard clearly in the presence of noise without raising the volume (-12 dB at noise = 90 dB(A) in comparison to cellular phone handset). Whisper is also effective in avoiding the annoying problem of the user’s voice being raised in a noisy situation. Feedback of the user’s utterance is boosted by bone conduction when covering the ear canal with a fingertip, then the user’s voice does not need to be raised in the presence of noise (-6 dB at noise = 90 dB(A) in comparison to cellular phone handset). Whisper is useful as a voice interface for a wrist-worn PDA and cellular phone.

## Keywords

handset, wearable computer, PDA, cellular phone, interface device, Whisper, UbiButton

## INTRODUCTION

The recent advances in mobile information systems such as PDAs or wearable computers have been remarkable, and some “wearable” interface devices have been proposed for improving both of portability and usability. Many of these interfaces, however, have been designed as character and graphical interfaces, leaving the area of audio (voice) interfaces relatively untouched.

The audio (voice) interface can be used every time even if both hands are occupied. It also can be used with no or little practice. Moreover, both wearability and usability can be achieved by attaching a simple earphone-microphone unit onto the helix or into the ear canal. Therefore, the technical merits of designing a new interface device seem to be insignificant and unnecessary. Despite the many merits of the voice interface, its proliferation into the public and everyday use has been met with a certain degree of apprehension. Only in special business situations or some science-fiction dramas have the actual implementation of the voice interface been apparent. We think that the main reason for this stems from a general societal sense of apprehension not from technical problems.

## Talking alone

Obviously, in information systems that have a voice control interface, voice commands must be uttered for operation. Today’s earphone-microphone unit is still large and requires some electrical wires, so the surrounding people can easily notice that it is being used. However, with the advances in technology and the downsizing of components, the “Ear Plug” style device integrating telephone or PDA functions will be realized. Thus it can be easily overlooked by surrounding people. Therefore, it will appear to these people as if the user is “talking to himself” or what we refer to as “talking alone”, when the user operates the PDA or makes a telephone call. This notion of “talking alone” is not considered socially acceptable to many people and this behavior seems very strange. This type of behavior will most likely become common place, if the voice interface comes into general use in the future and earphone-microphone style interface proliferates into the public. However, this style is currently not accepted in society. It is thought that the stigma attached to talking alone has hindered the spread of the wearable voice interface. Therefore, the important issue that must be addressed originates not from a technical aspect but rather the social aspect when designing and implementing the wearable voice interface.

However, the “talking alone” style of operation does not seem strange, when a person talks into an object grasped in the hand such as a telephone handset or handheld transceiver, even when the grasped object is too small to see directly. Furthermore, this effect can be achieved when the hand is used to mimic holding the object (hereafter called the grasping posture) even though no object

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is really held. Therefore, to help proliferate the voice control interface while retaining the benefits of the technological advances, devices that use the grasping posture should be implemented.

### Wearable telephone

Some voice interfaces that use the grasping posture have been proposed in the field of cellular phones. Miniaturizing cellular phones using conventional technology has reached its practical limit. Further miniaturization is possible but speaking becomes difficult, because the basic distance between the user's mouth and ear is fixed. Thus, further downsizing is difficult while retaining a conventional handset shape. To overcome this problem, some wearable telephones were proposed[1]. A wristwatch-type telephone[2][3] has a speaker mounted at the end of an arc-shaped boom, which composes a part of the wristband when it is not in use. To operate this device, the boom is rotated and the speaker is moved to the center of the palm. Then the hand is used to cover the ear. The microphone is mounted on the inside of the wrist. When this device is operated, it mimics the posture of holding an ordinary telephone handset. Moreover, interference from outside noise can be eliminated because the speaker is covered by the hand.

There is another device called the "Parasite Phone[4]". The microphone is mounted on the tip of the thumb and the speaker is mounted on the tip of the little finger. This posture pantomimes the use of the conventional telephone. However, because the mechanism and an electrical cord must be attached at the fingertips, it hinders other daily activities.

### Loud voice problem

These two devices reap the benefits of the technological advancements while incorporating the grasping posture. The distance between the microphone and the speaker is moderately extended, and the miniaturizing problem in a small sized handset can be resolved. However, these devices have not solved another important problem concerning the voice input interface. A PDA and a cellular phone are often used in noisy outdoor environments such as on a street or in a train station. This has led to another social problem that has come to light over recent years with the popularization of cellular phones. Often times, the user's voice becomes excessively loud in a noisy environment, and as a result, it is annoying to surrounding people. In recent cellular phones, a part of the utterance voice signal is electrically fed back to the receiver of the handset to suppress the utterance volume, but additional electrical power is required. It is more desirable to boost the feedback of the uttered voice without the need for an electrical amplification. Therefore, a novel voice interface mechanism is desired by which all these problems can be solved in one stroke.

### Fingertip into ear canal

In a noisy environment, users often cover their ears with their hands or insert a fingertip into the ear canal to shut out noise. From a distance, this posture is similar to that of grasping a small cellular-phone handset. Especially

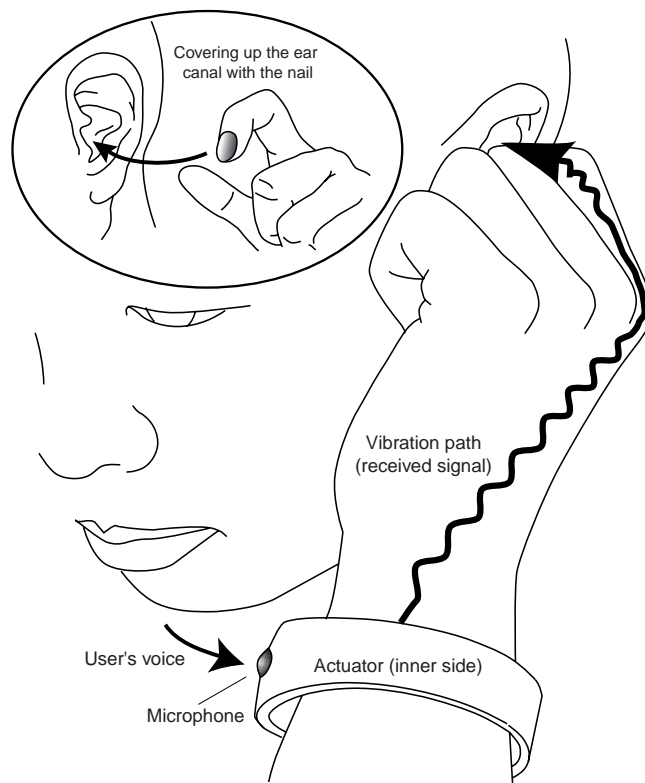


Figure 1: How Whisper works.

The received signal can be transmitted clearly with little force added to the fingertip when covering up the ear canal with the nail.

from the view of surrounding people, this posture can be regarded as "making a telephone call" when the user mumbles to himself. This posture not only shuts out the outside noise but also boosts the feedback of the user's utterance because of the bone conduction effect. That is, the following effects can be achieved at the same time by inserting the fingertip into the ear canal.

1. The grasping posture is used.
2. Outside noise can be shut out.
3. The feedback of the utterance increases.  
(thus decreasing the need to speak loudly in a noisy environment.)

Moreover, the received signal will become clearer under noisy conditions, if the received signal can be transmitted through the finger inserted in the ear canal using bone-conduction. Furthermore, this method enables mounting the receiver mechanism at the wrist or the base of the finger to increase wearability.

This paper proposes a new wearable handset called "Whisper", which is used by inserting the fingertip into the ear canal. Some variations of Whisper are also described. The performance of Whisper is evaluated in comparison with the conventional cellular phone handset, especially with respect to the receiving performance and loudness of utterance in a noisy environment.

## WHISPER

Whisper is a full-time wearable voice interface, which is used by inserting a fingertip into the ear canal. An actuator (= electric to vibration converter) is mounted on the wrist or the base of the finger, and is driven by the received audio (voice) signal. The received signal is conveyed from the actuator to the ear via the hand and finger through bone conduction (**Figure 1**). Whisper uses the grasping posture and simulates the use of an ordinary telephone handset. The bone conduction receiver in Whisper provides clear sound even under noisy conditions. Moreover, feedback of the user's utterance is boosted by covering the ear canal with the fingertip, therefore the user's voice does not need to be raised in a noisy environment. The bone conduction method enables the receiver mechanism to be mounted at the wrist or the base of the finger, which has better wearability than the fingertip. The microphone is attached on the inside of the wrist, so the microphone is naturally close to the user's mouth when the unit is in use. Moreover, the distance between the wrist (input) and the fingertip (output) is not changed when the device is miniaturized. Then Whisper can be downsized without decreasing usability. Therefore, Whisper can deal with the all problems mentioned earlier.

There are several variations of Whisper, each has the actuator in a different place. The prototype of Whisper for each variation is shown below.

### *Ring actuator*

A ring shaped actuator is mounted at the base of the index or middle finger. Transmission efficiency of the receiving signal is the best. However, it is necessary to mount the control circuit on the wrist or other position, because it is difficult with current technology to mount all circuits on the ring. Then, some electrical wires are needed to connect the actuator and control circuit. This may be inconvenient to wear all the time. For instance, a cord-reel mechanism is equipped into the wrist-worn module, and makes contact with the ring part when in use (**Figure 2**). This system increases the wearability, especially when the unit is not in use. The Whisper with ring actuator will become an all-in-one style ring-PDA or ring-telephone, if all of the circuits including the bone conduction microphone can be packed into the finger ring in the future.

### *Boom actuator*

For this version of Whisper, the actuator is placed at the end of the boom, which is mounted on the wrist-worn module. When using the unit, the boom is pulled out, and the user's hand is bent backwards. The actuator makes contact with the back of the hand, and vibrations are conveyed to the fingertip (**Figure 3**). For good transmission the actuator should make contact with the tendon (extensor digitorum superficialis) connected to the index or the middle finger. Some users, may feel fatigue because the hand must be bent backwards when using the unit. When not in use, the boom is accom-



Figure 2: Whisper (ring actuator)  
Hook switch is built into the cord-reel, and it turns on when the electrical wire is pulled.



Figure 3: Whisper (boom actuator)  
When operating, the boom is pulled out, and the user's hand is bent backwards.

modated into wrist module, to making it more comfortable to wear. For simple implementation, the manually handled boom mechanism, which doubles as the hook switch, is suitable. Of course, an automatic boom extension mechanism would increase the ease of use, however, a large electrical supply is required. The volume and tonal quality of the transmitted signal changes depending on the contact pressure between the actuator and the hand. Thus, the contact force should be detected using a pressure sensor, and the signal characteristics should be adjusted for stable receiving.

Table 1: Variations of Whisper

Position of actuator	Efficiency	Wearability	Notes
Ring	good	poor	future: all in one telephone hand bent backwards wristwatch style
Boom(back of hand)	normal	normal	
Wrist	poor	good	



Figure 4: Whisper (wrist actuator)

The actuator is mounted at the center of inside of the wrist, and the microphone is located beside the actuator.

#### Wrist Actuator

In the all-in-one style handset version of Whisper, the actuator and the microphone are mounted on the inside of the wrist (**Figure 4**). For good transmission, the actuator should make contact with the tendon (flexor digitorum superficialis) connected to the index or the middle finger. People in this present age seem to resist attaching machines onto the skin except for the wristwatch. This version of Whisper can simulate the shape of an ordinary wristwatch, and it is most suitable for the general public. However, transmission efficiency is worse than that of other methods (-15dB compared to the ring actuator). Moreover, an echo canceling circuit is required to avoid interference from the actuator to the microphone, because the actuator and the microphone are adjacent.

The characteristics of the three versions are shown in **Table 1**, and the frequency spectrum of each method is shown in **Figure 5**. The ring actuator has the best transmission efficiency, and can transmit typical voice signals (200Hz - 4kHz) sufficiently. Efficiency of the boom actuator is almost the same as that of the ring actuator. However, the performance of the wrist actuator is worse than that of the other methods, especially in the high frequency band. Because the connections among the bones in the wrist (ossa carpi) are weaker than those of the bones in the fingers, so the bone conduction effect becomes weaker.

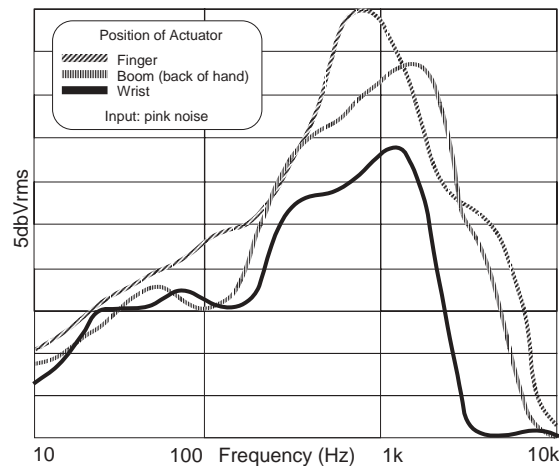


Figure 5: Frequency spectrum at fingertip  
The ring actuator has the best transmission efficiency.

Despite the lower transmission efficiency of the wrist actuator, it has many merits considering wearability. All circuits can be mounted at the wrist, and no sharply pointed module such as boom is included. In particular, the wrist actuator version can be modeled as a wristwatch, thus it is familiar to people and enable them to wear it comfortably. Therefore, we selected this version of Whisper in the following evaluations. A special actuator, which was originally developed for the bone-conducting headphone, is used to improve transmission efficiency. This actuator has another good characteristic, which is suppressing the amount of spilled sound overheard by other people. Moreover, a tone controller is used to improve the tonal quality of the received sound.

#### PERFORMANCE

The voice interface of a wearable PDA which is usually used outdoors, should have good performance under noisy conditions. Moreover, it is necessary to be able to operate the device at the lowest speech level possible to avoid annoying surrounding people. Then, the receiving performance and the volume of utterance in a noisy environment were evaluated compared with the conventional handset of a cellular phone.

#### Receiving performance in a noisy environment

First, the receiving performance in a noisy environment was evaluated. It is necessary to raise the volume of the received signal when operating in a loud noise environment. The smaller the rate of increase in the volume when the surrounding noise is increased, is the better the performance rating. The experiment was conducted by testing the rate of increase in the amplification level of the received signal when the surrounding noise level is changed.

The procedure of the experiment is shown below.

1. The subject is exposed to pink noise from a large speaker that is placed 1m in front of the subject. The noise level generated facing the subject is set from 30 dB(A) to 90 dB(A) in 10 dB increments.
2. [PS1]: A cellular phone handset is held to the subject's left ear with the left hand. The right hand is not used (placed on the knee).
3. A human voice is heard through the receiver of the handset. When beginning the experiment, the volume is inaudible, and then it is gradually increased.
4. The subject indicates when the content (a phrase) of what is said is understandable by pushing a foot switch. The amplification ratio at that time is recorded.
5. The noise level is changed, and phases (3) to (5) are repeated.
6. [WS1]: An experiment similar to [PS1] is repeated using Whisper worn on the subject's left wrist instead of using the cellular phone handset. The index or middle finger (selected by each subject) of the left hand is inserted into the left ear canal. The right hand is not used (placed on the knee).
7. [PD1]: An experiment similar to [PS1] is repeated with the right ear covered by the right hand.
8. [WD1]: An experiment similar to [WS1] is repeated with the right ear covered by the right hand.

The size of the noise attenuation room was 2.2m(W) x 3.2m(D) x 2.5m(H). The size of the cellular phone handset used in the experiment<sup>1</sup> was 39 mm (W) x 19 mm (D) x 113 mm (H), and length between the receiver and microphone is 94 mm. The sound source was a recorded tape of a lecture<sup>2</sup> and came from the receiver of the handset and Whisper. The recorded tape is about 50 minutes long and used repeatedly. An experimental time is about 60 minutes per one subject. Then same phrase of the tape is appeared at most twice through the experiment. The number of subjects is ten, and all subjects are adult. It was necessary to make adjustments to the difference in each subject's audibility and efficiency of the speaker unit. Then, the reference level (0 dB) of amplification for experiments [PS1] and [PD1] was set to the result at the noise level = 30 dB(A) of [PS1] for each subject. Similarly, the reference level (0 dB) of [WS1] and [WD1] was set to the result at the noise level = 30 dB(A) of [WS1] for each subject. Each trial is repeated more than three times for each noise level.

The results of the experiments are shown in **Figure 6**. Graph [PS1] of this figure indicates that the receiving volume should be raised by about 41 dB, when the surrounding noise is raised from 30 dB(A) to 90 dB(A) using the handset. For Whisper ([WS1]), the receiving volume should be raised by about 28 dB, and the difference is 13 dB compared with the use of the handset ([PS1]). At the noise level = 70 dB(A) which is the average noise on a

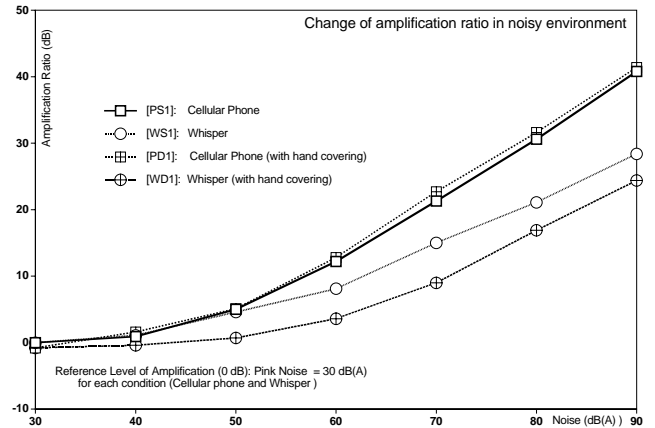


Figure 6: Change of amplification ratio in a noisy environment

Whisper can be audible well under the noise compared with the cellular phone handset.

street, Whisper (WS1) has an advantage of about 6 dB. This experiment indicates that Whisper can be clearly audible without significantly increasing the volume under noisy conditions as compared with the handset.

Moreover, graph [PD1] shows that covering the ear with the hand has little effect when the handset is used. Many people often cover their ears with their hands when using a cellular phone in a noisy environment. However, this result indicates that this posture will not directly improve the audibility. On the other hand, graph [WD1] shows that this posture can decrease the receiving volume by about 4 dB at all noise levels when using Whisper. It is said that audibility can be further increased by closing the opposite ear with the hand when Whisper is used. From this experiment, Whisper is more suitable for operation in a noisy environment than an ordinary cellular phone handset.

In addition, the posture for covering the right ear with the right hand was left to the discretion of each subject. There were three kind of postures: covering the entire ear with the hand (3 subjects), inserting the fingertip into the ear canal (5 subjects), and folding antitragus with the fingertip (2 subjects). In this experiment, no difference of audibility is observed among these three postures.

### Voice loudness in noisy environment

As mentioned earlier, the volume of utterance often becomes excessively high when using a cellular phone under noisy conditions. The microphone of the handset can sufficiently capture low volume utterances of a user, even in a noisy environment. Thus, the reasons for this problem are considered to be the following.

- Uneasiness of the user: "The other party may not hear my voice?" when the other party's voice can not be heard easily in a noisy environment (We call this the hearing effect).
- Uneasiness of the user: "The microphone is far from my mouth, therefore I must talk louder" (We call this the microphone effect).

<sup>1</sup>NTT-Personal(PHS) Paldio T331

<sup>2</sup>Kumiko, MUKOUDA: "I'm scary a word", Shinchousha ISBN 4-10-803101-6

- Decrease of feedback: the user cannot easily hear his own utterance in a noisy environment (We call this the feedback effect).

As mentioned earlier, the trouble caused to surrounding people (especially in a noisy public space) can be decreased, if the utterance volume can be suppressed using Whisper. The volume of utterance under ambient noise at various levels is compared between Whisper and the conventional cellular phone handset. The procedure of the experiment is shown as follows.

1. The subject is exposed to pink noise from a large speaker that is placed 1m in front of the subject. The noise level generated facing the subject is set from 30 dB(A) to 90 dB(A) in 10 dB increments.
2. The throat microphone is attached to the subject's larynx.
3. [PS2]: A cellular phone handset is held to the subject's left ear with the left hand. The right hand is not used (placed on the knee).
4. The subject has a short conversation with the user through the handset. The output level of the throat microphone in this talking session is recorded.
5. The noise level is changed, and phases (4) to (5) are repeated.
6. [WS2]: An experiment similar to [PS2] is repeated using Whisper worn on the subject's left wrist instead of the cellular phone handset. The index or middle finger (selected by each subject) of the left hand is inserted into the left ear canal. The right hand is not used (placed on the knee). Whisper's microphone is placed at the inside of the subject's wrist.
7. [PD2]: An experiment similar to [PS2] is repeated with the right ear covered by the right hand.
8. [WD2]: An experiment similar to [WS2] is repeated with the right ear covered by the right hand.

It is difficult to extract only the volume of the subject's utterance using a conventional microphone under loud noise conditions. A throat microphone is used that captures only the subject's utterance regardless of the surrounding noise. In this experiment, the volume of the received voice is set at an audible level in each trial. All other conditions are the same as the last experiment. The number of subjects is ten, and all subjects are adult. Each trial is repeated more than three times for each noise level.

The results of the experiments are shown in **Figure 7**<sup>3</sup>. Graphs [PS2] and [WS2] of this figure indicate that the utterance volume using Whisper (77 dB(A)) can be decreased about 6 dB(A) as compared with the conventional handset (83 dB(A)), when the surrounding noise level is 90 dB(A). At the noise level = 70 dB(A) which is the average noise on a street, Whisper (WS2) has about a 5 dB advantage. It is said that humans can clearly

<sup>3</sup>The value of the utterance volume is converted into dB(A) using the relationship between the output level of the throat microphone and the utterance volume (1m in front of the subject) measured beforehand.

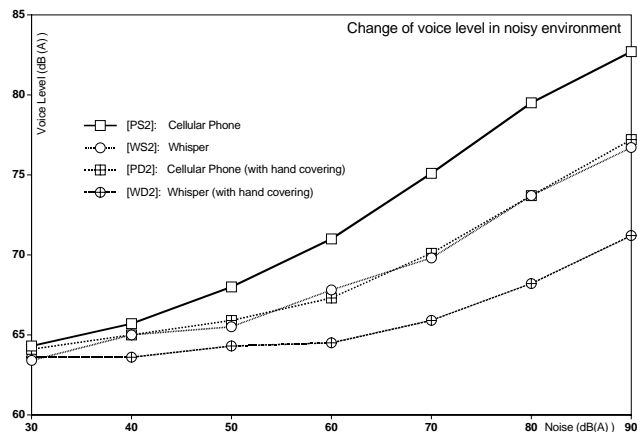


Figure 7: Change of utterance level in a noisy environment

The utterance volume can be suppressed using Whisper.

recognize a volume difference of 5 dB. Thus, the suppression of utterance volume using Whisper is effective.

Lines [PD2] and [WS2] of this figure almost overlap showing that covering the opposite ear with the hand when using a handset is effective in reducing the utterance volume. These two experiments can be thought as having the same condition from the viewpoint of "covering one ear with the hand or fingertip". The user's own utterance can be heard with a high volume when inserting the fingertip in the ear canal. It is thought that the "feedback effect" is decreased by covering the ear, and the utterance volume can be suppressed. Moreover, when using Whisper, the utterance volume can be decreased further by about 5 dB(A) under loud noise conditions by closing the opposite ear. In this operating style, the receiving voice can also be heard clearly, then the effect of the Whisper method can be enhanced even further.

The last set of experiment results indicates that covering the opposite ear with the hand has little effect in enhancing the audibility of a received voice when using a handset (cf. [PD1] of **Figure 6**). Then, the main reason for the increase in utterance volume in a noisy environment is caused by the "feedback effect". From these two sets of experiments, it is clear that the Whisper method has good audibility and can suppress the utterance volume in a noisy environment.

## DISCUSSION

### Efficiency of transmission

The transmission efficiency of a received signal of Whisper changes greatly depending on the contact condition of the fingertip and ear canal. Stronger insertion of the fingertip will bring louder and clearer sound, especially for the high frequency band. However, this forceful insertion causes user fatigue, and is not suitable for long-time operation. In general, to improve the transmission efficiency of bone conduction, hard body parts should be touching. Clear sound can be heard with only a slight amount of additional insertion force to the fingertip when

covering up the ear canal with the nail. In the future, regulating the volume and tone of the received signal will be realized regardless of changes in the contact condition, if a wrist-mounted sensing device which can detect the contact condition is developed.

### User fatigue

The following are possible reasons for user fatigue, excluding when exerting force with the fingertip.

#### Hand posture

As mentioned earlier, the user becomes fatigued by bending the hand backwards for a long time when using the boom actuator version of Whisper. This action is not required for the ring and wrist actuator versions of Whisper. However, since the microphone is mounted on the inside of the wrist, the user's voice cannot be captured clearly when the wrist is away from the user's mouth. This problem can be solved by using a bone conduction microphone. The user's voice is transmitted from the head to the wrist mounted bone conduction microphone via a finger and the hand, in the reverse order of the received signal. This method frees the position of the wrist when the device is in operation, and it can improve the performance of capturing the user's voice in a loud noise environment. However, this method needs a powerful echo canceller mechanism to separate sending and receiving signals, both of which are transmitted with the same bone conduction route.

#### Tightening of wrist

For the wrist actuator version of Whisper, the receiving signal is transmitted by contacting the actuator to the tendon on the inside of the wrist. Increasing the contact pressure of the actuator improves the transmission efficiency. However, this may cause the user fatigue and excess stress on the wrist. It would be quite meaningless to tighten the wristband when the device is not in use, which would represent long periods in daily activity. It is possible to improve wearability by adopting a mechanism that increases the contact pressure only while the unit is in use. Usability can be improved at the same time by combining into one lever or knob the main function switch (or hook switch) with the mechanism that presses the actuator against the wrist<sup>4</sup>.

Moreover, an after-mark sometimes remains on the surface of the skin when the actuator is in prolonged contact at the same position on the wrist. Changing the contact location of the actuator each time the unit is used would solve this problem. Fatigue associated with long-time operation should be examined.

### Another wrist-worn input method

It is effective to combine a wrist-worn input interface with Whisper for some simple operations that do not require interaction, such as controlling the PDA's own state for example "activate" or "inactivate". "UbiBut-

<sup>4</sup>An automatic pressure control mechanism employing an air pump or motor can significantly improve the usability, however, it requires a large electrical supply.

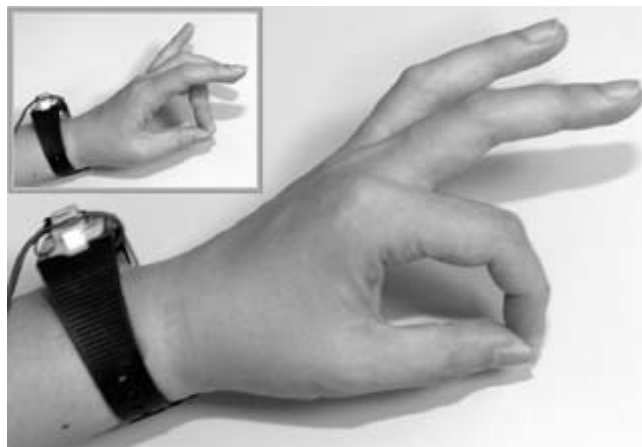


Figure 8: Sensor part of UbiButton  
The shape of the finger is an example of "OK tapping".

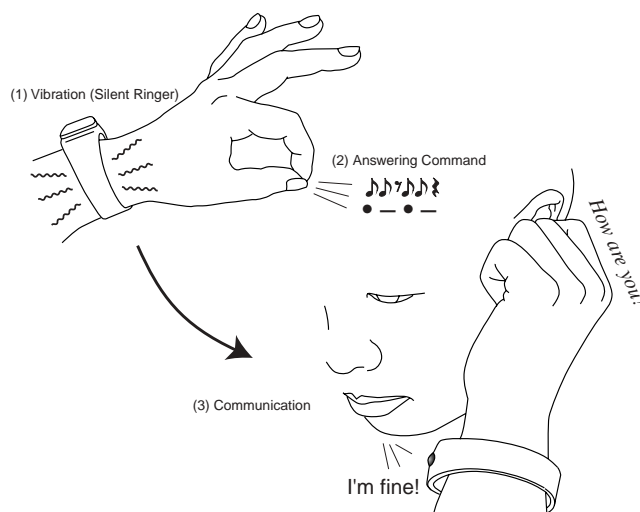


Figure 9: Application example of Whisper & UbiButton  
A sample operation by the combination of Whisper and UbiButton (answering a telephone).

ton" is a wrist-worn command input device[5]. It has one accelerometer mounted on the upper part of the wrist, and detects tapping actions performed by the fingertips on any support object. Commands are represented from the combination of tapping rhythms. Over 10 commands can be input by using UbiButton when the tapping sequence of 2 to 4 strokes is used, and it can cover major PDA commands such as menu selection. UbiButton can also be operated by an "OK tapping" action, i.e., touching the thumb and other fingertip even when a support object does not exist such as when walking. **Figure 8** shows the sensor part of the prototype of UbiButton. UbiButton can be operated by the hand on which it is worn, thus the usability in daily life can be improved.

### CONCLUSION

Whisper achieved a "telephone style" natural voice input/output function with good wearability. The wrist mounted PDA or wearable computer can adopt the voice interface by using Whisper. In addition, Whisper has

good receiving performance and can suppress the user's utterance volume, in a noisy environment.

We are making a testbed of wrist mounted PDAs that use the Whisper voice I/O, command input with UbiButton, and small LCD display, to test command structures and the feedback method. This testbed also has the function of a cellular phone and infrared remote controller. **Figure 9** shows a sample of cellular-phone operation employing the combination of Whisper and UbiButton. The actuator of Whisper vibrates in the very low-frequency to notify the user when the telephone rings without an audible alarm. The user issues the "answer telephone" command by "OK tapping", and starts conversing immediately. Since all operations can be done with just one hand, this style PDA can be used in many daily situations even when walking or carrying luggage.

The size of the current actuator is still large. Especially, the thickness of the actuator is important for improving wearability, because it is mounted on the inside of the wrist. The conversion efficiency of the actuator is an-

other problem, it causes increased power consumption and spilled sound. We are developing a small and thin actuator that has good conversion efficiency. We are also planning to use the bone conduction microphone to improve the uttered voice quality in a noisy environment, and to realize operation that is more comfortable where the user can freely position the wrist. Our goal is to realize an all-in-one wrist (or ring) mounted PDA.

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