Ultrasmall Audio Receiving Unit Using Infrared

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Abstract

Most of the IT services offered to date have provided an image-based communication platform. We have now endowed ultrasmall sensors and actuators with short-range wireless communication capability and developed devices that can be attached to all sorts of everyday things, embedded in the environment, or even worn. We have investigated some of the potential applications made possible by communication between people and all sorts of objects. This article presents an overview of *VoiceUbique*, an ultrasmall audio receiver that has a tiny dynamic speaker for the actuator and uses infrared waves for short-range wireless communication.

1. Introduction

Internet and email-centered information technology (IT) has primarily been concerned with the transmission of information in the form of text and images (corresponding to the graphical user interface (GUI)), so little attention has been paid recently to the conveyance of information by plain-old human speech. To some extent this can be attributed to the fact that modern-day data communication has come to rely on packet communication in which realtime delivery is not required, while speech needs the time sequence of the data to be preserved, so packet-delivery techniques are not very applicable. Yet for the widespread dissemination of IT, the age-old medium of human speech for providing information (voice user interface (VUI)) is as important as ever, and the implementation of an interface that is extensively available and can be used by anyone is a critical means of providing information. More particularly, the ability to use such an interface virtually anywhere becomes important as the need to convey information ubiquitously increases [1], [2], and this raises the issue of making terminals wearable. We have developed *VoiceUbique* as an example of a VUI terminal implemented in a wearable form. This article provides an overview of *VoiceUbique* and discusses its performance.

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2. System construction of *VoiceUbique*

VoiceUbique is an ultrasmall audio receiver implemented in the form of a ring that we developed as a wearable VUI device that could be used in ordinary and everyday living spaces. Going beyond the usual ubiquitous access attributes of *anytime* and *anywhere*, *VoiceUbique* can also aim audio messages at a single person—such as just you or just me. In order for the device to be available for use anytime and anywhere, the audio receiver must be worn constantly either on the hand or in the ear, which means that its size and weight must enable it to be worn the entire day without causing any discomfort or awkwardness to the wearer. And to enable one to listen to the device for extended periods without getting tired, the sound reproduction should be as natural as possible, noise should be screened out, and the sound quality should be good enough that one can listen to and enjoy music. And finally, to achieve an interface that is so simple that anybody can use the device, we had to get rid of buttons for selecting channels and other hard-to-figure-out controls. We came up with the following short list of requirements for a wearable *VoiceUbique* receiver:

1. Small enough to be implemented as a ring (total volume: a few cubic centimeters)
2. Capable of at least ten hours of continuous use on one small lithium coin cell
3. Standby power consumption of less than 10 µW
4. A user interface involving completely natural and inconspicuous actions
5. Good sound quality equivalent to FM-radio broadcast quality (signal bandwidth of 16 kHz and signal-to-noise ratio of 70 dB).

The tiny receiving units that are currently available for micropower, Bluetooth, and other low-power schemes are about the size of a postage stamp and consume only 30 mW of power, but these specifications are still not close to satisfying our requirements #1 and 2. A digital transmission scheme that is robust against transmission noise would be preferable to provide the sound quality stipulated in #5, so we chose to use infrared carrier communication and a digital transmission scheme based on 1-bit quantization technology for the *VoiceUbique* system.

Figure 1 shows the main components of the *VoiceUbique* system. The transmitter (a) is 70 mm × 40 mm × 15 mm. The infrared emitter (b) consists of IrDA (Infrared Data Association) units of the same type as used in personal computers, each 12 mm in diameter × 65 mm long. The ring-shaped receiver (c) has a hemispherical receiver in the middle 16 mm in diameter × 15 mm thick (2.5 cm^3); the volume of the entire device including the band of the ring is 3 cm^3, including a lithium non-rechargeable cell supporting continuous use for up to 35 hours, so it easily satisfies requirements #1 and 2.

Figure 2 shows a typical situation in which *VoiceUbique* might be used. Pausing in front of an exhibit at a museum or exhibition hall, the user nonchalantly brings her hand bearing the *VoiceUbique* receiver ring up to her ear, and is then able to hear a detailed description of the exhibit, background music, or other content. This allows the user to obtain information

(a) Transmitter (b) Infrared emitter (c) Receiver

Fig. 1. *VoiceUbique* system.

Fig. 2. Typical situation using *VoiceUbique*.

about the objects on display as she moves through the exhibit, and the interface for accessing the information is perfectly natural and inconspicuous.

3. Miniaturization and reduction of power consumption

The most problematic issues in miniaturizing the receiver were the continuous operating time requirement and the volume and weight of the battery. **Table 1** lists the volume, power, and weight specifications for some of the lithium non-rechargeable coin cells that are currently available. The four-digit numbers in the "battery type" column have the following meaning: the first two digits specify the diameter of the battery and the second two digits indicate ten times the thickness of the battery in millimeters.

Considering the thickness of the battery casing (2 mm) and our ring-shaped implementation, we settled on the CR1220 cell (diameter: 12 mm). An added advantage of using this size cell is that there are both rechargeable and non-rechargeable batteries available in this size, so it would be easy to implement a version of *VoiceUbique* using either type of battery.

We calculated that to satisfy requirement #2 (ten hours of continuous use) using the CR1220 battery, the power consumed by the receiver had to be reduced to 3 mW or less. Below we discuss the system configuration that enabled us to achieve this remarkably low power consumption.

Table 1. Size versus capacity for typical commercial lithium cells.

Battery type	Volume (cm^3)	Power (mAh)	Weight (g)
CR1216	0.18	25	0.7
CR1220	0.23	35	1.2
CR1616	0.32	55	1.2
CR1620	0.40	75	1.3
CR2016	0.50	90	1.6
CR2025	0.75	165	2.5
CR2032	1.00	220	3.1

Figure 3 shows a block diagram of the circuits of the *VoiceUbique* system. The sound source that stores messages or other types of audio content might be the same type of device as used in an analog signal output terminal or headphone output terminal. The transmitter receives the analog signal from the sound source, adjusts the gain with an amplifier, and then converts the analog signal to a digital signal through a bit-stream conversion process using a noise-shaping analog-to-digital (A/D) converter [3]. This digital signal is then converted to an ON-OFF keying[*1] infrared signal by an IrDA transmission device, and transmitted. The receiver converts the incoming infrared carrier to an electrical signal, adjusts the shape of the wave using an inverter, and recreates the original sound just by driving the speaker. An ultra-small dynamic speaker was used to achieve an ultra-small size.

The significant thing to note about this configuration is that it enabled us to omit some of the circuitry usually required for digital transmission from the *VoiceUbique* receiver (clock playback, frame synchronization circuitry, etc.) and also eliminated the need for a digital-to-analog (D/A) converter, so we were able to reduce both the size and the power consumption of the device at the same time. Indeed, we were able to bring the current consumption of the *VoiceUbique* receiver down to 1 mA, including the receiver operating current and the speaker drive current. **Figure 4** shows the actual measured continued usage time versus battery voltage for two different lithium batteries: CR1220 and CR1616. At the lower limit voltage of 2.2 V, the receiver could be operated

*1 ON-OFF keying sends data by switching the light beam on and off.

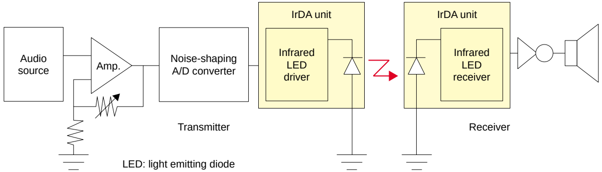

Fig. 3. *VoiceUbique* circuit block diagram.

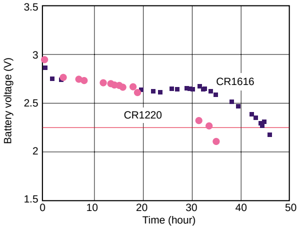

Fig. 4. Continued usage time vs. battery voltage.

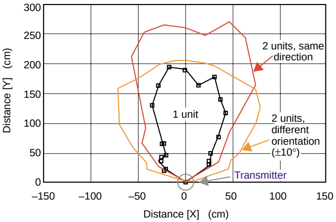

Fig. 5. Reception range of the receiver.

continuously for up to 35 hours on one CR1220 battery.

If the IrDA receiving unit is enabled, it consumes up to about 0.4 mA of current even when it is not receiving an infrared signal. This led us to implement a standby circuit that reduces the current to 0 mA when the device is in standby mode. Essentially, it works as follows: The IrDA receiver is enabled for 30 seconds after it is turned on, and if an infrared carrier is received during that 30-s interval, it remains enabled. However, if no signal is received during the 30-s interval, the IrDA receiver is automatically disabled. The circuit uses only a few nanoamperes of current when the IrDA receiver is disabled, which means that the power consumption of the *VoiceUbique* in standby mode is close to 0 mW. A uniaxial slanted switch was used for the standby circuit switch, so that the user can automatically activate the switch without being aware of doing so, just by moving his hand bearing the *VoiceUbique* receiver up to his ear.

We thus succeeded in implementing a ring-shaped wearable audio receiver that satisfied our first three requirements: 1) ultrasmall size was achieved by implementing a tiny 3-cm^3 receiver powered by an even smaller lithium battery, 2) the device can be continually operated for up to 35 hours using infrared transmission based on 1-bit quantization and a standby circuit, and 3) the standby power consumption was reduced to a few nanowatts. Although the implementation created in this work was in the shape of ring, these same technologies could just as easily be used to develop ultrasmall earphones, a strip-shaped listening device, or tiny audio receivers in all sorts of shapes.

4. Communications distance and optical radiation safety concerns

Figure 5 shows the coverage of infrared rays when the infrared transmitter is set at Y = 0 and X = 0. The three lines show fields of error-free reception for an infrared digital carrier sent from an IrDA transmitter. Good audio reception can be received up to a distance [Y] of 150 cm and radius [X] of ±30 cm in the case of one receiver, and for a distance [Y] of 250 cm and a radius [X] of ±50 cm in the case of two units. When two units are set at an angle of ±10°, good sound quality can be received up to a distance [Y] of 150 cm and radius [X] of ±60 cm. It is thus clear that by using infrared transmission, the reception range can be easily adjusted or modified by using a different number of receiving units or by deploying them differently. This is a potentially useful feature that cannot be obtained using radio waves to transmit audio, and could for example be exploited to transmit audio content to a select audience within a specified area.

Because *VoiceUbique* uses invisible infrared signals, we must verify that they do not have any adverse health effects on people. The most vulnerable part of the human body is the eyes. The infrared carrier used by IrDA is dispersed light from a light emitting diode (LED) not the collimated energy of a laser, so it will be perfectly safe if there is sufficient distance between the light source and the eye. According to Japanese standard JIS-C-6802, a value of 180 mW/sr[*2] means that one could stare into a light source (a 2.7-mm diode) positioned 10 cm away for eight straight hours and not sustain any ill effects

*2 mW/sr: milliwatts per steradian (solid angle)

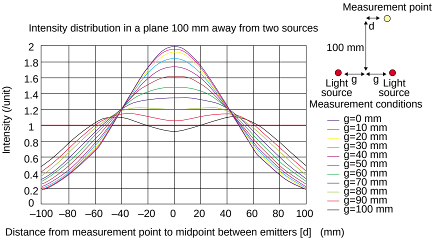

Fig. 6. Light intensity as a function of distance between units.

(class 1 safety). The IrDA emitters used in the VoiceUbique system emit 89 mW/sr, so although a single IrDA emitter would be perfectly safe, the above safety criterion could be exceeded when several units are used at the same time. We found, however, that if the units are set a certain distance apart, then the safety standard is satisfied. **Figure 6** shows the light intensity measured at a point located 100 mm from the midpoint between two transmitters that are emitting simultaneously as a function of distance between the two emitters. When they are far apart, the light intensity approaches the value for a single unit. When they are close together, the light intensity is twice that of a single unit, but the intensity weakens and safety standards are met when the units are at least 100 mm apart and the midpoint between the light sources is at least 100 mm away.

This ability to allow us to freely design the communication distance and range to ensure eye safety by specifying the number and positioning of units is a unique attribute of the *VoiceUbique* system.

5. Built-in ID transmission function

Miniature RF-ID (radio frequency identification) tags could be built into *VoiceUbique*, so that audio messages targeting just specific individuals could be easily implemented by incorporating RF-ID tag readers in transmitters. For example, if we assume passive RF-ID tags (64 bit, 125 kHz) that can only be read and are only viable for transmission ranges up to a few centimeters, then miniature tags (2 mm in diameter × 12 mm long) could be built into *VoiceUbique*. **Figure 7** illustrates that, with these miniature tags embedded in the system, a user could pass her hand

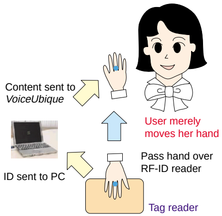

Fig. 7. Typical use of *VoiceUbique* with RF-ID tags.

bearing the *VoiceUbique* ring over a tag reader, and then by bringing her hand up to her ear, could hear messages intended just for that one individual.

This capability might be put to good use at an exhibition. For example, based on information collected in advance about the people attending the exhibition, a message system tailored to individual preferences and interests could be set up that provides more detailed information about the objects that people are interested in and less information about other objects.

6. Conclusion

In seeking to devise a voice user interface that can be used to gain ubiquitous access to information in everyday public places, we have developed an audio receiving unit that we have dubbed *VoiceUbique*. Implemented in the form of an ordinary ring, *VoiceUbique* uses infrared signals, consumes only 3 mW of power, and can be used continuously for up to 35 hours. Leveraging the unique characteristics of infrared digital transmission, the system permits high-quality audio content to be delivered to certain specified users within a specified area. If RF-ID tags are embedded into the receivers, content could be delivered just to certain specific individuals. Building on this approach, we plan to promote even more ubiquitous access using this voice user interface by implementing the baseband signal processing part as an LSI to make the transmitter smaller, by further reducing the power consumption of the device, and by embedding sound sources in all sorts of everyday living places.

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