ComTouch: Design of a Vibrotactile Communication Device

Angela Chang MIT Media Lab

Sile O'Modhrain Media Lab Europe

Rob Jacob Tufts University

Eric Gunther MIT Media Lab

Hiroshi Ishii MIT Media Lab

ABSTRACT

We describe the design of ComTouch, a device that augments remote voice communication with touch, by converting hand pressure into vibrational intensity between users in real-time. The goal of this work is to enrich interpersonal communication by complementing voice with a tactile channel.

We present preliminary user studies performed on 24 people to observe possible uses of the tactile channel when used in conjunction with audio. By recording and examining both audio and tactile data, we found strong relationships between the two communication channels. Our studies show that users developed an encoding system similar to that of Morse code, as well as three original uses: emphasis, mimicry, and turn-taking. We demonstrate the potential of the tactile channel to enhance the existing voice communication channel.

Keywords

Tangible user interface, haptic interpersonal communication, remote communication, touch-vibration mapping, vibrotactile communication, tactile communication, tangible telepresence

INTRODUCTION

A case for tactile remote communication

Touch offers a private means of communication and serves as a powerful personal communication tool. Touch provides subtle nonverbal cues, and acts as an extension of the physical body. However, communication devices that use touch are less common than devices that use audio and video.

Due to the broadcast nature of audio and video, many existing communication devices compete for our attention. The senses can become overloaded and important information may be overlooked. The personal communication devices of others often needlessly interrupt our attention and compromise our privacy. One solution is to employ the underused modality of touch.

The goal of this research is to design and implement a sensory augmentation tool that communicates the sense of touch. A necessary step toward this goal is to explore the possible effects of the tactile communication channel on audio communication. We believe that the extra tactile channel enhances audio interaction by providing auxiliary information.

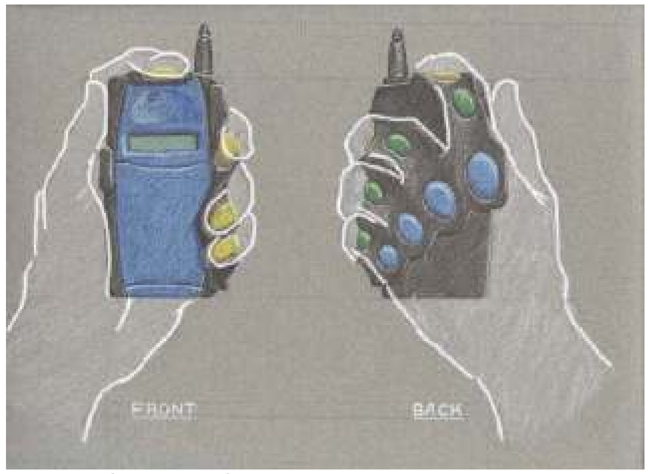

Figure 1. ComTouch Concept drawing showing a handheld sleeve that fits onto the back of a mobile phone

The proposed device, called ComTouch, is a vibrotactile device sleeve that fits over the back of a mobile phone. The basic concept is a handheld device that translates finger pressure into vibration. The devices are bi-directional and both users can send and receive signals simultaneously. Figure 1 shows an artistic rendering of the concept.

Touch is a common medium used by the general population and the sensory-impaired (Figure 2). We observed that most current mobile communication methods utilize audio and video. We decided to build a mobile, handheld communication device that transmits touch that can be used by a universal population.

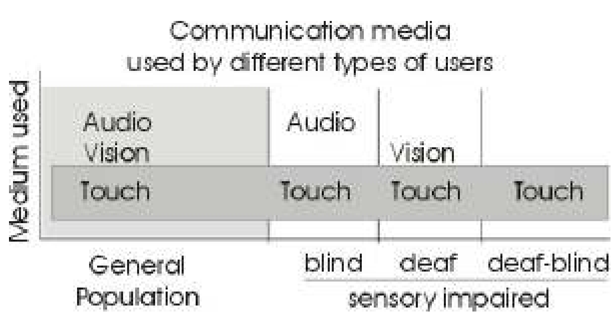

Figure 2. The sense of touch is common among the general population and sensory impaired people.

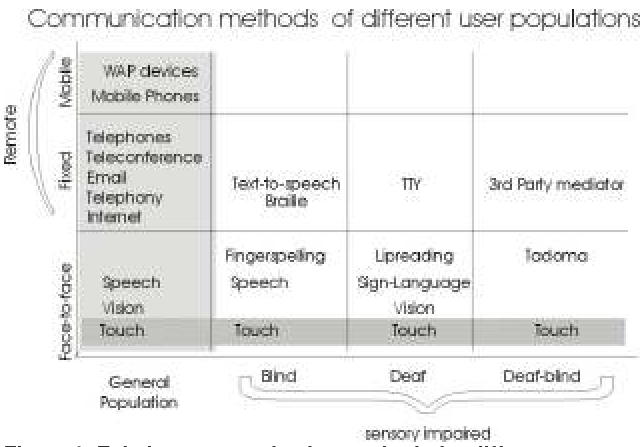

Figure 3. Existing communication methods for different user scenarios.

IDENTIFYING USER NEEDS

To gain insight on the existing needs of potential users, we studied potential users and their communication habits.

Remote communication methods (email, pagers, instant messaging, video-conferencing, and telephones) are not designed to convey subtle nonverbal signals. A device that conveys touch might allow for more expressive interactions.

Blind people use touch-based languages in face-to-face communication. However, for remote real-time communication, the blind and deaf-blind normally use a third party to mediate their conversation. Most remote communication devices available to the blind are costly.

We also asked about which kinds of tactile input and output mappings that would be suitable to blind people and determined that glove-like devices were not ideal because of the constrictive nature. Our subjects expressed dislike of force-feedback devices because of the difficulty in overcoming the feedback force to communicate. There was also the concern of unintentional injury due to the force applied by a machine; for example, if a force-feedback glove forced the hand into an unnatural position.

RELATED RESEARCH

Haptic interpersonal communication

ComTouch was primarily influenced by prior work in the field of haptic interpersonal communication. This work demonstrated that technology was capable of connecting people using touch in real time. Many previous attempts to communicate touch in real time employed the use of mechanical linkage. In the early 80s, *Telephonic Arm Wrestling* introduced the idea of haptic remote communication using simulation over a telephone line that controlled levers [25].

Later research focused on the interactions afforded by these devices. Fogg's *HandJive* used linked hand-held joysticks for haptic entertainment [9]. Brave's research on computer-mediated communication provided additional evidence that the context of the device usage can either foster cooperation or competition [4]. Work by FXPal has focused on integrating media and modalities with research on calm technology [17].

Several artistic explorations advanced the idea of haptic interpersonal communication by using digitally augmented objects to transmit presence information remotely, such as Dunne and Raby's *Doors of Perception* Exhibit [8]. Exploratory combinations of various interface modalities and input-output mappings evoke awareness of a remotely located person. *Feather, Scent, Shaker* demonstrated how touch could be mapped to scents, light and vibration [19]. Ishii's *InTouch* recreated a symmetric mapping of touch over distance by preservation of the physical analog movement of rollers [3, 14]. Tollmar *et al.* described presence by representing the interaction of people with everyday objects such as stones, chairs and portraits [23]. The *Kiss Communicator* by IDEO used the active motion of a kiss to display colourful lights on remote objects [5]. *LumiTouch* is a digitally augmented picture frame that explored the passive communication of presence [7]. Grimmer's *Heart2Heart* vest allowed a touch to convey heat, pressure, and heartbeat wirelessly to mimic a physical embrace [12].

Vibrotactile research

The design and implementation of ComTouch relies mainly on the existing body of *vibrotactile* (touch and vibration) research. Geldard first introduced the notion of applying vibrotactile stimuli to the skin, and suggested that people could learn an invented tactile body language called *vibratese* [10,11]. Tan, Reed and Durlach proved that the hand-based reception language of *Tadoma* could transmit very accurate information [21,22]. Tan further investigated the use of vibrotactile interfaces to engage the full hand [19, 20]. Her *Tactuator*, a three-fingered sensory substitution device, used a tactile interface for improving the reception of speech [22]. Gunther's *SkinScape* used vibration devices distributed throughout the body to enhance the audio experience by immersing audience members in musically synchronized tactile compositions [13].

Tactile languages

A brief review of tactile communication languages suggests the potential use of touch as a primary communication medium. Deaf-blind people can use a variety of tactile communication languages. *Fingerspelling* is a tactile language in which the pressure and expressive movement of one hand are received on another hand. *Tadoma* is a method where the receiver places his thumbs on the lips of the speaker, with fingers on the throat. Tadoma can be precise enough to allow the user to detect intonation information from the vibrotactile stimuli [22]. In comparison, *Braille* is a static alphabetic representation coded using raised dots. Because Braille consists of discrete patterns, it can be computerized, and thus provide remote communication possibilities. However, the transmission and reception of Braille is much slower than Tadoma. *Morse code* is an alphanumeric tactile language consisting of dots and dashes. Advanced users were able to efficiently use shorthand and perform simultaneous speech encoding and decoding of Morse messages [23]. These findings suggest that a touch-based communication language can be a versatile communication tool.

REVIEW OF COMMERCIAL PRODUCTS

Assessment of the commercial products allowed us to develop an idea of technological advances and market needs. We noted the use of force feedback and vibration in entertainment devices (like Aura

Variable	Range of design axis	
Data direction	bi-directional	uni-directional
Data transfer	asynchronous	synchronous
I/O Mapping	asymmetric	symmetric
Data content	Continuous	discrete

Table 1. Variables in design space for touch communication

System's *Interactor Vest*, Immersion's *Impulse Engine 2000 Joystick,* BSG System's *Intensor chair*, *VRF's Tactile Feedback System*, and SensAble's *PHANToM*) to provide more physical interaction with computer games, enhancing the gaming experience.

An interesting input device used in wearable computing was HandyKey's *Twiddler*, a mobile, compact and wireless chording keyboard that allows for single-handed mouse and alphanumeric input.

Commercially available vibration devices, such as Logitech's *iFeel mouse*, serve as a redundant sensory display for visual information by enabling users to physically feel onscreen boundaries. Vibrating pagers and mobile phones can subtly get a user's attention during an important meeting.

Many tactile aids for the deaf translate audio signals into vibration. Multimodal communication devices, such as the *Tactaid* device [24], are often used when the information transmitted using a particular single modality could be lost due to the environment or the abilities of the individual.

Choosing a design space

By listing the touch communication variables, we can articulate the area of the design space of interest. Some common ways of describing the design space use the variables in Table 1. The following features were chosen for our exploration into the touch-based communication design space:

- Bi-directional: Each device will have the ability to send and receive signals.
- Asynchronous: Users can send and receive at the same time. The device will not require a protocol for the users to synchronize the transmission of data.
- Asymmetric: Symmetric mappings using tangible interfaces have been shown to result in users fighting for control [4, 9]. The device has separate input and output channels to prevent users from interrupting an incoming transmission.
- Continuous: The ability to communicate using analog signals allows more variety in communication.

Metaphor of hand gestures

We were inspired by the communication metaphor of shaking hands as a part of nonverbal communication [1]. Although Geldard and Gunther both distributed tactile signals over the whole body, the hand provides a compact site on the body for tactile input and output [3]. Fingers can couple the sensory manipulation between sensing and sending a signal [6]. The rich receptors on the fingers are capable of sensing signals and flexors on the fingers can apply pressure to actuate a signal.

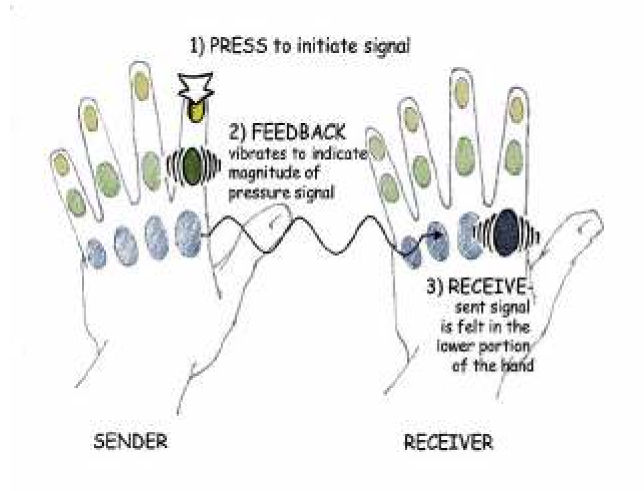

Figure 4. ComTouch touch-to-vibration mapping.

Vibration vs. Force Feedback

Most mechanical representations of touch are expensive to build because motors, gears and control systems are required for representing the analog qualities of touch. These mechanical components are cumbersome to carry, and often wear out with use. Our approach was to use vibration to represent the analog pressure of touch. The uses of vibration in prior research suggest it as the obvious choice of output display. Vibration also was chosen because it was already implemented in many commercial communication devices. Each finger could also serve as a place to output vibration.

Feedback channel

We implemented a feedback channel for the user, so that as she communicated there would be some indication as to what was sent. In some devices, such as telephones, there is a small feedback channel to allow users to gauge how their transmission is received. Previous research hinted that users struggled when control of a single output was shared, perhaps due to the inability of one user to distinguish her own contribution from that of her partner [9]. As a result, ComTouch affords each user singular control over his or her output signal. Local feedback allowed users to gauge the intensity of the signal to be transmitted.

Sensor and Actuator Placement

Figure 4 depicts the touch-to-vibration mapping. The input was located on the fingertips because the flexor muscles would have dynamic physical range to control a downward pressure. The output vibrations would be located on the middle and base of the finger, as this area gives the most contact surface on the hand.

Touch-based communication scenarios

When we began to think of users other than the sensory-impaired, we generated a list of scenarios to help identify possible user interactions.

Situations requiring privacy

Where audio communication is impossible, a touch-based device could provide a private channel for communication. For example, one might wish to remain connected even when inside a library. Touch-based communication could allow discreet notification of personal messages without broadcasting an interruption to others.

Figure 5: Exploration of different form factors using rough prototypes made from clay, foam and wire.

Multiplexing of information and emotional communication channels

In places where remote communication already takes place, touch devices could allow people to increase their communication by multiplexing existing communication channels. For example, politicians would be able to talk and get feedback from their advisors about how the audience is receiving them during a live debate.

Loved ones, when separated, often want to communicate without interrupting the flow of each other's work by active conversation. For example, when one partner is in a meeting, the other one might want to express support.

Special needs users

Existing technologies do not address the need of the deaf-blind to express themselves. In a wireless touch-based communication system, a deaf-blind person could communicate remotely with anyone who has a sense of touch.

Concept generation

The basic form was a hand-held device that allowed each finger to squeeze independently. A series of exploratory form factors are help to visualize possible user interfaces. The dimensions for gripping and the elasticity of the materials were varied to gauge user preferences. Figure 5 displays some form factors considered in the embodiment of the device. These prototypes explored features of two-handed, squeezable, ergonomic, wearable, and strapped physical interfaces.

One key issue is that the use of the device should feel comfortable and not obstruct the natural functions of the hand. In particular, the device should allow communication only when intended. For example, a user might send a squeeze signal when they are simply trying to hold the device. The solution was to use a strap for supporting the device in the users hand, or implement an on/off switch so that tactile communication must be intentional.

Establishing device specifications

We decided on the following device specifications to guide the development of the technology:

- Communication using vibrotactile data. Users will be able to send data by squeezing and receive via vibration. The squeeze force will be linked to the intensity of the vibration.
- The device should be handheld and feasible to build. It is also important for the input and output areas to be localized so the hand does not have to do too much work.
- The device should be small enough for discreet use and mobility.

TECHNOLOGY

Given the specification for a touch-to-vibration mapping, the circuit is designed to convert pressure into vibration.

Pressure Sensitive Inputs

Force sensing resistors (FSRs) measure pressure. FSRs are sensitive enough to discern a range of pressures from approximately 0.45psi (light squeeze) to 150psi (hard squeeze).

Speaker Actuators

Vibrotactile research typically applies a maximum frequency of 250 Hz to maximize the skin sensitivity to vibrations. After trying the pager motors typical of consumer devices like the iFeel mouse, we determined that their dynamic range was too limited for adequate expression. We found a dime-sized commercial acoustic speaker quite suitable in range, and its response was quick and precise enough to represent subtle changes in analog signal. These speakers, the V1220 model from AudioLogic Engineering, are commercially used in the Tactaid device for the hearing impaired (Figure 6).

Figure 6. V1220 speaker actuator (a finger is included for scale)

Touch-to-Vibration System

A touch-to-vibration mapping was implemented using a voltage-controlled oscillator (VCO). When the FSR was pressed, a voltage was input into the VCO. This signal was converted into an oscillation, and the resulting signal was fed into an audio amplifier circuit to drive the speakers. The VCO output was designed such that maximum pressure corresponded to a maximum frequency of 250Hz.

Preliminary system implementation

Because this touch-to-vibration mapping is so unusual, we needed to test whether the mapping could be used for communication. A preliminary system implementation is depicted in Figure 7. Coloured areas helped users to understand the touch-to-vibration mapping. The prototype allows one finger to communicate using the touch-to-vibration mapping.

Figure 7: ComTouch preliminary implementation. One-finger of vibrotactile communication is conveyed between two pads.

In this implementation, each hand rests on a plate. The tip of the index finger presses down on the yellow pad to cause a vibration in the middle of the finger (the green pad). This vibration is the local feedback signal, and allows the user to gauge the amplitude and frequency of her signal. The signal is also sent to the corresponding pad, and received at the base of the finger (the blue pad). The preliminary implementation allows two people to engage in vibrotactile communication via their index fingers.

Experiment design

An experiment was designed to evaluate whether the new vibrotactile mapping could convey information. Our hypothesis was that one-finger vibrotactile communication could show whether there is a relationship between audio and tactile channels. We also wanted to confirm that there is information conveyed in the tactile channel (expressed as equation 1).

$$\text{VOICE} + \text{TOUCH} \geq \text{VOICE} \qquad \textbf{Equation 1.}$$

The experiments use two scenarios: a general talking scenario and a negotiation scenario. The talking scenario allowed the users to talk freely over an audio link, with an additional tactile channel. The negotiation scenario allowed only the tactile channel. The users had to use only the tactile channel to agree on a ranking of 5 things out of a list of 15 items.

The first task, a chatting task, was designed to observe whether the participants could use the tactile channel, and to monitor how the device would be used without specified instructions. After a brief explanation of the device, participants were asked to chat for 5 minutes. Some preliminary topics were given as conversation starters, but subjects were allowed to deviate from these topics. The first task allowed participants to partially overcome the novelty of the device by using the tactile device as a supplement to audio. If the participants finished talking about the suggested topics before the time limit, they would just keep talking until the end of the duration of the task. Audio and tactile data were recorded for this interval using an audio mixer.

The second task, named the Desert Survival Problem (DSP), was devised to get participants to rely on the device to communicate specific data to each other. DSP is commonly used as a negotiation skills task [2]. The DSP scenario gives the users a context in which to use the device; they are stranded in the desert and need to get to safety together.

Figure 8. Some uses communicating using the audio and tactile channel.

The participants were given 5 minutes to individually rank a list of 15 survival-related items in order of importance and then asked to rank a smaller set of 5 items together using mainly the tactile channel. We wanted them to have access to the audio channel to hear whether they had any problems communicating.

This second task gave users some incentive to use the tactile device and avoid the audio channel. The participants were told that the use of the audio channel was insecure, and could be overheard by enemies. When the participants engaged in too much audio conversation, they were warned using a printed sign that enemies were in the area to further reinforce the need for using the device. A time limit of 10 minutes was given to apply time pressure in order to speed up negotiation. Again, audio and tactile data were recorded for this interval.

When the subjects were finished ranking the items, they answered a questionnaire designed to obtain feedback about the experiment and their communication methodology. The data was reviewed using Sony Foundry Acid, a program that allows simultaneous review and replay of all four channels.

Preliminary user studies

A preliminary study of methods for encoding and detection of tactile information was performed on 24 college students. Participants, aged 18-27 (M=20), volunteered in response to a general email to MIT college living groups. All of the participants had science and engineering backgrounds. The participants came in as pairs; partners knew each other before the experiment.

Each pair was asked to use the device in the two communication tasks while tactile and audio information was recorded. Participants wore headphones and spoke into microphones to isolate the audio signal (Figure 8). Addition of white noise to the headphone outputs masked out the noises from the device and the environment. Participants were positioned facing away from each other such that they had no visual contact.

After the experiment, the two audio and tactile channels were replayed and graphed. A reviewer marked the occurrences of interrelation between both channels.

OBSERVATIONS

After a brief introductory demonstration of the device operation, most users were able to understand the touch-to-vibration mapping. The separation of the local and remote feedback areas needed some explanation. Initially, many users giggled when trying out the device, due to their unfamiliarity with the vibration. However, all were able to adjust to the device, and no audio or tactile level adjustments were needed.

All the participants were able to complete both tasks quicker than the allotted time, resulting in successful completion of both tasks.

Resulting user interactions

Occurrences of interaction between the audio and tactile channels in 12 trials (two tasks per trial) were marked. Reoccurring patterns were categorized. Figure 9 shows a tally of the observed patterns. In the first task, participants learned to use the device quickly, and were able to talk freely using the device without asking for help. Most users spent only a few seconds testing and talking about the buzzing before moving onto other conversation topics. Patterns in the signal data clearly indicate that subjects employed 3 meaningful *tactile gestures*, or representations of touch for expression: emphasis, turn-taking and mimicry.

EMPHASIS

Participants often synchronized their tactile pattern to their speech, in order to emphasize their message. Only 5 participants reported an awareness of using the tactile channel for this purpose. Emphasis was the most frequently observed tactile gesture, and was observed for 8 of the 12 conversation trials. Many of the trials contained repeated use of emphasis.

Often, the speaker would press and talk at the same time to highlight a phrase (Figure 10). The audio rhythm and tactile signal sometimes coincided in such a way that the taps seemed to accent certain syllables. The redundant tactile information drew the listener's attention to selective portions of the speaker content.

TURN-TAKING

Turn-taking cues are auxiliary information to aid in the flow of conversation. Glances, gestures, or speech pauses are typical turn-taking cues to pass the flow of conversation onto another person. In 8 of 12 conversation trials, participants appeared to use the vibrotactile signal as a turn-taking marker. A press or series of presses was often given before the subject spoke (Figure 11). These signals were sometimes used to interrupt the other speaker to signal that the other participant intended to speak. However, participants never indicated such a usage in their reports.

In the trials, the tactile signal allowed users to indicate a desire to speak by preceding comments with a buzz. Note that this use of the tactile signal was not redundant to the audio signal.

MIMICRY

Participants tapped out a complex pattern and echoed it back to one another (Figure 12). Rhythm, duration and intensity of the first pattern were duplicated in the second. These patterns sometimes happened in silence, sometimes in conjunction with an audio signal that was independent of the tactile signal. Mimicry was observed at least once in 7 out of 12 trials.

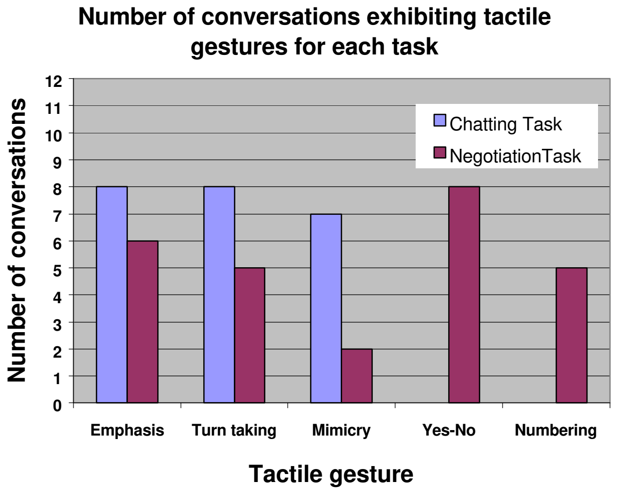

Figure 9. Number of conversations exhibiting tactile gestures.

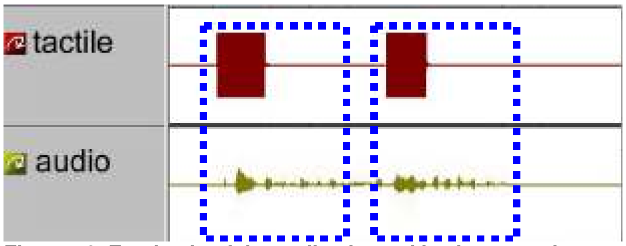

Figure 10. Emphasis of the audio channel is shown as the user presses to draw attention to certain words.

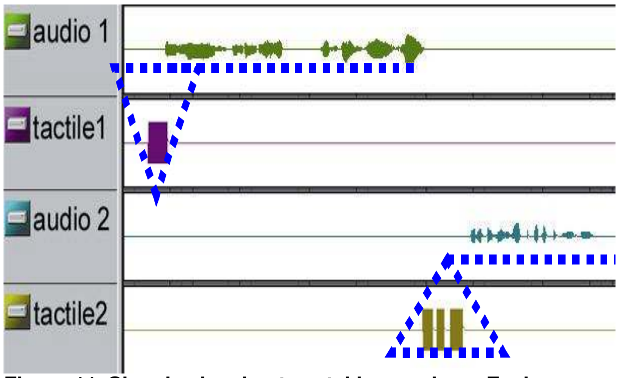

Figure 11. Signals showing turn-taking markers. Each person takes a turn by preceding audio with tactile presses.

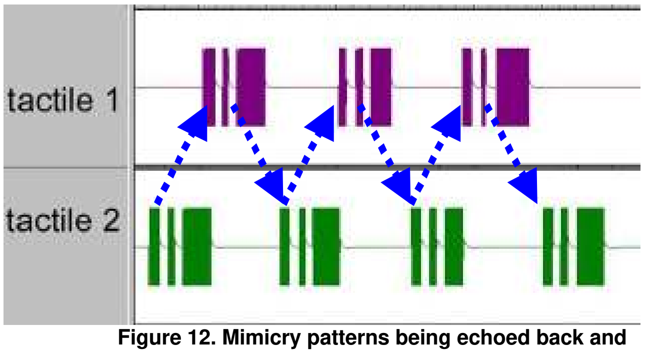

Figure 12. Mimicry patterns being echoed back and forth, independent of the audio channel.

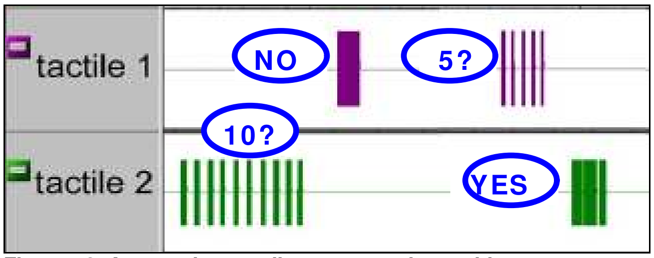

Figure 13. A numeric encoding pattern, along with an agreement arrangement is shown. A single long press means no, while three long presses means yes.

Four participants reported using the channel to send echoes to one another. According to these participants, this information served as a means of ensuring their partner's presence and attention. The tactile signal took the place of nodding or verbally signifying that the other person was listening. Other participants claimed that this behaviour was an extension of physical interactions they had, e.g. patting each other on the arms as a form of camaraderie.

ENCODING

In the second task, voice interaction was intentionally limited. There was an observed decrease in the number of conversations exhibiting the emphasis, turn-taking or mimicry. Participants reported the method of their encoding schemes. The data confirmed that subjects devised tactile encoding schemes during the second task. Using different durations of taps for agreement was observed in conjunction with summing the occurrence of a succession of taps to represent a number.

All 12 trials successfully completed the negotiation task. 8 out of 12 trials devised a tactile encoding system. A binary yes-no scheme was used in 8 of the 12 trials, while 5 trials used a numbering scheme for indicating the position of the list items. Four of 12 trials used both schemes. Figure 13 shows a tactile communication example of a numbered suggestion, with a binary reply.

EVALUATION

The central finding of the preliminary trials was that there is a relationship between the audio and tactile channels. As expected, the information transmitted over the tactile channel was meaningful, and also proved that vibrotactile mappings can be used. Emphasis, for example, is a redundant gesture. Syllables and words already stressed orally were additionally weighted with a buzz. Mimicry, at the other extreme, was largely independent of the audio channel. Turn-taking falls somewhere in between the two. On the one hand, a buzz can serve to highlight the beginning of a speech. On the other, a buzz unaccompanied by audio can indicate impatience born of the desire to interrupt.

Although some participants reported being confused by the unspecified purpose of the tactile channel, the data indicated that 83% of the subjects employed at least one of the three tactile gestures.

The second task demonstrates that information can be structured and sent via the tactile channel in such a way as to make audio less necessary. The existence of numerous tactile communication languages supports this finding (e.g. Morse code and the deaf languages). However, these results are surprising because the touch-to-vibration interface is a new mapping, and users were not instructed as to how to use the interface. Nevertheless, 67% of the users reported establishing their own coding schemes.

These results shed light upon the possible benefits of a tactile communication device in everyday use. A touch-based device can provide an informative and private way to augment existing communication. Touch based communication can allow discreet notification of personal messages without broadcasting an interruption to others.

Participants suggested that some improvements could be made on the test. There are two main limitations to this study. First, the participants in each trial were very familiar with one another. Thus, no claims may be made about the potential for successful tactile communication between strangers. Second, visual contact between participants was eliminated by the experimental design. Availability of a visual channel may have a lessened the reliance on the tactile channel.

Ergonomics

Approximately half of the participants reported that their use of the device was affected by the lack of ergonomics in the device. Users with small hands reported having trouble applying the maximum pressure and being able to position their hand over the reception area at the same time. Figure 14 shows how a user would place their hand on the plate. The mechanics of the finger necessitate that when the sensor is pressed with the fingertip, the rest of the finger must lift off the vibrating areas slightly. This lessens the ability of the user to sense the vibrations.

Figure 14. The hand rests on top of the flat plate.

The most likely solution would be to design a curved and formfitting surface, instead of a flat plate. This would allow the fingers to maintain contact with the speakers even though the fingertip is pressing on the squeeze sensor.

Three participants were left-handed. Although it was expected that there might be problems with left-handed users adapting to the right-handed pad, none of these participants reported problems in using the device.

Lack of resolution of vibration intensity

While some participants were able to perceive and use the dynamic range of the channel, approximately half reported that the resolution of the vibration seemed to have only 3 states- high, low and off. This may be related to the aforementioned ergonomic concerns.

More channels, please

More than half of the participants expressed a need for more of the fingers to communicate. Although subjects could not clearly indicate why they would need to engage more fingers, most felt strongly that engaging only a single finger was limiting. "One button is not enough," said one participant.

Audible Vibration

In the test, the noise of vibration was masked by white noise in the headphones. However, there was an audible buzzing resulting from the vibration of the speakers against the material restraints. The audible buzzing was due to the nature of the vibration, and could be a problem when using the device in conjunction with audio. Future versions will mask the vibration from the audio signal.

An expanded prototype for tactile communication

A more functional prototype will allow for more study of the tactile channel. The current study has indicated that the combination of tactile and audio modalities provides interesting possibilities for conveying nonverbal cues. Our future plans involve improving ergonomics and increasing the tactile bandwidth.

In order to engage as much of the hand as we can, the next design should accommodate the use of all five fingers. We are curious as to the how much information this increased tactile bandwidth can convey and what new usages will arise. We expect that the ability to use more fingers will better convey nonverbal information. Perhaps many-fingered vibrations will suggest known visual hand gestures.

We quickly prototyped the experience of vibrations on 4 fingers using spare foam, cheap headphone speakers and a waveform simulation program called Matlab, to determine whether four fingers might work (Figure 15). We found that the separate vibrations could indeed be distinguishable.

Figure 15. Prototype of four channels.

OBSERVATIONAL PROTOTYPING

Next we went outside the laboratory to observe how people use their mobile phones. We were interested in the ergonomics of how the mobile phones were held when used. We took pictures and noted how users gripped the phone (Figure 16). We realized that the way people hold mobile phones will be similar to the way they hold the ComTouch.

A visiting researcher in the field of ergonomics pointed out that there are two different kinds of grips people use. We took some pictures to illustrate the two grips in Figure 17. Notice that there are two types of grips, the precision grip where the index finger is used to position an object, and the strength grip, where all the fingers act together to tighten the hand around an object.

We observed that people used their index fingers to position the mobile phone. This pose allowed them to hold the earpiece against the ear, and point the other end toward their mouth. The result was an exploration into more ergonomic form factors that utilized the precision grip (Figure 18).

Figure 16. Mobile phone users grip for precision as they walk on a busy shopping street.

Figure 17. Precision grip uses the index finger to position an object (left). Strength grip uses all fingers in tandem (right).

FUTURE WORK

We began to realize that there was much future work to be done to show how a tactile language could be developed. Some underlying questions continued to arise periodically. We found that the main challenges of creating an effective touch-based communication device involve the semantics or grammar that the people using the device might employ. We hope that this research might help us determine whether a vibrotactile language is possible.

We are interested in whether a touch language should be alphanumeric or conceptual. Examples of alphanumeric language devices are chording keyboards, Braille communications, and telegraphs. Examples of conceptual languages are voice communication, hand gestures, and body language. Ideally, a touch language would convey both types of information.

How would users communicate ideas? The components of communication we propose are squeeze force and the duration of force on each finger. Combinations of temporal structure, intensity (vibration frequency), and available channels could provide primitive tools for semantics, syntax and grammar for communication. This may be related to the number of

Figure 18. ComTouch concept drawing depicts the ergonomic grip.

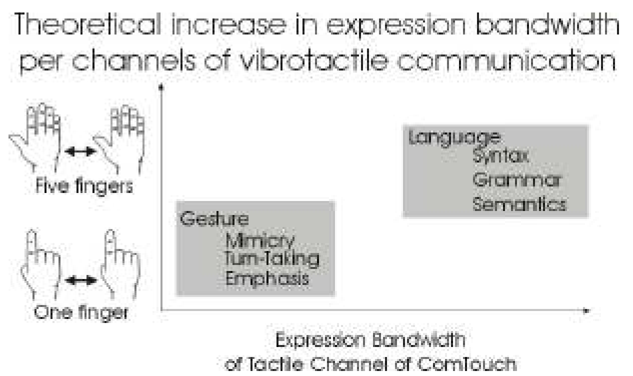

Figure 19. Increase in expressive bandwidth content per channels of vibrotactile communication.

distinguishable channels that are available. Figure 19 depicts the design space for tactile communication in relation to the tactile channels in ComTouch.

Another question is how to envision the correct application to illustrate the usage of tactile communication. The nature of touch will allow personal content to be conveyed in a private manner. Perhaps a specially designed messaging application could exploit this capacity for diverse types of personal content, communicating both complex meanings and simple ideas. By considering touch in contrast to existing modes of communication, we have begun discussion of the architecture of a touch language for remote communication.

CONCLUSION

The strength of the ComTouch project lies in its use of integrated modalities of touch and audio. This investigation into the mixed modality of audio-tactile interaction provides some insight on the use of the tactile channel. Touch communication was shown to enhance an audio conversation by providing redundant and independent information in the form of tactile gestures. This allows communication of nonverbal cues that can be lost or overlooked when only the audio channel is present. Within moments, people new to the device were able to communicate through the tactile channel in a non-trivial and successful way (i.e. using mimicry, emphasis and turn taking).

We hope that this kind of research will contribute to enabling mobility for the sensory-impaired population one day, in addition to enhancing existing communications by adding the underused sense of touch. Understanding the nature of touch and its role in communication may eventually inform the development of a touch communication language.

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