Touch-Aware Communication for Portable Devices

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Abstract. We have constructed an electronic circuit that makes a device *touch-aware*: it can communicate with a user's wearable device if the user completes an electric circuit by touching it. Touch-aware devices are useful in ubiquitous computing environments for distinguishing between multiple individuals and devices. Our design is inspired by recent work by Zimmerman and by Matsushita in intrabody signaling. We have augmented our original transceiver with a vibration sensor to avoid spurious communication when a device is not touched. Our experiments show 1) that the vibration sensor prevents most spurious communication, and 2) that a handshaking protocol we designed can be effective for distinguishing multiple people.

1 Introduction

Touch is an often underused aspect of physical user interfaces. Because touch is usually a necessary part of interacting with an object, knowing what a person touches and when he or she touches it can supply useful information for both desktop environments [3] and ubiquitous computing environments. For example, in a smart biology laboratory [1], touched devices could be associated with an experimenter's laboratory tasks, allowing automatic device configuration or data capture. Touch could also be used to physically "pick and drop" data from one place to another [7], or to control access [4].

Although this functionality could be achieved in other ways, touch has several advantages. It is completely passive; the user need not change his or her behavior. Password entry or card swiping add extra latency and can distract the user both physically and mentally from his or her current task. Touch also performs well in environments with multiple people and multiple devices. Radio signal strength and infrared approaches may make mistakes if several users' transceivers are near each other. Knowing who touched what provides more precise information.

One way to collect information about touch is by Intrabody Signaling (IBS) [4, 12]. Using IBS, imperceptible low-power electrical signals travel through a human body between a carried device and a touched device. Unfortunately, IBS systems are not easily tunable to respond only to touch [5, 8, 13]. A lower-power signal cannot be reliably received because of the highly dynamic electrical environment. A higher-power signal can be received more reliably, however the signal can also be received by nearby transceivers that are not touched. Although signal strength increases with touch, our experiments lead us to believe that it cannot be used as a definitive indicator. We believe that this tradeoff is an inherent difficulty with the technology.

We have added a vibration sensor to our transceiver to supply additional hints about whether a user might be touching a device. The sensor is sensitive enough to be able to distinguish when a portable device is held, and when it is resting on the table. This short paper describes our implementation, sensor design tradeoffs based upon our experiments, and our progress toward building a touch-aware device using the sensor.

2 IBS Implementation

Fig. 1 shows a basic diagram of an IBS system. A transmitter places a low frequency (under 1 MHz) potential difference across two conductive surfaces T1 and T2 (called "plates"). This generates an electric field that behaves roughly like a dipole. A receiver can pick up the signal by measuring the potential difference between two additional plates R1 and R2 placed inside the generated electric field. Conductive objects, such as people, deform the field. Placing one of the transmitter plates and one of the receiver plates near the person distorts the field to increase its strength between the receiver plates. On the right side of Fig. 1, T2's tight coupling to the person causes the entire arm to act like a plate, producing a stronger field between R1 and R2. Stacking R1 and R2 vertically around the hand is not a requirement for this effect; it is also observed with other plate topologies. See [5, 10, 11] for a more detailed description of IBS.

Our transceivers both transmit and receive. They measure 10 cm x 8 cm, and were optimized for ease of modification, not physical size. They reach speeds up to 38.4 kbps with error rates in the best conditions less than 5%. Error rates vary significantly depending upon a person's physical positioning. We are still refining the performance of our underlying IBS system. See [5] for more details.

Although the distance between a person's hand and the touched object correlates well with signal strength, signal strength also depends upon other factors, such as the distance to other nearby conductive objects, the coupling of the person to earth ground, and the relative positions of plates T1 and R1.

3 Vibration Sensor

The vibration sensor outputs a digital value that indicates whether the object it is attached to is being handled. Fig. 2 shows the circuit schematic. The signal from the piezo is amplified, smoothed, and passed to a comparator with hysteresis to produce the digital output.

The piezo is a thin film that generates a voltage across its terminals when it moves. When the object the piezo is attached to is picked up, set down, or even just held, a voltage is generated. We amplify the signal by 100 times. Typical

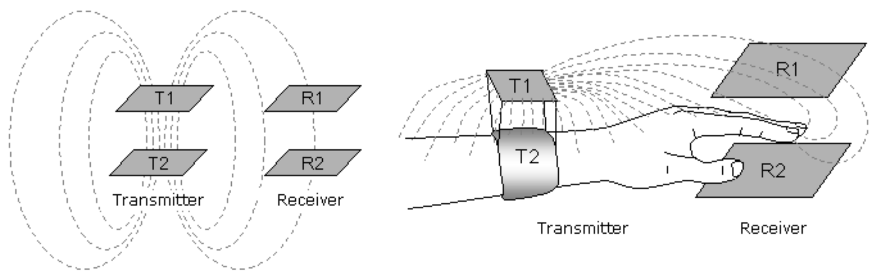

Fig. 1. IBS system model

pick-up and set-down vibrations produce amplified voltages between 0V and 5V; greater amplification would saturate the output and increase the noise level.

Potentiometers A and B control the behavior of the sensor. Pot. A determines how quickly capacitor C1 charges when new motion is detected. When Pot. A has a small value, the circuit is sensitive to bumping of the table it rests on. When Pot. A has a large value, the device may think it has been set down if the user holds it too steadily. Pot. B controls the discharging of capacitor C1 to the current sensor reading. When Pot. B has a small value, the signal is unfiltered and ringing from the piezo is passed directly through to the sensor output. When Pot. B has a large value, C1 discharges slowly, and setting down a device is not noticed by the circuit for several seconds.

Our best effort to tune the circuit was not able to completely mask these problems. Even with a large discharge latency, the vibration sensor occasionally indicated no motion if the device were held still enough. Large bumps of the table also triggered the sensor. The circuit seemed to require frequent tuning, perhaps indicating a sensitivity to temperature. However, given that in practice users will likely be physically manipulating the portable devices, large forces may be generated and the sensor may not require such fine tuning.

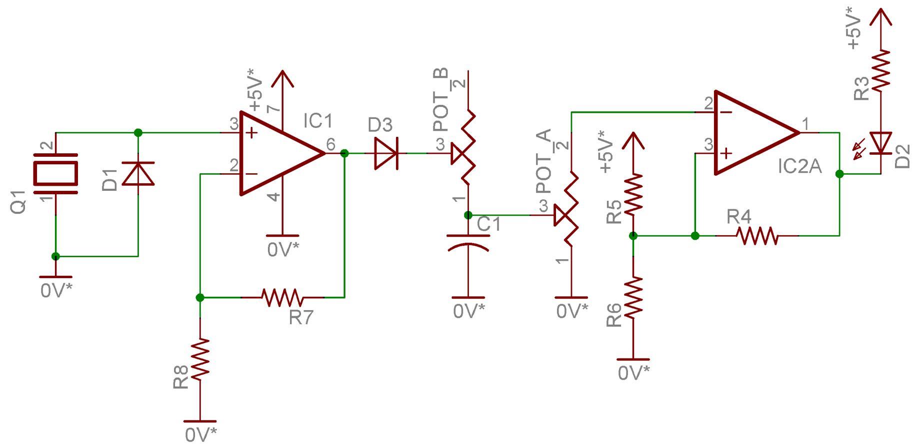

Fig. 2. Vibration sensor circuit

4 Touch-Aware Communication

We conducted an experiment to test how well the vibration sensor prevents spurious communication. We programmed a device transceiver to constantly emit a looping counter value. The counter counted down if no vibration was detected, and up if it was. The wearable lit a green LED if it received an increasing sequence, and a yellow LED for a decreasing sequence.

We found that as expected the wearable was frequently able to hear the signal from the portable device, even without touch. Although the vibration sensor did occasionally misfire, the received sequence behaved properly given the sensor's behavior.

If only one user ever had a wearable, simple masking of communication with the vibration sensor might be sufficient. However, if two or more wearables are near a portable device, when one user picks it up, both wearables might be able to hear the device. The user who picks up the device is not unambiguously identified.

We devised the handshaking protocol in Fig. 3 to resolve user ambiguity. When one person picks up the portable device, it broadcasts a message to indicate that it has been picked up. Both receivers might pick up the signal. Both receivers reply to this message with their id. During the simultaneous transmission, signals from touched transceivers generally dominate signals from untouched transceivers. Only the message from the touched wearable is received by the portable device. The portable device responds with the receiver id it hears, and the wearable hearing its own id back knows that its user picked up the device.

We ran an experiment to see how well this protocol performed. Two users picked up and set down a portable device ten times each. The wearables were

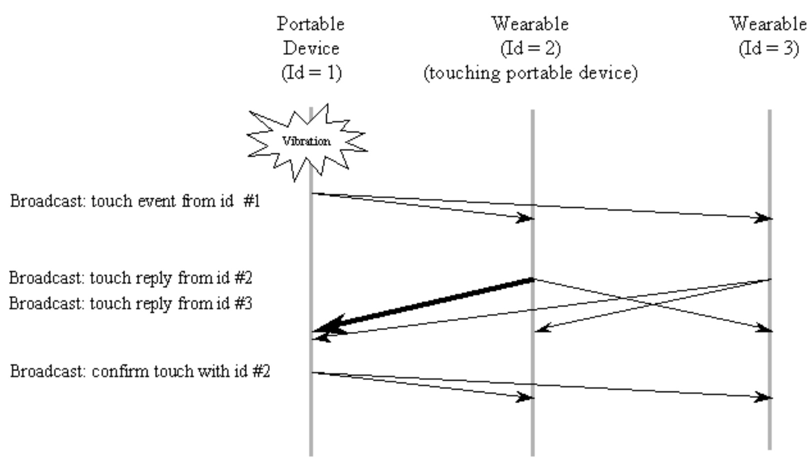

Fig. 3. Handshaking Protocol

coupled to the users through sandals (one plate inside the sandal; one plate on the sandal bottom). On each wearable, one LED indicated whether the initial message was received from the portable device, and a second LED indicated whether the portable device confirmed receipt of the wearable's reply to select it.

In every trial, the correct wearable indicated that it had been picked up. However, in all but two of user #1's trials, user #2's wearable also received a notification that he had picked up the device, and in two of user #2's trials, user #1 also received such notification. However, such notifications were always an instance or two when the other user received multiple (> 20) notifications in the same time period. We estimate that looking at a time period over a few seconds would provide an virtually certain indication.

During all trials, communication was fairly intermittent, depending on body position and how the plates on the portable device were held. Because the users could observe the LEDs, it was not clear whether the intermittent communication would be a problem in everyday use.

We also tried coupling the signal at the wrists instead of at the feet. The communication was even more intermittent, and successful completion of the protocol was difficult to achieve. We believe that the poor performance was due to the IBS design, such as the wrist straps' smaller surface area, rather than the vibration sensor or protocol. We are actively working on improving our basic IBS system.

5 Future Work

Looking at both the vibration sensor and IBS signal strength may mask errors caused by bumping the table. Signal strength rises as the user's hand approaches the plates. If a rise in signal strength is not present, this might indicate a bump. We have also noticed a curious tendency for signal strength to drop by about a factor of two upon direct physical contact with a plate; it might be possible to leverage this phenomenon once we understand it more fully. Using a more robust sensor such as an accelerometer might also eliminate these errors and also the tuning problems.

We intend to miniaturize the transceivers so they can be more easily attached to portable devices. We plan to observe their operation in a real biology laboratory. For this deployment, we may also extend the handshaking protocol to cover stationary objects, using knob twiddling or other physical user interface aspects in place of the vibration sensor.

6 Acknowledgements

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References

1. Arnstein, L., Sigurdsson, S., Franza, R.: Ubiquitous Computing in the Biology Laboratory. Journal of Lab Automation (JALA). **6(1)** (2001)
2. Gray, M.: Physical Limits of Intrabody Signaling. Bachelors Thesis, MIT (1997)
3. Hinckley, K., Sinclair, M.: Touch-Sensing Input Devices. CHI (1999) 223–230
4. Matsushita, N., Tajima, S., Ayatsuka, Y., Rekimoto, J.: Wearable Key: Device for Personalizing nearby Environment. ISWC (2000)
5. Partridge, K., Dahlquist, B., Rosencrantz, M., Veiseh, A., Borriello, B.: Practical Considerations in Intrabody Signalling. University of Washington CSE Technical Report (to appear).
6. Post, E., Reynolds, M., Gray, M., Paradiso, J., Gershenfeld, N.: Intrabody Buses for Data and Power. ISWC (1997)
7. Rekimoto, J.: Pick-and-Drop: A Direct Manipulation Technique for Multiple Computer Environments. UIST (1997)
8. Tajima, S.: Personal Communication (2000).
9. Vigoda, B., Gershenfeld, N.: TouchTags: Using Touch to Retrieve Information Stored in a Physical Object. SIGCHI Conference on Human Factors in Computing Systems (1999)
10. Zimmerman, T., Smith, J., Paradiso, J., Allport, D., Gershenfeld, N.: Applying Electric Field Sensing to Human-Computer Interfaces. CHI (1995)
11. Zimmerman, T.: Personal Area Networks (PAN): Near-Field Intra-Body Communication. Masters Thesis, MIT Media Lab (1995)
12. Zimmerman, T.: Personal area networks: Near-field intrabody communication. IBM Systems Journal **35(3)** (1996)
13. Zimmerman, T.: Personal Communication (2000).