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Skinput Technology

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Abstract:

Skinput is a technology that appropriates the human body for acoustic transmission, allowing the skin to be used as an input surface. In particular, the location of finger taps on the arm and hand is resolved by analyzing mechanical vibrations that propagate through the body. These signals are collected using a novel array of sensors worn as an armband. This approach provides an always available, naturally portable, and on-body finger input system. The capabilities, accuracy and limitations of this technique are assessed through a two-part, twenty-participant user study.

Introduction

Devices with significant computational power and capabilities can now be easily carried on our bodies. However, their small size typically leads to limited interaction space and consequently diminishes their usability and functionality [1-3]. Since we cannot simply make buttons and screens larger without losing the primary benefit of small size, we consider alternative approaches that enhance interactions with small mobile systems. One option is to opportunistically appropriate surface area from the environment for interactive purposes. For example a technique that allows a small mobile device to turn tables on which it rests into a gestural finger input canvas. However, tables are not always present, and are not usable in a mobile context [4-6] However, there is one surface that has been previous overlooked as an input canvas, and one that happens to always travel with us: our skin. Appropriating the human body as an input device is appealing not only because we have roughly two square meters of external surface area, but also because much of it is easily accessible by our hands (e.g., arms, upper legs, torso).

Skinput is a method that allows the body to be appropriated for finger input using a novel, non-invasive, wearable bio-acoustic sensor

In Skinput, a keyboard, menu, or other graphics are beamed onto a user's palm and forearm from a pico projector embedded in an armband. An acoustic detector in the armband then determines which part of the display is activated by the user's touch [7]. As the researchers explain, variations in bone density, size, and mass, as well as filtering effects from soft tissues and joints, mean different skin locations are acoustically distinct. Their software matches sound frequencies to specific skin locations, allowing the system to determine which “skin button” the user pressed [8-9].

The prototype system then uses wireless technology like Bluetooth to transmit the commands to the device being controlled, such as a phone, iPod, or computer [10-11]. Twenty volunteers who have tested the system have provided positive feedback on the ease of navigation. The researchers say the system also works well when the user is walking or running.

Skin Sensing

SKINPUT:

To expand the range of sensing modalities for always available input systems, we introduce Skinput, a novel input technique that allows the skin to be used as a finger input surface. In our prototype system, we choose to focus on the arm (although the technique could be applied elsewhere). This is an attractive area to appropriate as it provides considerable surface area for interaction, including a contiguous and flat area for projection (discussed subsequently). Further more, the forearm and hands contain a complex assemblage of bones that increases acoustic distinctiveness of different locations. To capture this acoustic information, we developed a wearable armband that is non-invasive and easily removable In this section, we discuss the mechanical phenomena that enables Skinput, with a specific focus on the mechanical properties of the arm. Then we will describe the Skinput sensor and the processing techniques we use to segment, analyze, and classify bio-acoustic signals.

BIO-ACOUSTICS:

When a finger taps the skin, several distinct forms of acoustic energy are produced. Some energy is radiated into the air as sound waves; this energy is not captured by the Skinput system. Among the acoustic energy transmitted through the arm, the most readily visible are transverse waves, created by the displacement of the skin from a finger impact (Figure 2). When shot with a high-speed camera, these appear as ripples, which propagate outward from the point of contact . The amplitude of these ripples is correlated to both the tapping force and to the volume and compliance of soft tissues under the impact area. In general, tapping on soft regions of the arm creates higher amplitude transverse waves than tapping on boney areas (e.g., wrist, palm, fingers), which have negligible compliance. In addition to the energy that propagates on the surface of the arm, some energy is transmitted inward, toward the skeleton. These longitudinal (compressive) waves travel through the soft tissues of the arm, exciting the bone, which is much less deformable then the soft tissue but can respond to mechanical excitation by rotating and translating as a rigid body. This excitation vibrates soft tissues surrounding the entire length of the bone, resulting in new longitudinal waves that propagate outward to the skin. We highlight these two separate forms of conduction –transverse waves moving directly along the arm surface, and longitudinal waves moving into and out of the bone through soft tissues – because these mechanisms carry energy at different frequencies and over different distances. Roughly speaking, higher frequencies propagate more readily through bone than through soft tissue, and bone conduction carries energy over larger distances than soft tissue conduction. While we do not explicitly model the specific mechanisms of conduction, or depend on these mechanisms for our analysis, we do believe the success of our technique depends on the complex acoustic patterns that result from mixtures of these modalities.Similarly, we also believe that joints play an important role in making tapped locations acoustically distinct. Bones are held together by ligaments, and joints often include additional biological structures such as fluid cavities. This makes joints behave as acoustic filters. In some cases, these may simply dampen acoustics; in other cases, these will selectively attenuate specific frequencies, creating location specific acoustic signatures.

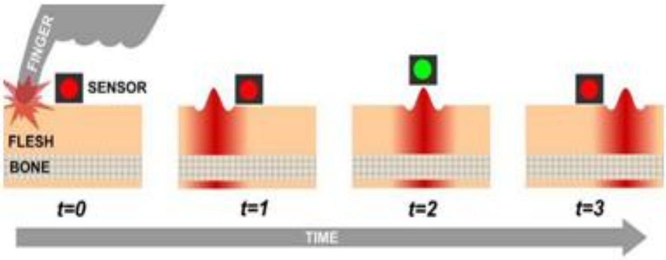


Figure 1.Transverse wave propagation: Finger impacts displace the skin, creating transverse waves

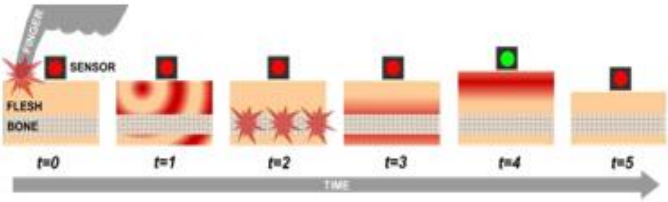
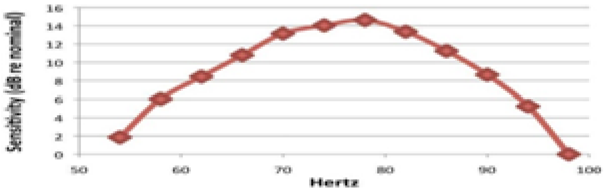


Figure 2. Longitudinal wave propagation: Finger impacts create longitudinal (compressive) waves that cause internal skeletal structures to vibrate. This, in turn, creates longitudinal waves that emanate outwards from the bone (along its entire length) toward the skin.

SENSING

To capture the rich variety of acoustic information described in the previous section, we evaluated many sensing technologies, including bone conduction microphones, conventional microphones coupled with stethoscopes, piezo contact microphones, and accelerometers. However, these transducers were engineered for very different applications than measuring acoustics transmitted through the human body. As such, we found them to be lacking in several significant ways. Foremost, most mechanical sensors are engineered to provide relatively flat response curves over the range of frequencies that is relevant to our signal. This is a desirable property for most applications where a faithful representation of an input signal – uncolored by the properties of the transducer – is desired. However, because only a specific set of frequencies is conducted through the arm in response to tap input, a flat response curve leads to the capture of irrelevant frequencies and thus to a high signal- to-noise ratio. While bone conduction microphones might seem a suitable choice for *Skinput*, these devices are typically engineered for capturing human voice, and filter outenergy below the range of human speech (whose lowest frequency is around 85Hz). Thus most sensors in this category were not especially sensitive to lower-frequency signals (e.g., 25Hz), which we found in our empirical pilot studies to be vital in characterizing finger taps. To overcome these challenges, we moved away from a single sensing element with a flat response curve, to an array of highly tuned vibration sensors.



ARMBAND PROTOTYPE

Our final prototype, shown in Figures 1 and 5, features two arrays of five sensing elements, incorporated into an armband form factor. The decision to have two sensor packages was motivated by our focus on the arm for input. In particular, when placed on the upper arm (above the elbow), we hoped to collect acoustic information from the fleshy bicep area in addition to the firmer area on the underside of the arm, with better acoustic coupling to the *Humerus*, the main bone that runs from shoulder to elbow. When the sensor was placed below the elbow, on the forearm, one package was located near the *Radius*, the bone that runs from the lateral side of the elbow to the thumb side of the wrist, and the other near the *Ulna*, which runs parallel to this on the medial side of the arm closest to the body. Each location thus provided slightly different acoustic coverage and information, helpful in disambiguating input location. Based on pilot data collection, we selected a different set of resonant frequencies for each sensor package (Table 1).

PROCESSING:

In our prototype system, we employ a Mackie Onyx 1200F audio interface to digitally capture data from the ten sensors (http://mackie.com). This was connected via Firewire to a conventional desktop computer, where a thin client written in C interfaced with the device using the Audio Stream Input/ Output (ASIO) protocol. Each channel was sampled at 5.5kHz, a sampling rate that would be considered too low for speech or environmental audio, but was able to represent the relevant spectrum of frequencies transmitted through the arm. This reduced sample rate (and consequently low processing bandwidth) makes our technique readily portable to embedded processors. For example, the ATmega168 processor employed by the Arduino platform can sample analog readings at 77kHz with no loss of precision, and could therefore provide the full sampling power required for *Skinput* (55kHz total). Data was then sent from our thin client over a local socket to our primary application, written in Java. This program performed three key functions. First, it provided a live visualization of the data from our ten sensors, which was useful in identifying acoustic features (Figure 6). Second, it segmented inputs from the data stream into independent instances (taps). Third, it classified these input instances.

OPERATION

Skinput has been publicly demonstrated as an armband, which sits on the biceps. This prototype contains ten small cantilevered Piezo elements configured to be highly resonant, sensitive to frequencies between 25 and 78 Hz. This configuration acts like a mechanical Fast Fourier transform and provides extreme out-of-band noise suppression, allowing the system to function even while the user is in motion. From the upper arm, the sensors can localize finger taps provided to any part of the arm, all the way down to the finger tips, with accuracies in excess of 90% (as high as 96% for five input locations).[5]Classification is driven by a support vector machine using a series of time-independent acoustic features that act like a fingerprint. Like speech recognition systems, the Skinput recognition engine must be trained on the "sound" of each input location before use. After training, locations can be bound to interactive functions, such as pause/play song, increase/decrease music volume, speed dial, and menu navigation.

Conclusion

In In this paper, the approach is to appropriate the human body as an input surface. A novel, wearable bio-acoustic sensing array built into an armband in order to detect and localize finger taps on the forearm and hand is developed. Results from experiments have shown that the system performs very well for a series of gestures, even when the body is in motion.

Additionally, presented initial results demonstrating other potential uses of the approach, which are hoped to further explore in future work. These include single-handed gestures and taps with different parts of the finger.

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