A Review of Wearable Computing Applications employing Acoustic Wave Propagation in Human Tissue

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Abstract

This paper presents a review of acoustic waves applied to wearable device applications. The Wearable Devices Market is described to provide insight into the future relevance of wearable devices. Recently published proposals for gesture recognition, Haptics and Intra-body Communications based on the use of acoustic waves are discussed to highlight the potentials and research opportunities that offer the acoustic waves into wearable devices.

Keywords: Acoustic Transducers, Human Tissue, Wearable Devices, Gesture Recognition.

1. Introduction

The miniaturization of ultra-low power microcontroller, sensors and actuators have enabled a new era of computing. Devices embedded into everyday objects that can adapt to a person needs, time or context of use. These devices known as wearable devices have been attracting several companies such as Apple, Samsung and Google. In fact, one of the most famous wearable devices nowadays is Google Glasses. Indeed, the wearable devices market is growing and some analysts estimate that by 2018 it will reach anywhere from $30Bn to $50Bn in revenues. Thus, the development of wearable related technologies is in demand nowadays. Hence, novel human interface and device-to-device networking technologies are crucial for the development of the upcoming wearable devices and applications.

In this regard, beyond their use in medical imaging and diagnostics, acoustic waves have been recently proposed for different applications related to wearable computers and human-machine interaction. The applications include user input detection [6], user's feedback [10] and body-centric communications [7]. This paper reviews the aforementioned recent applications and outlines the remaining research opportunities and challenges for its commercial deployment.

Incidentally, wearable devices take advantage of one or several sensors. Some of these sensors are cameras, accelerometers, and gyroscopes. Alternatively, acoustic transducers offer advantages like no need for voltage supply to sense or act, small size and low price. However, application of acoustic transducers for wearable devices has not been explored thoroughly.

This paper presents a review of the application of acoustic waves to wearable devices and acoustic transducer technology. Section 2 provides an overview of the Wearable Devices Market while Section 3 provides a review of selected wearable devices applications based on acoustic waves.

2. Wearable Devices Market

Wearable technology is the expression of pervasive computing expressed in the sense of interweaving devices that can be embedded into the clothing and/or personal items such as watch, glasses or belts. Wearable devices should be capable of monitoring physiological functions of the user as well as allowing the wearer to access information from several sources. Therefore, these devices must contain a sensor or a group of sensors, a processing unit and a transceiver that can communicate the processed signal into a server, computer or cloud [1]. One of the main applications of these devices is in the medical field. Wearable medical devices could eliminate dependence on clinical environments to allow monitoring of patient in their everyday life activities. The benefits could include the determination of triggering of abnormal events which happens under unsupervised scenarios [1]. Medical wearable devices can be possible due to the availability of ultra-low power microcontrollers, energy efficient transceivers as well as high power density batteries.

The research challenges in this area have been attracting developers toward wearable devices. Strategy Analytics made a survey to recognize the developers' preferences [2]. The results collected from 1710 developers' answers are shown in Fig. 1 [2]. One question included in the survey was: Which devices do you develop for? The results confirm an increment from 3.5% (2012) to 27.4% (2014) showing that the interest in wearable devices is increasing. Other question was: Which device do you primarily develop for? Similar behavior is shown; there is an increment in wearable devices, from 0.2% (2012) to 4.7% (2014). These trends give an idea about the popularity growth toward wearable devices.

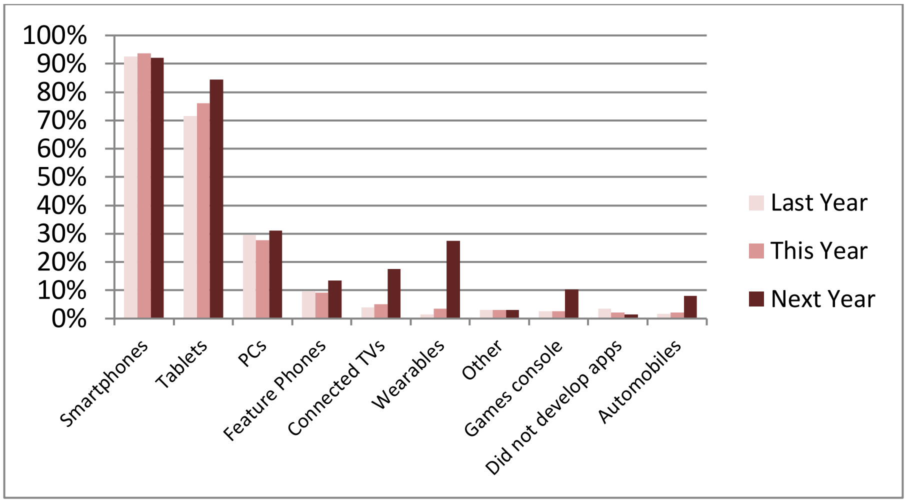

Fig. 1. Developer Survey [2].

Information Handling Services (IHS) reports that volume of sales for wearable devices was 10,000 Million USD in the 2012 and predicts almost 60,000 million USD for 2018 as shown in Fig. 2 [3]. The forecast is that wearable technology will become the 8th largest revenue driver within consumer and mobile devices behind handsets, media tablets, laptops, standalone projectors, gaming, and cameras. One of the most famous wearable devices at this moment is google glasses with projected sales shown in Fig. 3 [2].

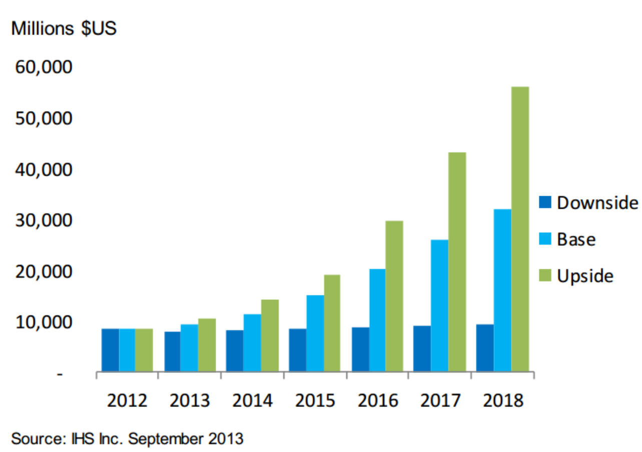

Fig. 2. Preliminary Scenario Forecast- Wearable Technology [3].

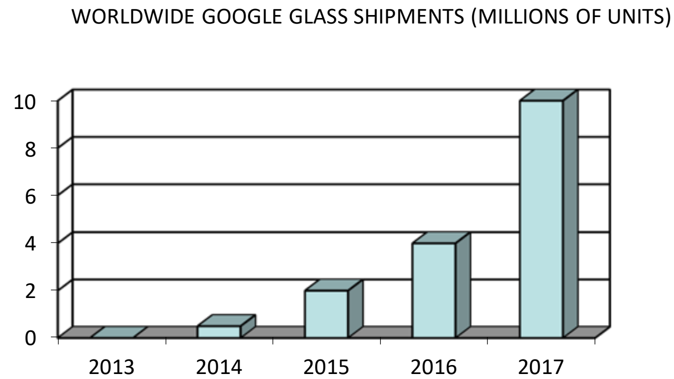

Fig. 3. Worldwide Google Glass Shipments Forecast [2].

One of the main reasons for such interest in wearable devices is the great amount of applications that can be involved such as health care, fitness, wellness, industrial and military. Table 1 shows examples of these applications.

Application	**Product Categories**	
Health Care and Medical	Blood Pressure Monitors	Insulin Pumps
	Continuous Glucose Monitoring	Smart Glasses
	Defibrillators	Patches
	Drug Delivery Products	PERS
	ECG Monitors	Pulse Oximetry
	Hearing Aids	
Fitness and Wellness	Activity Monitors	Sleep Sensors
	Emotional Measurement	Smart Glasses
	Fitness & Heart Rate Monitors	Smart Clothing
	Foot Pods & Pedometers	Smart Watches
	Heads-up Displays	Other, Audio
	Ear buds	

Infotainment	Bluetooth Headsets Head-up Displays Imaging Products Smart Glasses Smart Watches
Industrial	Hand worn Terminals Heads-up Display Smart Clothing Smart Glasses
Military	Hand worn Terminals Head-up Display Smart Clothing

Table 1. Wearable Technology Market [3].

3. Acoustic Waves Based Wearable Applications

Beyond their use in medical imaging and diagnostics, acoustic waves have been recently proposed for different applications related to wearable computers and human machine interaction. The acoustic waves have been used for input detection, tactile feedback, or intra-body communication [6]-[13]. The impinging of acoustic waves on human tissue is the mechanism used to enable this technology. The technology behind acoustic waves traveling on human tissue has not reach maturity and offers several opportunities for original contributions.

3.1. Gesture Recognition based in Acoustic Waves

Skinput is composed by an Armband which contains 10 piezoelectric sensors and a pico projector as shown in Fig. 4 [6]. Prototype is shown in Fig. 5 [6]. Acoustic waves traveling through the skin and bones are captured with the piezoelectric transducers; then these signals are sampled with a sound amplifier, the last stage is the signal processing. The project consists in a proof of concept to locate the position in which occurs a finger tap over the forearm or palm hand.

Fig. 4. Skinput Armband with 10 piezoelectric transducers [6].

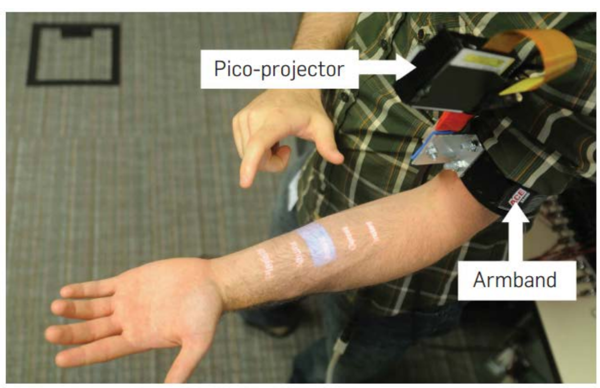

Fig. 5. Armband prototype for Skinput [6].

The finger tapping in the forearm (Fig 6, t=0) produces acoustic waves and surface skin propagation. The signal propagation on the skin is shown in Fig 6 (t=1). The wave traveling on the skin surface make contact with the sensor (Fig 6, t=2) so an acoustic signal based in movement is captured. The ripples formed in the skin when a finger taps it can be seen by a high speed camera.

Important differences are found between zones with “soft” tissue and “hard” tissue. Hard tissues are regions in which the bones are closer to the zone of the finger tap like wrist, palm and fingers. Soft tissue includes only forearm in this case. Amplitude of the ripples is correlated with the tapping force, with the volume of the skin displaced and with the tissue zone. Amplitude in “hard” tissue is lower than amplitude in “soft” tissue.

Acoustic wave propagation in bones is shown in Fig. 7. Energy propagating in the arm’s surface is transmitted inward, toward the skeleton (Fig. 7, t=1). The longitudinal waves travel through the tissue and excite the bone (Fig. 7, t=2), it is less deformable compared with tissue, and resulting in new waves propagated outward the skin (Fig. 7, t=3) that reach the sensor (Fig. 7, t=4).

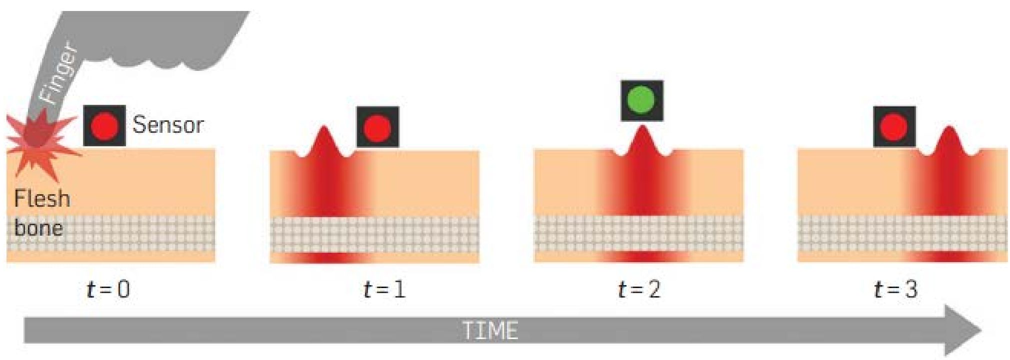

Fig. 6. Transverse Wave propagation [6].

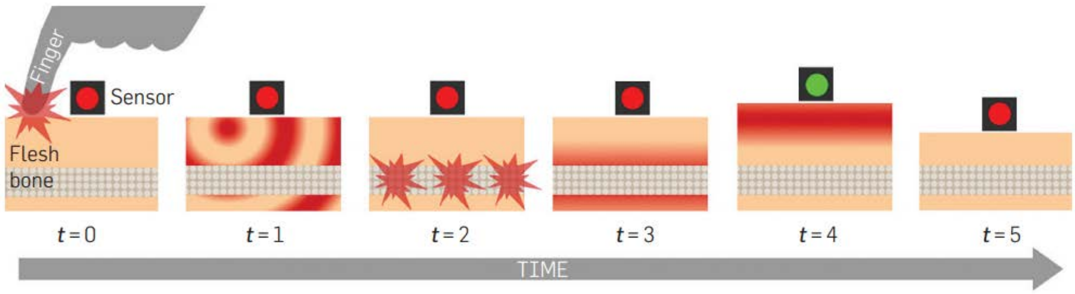

Fig. 7. Acoustic Wave Propagation in bones [6].

Different experiments to determine the location of a user finger taping onto his forearm were reported in [6]. Fig. 8 shows the experiments. They consist in taping at different locations (black dots) in the forearm. Experiments show that the system is able to detect correctly the tap location even when the body is in movement.

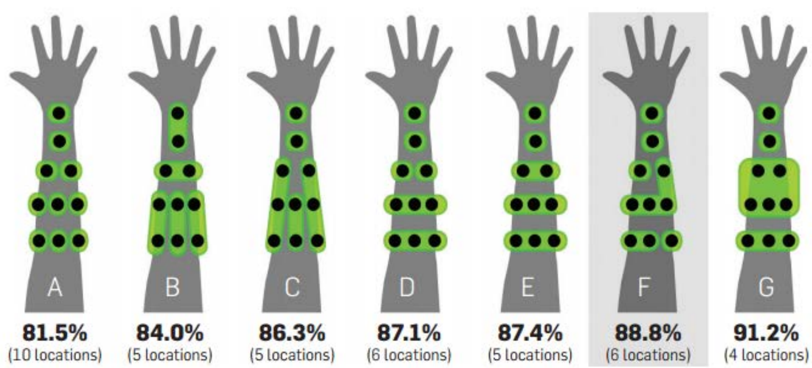

Fig. 8. Skinput Detection Results [6].

3.2 Intra Body Data Communications

The human body is composed by water in 65%, so the RF electromagnetic waves do not propagate easily in this medium. In addition the human body distorts and delay transmitted RF signals [7]. For this kind of applications acoustic transducers used are ultrasonic. Ultrasonic advantages over RF communication used in in *Body Area Networks (BAN)* include a better propagation of the signals and lower perceived health concerns [7].

Ultrasonic waves are subject to lower absorption compared with electromagnetic waves. Attenuation values from 20dB at 100 MHz are present in distances below 10 cm. This makes RF communication in human tissue very difficult [7].

Ultrasound has been used for therapeutic and diagnostic purposes since 1960s with no consequences in health, no lethal effects had occurred for temperatures lower than 41° C. In order to avoid harm to the user, the temperature must be contained by controlling the signal duty cycle, since heating is strictly caused by the wave intensity of transmitted pulse. For these reasons ultrasonic transducers are very popular in *Intra Body Area Networks* (IBANs).

The network of body sensors and actuators are considered an Intra-Body Area Network (IBAN) [8]. The IBAN has been used in biomedical applications, such as sensor implanted in diabetic patients to measure glucose´s level. Depending on the level, the actuator injects insulin to achieve an acceptable level. System architecture for IBANs is shown in Fig. 9.

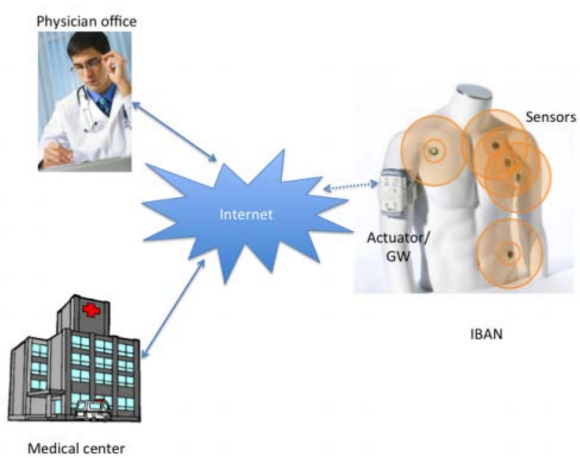

Fig. 9. System architecture for IBAN [8].

Ultrasonic Acoustic Sensors have been used to achieve IBAN network due to the good propagation of mechanical vibrations in body tissues. The ultrasonic waves are the result of mechanical vibrations in elastic medium at frequencies above 20 kHz [7]. Attenuation in human tissue is represented as

$$P(d) = P_0 e^{-\alpha d} \quad \textbf{(1)}$$

where $P(d)$ is the pressure in the medium (tissue) at the distance d, P_0 is the initial pressure in the medium (tissue), α is the amplitude attenuation coefficient, and is a function of the carrier frequency as [8].

$$\propto = a f^b \quad \textbf{(2)}$$

where f represents carrier frequency, ***a*** and ***b*** are attenuation parameters in tissue. Table 2 shows the attenuation parameters for different tissues. [8].

Tissue	***α***	***A***	***b***
Blood	0.095-0.13 @ 5 MHz	0.014-0.018	1.19-1.23
Heart	0.23 @ 1MHz	0.23	1
Kidney	0.23 @ 2MHz	0.115	1
Liver	0.17-0.57 @ 5 MHz	0.041-0.07	0.9-1.3

Table 2. Parameters characterizing body tissues. [8].

3.3 Haptic Applications

Haptic technology, or “haptics”, is a tactile feedback technology that takes advantage of the sense of touch by applying forces, vibrations, or motions to the user. Haptics can be used in videogames, touchscreen technology, medical applications, and any activity involved in touch sensitivity. Some examples are tactile displays [10], Vibro tactile haptic devices [11], Learning Gloves [13] and sonochromatic devices [12].

In a tactile display, a vibration is generated in the finger’s skin if a finger is sliding over the surface or a real object. The frequency of the signal generated depends on roughness of the surface and the sliding speed [10]. The vibration received in tissue by mechanoreceptors is recognized as tactile feeling. Surface Acoustic Waves (SAW) tactile display is a thin device with very simple structure. Fig. 10 shows the schematic view of the SAW tactile display [10].When alternative voltage is applied to the interdigital transducer (IDT), the SAW is excited and the waves reach the substrate surface. This method is using friction distribution of SAW.

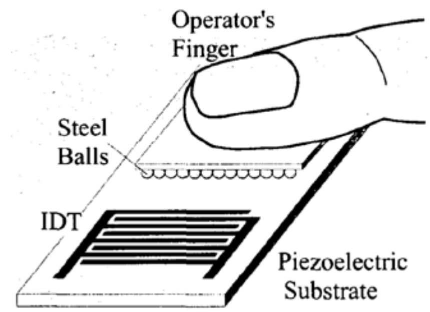

Fig. 10. The Schematic view of the SAW tactile display [10].

The EyeBorg is an application that uses a camera to detect colors to translate them into sounds or vibrations that the user can discern [12]. This device is used by colorblind people. It is considered in this area because it uses feedback information to create a sensation in the body to enable the user “feel” or “hear” the colors. The first prototype had only basic colors and limited sounds, right now the device consist in 360 colors including infrared. Sounds to distinguish ultraviolet are in development phase. The Fig. 11 is called Pure Sonochromatic scale of Harbisson.

PURE SONOCHROMATIC SCALE		
(invisible)	Ultraviolet	Over 717.591 Hz
	Violet	607.542 Hz
	Blue	573.891 Hz
	Cyan	551.154 Hz
	Green	478.394 Hz
	Yellow	462.023 Hz
	Orange	440.195 Hz
	Red	363.797 Hz
(invisible)	Infrared	Below 363.797 Hz

SONOCHROMATIC MUSIC SCALE (basic 12/360)		
	Rose	E
	Magenta	D#
	Violet	D
	Blue	C#
	Azure	C
	Cyan	B
	Spring	A#
	Green	A
	Chartreuse	G#
	Yellow	G
	Orange	F#
	Red	F

Fig. 11. Pure Sonochromatic Scale and Sonochromatic music scale [12].

4. Conclusions

True wearable devices are becoming feasible due to the miniaturization of ultra-low power microcontrollers, sensors and actuators. Moreover, the important growth of the Wearable Devices Market will make it one of the driving factors in future personal computing. Thus, development of new devices under this paradigm is attracting researches and opening new opportunities for contributions. Wearable device applications based on acoustic waves have been recently proposed in the literature. Applications including user interface, haptics and intra-body communications were described in this paper. However, the literature survey shows that these applications are fairly recent and small in number. Therefore, important opportunities for novel research and technology innovation are present in this field. It was also highlighted that acoustic waves show some advantages. For example, for intra-body communications, acoustic waves suffer from lower propagation losses compared to electromagnetic ones.

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