Intrabody Communication Methods – A Short Overview

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***Abstract*—This paper is an introduction to underlying mechanisms and the current state of technologies in the field of intrabody communication (IBC). IBC technologies utilize the human body as a communication channel to achieve communication between different devices that can be positioned inside or on the surface of the body. Current developments in the field of mobile gadgets, smartwatches and medical devices make this field of particular interest due to very low energy expenditure, security, and ability to protect private data. Since there are multiple subfields in the field of IBC technologies, this paper will focus on summarizing the principles of work for galvanic coupling and capacitive coupling and compare the tradeoffs of using one approach over the other.**

***Keywords*— body channel communication, galvanic coupling, capacitive coupling, biomedical engineering**

I. INTRODUCTION

In the recent years there was a steady increase in the number of sold wearables such as smartwatches and wristbands that can track many vital functions such as heart rate, body activity or respiration [1]. These devices usually employ standard wireless data transmissions based on radio frequency (RF) such as Bluetooth, Bluetooth Low Energy and Zigbee, which even though strive for lower power consumption, can still prove inadequate for 24-hour medical usage [2], [3]. The IEEE 802.15.4. standard for low power Zigbee protocol indicates the output power of 0 dBm (1 mW) for transmission at the maximum rate of 250 kb/s which can use up a normal lithium-ion battery in a few hours [4]. The research on military grade equipment that would provide a very low energy consumption for devices that are a part of wireless body area network (WBAN) has stated that the highest battery usage came from RF communication and that significant savings could be made by performing data fusion on the sensor nodes themselves and by reducing the transmission rate [5]. Furthermore, since standard technologies operate at higher frequencies, the range that those devices have is usually much larger than necessary, which wastes energy and can become a security risk for outside intruder attacks such as eavesdropping on the highly private information and even extracting them while impersonating a legitimate WBAN client [4]. In 2007, a former vice-president of the United States Dick Cheney has requested that a wireless control compartment of his defibrillator be removed as he feared that it might be used in a hacking attempt to deliver a fatal electric shock directly to his heart [6].

The concept of using human body as a conductor for electrical current and to transmit information was first explored by Zimmerman [7] who labeled those systems as Personal Area Networks (PAN). PANs would be able to unite multiple in-body and on-body devices without usage of excess cables and I/O redundancies through usage of intrabody communication (IBC). This opens the possibilities of developing medical devices that use IBC to perform communication between each other. For example, an insulin pump could be used in conjunction with a glucose level sensor to measure the levels of glucose in a human body and achieve a continuous transfer of the data to the insulin pump via IBC [8] or to a wearable bracelet which can then display the measured glucose levels to the user [9]. Furthermore, this way of communication can be established between two bodies that are touching, which could enable the transmission of data between two people [10] by simply touching fingers or shaking hands.

There are multiple methods of intrabody communication which have been explored so far that offer a possibility of better characteristics in terms of battery usage, safety, and speed than standard RF communications, such as ultrasound, magnetic resonant coupling, galvanic coupling, and capacitive coupling [9]. Research by Galluccio *et al.* [11] has shown that due to the human body composition which is 65% water, a communication using audio waves at frequencies above 20 kHz (ultrasonic) had significant potential, but issues such as tissue heating and cavitation (bubbles of air within an acoustic field can expand and burst, causing damage to biological tissues) presented that there are still drawbacks that must be further explored. Meanwhile, research by Koshiji *et al.* has proposed usage of loosely fitted coupled coils around parts of human body that could be used to transmit and receive magnetic energy [12]. This method used the property of magnetic fields to freely flow through biological tissue. While these two methods of coupling for intrabody communication have been researched and have their benefits and drawbacks, this paper will focus primarily on two main methods of intrabody communication, which are capacitive and galvanic coupling. Both methods employ a transmitter and a receiver that are battery powered and have a pair of electrodes. They differ in the way electrodes are set up on the human body and the way the signal propagates through the communication channel.

II. INTRABODY COMMUNICATION

A. *Capacitive Coupling*

Capacitive coupling method utilizes a transmitter and a receiver which consist of two electrodes, a signal electrode which is attached to the human body and a ground electrode which is oriented towards the environment. Both transmitter and a receiver are electrically isolated and battery powered. When a weak electric field is present, human body acts as a signal guide and couples the signal electrostatically [7] while the return signal passes through the environment as shown in Figure 1. These induced electric fields appear between all parts of system that are at different potential. The

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transmission signal is generated by modulating the voltage between two signal electrodes and is then received and decoded by the receiver. The induced current through the human body is measured in order of magnitude of picoamperes, and therefore presents no harm to organism [13]. Furthermore, as most of signal is confined to the body while the human body acts as an electric conductor, this minimizes the required transmission power [14]. The received signal level is affected by many factors, such as the signal frequency, position of electrodes, orientation of the transmitter to the receiver, the size of the receiver ground plane, and the surrounding environment. Usual ranges of signal frequencies are between 1 and 100 MHz. Lučev *et al.* [15] have shown that for capacitive coupling in this frequency range the channel gain increases with signal frequency for 20 dB/dec up to around 45 MHz, after which it decreases. But as the frequency increases, the human body starts acting as an antenna and the radiation of signal into the environment is no longer negligible [14].

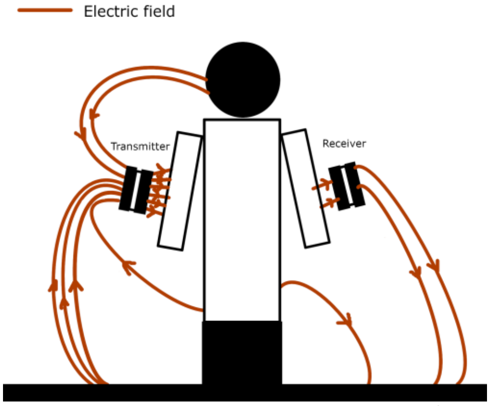

Fig. 1. Capacitive coupling diagram showing the flow of the electrical field from the environment to the electrodes and from electrodes to the human body

Research by Fujii *et al.* has shown that by reducing the size of transmitter by half the received signal voltage was reduced by nearly 50%, compared to only 10% drop when increasing frequency from 10 MHz to 100 MHz [16]. Haga *et al.* have shown that the most sensitive factor for the signal strength maximization was the separation distance between two electrodes, as increasing the distance reduced the capacitance and therefore induced more energy into the body [17]. Furthermore, the size of the ground electrode also had an impact on the transmission gain, with larger electrode increasing it. The gain was also not affected by the size of signal electrode in case it was in contact with the human body. If the signal electrode was not in contact with the human body, then the size of signal electrode also should be maximized to reduce the capacitive loss between the signal electrode and the body. Zhao *et al.* [18] have experimented with design of wristband and found that the best result for wristband was achieved when the separation of two electrodes was maximized, with the signal electrode being in a direct contact with human body and ground electrode being on the top of the wristband. However, for the mobile phones, it was shown that due to huge variety of ways to hold a mobile phone, an optimal design must be found that would prevent the user from short-circuiting the electrodes. Even though the larger sizes of electrode produced better results, the size of wearables and medical instrumentation cannot be too large as it would cause inconvenience or burden for the user. Therefore, a compromise must be found while designing such devices.

When analyzing the effect of body positions on capacitive coupling, Lučev *et al.* have analyzed different positions such as sitting and standing while the transmitter and receiver electrodes were either on the same arm, or on the different arms which increased the distance [15], [19]. Subjects were asked to sit, stand, hold one arm upwards, swing the arm, or hold both arms parallel to the floor. The results showed that for lower frequencies, the body geometry and arm movement had little to no influence on the measured transmission, while for 40 MHz and higher frequencies the change in gain increased to around 20 dB and was influenced by body geometry. Seyedi *et al.* have explored the effect of the limb positions and joints to the transmission gain by placing electrodes on the left forearm and upper left arm [20]. Subject was then asked to stand and perform four different positions with left arm being bent at 45°, 90°, 135°, and 180°, respectively. It was shown that the presence of a joint has attenuated the signal more in frequency range between 60 MHz and 170 MHz. It was also again shown that the position had almost no influence for frequencies lower than 40 MHz in case the distance between transmitter and receiver remained the same, while for higher frequencies the attenuation was proportional to the angle between forearm and upper arm. Sasaki *et al.* have researched the contribution of the ground loop through the floor in IBC by placing the subjects on different types of floors [21]. The subjects wore transmitter or receiver wrists and stood on a carpet-covered metal floor, concrete floor, hardwood floor and wooden chair to be above the floor while touching a receiver on an aluminum stand. The results have showcased that the influence of the ground loop was not significant, as most of signal transmission occurred through the capacitive coupling between the transmitter, the receiver, the human body, and the aluminum stand.

Hou *et al.* have designed an IBC system based on capacitive coupling capable of transmitting image data [22]. By using on-off keying (OOK) modulation with a 20 MHz carrier signal, they achieved a stable image transmission through the body at a rate of 445 kbps. They have also achieved the transmission between two bodies using the handshake as a contact point. OOK modulation was used as it outputs no carrier when transmitting low level and therefore saves energy which makes it suitable for IBC systems which aim to achieve low power consumption. Cho *et al.* have designed a transceiver which can achieve 80 Mb/s data rate with half duplex communication or 40 Mb/s data rate for full duplex communication, with an energy consumption of 79 pJ/b [23]. As described in the paper, this transceiver has been designed to support two modes of operation: the entertainment mode in which the speed and full-duplex is prioritized and healthcare mode with ultra-low-power consumption and high Q-factor. Recently, it was shown that a stable capacitive return path can be accomplished even in implantable devices in case the ground electrode is isolated from the human tissue [24].

B. Galvanic Coupling

Galvanic coupling was first observed by Handa *et al.* in 1997 [25]. Like capacitive coupling, it uses human body as a transmission channel for signal propagation, but the signal return path in galvanic coupling is confined fully within the human body. In galvanic coupling both signal and ground electrodes must be in contact with the body on transmission and receiving side. Primary current flows between the transmitter electrodes, while a small portion of it propagates through human body and can be detected as an alternating potential difference between the receiver electrodes [13], as seen in Figure 2. The propagation of the signals through human body is possible due to the relative permittivity and electrical conductivity of the body [26]. Same as capacitive coupling, galvanic coupling also offers low power consumption and low frequency signals. Galvanic coupling is advantageous in that the signal path loss is lower within the human body than it is through the air. This means that the return signal path is not affected by the environment as it is in capacitive coupling. However, due to attachment of low impedance ground electrode in proximity of signal electrode, the signal attenuation is larger. The signal attenuation also increases with the distance [27].

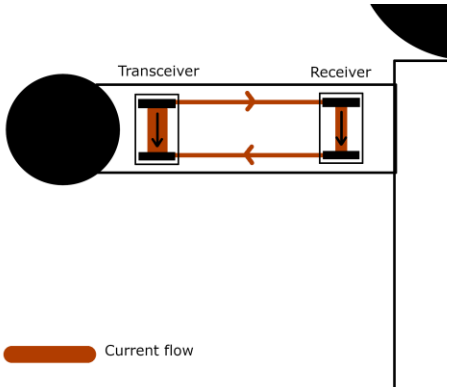

Fig. 2. Galvanic coupling between transmitter and electrode on a human arm

Wegmueller *et al.* have compared different electrodes that can be used for galvanic coupling by generating a 1 mA current signal modulated in the frequency range of 10 kHz to 1 MHz. The tested electrodes were *Swaromed REF 1008, Neuroline 715* and *Blue Sensor BR*. For *Blue Sensor* electrodes, different sizes of electrodes were also tested. In conclusion, the electrodes with a lower resistance led to a lower attenuation. If the electrode was smaller, the measured resistance was larger, and the capacitance lower, therefore larger electrodes proved to be better for galvanic coupling. Furthermore, solid-gel electrodes with lower capacitive values have achieved better results than pre-gelled electrodes [28]. Wegmueller *et al.* also kept the transmitter and receiver electronically isolated by using battery powering of the transceiver units and a serial optical connection to connect the units via a universal serial bus (USB) to a standard computer. This way, the units were entirely electrically decoupled from any power lines and adhered to safety limits [29].

Galvanic coupling signals can travel through skin, muscle and fat tissues and its properties are affected by the tissue layer that is used as a medium [9]. Research by Song *et al.* has discovered that distribution of electrical potential was mainly confined in the upper layers of skin and fat, while the muscle had relatively lower potential. When transmitting signal through the extremities, the attenuation increased with distance, while the signal attenuation through thorax was relatively independent of location. The signal transmission distance had less influence on signal attenuation at lower frequency ranges such as 10 kHz – 100 kHz, at 100 kHz – 500 kHz the distance started to influence the attenuation and at 500 kHz – 5 MHz range, the signal attenuation was highly influenced by distance. Same as in capacitive coupling, joints acted as a blockage and added an attenuation of more than 10 dB [29], [30]. This was because joints mostly consist of low-conductivity bone tissue, with less high-conductivity muscle and fat tissue.

Galvanic coupling uses low frequency ranges, usually between 10 kHz and 1 MHz [14]. Since low frequencies cannot support high bandwidth, Asan *et al.* have proposed usage of fat tissue to achieve low loss microwave communication in frequency range of 1.7 GHz to 2.6 GHz [31], [32]. The measurements have shown that loss was around 2 dB per 20 mm in phantom, while in *ex vivo* model the loss was around 4 dB per 20 mm. Compared to transmission of the same frequency signal through the muscle tissue, the loss was two times lower. The optimal thickness of fat layer for signal transmission was 25 mm, however the research did note that variation in body composition has not been considered and the signal quality might be affected in patients with low body mass index as thickness of fat layer decreases.

Usefulness of galvanic coupling in field of practical application was already demonstrated in several cases. Vizziello *et al.* have transmitted electromyography data in both *ex-vivo* and *in-vivo* tissues using galvanic coupling [33]. The achieved SNR for 9 cm distance was 20.45 dB and the performance was almost error free, therefore showcasing the reliability and robustness of this type of communication. This application of galvanic coupling could be used to transmit sensed signals from a healthy muscle to a close one that is unable to receive natural input signals due to a nerve compression. Hachisu *et al.* have designed bracelets that were worn around wrists and could detect whether a contact was made with another person who was also wearing the bracelet [10], [34]. The bracelets contained a three-axis digital acceleration sensor, and the acquired values were then used to determine the type of contact. The bracelet could recognize with an accuracy over 85% if the contact has been conducted with a handshake or only fingertips, and if only with fingertips, with how many. The bracelets could also glow if the contact was made. Noormohammadi *et al.* proposed an ultra-low-power communication approach between an implant and an on-body device [35]. A carrier-less signal was used to reduce power consumption. The total power consumption for this method was 45 µW for the data rate of 64 kb/s. The bit error rate was less than 0.5% for 14 cm distance in homogenous medium and less than 2.5% for 10 cm distance in a multilayer and complex medium without any channel coding techniques. This showed that galvanic coupling could be used for communication with implants that were placed inside the body.

III. CONCLUSION

In this paper a short overview of two main methods of IBC have been described: capacitive and galvanic coupling. Both methods showcase the possibility of using human body as a communication channel for transmission of data using small amount of energy which is important for medical devices that must operate 24 hours a day. While capacitive coupling can achieve higher transmission rates than galvanic coupling, it is much more influenced by the environment. Galvanic coupling on the other hand despite slower speed achieves safer transmission of private data as there is no leakage of signals. Moreover, both methods were already used to achieve continuous, low error communication without using error correction algorithms, therefore proving their robustness and reliability as communication methods. More research is needed in these fields as to explore the possibilities of usage of such communication methods in medicine and in other fields.

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