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A study of wireless communication links on a body centric network during running

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Abstract

Wireless Body Area Networks (WBAN) is a developing area of research that allows wireless sensors to be attached in or on the human body. The object of this paper is to establish a WBAN to acquire movement and physiological data using sensors at various places on the body and to send their data to a central node. This node processes and re-transmits information to a remote computer (locally or in the cloud) for further processing and presentation. The real time feedback that can be provided by these nodes is very important in sport for the athletes, coaches and the viewing public. However, the challenge is to sustain good wireless communications between the nodes while the athletes are moving. In this paper we report an investigation into the best node locations on the human body to achieve maximum connectivity to a receiving unit (gateway) located on the chest, as well as the best angular window for the nodes to transmit the data during typical human movements such as running and walking. The results showed that while the distance between the transmitting and receiving nodes changes significantly, the presence of scattering from limbs provides the most significant effect on the received signal strength. These measurements demonstrated that a received signal strength of greater than -70 dBm is available for 20% to 74% of the time for different node locations. The use of an accelerometer sensor at each node allows these positions to be identified in real time for burst transmission to occur reliably.

Selection and peer-review under responsibility of the Centre for Sports Engineering Research, Sheffield Hallam University

Keywords: WBAN; BAN; Body Centric Network; On Body Communication; Received Signal Level; Sport; Running

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1. Introduction

The ongoing efforts on the miniaturization of hardware embedded devices and sensors have made on-body communications more practical during human movement actions using the wearable wireless nodes; Hall and Hao (2006). However, the propagation of the radio waves is affected by the presence of the human body as an obstacle and the radiation pattern of the antennas changes when placed on the body and the relative polarization of the antennas also changes with limb position. There is a lot of interest in the different antenna designs proposed to minimize this effect; Alomainy, Sani, Rahman, Santas, and Yang (2009). Multipath fading and scattering effects of the transmitted signals resulting from the body limbs can interfere with the line of sight (LOS) propagation path between the transmitting and receiving nodes during human movement; Cotton and Scanlon (2006). As such, a slightly different posture can result in a significantly different channel characteristic because line of sight communication is impossible.

The importance of WBAN in communications resulted in a new standard (IEEE_802.15.6) to utilize the technology in different applications that involve smart sensors placed inside or on the human body to share information between themselves and external units; Garcia-Serna, Garcia-Pardo, and Molina-Garcia-Pardo (2013). Each smart node is capable of performing many actions such as signal sensing, storing and processing, and data transmission to other nodes; Otto, Jovanov, and Milenkovic (2006). The applications for WBAN are wide and vary in nature, including patient monitoring, sports, gesture recognition (capturing human movement), biomechanical analysis of movement, physiological measurements and much more. A complete survey of WBAN is presented in Malik and Singh (2013).

Utilizing WBAN in sports can provide real time feedback for athletes which lead to a better understanding the players' performance and can help coaches to effectively measure training sessions. The provision of accurate information can prevent injuries and support the rehabilitation process through monitoring performance levels over time; Brunelli et al. (2006); Neville, Wixted, Rowlands, and James (2010).

The aim of this work is to assess the performance of a WBAN based on various sensor locations on the human body and to achieve maximum connectivity to a receiving unit (gateway) located on the chest. This can be achieved by allocating time windows for each node to transmit during typical human movements such as running.

2. Methods

In all communications systems, the received signal is affected by the transmitted power, the directivity of the transmitting and receiving antennas, the pointing angle of the two monopole antennas, the distance between the antennas and the presence/absence of obstructions in the straight LOS between the two nodes.

A linearly polarized transmitter and receiver were mounted on the body, and the signal level was measured as a function of limb position. The small, portable RF receiver with an average noise level of -105 dBm was used to monitor the received signal level from the wireless transceiver node which was set to transmit continuously at 0 dBm and 2.45 GHz. The tests were performed using a volunteer to identify the body effect on the received signal level. The measurements were taken in free space to minimize possible multipath effects from nearby objects. The z-core transmitter was placed at six different locations on the legs and arms of the human body and the participant was asked to assume 48 different stationary positions of the arms and legs. These positions are characteristic of running movements; Vaughan, Davis, and Connor (1999). At each position the received signal level was recorded. All participants involved in the tests signed informed consent forms which complied with Griffith ethics approval ENG/20/13/HREC.

To make sure the wearable wireless node is stable during movement and for easily on body mounting, the sensor was attached in a fabric band to the outside part of the wrist and arm (above the elbow), the upper surface of the foot, the lower and upper parts of the leg and on thigh just above the knee. These locations are shown in Fig. 1. Both the transmitting and receiving antennas were vertically polarized when the human stands upright with hands by the side. The one exception is for the transmitter placed on the upper surface of the foot.

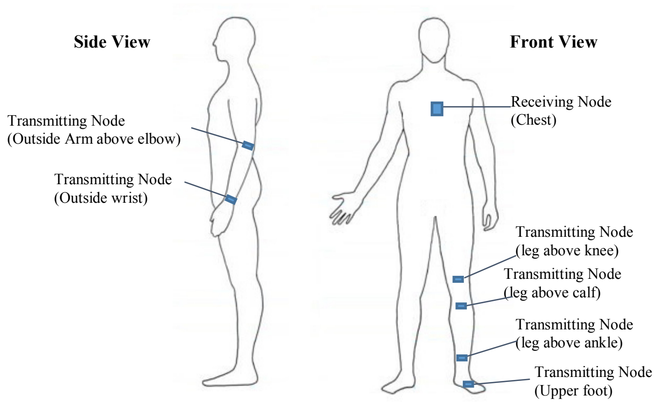

Fig. 1. Wireless sensor node locations.

For all of the six wireless sensor locations, the participant was asked to assume a total of 108 positions. In these positions, the leg and arm joints were rotated about a horizontal axis that is perpendicular to the front of the body for maximum rotation in order to simulate the running and walking positions through the likely arm and leg movements. Fig. 2 shows the leg and arm positions used in this study, and the position number. These positions were repeated after changing the wireless node location to measure the received signal level at each location. The leg and arm positions were rearranged to show the received signal level during the leg and arm movement from the very far point behind the body to the closest point in front of the receiving node attached to the chest.

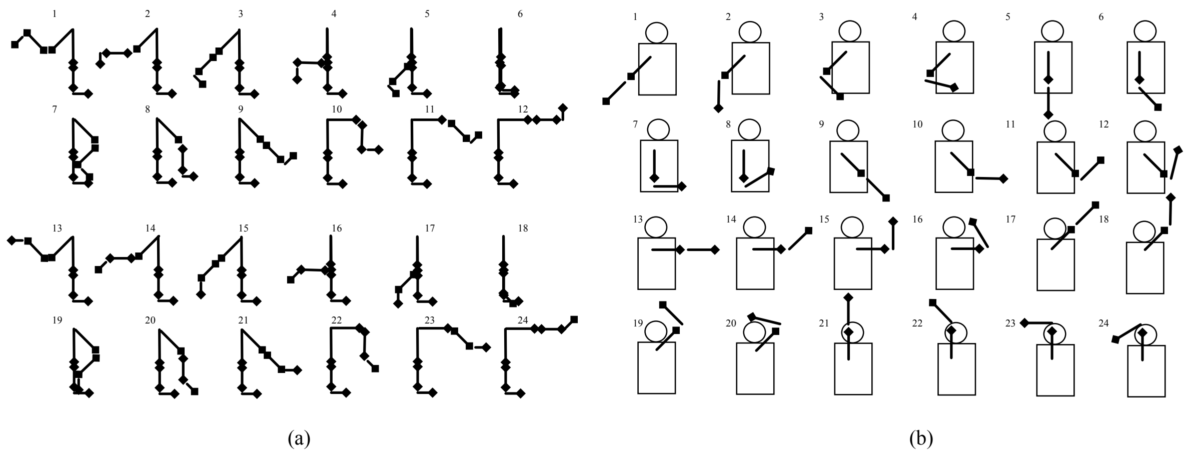

Fig.2. Transmitter locations on the body shown by♦: (a) Leg positions; (b) Arm positions.

3. Experimental Results

The received signal level for all sensor locations and for all leg positions assumed by the human during running is shown in Fig. 3(a). For all of the leg sensor locations the received signal level is increasing relative to the positions in order to reach a maximum value between -56 and -61 dBm. Fig. 3(b) shows the received signal level for the sensor mounted on wrist and on the arm and for all limb positions. The results show that the highest signal level during the arm movement is around -65 dBm at positions 13 to 16 [as shown in Fig. 2(b)]. When the sensor is attached to the wrist, the received signal level increases with the arm movements to reach a highest power level above -55 dBm at positions 10 & 11 (when the wrist is facing the chest) and decreases to a value of -72 dBm as the arm moves up and away from the chest.

These results were analyzed using a Matlab program to show the best possible location at which a wireless node on a limb can have a reliable wireless communication with another node attached to the chest. It was concluded from Vidojkovic et al. (2011) that, in a WBAN operating at 2.4 GHz with a receiver sensitivity level of -75 dBm, more than 95% reliability could be acquired. Fig. 4 shows that 74% of the total signal recorded has a received signal level greater than -70 dBm when the sensor is attached to the wrist while only 20% when it is attached to the arm above the elbow. This means that during all possible positions of the human wrist [shown in Fig. 2(b)] the possibility of reliable wireless communication is more than three times when compared to the situation with the sensor attached to the arm. The results of 68% and 35% of a received signal of greater than -70 dBm was achieved when the sensor was attached to the thigh and lower leg positions respectively (shown in Fig. 1).

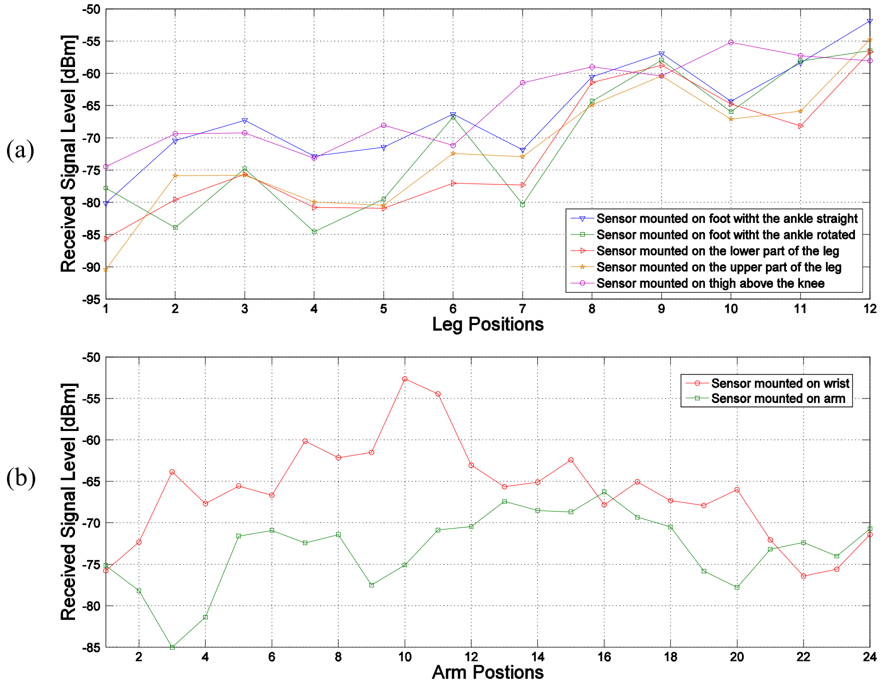

Fig. 3. Received signal level for all (a) leg positions; (b) arm positions.

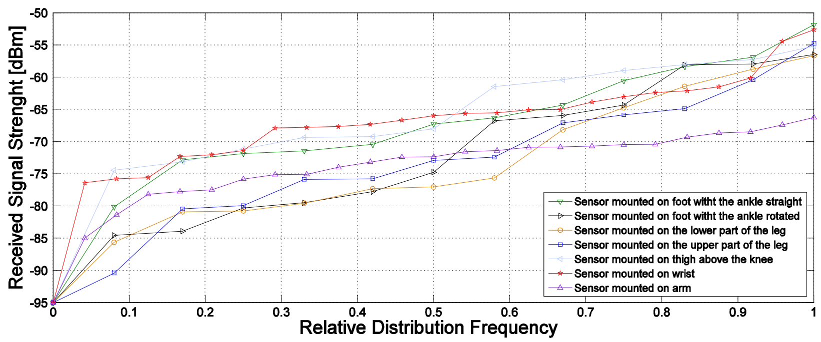

Fig. 4. Relative distribution frequency for the received signal level at all node locations.

The change in the position of the arm/leg and mounted transmitting node location affects the signal level and can help identify a pattern at which all the nodes will have reliable, burst wireless communication when the receiving wireless node is attached to the chest. The body measurements of the participant were taken and a geometrical and mathematics analysis software (GeoGebra) was used to calculate the distances and angles between the receiving and transmitting wireless nodes as shown in Fig. 5.

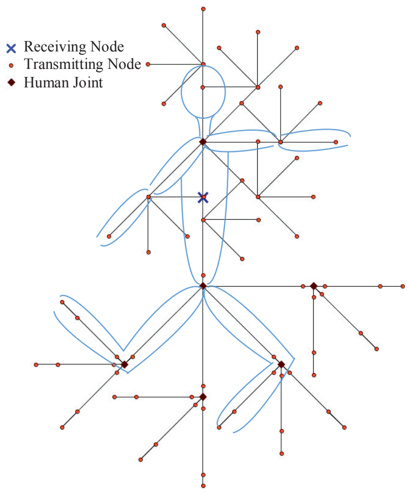

Fig. 5. Human model shows the receiving and transmitting nodes for all leg and arm positions.

Fig. 6 illustrates the relationship between the received signal level and the distance/angle between the receiving and transmitting nodes. It can be seen that while the distance to the chest is shorter when the sensor is installed on the wrist and arm (green square points) compared with the leg sensor locations (blue triangle points), the signal level is randomly distributed across the distance axis and the same signal level can be obtained with different distances for both leg and arm sensor locations [Fig. 6(a)]. In Fig. 6(b) the relationship between the received signal level and the receiver angle shows more consistency. For the leg, the received signal level increased when the angle changed from the non-line of sight (NLOS) to LOS position. The result resembles a sinusoidal function for the arm as the angle changes. This angular relation is explained in a polar plot of the received signal level in Fig. 6(c). The received signal level is higher for the LOS positions. A received signal of -70dBm was obtained for all limb positions at angles of (17 to 65 degrees) and (110 to 150 degrees) for the leg and arm sensor locations respectively. The repetitive movement of the human leg and arm during running or walking make it easier for the transmitting nodes to send the information through that angular window. These windows will be used to schedule burst transmissions from individual nodes and to maintain time synchronization between the hub and the sensor nodes located at different positions on the body.

4. Conclusion

The received signal level was recorded at 108 static body positions to simulate the human running and walking actions and for six different transmitter locations on the human body. The results showed that the sensor on the wrist provided the most reliable communications with another node attached to the chest. The receiver angles for all sensor positions were identified as the best LOS positions that can provide the most reliable wireless communications link. This study explored the effect of human position on the transmission link during movement. The next step is to make dynamic signal strength measurements during running and walking and for other human movement actions as occur in many different sports. It is anticipated that during dynamic tasks, runner speed and running style may influence the transmission. Human movement can also alter the position of the sensors due to skin movement and muscle flex.

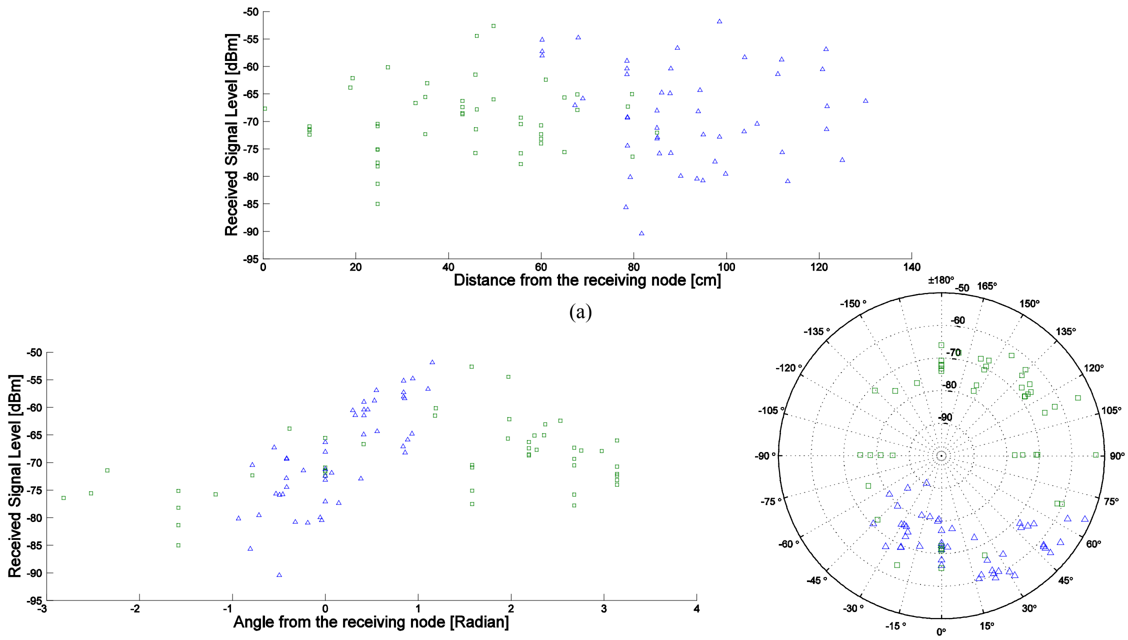

Fig. 6. Distance (a) and Angle in radians (b) and Angle in degrees (c) between the receiving and transmitting nodes for arm mounted "□" and leg mounted "Δ" transmitter positions.

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