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An Approach to Analyze the Movements of the Arms while Walking using Wearable Wireless Devices

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***Abstract*—Rhythmic movement of the arms while walking is an important feature of human gait. In this paper, we present an approach to analyze the movements of the arms while walking by using three wearable wireless devices placed around the torso. One of the devices is transmitter placed at the back and the other two are symmetrically placed receivers that record the power variation due to movements of the arms while walking. We show that the power received by the receivers will have symmetrical variation if the arms' swing is symmetrical. An analytical model has been used to calculate the position of the receivers. Full wave simulations on a walking phantom are done to confirm the results.**

I. INTRODUCTION

Wearable wireless medical devices or sensors have improved the healthcare facilities. They are used for the monitoring of vital health parameters like temperature, blood pressure, glucose level and for ambulatory monitoring [1]. One of the benefits of the wearable medical devices is that they are non-invasive and hence have minimal risk of infection. Wearable devices have been developed for recording human kinematics and posture by using sensing fabrics [2]. Monitoring of human kinematics and analyzing posture is of importance in the field of bioengineering. It is also beneficial in the field of sports biomechanics for improvements in athlete performance. Moreover, they are used for recovery and rehabilitation of people with injuries having movement related problems.

The pattern of movements of the arms, legs and trunk during activities like walking is called gait. Gait is an important health indicator and has been widely studied for treating patients with walking disability arising due to injuries, neurological disorders like Parkinson's disease [3], [4]. Moreover, it can be used for fall prediction and prevention [5]. Arm swing during human gait is an important component for locomotion enhancing gait stability and decreasing the metabolic cost of walking [6]. There is a rhythmic symmetric swing of the arms while walking and a high asymmetry in the arms' swing can be an early sign for Parkinson's disease [7], [8]. In [7], authors have used motion analysis with ultrasound based recordings of limb kinematics for measuring and analyzing the arms' swing. In [8], accelerometer assemblies are affixed to the right and left forearms of each subject to detect the arms' movements. In this paper, we have used three wearable wireless sensors around the torso to observe the movements of the arms while walking. We have shown in [9], that there is a variation in the power received by the wireless sensors placed around the torso from a transmitting sensor at the back, with the variation in the arms' position. This is due to the difference in the reflected power from the arms when they are at different positions. Further, in [10], an analytical model considering the effect of the arms, for signal propagation around the torso is developed. This model has been used to calculate the positions of the receiver sensors when the arms' swing while walking. Simulations have been done on a numerical phantom with different snapshots of one gait cycle to observe the pattern of the power variation recorded by the receivers.

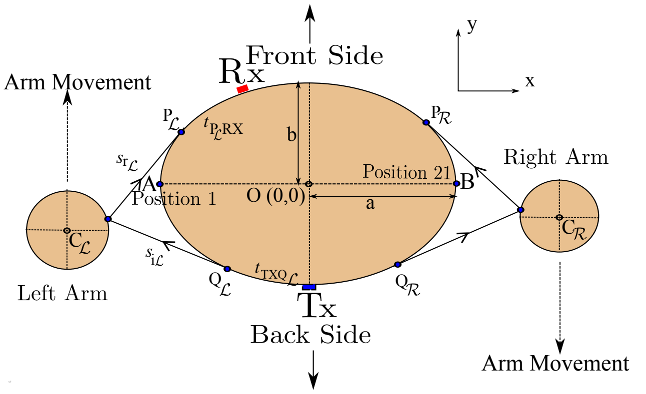

Fig. 1. Cross-sectional view of the torso at the level of the antennas. Different path-lengths are also shown.

II. ANALYTICAL MODEL FOR WAVE PROPAGATION AROUND THE TORSO IN PRESENCE OF THE ARMS

In [11], an analytical model for propagation around the torso without considering the effect of the arms was presented. The model was based on the attenuation of creeping waves over an elliptical approximation of the torso. In [10], the model was extended to include the reflections from the arms. The reflected waves from the arms adds up at the receiver with the clockwise and the anti-clockwise creeping waves constructively or destructively depending upon the position of the receiver and the position of the arms. The link loss at the n^{th} position of the receiver (Rx), in the presence of the arms can be modeled as (1) [10] shown at the bottom of the next page. In (1), G is the gain of the antenna for receiver or the transmitter (Tx) denoted by the subscript RX or TX respectively. λ is the wavelength in a free space. L is the complex attenuation over the elliptical path with subscript ac for the anti-clockwise creeping wave path, c for the clockwise creeping wave path, TQ for the path between the transmitter and the point of leave Q and PRX_n for the path between the point of contact Q of the reflected wave and the receiver.

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These paths and other path lengths in (1) are shown in Fig. 1. p is the perimeter of the elliptical fit of the torso and d_n is the length of the anti-clockwise path from the transmitter to the receiver at the n^{th} position. $\mathcal{L}$ is used for the left side of the body and $\mathcal{R}$ for the right side. The transmitter is fixed at the central back position. The receiver is moved from position 1 (point A) to position 21 (point B). The on-body antenna described in [12] is used at the transmitter and the two receivers. While walking, the arms will swing back and forth. It is assumed that the arms' centers remain at a fixed distance from the origin along the x-axis. We call this distance x_0. One cycle of the arms' movement during walk is divided into 25 arm positions. The first position is when the left arm's center, $C_{\mathcal{L}} = (-x_0, -2b)$ and right arm's center, $C_{\mathcal{R}} = (x_0, 2b)$ whereas at the 25^{th} position, $C_{\mathcal{L}} = (-x_0, 2b)$ and right arm's center, $C_{\mathcal{R}} = (x_0, -2b)$. Fig. 2 shows S_{21} variation, where $S_{21}|_{dB} = -LL|_{dB}$, for one cycle of the arm swing over all the receiver positions calculated using (1) for $x_0 = a + 2r$ (r is the radius of the arms). A typical human dimension with $a = 144$ mm, $b = 94$ mm and $r = 45$ mm is considered.

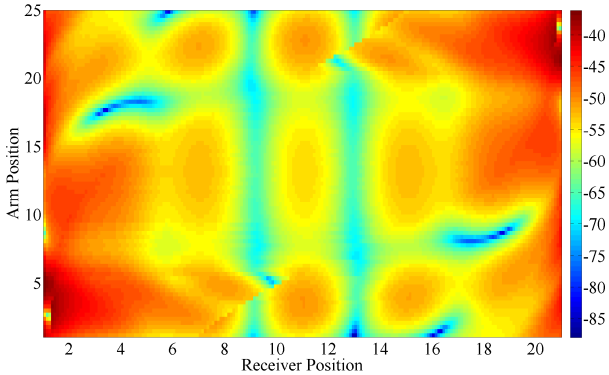

Fig. 2. S_{21} (dB) for different receiver position and one cycle of the arm swing

A. Position of the receiver

From Fig. 2 it could be seen that as the arms move, at some receiver positions, there is a large variation of S_{21} whereas at some positions, the variation is not so significant. Additionally, a symmetrical power variation with respect to the position 13, when both the arms are at side of the torso, can be observed from the figure. We propose to place one receiver for each arm at the position where there is a significant influence of the arms' movements. These positions could be found by taking the variance of the difference of S_{21} at each successive arm position for all the receiver positions. The variance at different receiver positions is shown in Fig. 3. The receivers should be placed at the positions where the variance is high. The maximum peak of the variance is around position 3 and position 19. However, we place the receivers at position 1 (for the left arm) and position 21 (for the right arm) as the variance is still high at these positions and they are easily identifiable on the phantom.

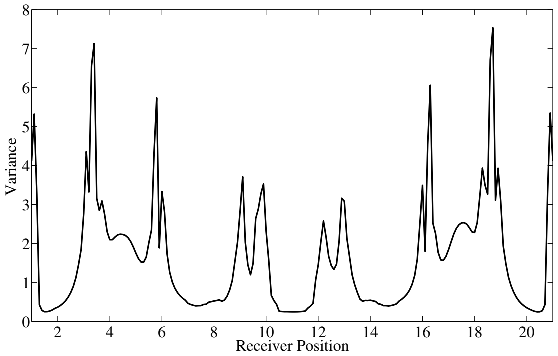

Fig. 3. Variance of the difference of S_{21} at successive arm position for different receiver position in one cycle of the arm swing

III. SIMULATIONS

The simulations have been done on a numerical phantom of an adult human size (height 171 cm) created in a 3D animation software POSER [13] in a commercial full wave simulator SEMCAD-X [14] which uses the FDTD method. The phantom is animated to walk and different frame of the one gait cycle is saved as a separate file and then imported to SEMCAD-X. There is asymmetry in the arms' movement of the phantom. The elliptical fit for the torso of the phantom gave $a = 144$ mm, $b = 94$ mm, $r = 45$ mm approximately. These values change slightly while walking. The electrical properties of human muscle at 2.45 GHz (permittivity = 52 and conductivity = 1.7 S/m) is assigned to the phantom. The transmitter is kept fixed at the back of the phantom and two receivers, one on the left side of the torso and other on the right side is placed to record the variation in S_{21} between the transmitter and the two receivers when the arms move while walking. The phantom with different arm positions for one gait cycle is shown in Fig. 4.

$$LL_n|_{\mathrm{dB}} = -10\log_{10}\left[\frac{G_{RX}G_{TX}\lambda^2}{4\pi^2}\left(\left|\frac{e^{-L_{acn}}}{d_n}e^{-jkd_n} + \frac{e^{-L_{cn}}}{p-d_n}e^{-jk(p-d_n)} + \sum_{\mathcal{J}=\mathcal{L}}^{\mathcal{R}}\frac{\rho}{2\sqrt{2}}\frac{e^{-L_{\mathrm{TQ}_\mathcal{J}}}e^{-L_{\mathrm{P}_\mathcal{J}\mathrm{RX}_\mathrm{n}}}\cos\gamma_\mathcal{J}}{t_{\mathrm{TXQ}_\mathcal{J}} + s_{\mathrm{i}\mathcal{J}} + s_{\mathrm{r}\mathcal{J}} + t_{\mathrm{P}_\mathcal{J}\mathrm{RX}_\mathrm{n}}}e^{-jk(t_{\mathrm{TXQ}_\mathcal{J}}+s_{\mathrm{i}\mathcal{J}}+s_{\mathrm{r}\mathcal{J}}+t_{\mathrm{P}_\mathcal{J}\mathrm{RX}_\mathrm{n}})}\right|\right)^2\right] \tag{1}$$

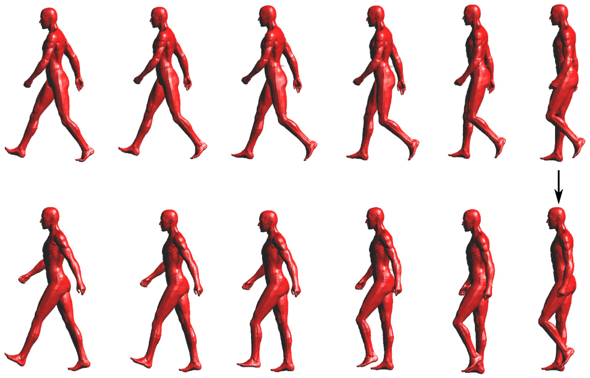

Fig. 4. Arm movement in one gait cycle

IV. RESULTS AND DISCUSSIONS

The S_{21} between the transmitter and the receiver for the left arm and the receiver for the right arm is shown in Fig. 5. It can be seen that the plots for the receivers are not symmetrical as the movements of the arms of the phantom are not symmetrical. It should be noted that the symmetry here is w.r.t. the position when both the arms are exactly at the side of the torso (position 13). Additionally, there is about 22 dB difference between the maximum and the minimum S_{21} for each arm which can be easily detected by the receivers. An agreement between the simulated S_{21} for the left arm and S_{21} predicted by (1) was also found.

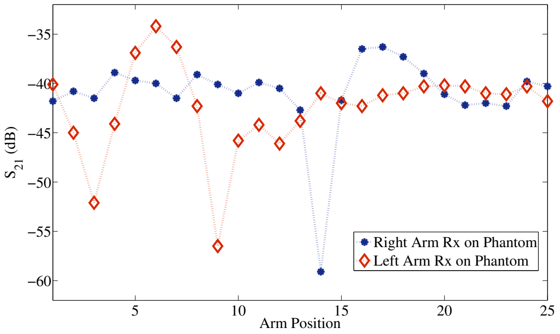

Fig. 5. S_{21} between the transmitter and each of the receiver for the analysis of the arm movement

V. CONCLUSIONS

An approach to analyze the arms' movements while walking by using three wearable devices attached on the torso was presented. An analytical model was used to determine the placement positions of the devices. The transmitter was placed at the central back position and the two receivers, one for each arm, was placed at the side of the torso. It was found that the rhythmic symmetric movement of the arms while walking will cause symmetrical variation in the received power by the two receivers whereas asymmetry in the arms' movements will result in asymmetrical power variation. The result was confirmed by the simulations done on a walking phantom with asymmetrical arms' swing. Hence, such a wearable system might be a simple solution for the analysis of the movements of the arms. It could be used for detecting asymmetry in the arms' swing while walking.

Future work will consist of doing simulations on walking phantom with different arm movements. The influence in the power variation due to the sensitivity in positioning of the receivers will be investigated in order to find robust placement positions. Measurements on humans subjects will also be done.

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