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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.

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. $\lambda$ 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 $PRX$, for the path between the point of contact $Q$ of the reflected wave and the receiver.
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 \( d_o \)
is the length of the anti-clockwise path from the transmitter
to the receiver at the \( n^{th} \) position. \( L \) is used for the left
side of the body and \( R \) 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, \( C_L = (-x_0, -2b) \) and right arm’s center,
\( C_R = (x_0, 2b) \) whereas at the 25th position, \( C_L = (-x_0, 2b) \)
and right arm’s center, \( C_R = (x_0, -2b) \). 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](image)

**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,
asymmetrical 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.

**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.

\[
LL_{21|dB} = -10\log_{10} \left[ \frac{G_{RX} G_{TX} \lambda^2}{4\pi^2} \left( \frac{e^{-L_{ac|n}} - e^{-jkd_n}}{d_n} + \frac{e^{-L_{ic|n}} - e^{-j(p-d_n)}}{p-d_n} \right) \right] \\
+ \sum_{j=L}^{g} \frac{1}{\sqrt{2}} \left( e^{-L_{TQ}} e^{-L_{p,RX_n}} e^{-j\gamma_s} e^{-j(\ell_{TXQ} + s_{ij} + s_{ef} + t_{p,RX_n})} \right)^2 \right]
\]

(1)
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.

REFERENCES

[13] POSEIR, Curious Labs Inc. 655 Capitola Road, Suite. 200, Santa Cruz, CA 95062