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A New Simulation Model for Respiration Signal Measurements from Walking Human

Tae-Yun Lee, Vladimir Skvortsov and Min-Ho Ka

***Abstract*—There has been research interest in using the micro Doppler effect for contactless measurements of human respiration. Most of the research assumes that the test subject remains stationary. The purpose of this paper is to detect a respiration signal from a walking human. This work is at an early stage, and MATLAB model for a walking human with respiration movement was used, instead of recreating an actual human walking case. The results from this study show that a respiration signal can be successfully extracted from a walking human model.**

***Keywords*—micro-Doppler effect, radar, vital sign, respiration, walking human**

I. Introduction

Doppler radar is extensively used for medical applications. There are some areas in the medical application field that use Doppler radar for detecting heart and respiration rates, for which some algorithms have been proposed in [1]-[6].

Previously reported Doppler radar systems [1]-[3] transmit a Continuous Wave(CW) signal, which is reflected by a target and then demodulated in the receiver. A Doppler radar using the human body as a target, will receive a signal with its phase modulated by a time-varying position targeting the thorax. Demodulating the phase will then give a signal, proportional to the thorax position, that contains information about respiration movement.

For detection of a respiration signal, most current research assumes that the human test subject is either stationary or movement has been restricted. In this paper, a model measuring respiration signals in walking humans will be demonstrated. This work is at an early stage, and as a result, this study used a MATLAB model for walking humans with respiration movement instead of an actual case using human subject. The existing walking human model will be used [7] and adjusted to include a respiration signal received from the thorax.

The mathematical background for the micro-Doppler effect is presented in Section 2. The methodology is introduced in Section 3, and the experiment results are discussed in Section 4, with concluding remarks presented in Section 5

II. Background

To estimate the movement of a walking human, the micro Doppler effect was used. A walking human exhibit two types of motion categorized as rigid body motion and non-rigid body motion.

A. *Rigid Body Motion*

A rigid body refers to a solid body without deformation. Fig. 1 shows an example of a rigid body, which has two types of motion, a translation motion and a rotation motion. If measurement intervals are very short—when ***dt*** is similar to zero—Doppler frequency of translation motion is approximately

$$f_{Translation} = \frac{2f}{c} \cdot n \tag{1}$$

where ***f*** is the frequency of the transmission signal, ***c*** is the speed of light, ***v*** is the velocity of the translation and ***n*** is the unit vector of the translation direction. Doppler frequency of rotation motion is approximately

$$f_{Rotation} = \frac{2f}{c}[\omega \times r] \cdot n \tag{2}$$

where ***ω*** is an angular velocity of rotation and ***r*** is the distance to the object.

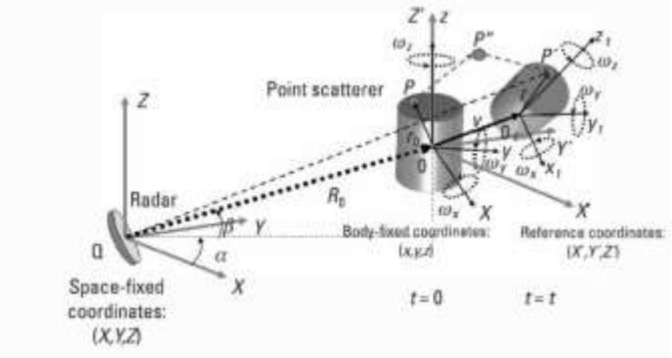

Figure 1. An example of a rigid body motion[7]

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B. Non-rigid Body Motion

A non-rigid body refers to a deformed body that changes its shape when a force acts upon it. Fig. 2 shows the slider-crank mechanism, which is an example of a nonrigid body.

The piston displacement ***x*** can be rewritten as

$$x = R\cos\theta + L\cos\varphi + \left(L^2 - R^2\sin^2\right)^{1/2} \tag{3}$$

where ***L*** is the connecting rod, ***R*** is the length of the crank, ***θ*** is the crank angle and ***φ*** is the connecting-rod angle.

The angular velocity of the connecting rod is defined as follow

$$\frac{d\varphi}{dt} = \frac{-R\cos\theta}{\left(L^2 - R^2\sin^2\right)^{1/2}} \cdot \Omega \tag{4}$$

Where ***Ω = dθ/dt*** is the angular velocity of the rotating crank.

The slider translational velocity is

$$\frac{dx}{dt} = -R\cdot\sin\theta\cdot\Omega - \frac{R^2\cdot\sin\theta\cdot\cos\theta}{\left(L^2 - R^2\sin^2\right)^{1/2}} \cdot \Omega \tag{5}$$

The acceleration of the connecting rod and the slider translational acceleration can be easily obtained using a derivative of (4) and (5).

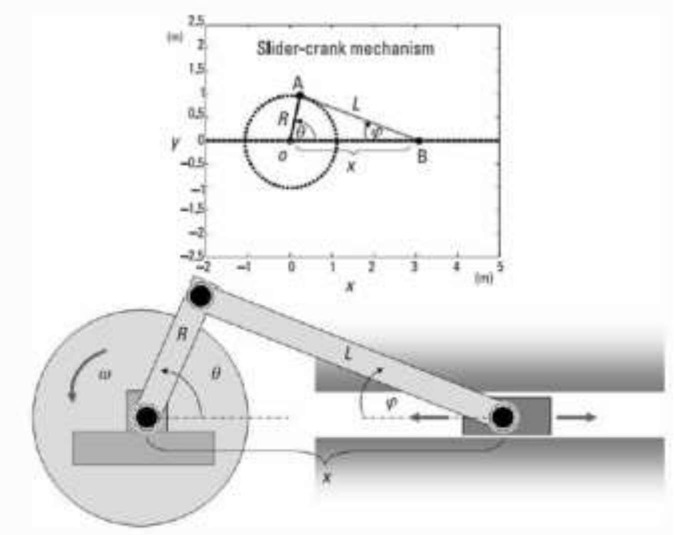

Figure 2. An example of a non-rigid body motion[7]

III. Methodology

A. Movement of Thorax for Respiration

In previous research, the movement of respiration in the thorax was obtained using Ultra Wide Band(UWB) radar on a breathing human subject. Fig. 3 shows the result of this study [8].

The thorax moves in a front to back manner with a 0.005mm displacement. The motion is similar to a sinusoidal curve with an approximate frequency of 0.2~0.4Hz [9]. In this paper, thorax movement is assumed to be sinusoidal, with a 0.292Hz frequency. Fig. 4 shows the input signal for respiration movement.

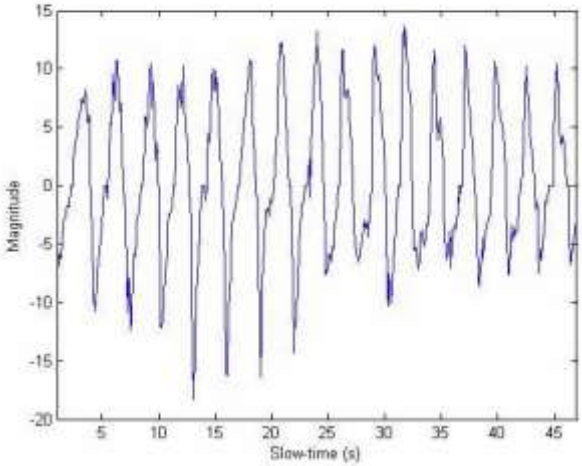

Figure 3. Movement of the thorax in a breathing human.

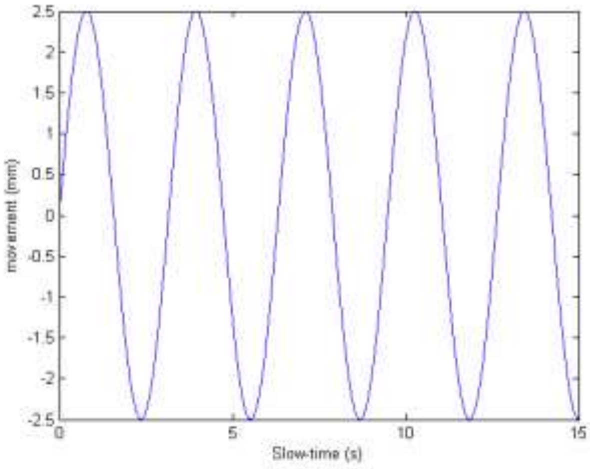

Figure 4. Input signal for the respiration movement

B. 3D Modeling for walking human

A conventional and workable walking model is introduced in [7]. The model contains the following 17 reference points from the human body, within 3-D space: the head, neck, base of the spine, left and right shoulders, elbows, hands, hips, knees, ankles, and toes. Walking motion is described by 12 trajectories, 3 translations, and 14 rotations, five of which are duplicated for both sides of the body. To add a respiration movement to the model, an additional reference point was added at the thorax, as well as a trajectory using the translation of the front to back movement of the thorax. The human body segments are modeled by ellipsoids. An approximation for the Radar Cross Section (RCS) of an ellipsoid backscattering is given by following equation

$$RCS_{ellip} = \frac{\pi a^2 b^2 c^2}{\left(a^2 \sin^2 \theta \cos^2 \varphi + b^2 \sin^2 \theta \sin^2 \varphi + c^2 \cos^2 \theta\right)} \quad (6)$$

where ***a***, ***b***, and ***c*** represent the length of the three semi-axes of the ellipsoid, and ***x***, ***y***, and ***z*** represent direction. The incident aspect angle θ and the azimuth angle ϕ represent the orientation of the ellipsoid relative to the radar.

All segments are made from the same material except for the thorax segment. The thorax is assumed to have more reflectivity. Fig. 5 shows a 3D model of human body segments.

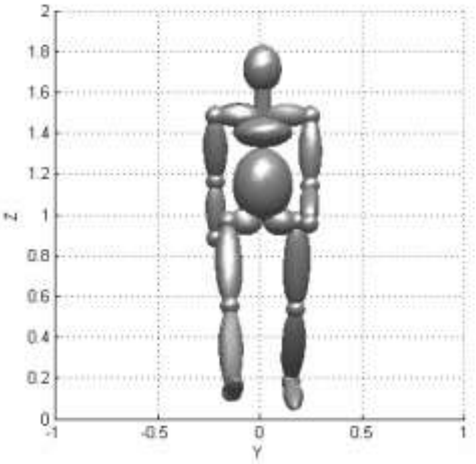

Figure 5. YZ plane view of the 3D model of human body segments

C. *A Simulation Setup for the Global Human Walking Model*

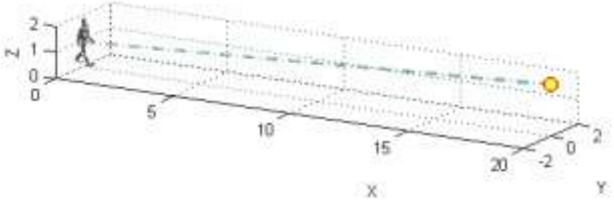

Figure 6. The space model of the radar and a walking human

This research used the global human walking model with thorax movement for respiration and the following methodology. A radar with a wavelength of 0.01m is assumed at (***X1*** = 50m, ***Y1*** = 0m, ***Z1*** = 2m), a walking human is started from the base point located at (***X0*** = 1m, ***Y0*** = 0m, ***Z0*** = 0m), the relative velocity of the walking person is ***v*** = 1.16m/s, and the height of the person is assumed to be ***H*** = 1.80 m/s. The MATLAB source code for the global walking human model is based on [7]. Fig. 6 shows the space model of the radar and a walking human.

D. *Algorithm*

The proposed detection algorithm has 7 steps. It is capable of detecting respiration rate from a simulated walking human. First, a conventional walking model was used, with thorax movement added for respiration. Next, a walking model with respiration movement was simulated and the data received was saved. After that, the micro-Doppler effect was calculated to obtain the walking movement. To extract a respiration signal, a modified Moving Target Indicator (MTI) algorithm [8], Fast Fourier Transform (FFT), and bandpass filtering were used. The input respiration signal, which appeared to be similar.

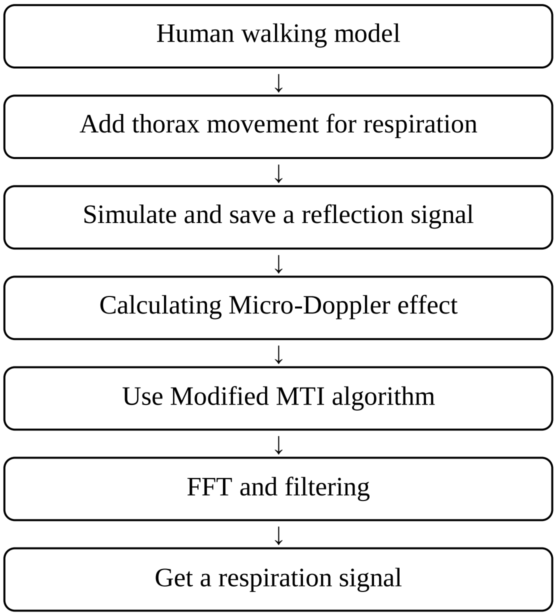

Figure 6. The proposed detection algorithm

IV. Test Results

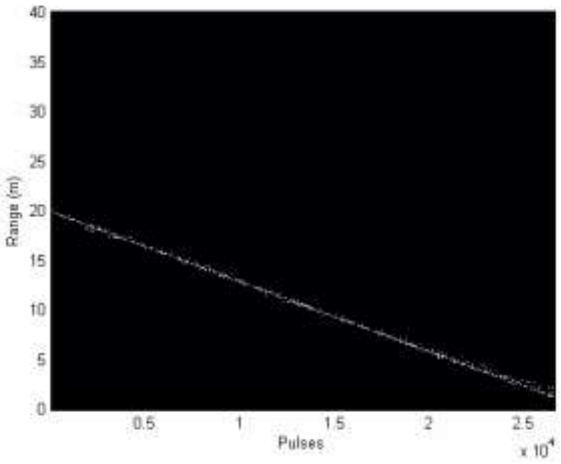

Figure 7. The radar 2-D pulse-range profiles

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The radar back-scattering from a walking human can be calculated using (6). Fig. 7 shows received data as 2-D pulse-range profiles. A micro-Doppler signature derived from the range profiles can be obtained.

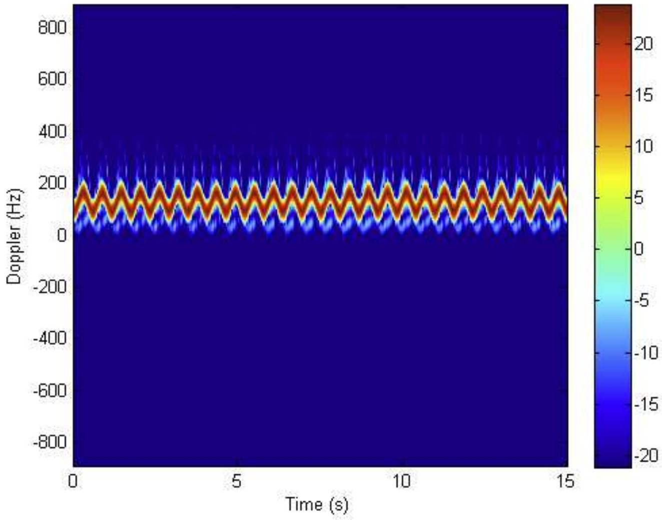

Figure 8. The micro-Doppler signature of the walking human

Fig. 9 shows the signal after using the MTI algorithm. Subsequently, bandpass filtering with a 0.2~0.4Hz band was used because the frequency of the respiration signal was in the bands. The result are shown in Fig 10.

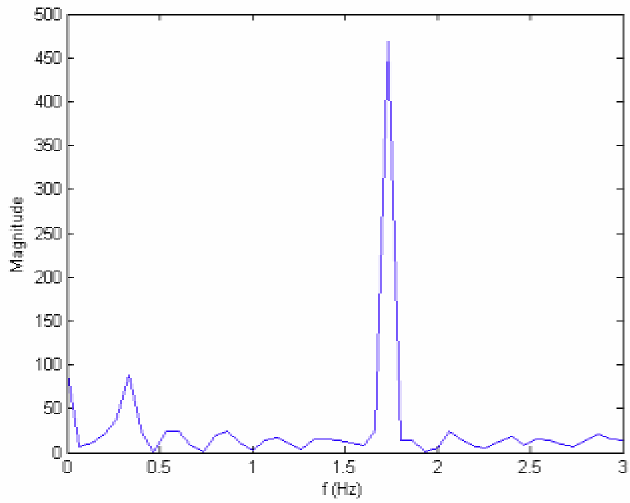

Figure 9. The signal after using a modified MTI algorithm and FFT

Fig. 11 shows the respiration signal extracted from the working human model. This research can confirm that the detected signal is similar to the input signal.

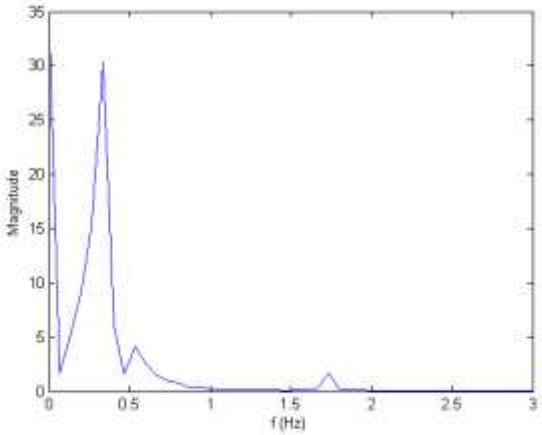

Figure 10. Bandpass filtered signal

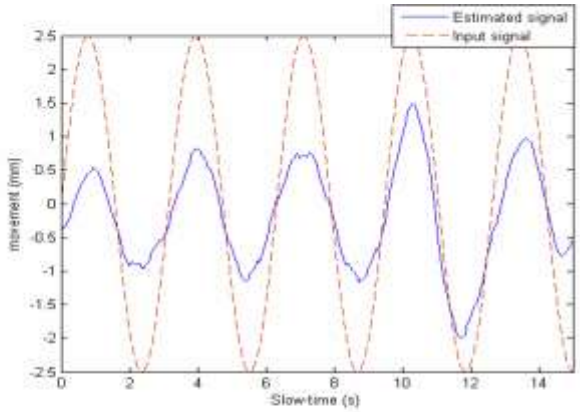

Figure 11. The extracted respiration signal. The solid line is the extracted respiration signal, and the dotted line is the input signal

V. Conclusions

Previous research focused on detection without movement. In this paper, a framework for simulation of respiration signal detection using a walking human. The simulation results show that the estimated respiration signal is similar to the input signal, which is analogous to respiration movement of the thorax. However, the received thorax movement signal has a very weak amplitude. The thorax is assumed to have a higher RCS than other parts of the human body. In future research, a human walking model without the exaggerated RCS at the thorax and experiments on a real human target with more complex motion will be used to develop algorithms for measuring respiration signal from a walking human..

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