An Experimental Study of 2-D Cardiac Motion Pattern Based on Contact Radar Measurement

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***Abstract*—This paper presents an experimental study of human cardiac motion pattern detection using Doppler radar. The measurement results show that with contact radar detection, more motion information can be detected compared with the remote detection. Besides, measurements at three chest positions confirm that cardiac motion pattern has 2-D variance on the chest plane. These detection experiments indicate that lots of valuable cardiac motion information would be lost if we only measure it remotely or treat it as a simple 1-D back and forward motion.**

***Index Terms*—Cardiac motion, Doppler radar, 2-D motion pattern variance, contact radar detection.**

I. Introduction

Radar-based remote vital sign detection has been investigated by many researchers for its applications in health care, emergency rescue, and security systems. Much research effort has been spent on improving the detecting range, accuracy and removing interferences from random body motion [1]-[5]. Although it has been demonstrated that stand-off radar measurement can detect the existence of heartbeat, relatively few efforts have been devoted to decoding the details of the heart motion patterns. In [6], the authors experimentally demonstrated the feasibility of using Doppler radar to measure the 1-D displacement of human ventricle cavities. The measured motion profile agrees well with known medical data from magnetic resonance imaging (MRI) measurements. Still, the work in [6] is based on remote detection at a distance of 1 m.

In this work, we present studies that show that more details of heart motion could be extracted when the radar sensor is in close contact with the subject. We demonstrate that the radar return signal depends on where the radar antenna is mounted on the subjects body. It is recognized that the human heart is a complicated 3-D object with an equally complicated motion pattern. Therefore, when the relative distance between the radar antenna and the human body is comparable to the length scale of the human heart, different return signals are expected from measurements from different angles relative to the heart. Fig. 1 illustrates this scenario.

In this work, an instrument-based Doppler radar is constructed and validated against a linear actuator carrying a reflector as a known reference. Contact-based radar detection is then performed with human subject at 3 different chest positions.In addition, we provide electrocardio diagram (ECG) measurement that is shown to be in good correlation with the radar measurement.

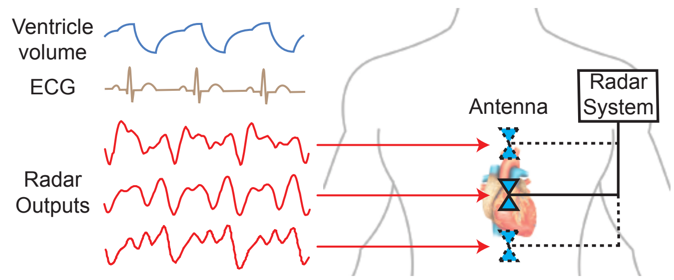

Fig. 1. Investigation of 2-D cardiac motion pattern variance based on contact-based Doppler radar measurement.

II. Radar System Setup and Validation

Fig. 2 shows the Doppler radar setup used in this work. An HP8665B signal generator is used to generate a continuous wave (CW)

$$T(t) \quad = \quad \cos{(2\pi f t)} \tag{1}$$

where the signal frequency f = 2.5 GHz. The CW signal is split into the transmit and receive path by a Mini-Circuit ZX10-2-332-S+ power splitter. The transmit signal passes through a Mini-Circuit D3C2327 circulator and is radiated through a custom designed bow-tie antenna. The other output from the splitter coherently demodulates the radar return signal through a Mini-Circuits ZX05-43MH-S+ mixer as the LO signal. Mathematically, the received signal can be expressed as

$$R(t) \quad = \quad \cos{(2\pi f t - \frac{4\pi d}{\lambda} + \frac{4\pi \cdot x(t)}{\lambda})}, \tag{2}$$

where d indicates the nominal distance between the antenna and the target, $x(t)$ represents the relative motion of the target, and λ is the wavelength at frequency f. d determines the initial phase of the cosine function output. The demodulated signal passes through a baseband amplifier and an active band-pass filter with a bandwidth of 0.2–140 Hz before captured by an oscilloscope. Mathematically, the signal is represented as

$$Y(t) \quad = \quad \cos{(\frac{4\pi d}{\lambda} - \frac{4\pi \cdot x(t)}{\lambda})}. \tag{3}$$

In order to validate the performance of the radar setup, a linear actuator carrying a reflector shown in Fig. 3-a is used as a known reference. For simplicity, the actuator motion pattern is set to a simple triangle wave (Fig. 3-b) whose waveform is also fed into the Keysight Advanced Design System (ADS)

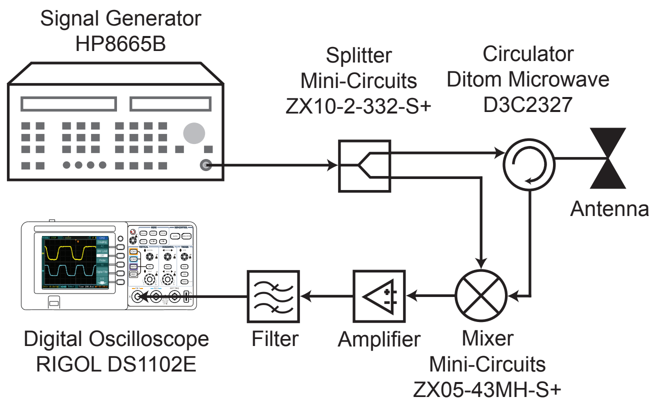

Fig. 2. Radar system setup.

circuit simulator. Three sets of representative simulated and measured baseband return signals are presented in Fig. 3-c,e,&g, and Fig. 3-d,f,& h, respectively. It is observed that the return signal has different characteristics depending on the distance between the radar and the actuator. For example, Fig. 3-c&d show 2 equal-amplitude "spikes" in each cycle, whereas Fig. 3-e&f show only 1 spike in each cycle, and Fig. 3-g&h show one large spike followed by a smaller one in each cycle. Since this investigation is focused on the time dependence of the motion pattern, all plots are normalized in amplitude.

The simulation output patterns agree well with the experimental results, thus it validates the performance of the radar system and the consistency between ADS simulation and the experimental measurement. Besides, with different values of d (or initial phase), Doppler radar output waveforms varies. It also worth noting that for a simple triangle-wave motion pattern, at most 2 spikes in each cycle can be observed.

III. Human Measurement and Discussion

A. Remote Cardiac Motion Measurement and Simulation Validation

With the radar setup, we first conducted a series of stand-off measurements with a human male subject at around 30-cm distance. The subject is a 24 years old male who is 178-cm high and weighs 65 kg, without known cardiac disease. The subject holds his breath during the data recording process. Three representative sets of measured waveforms are shown in Fig. 4-b,d,&f. As a comparison, we use a typical ventricular displacement profile [7] as the input waveform to the circuit simulator. Fig. 4-c,e,&g show the corresponding simulated waveforms. A good agreement is seen between the measured and simulated data. These measurement results confirm observations in [6] and that the ventricle beating contributes the most to the cardiac motion pattern. Similar to the validation measurement in Section. II, at most 2 spikes can be observed during each cardiac cycle.

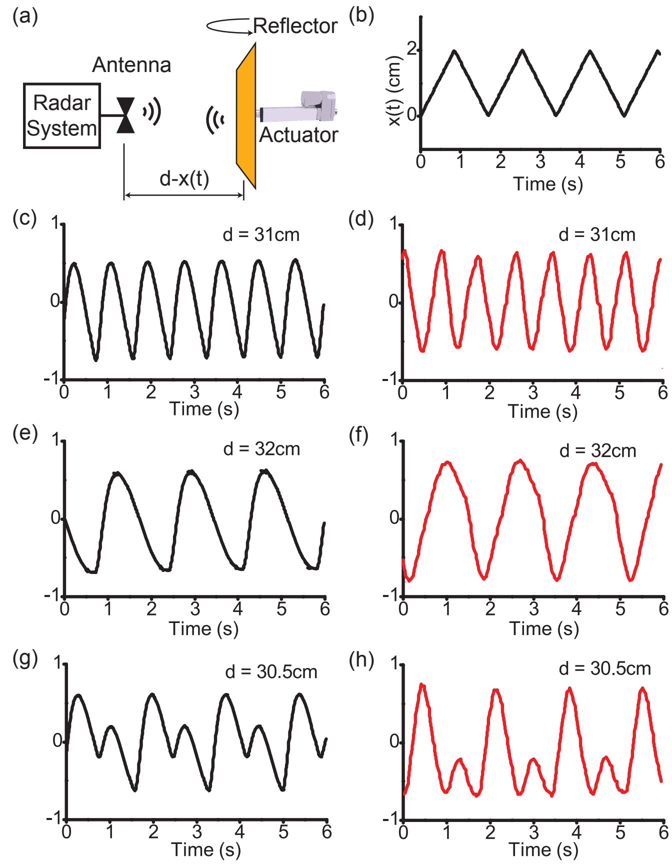

Fig. 3. (a) Actuator validation setup. (b) Actuator moving pattern. (c-h) Simulation and radar measurement results for various d values.

B. Contact Cardiac Motion Measurement

A second set of experiments were conducted using the same setup except that the antenna was placed onto the subject's chest and fastened by a tape. This setup eliminate variations in the distance. ECG signal was also recorded simultaneously as a reference. Three representative measurements were taken with the radar antenna mounted at the different positions on the subject's chest labeled as A, B and C in Fig. 5-a.

Fig. 5-b,c&d illustrate the measurement results of 3 positions. There are two interesting observations:

1) When the antenna is placed on the human chest, i.e. in contact condition, the radar can observe more than 2 spikes in each cardiac cycle.
2) At different chest positions, radar outputs show different motion patterns.

When comparing the two sets of measurements above, remote radar detection shows that at most two spikes in each cycle can be observed, while the contact radar detection shows 3 or even 4 spikes exist for each cycle. Since the two-spikes waveform fits well with the simulation results using ventricle beating data in the signal source, the extra spikes observed in the contact radar measurement indicate a more complicated heart motion pattern than expected.

Besides, the experiments demonstrate that different motion

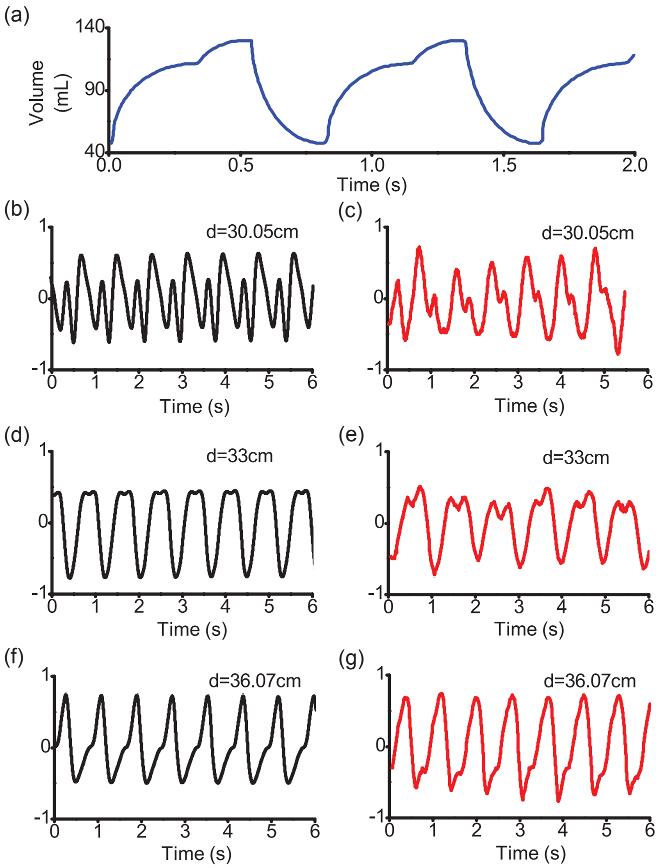

Fig. 4. (a) Human ventricle volume change. (b-g) Simulation and radar measurement results for various d values in remote motion detection.

patterns can be observed at various chest positions. This is reasonable because the human heart is a complicated 3-D structure and cardiac motion is also a complication one. If we measure this complicated 3-D motion from various angles and positions, it is not surprising to expect that the radar output waveforms should be different. Based on these results, it is anticipated that 2-D imaging of the thorax cavity may be possible with contact radar measurement.

IV. Conclusion

A Doppler radar is built to investigate characteristics of human cardiac motion. Contact radar measurement was demonstrated to provide potentially more motion details than the traditional remote detection setup.

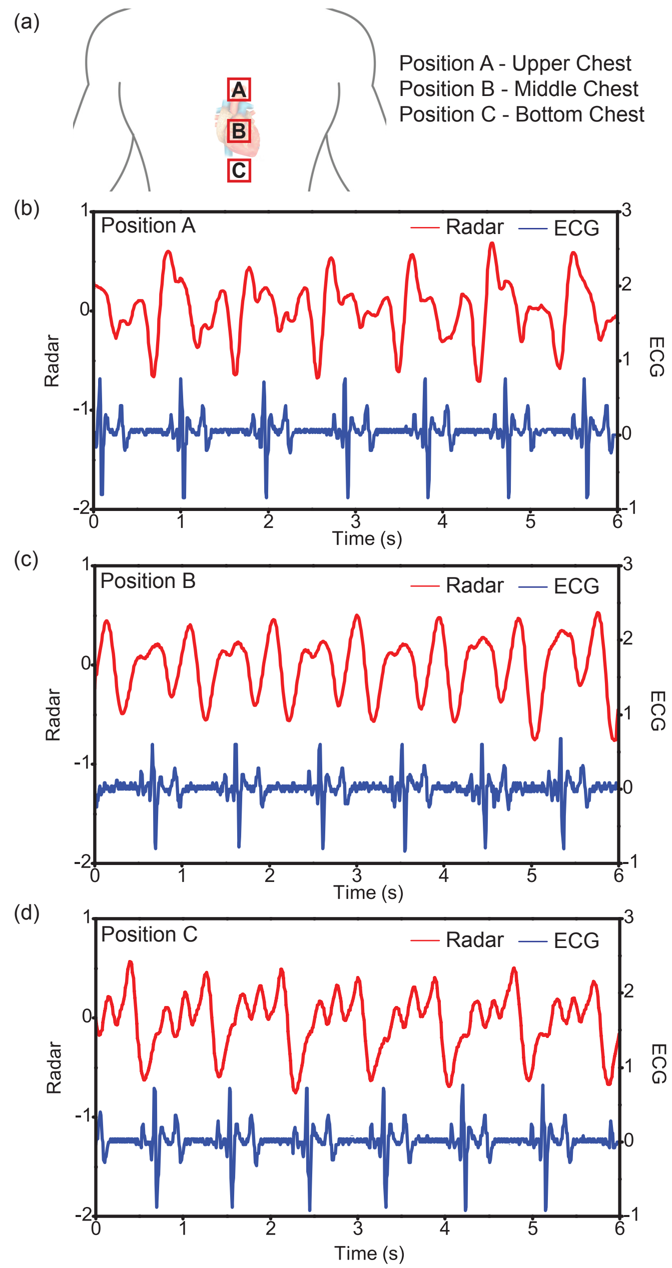

Fig. 5. (a) Antenna positions for human measurement. (b-d) Radar measurement results at 3 chest positions and corresponding ECG signals.

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