Contact-based Radar Measurement of Cardiac Motion — A Position and Polarization Study

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***Abstract*— This paper presents quadrature demodulated data on cardiac motion from contact-based measurement using a Doppler radar and a planar antenna. Measurements were taken at several different locations on the chest of the test subject with both vertical and horizontal polarizations. Test data reveals different characteristics in terms of signal amplitude and time-domain waveform depending on the location/polarization, which shows the potential of using contact-based radar measurement for heart monitoring applications.**

***Index Terms*— radar, vital sign**

I. Introduction

There has been a surging interest in vital sign detection using Doppler radars in recent years [1]–[4]. The majority of the reported works, however, focus on remote detection with the radar sensor placed at a distance from the subject under test. Due to the large difference in material properties (mainly the permittivity and conductivity) of the skin and the air, remote radar-based detection of vital signs relies on the measurement of the movement of the skin-air interface induced by the actual cardiac and respiration movements.

Recently, we reported results from contact-based measurement of the cardiac motion with the radar antenna placed in contact with the skin [5]. The results revealed interesting characteristics in the radar return signals. Most notable is the fact that the return signals are dependent on where the antenna is attached to the chest, which implies that more information of the detailed heart movement may be obtained by contact-based measurement. However, our previous works relied a simple passive mixer to down-convert the received signal, which may lose significant information and lead to distortion of the radar return signal.

In this work, we demonstrate position dependent contact-based measurement of cardiac motion using a quadrature radar receiver. We also demonstrate that such measurement is dependent on the antenna polarization.

II. Method

Fig. 1 shows the measurement setup used in this work. A Texas Instruments TRF371135 quadrature receiver integrated circuit (IC) is used as a direct-conversion receiver for demodulating the return signal. In addition to a quadrature mixer, the TRF371135 IC has built-in baseband amplification and dc-offset calibration. The transmitted signal is generated by a Hittite HMC385 voltage controlled oscillator (VCO) and amplified by a Hittite HMC374 power amplifier. The components are integrated on a custom-designed printed circuit board (PCB) with edge-mount connectors for the antennas. In our experiment, 2.4 GHz is arbitrarily chosen to be the operating frequency.

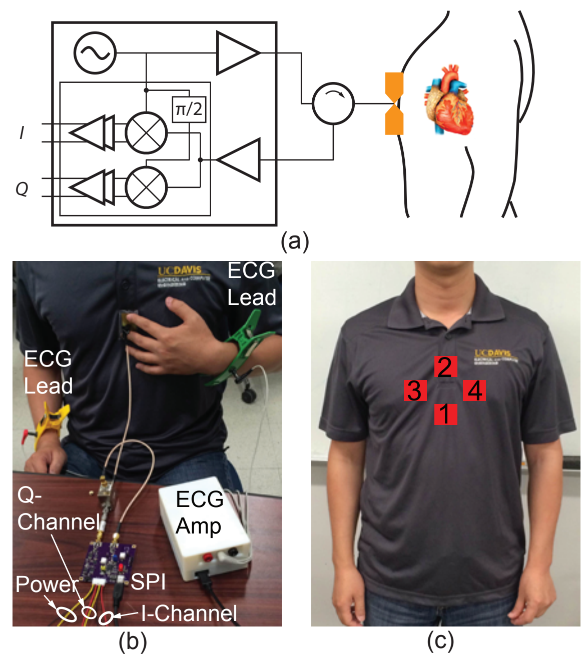

Fig. 1. (a) General schematic of the radar system. (b) Picture of the measurement setup. (c) Four measurement locations.

A simple planar dipole antenna fabricated on an FR-4 substrate is used in the measurement. The center conductor and the ground shield of the antenna feed-line are connected to the two arms of the dipole through an SMB connector. The antenna is designed to operate in contact with the chest. Realistic material properties of human tissues are used in the design to ensure good impedance matching [6].

In a contact-based measurement, it is necessary to use a single antenna for both transmit (TX) and receive (RX) if monostatic detection is desired. This is due to the relatively short distance between the antenna and the heart. Because of the finite size of the antenna, using two of them side by side will result in effectively a bi-static measurement and the close distance between the two antennas may lead to interference and dc-offset issues. Therefore, a circulator is used so that TX and RX can share the same antenna.

In the tests, the antenna is placed firmly against the test subject's chest[1] to eliminate the effect of the skin movement. To eliminate the movement due to respiration, the test subject holds his breath during the measurement. Measurements are taken with the antenna placed at four different locations, labeled 1-4 in Fig. 1-c. At each location, measurements with both horizontal and vertical antenna polarization are taken. In addition, electrocardiogram (ECG) measurement is also taken simultaneously with the radar measurement, providing time-correlation between the two.

III. Measurement Results and Discussion

Fig. 2 presents the measurement data, including the in-phase and quadrature data as well as the time-correlated ECG data, at the four measurement locations with both vertical and horizontal antenna polarization.

Although the test subject held the breath during the measurement, a slow drift of the measured signal can still be observed. The baseline of this slow drift can be fitted from the peaks—or any other distinguishing feature of the signal within a cardiac cycle—from the measurement data. The measured I/Q data can then be corrected by subtracting the fitted baseline drift. In order not to corrupt the relative magnitude of the I/Q data, the first cardiac cycle from each measurement is used as a reference. In Fig. 2-f, we have included an example where both the raw measurement data and the corrected one are presented.

Radar measurement data shows at different measurement locations and polarizations. For example, measurement at location 3, which is on the right side of the body, is much weaker in magnitude[2]. This may be due to the fact that the antenna is farther away from the heart than the other locations. Variations due to polarization may be attributed to the complex geometry and motion of the heart.

In the current literature, arctangent or complex signal demodulation is used to extract the object movement. An implicit assumption made is that the object is located in the far field where the phase change of the return signal is linearly proportional to the distance between the radar and the object. In a contact-based measurement of cardiac motion, it is likely that this assumption can no longer be held true. The short distance between the antenna and the heart muscle means that the cardiac movement is in the near-field region of the antenna. Further theoretical and experimental studies are needed to understand the exact distance-phase difference.

In remote radar measurement, the return signal amplitude variation can be neglected because of the small movement (0.1–1 mm) relative to the stand-off distance (>1 m). On the complex I/Q plane, the return signal trajectory follows an arc. In contact-based measurement, however, amplitude variation can no longer be neglected due to the relative close distance between the antenna and the heart. This effect manifests itself as an excursion along the radial direction on the complex I/Q plane (Fig. 3).

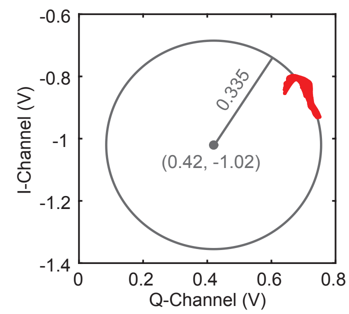

Fig. 3. I vs. Q plot of measurement (g).

IV. Conclusion

We have presented measurement data related to physiological movement inside the thorax cavity, particularly cardiac movement, based on contact-based radar measurement. Compared with previous work using remote measurement, the presented data shows significant variation in time-domain waveforms depending on the location and polarization of the antenna. Such data may shed light on the detailed movement profile of the heart and may be useful for health monitoring applications.

References

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[1] The test subject is a 33 year old male with average weigth.

[2] Worth pointing out is that the vertical scale for the plots are different.

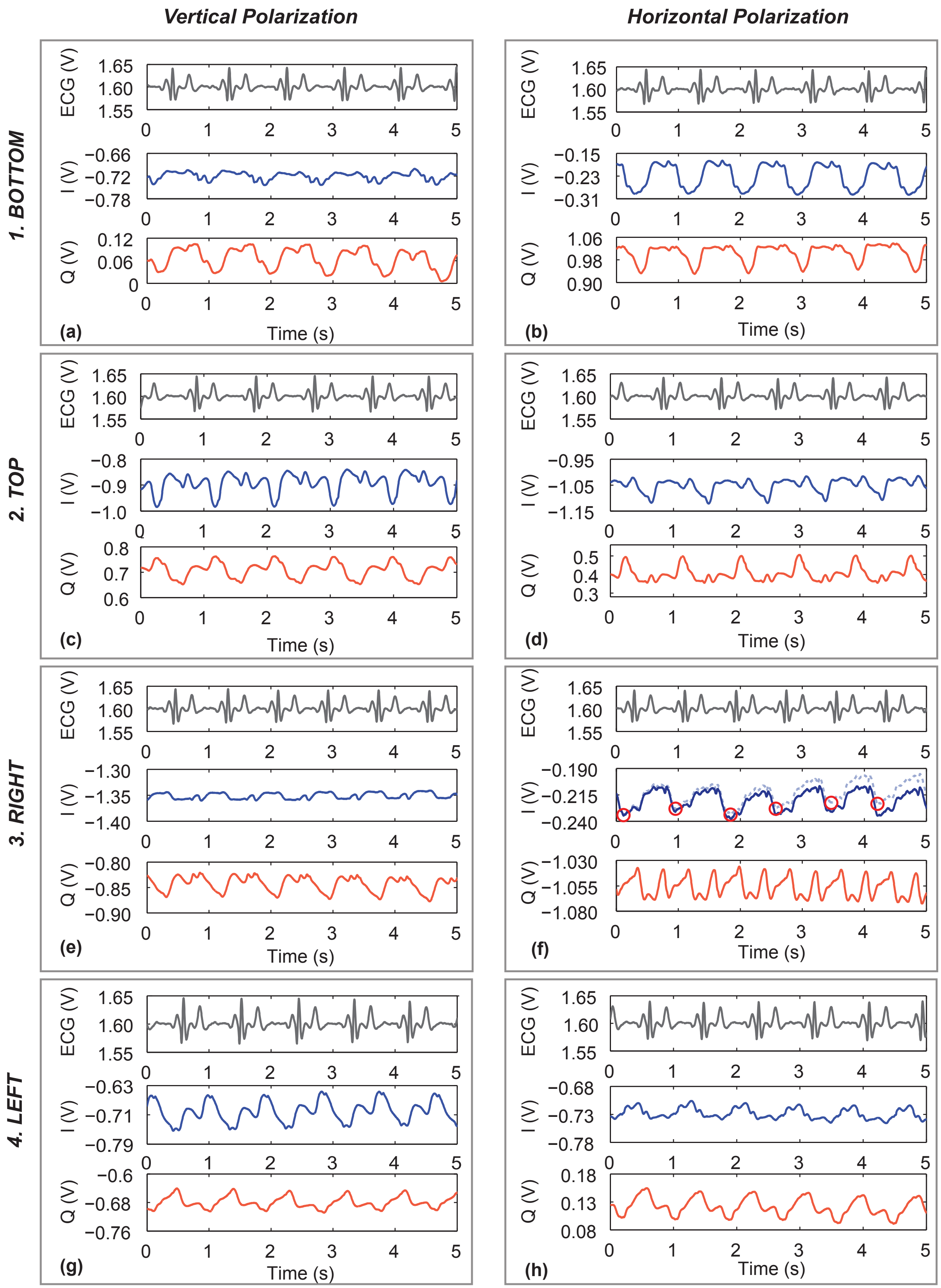

Fig. 2. Contact-based radar measurement of cardiac motion. (a-d) represent measurement taken from location 1-4, each with time-correlated ECG measurement.