Experimental Comparison of Vital Sign Extraction Using Off-The-Shelf MIMO FMCW Radar at Different Angles

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***Abstract*—Radar sensor provides a continuous and non-contact solution for human vital sign extraction. Radar sensor records the human chest vibrations and the received radar returns are processed to extract breathing rate (BR) and heart rate (HR). For directional radars, with an increase in angle of arrival (AOA), the strength of the signal reflected from target decreases. Since beamforming can increase the signal strength by steering the beam towards human target, this paper evaluates the performance of vital sign extraction with and without beamforming cases. Experiments were performed with human subject located at different AOA and vital signs were extracted in three different scenarios, which are (1) without beamforming, (2) with transmitter beamforming, and (3) with receiver beamforming. Preliminary comparison shows that focusing the radar signal towards the AOA decreases the mean absolute error (MAE) between the radar and the gold standard reference.**

Keywords-FMCW radar; beamforming; human vital sign extraction.

I. INTRODUCTION

Short-range millimeter wave radars have enabled several wireless sensing applications such as human behavior monitoring, gesture recognition and vital sign detection [1]. Radars were used only to detect large targets until 1970s when Lin [2] proved the feasibility of human and animal breathing rate detection using microwaves. Human vital sign measurement through radar has gained huge attention amongst the research community due to the fact that the abnormality in human vital sign can directly lead to several health related complications. Monitoring the patients and elderly persons continuously let the early diagnostics to avoid serious outcomes.

Unlike the other traditional Electrocardiogram (ECG) based vital sign monitoring, radar sensor provides a non-invasive and non-contact solution for continuous vital sign measurement [3]. The principle of vital sign detection works on detecting and processing the chest displacement with time. The acquired chest displacement signal is passed through a signal processing chain to extract breathing rate (BR) and heart rate (HR).

Off the shelf (OTS) radar sensors have a directional antenna which implies that as we move away from the center of radar beamwidth, the signal strength will decrease [4]. To overcome this loss, using beamforming concepts, multi-input multi-output (MIMO) radar are able to steer the beam towards the target under consideration [5]. However, the effectiveness of beamforming for vital sign extraction is yet to be explored. This study presents experimental comparison vital sign extraction with and without beamforming cases. For this purpose, we used an OTS frequency modulated continuous wave (FMCW) radar manufactured by Texas Instruments (TI IWR6843).

II. METHODOLOGY

In this paper, both transmitter (TX) and receiver (RX) side beamforming concepts are utilized while making comparison. To achieve high signal-to-noise ratio (SNR) using TX beamforming, the TX signals are aligned in such a way that the resulting constructive interference increases the TX signal energy in a particular direction. The TX system considered in this study comprises of horizontally aligned two TX channels as shown in Figure 1(a). Note that there must exist a phase difference of $\Delta\varphi$ between the transmitted signals $s_{t1}(t)$ and $s_{t2}(t)$ to achieve beamforming for a target at angle θ. The phase delay $\Delta\varphi$ is equivalent to the product of distance between two transmitters and the term $\sin(\theta)$ [5].

On the other hand, receiver beamforming is also achieved by delaying the received signal at each channel by a multiple of a phase difference $\Delta\phi$. The RX beamforming system with 4 RX channels is illustrated in Figure 1(b). In order to synchronize the phase of the received signal at each RX channel, the received signals $s_{r4}(t)$, $s_{r3}(t)$, and $s_{r2}(t)$ must be phase delayed by $3\Delta\phi$, $2\Delta\phi$, and $\Delta\phi$, respectively. The resultant vectors are added to achieve the RX beamforming.

Figure 2(a) shows the experimental setup for human vital sign detection. We considered five different angles. Vital signs with radar and the reference gold standard sensor are simultaneously extracted in three different scenarios: (1) without beamforming, (2) with TX beamforming, and (3) with RX beamforming. We used GDX-RB Respiration Belt and PSL-iECG2 Electrocardiogram Device as reference sensors to measure BR and HR, respectively. For robustness, three different participants were involved in the data acquisition process. Data from each participant were collected separately for all three aforementioned scenarios

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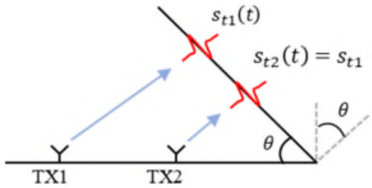
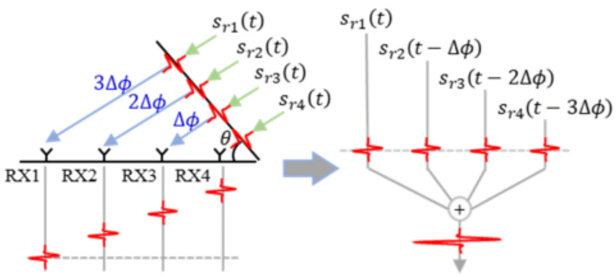
and mean absolute error (MAE) values between radar and reference sensors were computed. Figure 2(b) shows the OTS FMCW radar (TI IWR6843) used in the experiment.

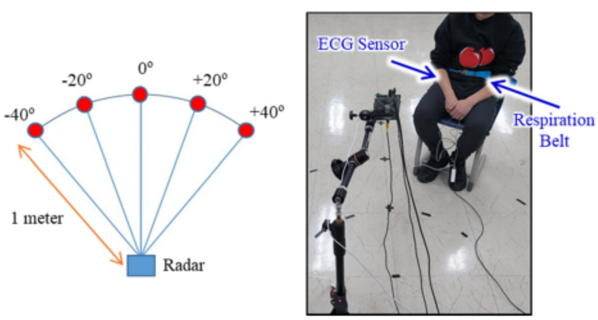


(a)

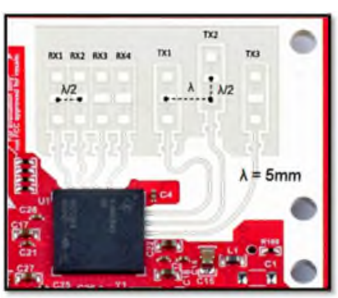


(b)

Figure 1. (a) TX beamforming and (b) RX beamforming considered in this paper.



(a)



(b)

Figure 2. (a) Experimental setup to test vital sign at different angles and (b) the OTS FMCW radar (TI IWR6843) used in the experiment.

III. RESULTS AND DISCUSSION

We compared the MAE between radar and reference sensor device in all the cases, and the results are summarized in Tables I and II for BR and HR respectively. Tables I and II suggest that the TX and the RX beamforming has slightly reduced the MAE of the HR mainly. Based on results gathered with OTS radar under consideration, HR seems to be the main beneficiary of beamforming. The MAE for the BR on the other hand is not decreased significantly in comparison to the HR. Hence, it can be concluded that for this particular OTS FMCW radar, beamforming can be deployed mainly for HR extraction whereas BR can be extracted without using beamforming. In addition, when the participant is in front of radar, beamforming does not increase the performance of HR extraction. In fact, Table II shows a slightly increased MAE for the case of zero degree.

In the future, we plan to extend the beamforming concept to extract vital signs for each of multiple humans coexisting at different distances and angles.

TABLE I. MAE COMPARISON FOR BREATHING RATE

Angle (degree)	Without Beamforming	TX Beamforming	RX Beamforming
-40	0.71	0.73 (-2.3 %)	0.7 (1.4 %)
-20	0.33	0.33 (0 %)	0.36 (-0.1 %)
0	0.56	0.52 (7.1 %)	0.52 (7.1 %)
+20	0.77	0.54 (29.8 %)	0.44 (42.8 %)
+40	1	0.72 (28.0 %)	0.96 (4.0 %)

TABLE II. MAE COMPARISON FOR HEART RATE

Angle (degree)	Without Beamforming	TX Beamforming	RX Beamforming
-40	2.8	2.60 (7.1 %)	2.24 (20.0 %)
-20	2.40	1.69 (29.6 %)	1.71 (28.7 %)
0	1.12	1.51 (-34.0 %)	1.68 (-50.0 %)
+20	3.06	2.19 (28.4 %)	2.39 (21.8 %)
+40	2.23	1.85 (17.04 %)	1.60 (28.5 %)

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