# Remote Heart Rate Sensing with mm-wave Radar

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***Abstract*— There are so many patients who need a continuous vital sign monitoring. Monitoring a patient with a wearable device such as using electrode-based electrocardiography (ECG) signal recording device for a long time is very inconvenient. One possible solution is using contactless sensors such as radars to find vital signs of the subjects. In this paper, we demonstrate the use of frequency-modulated continuous wave (FMCW) radar operating at 77 GHz for monitoring a patient's heart rate in a retirement environment. Several experiments were conducted to validate the reliability of the radar responses. Finally, the whole system is tested in a bedroom with the radar above a bed and a patient lying on it.**

***Keywords—FMCW radar, health monitoring, wireless sensors, heart rate, vitals monitoring***

## I. INTRODUCTION

Monitoring human vital signs like heart rate and breathing rate is very critical in many scenarios such as during exercise or during sleep. Resorting to wearables may not be suitable in certain cases, but a more desirable method would be monitoring remotely. Here, we investigate the use of mm-wave frequency modulated continuous wave FMCW radars in detecting chest motion due to both breathing and heartbeat.

FMCW radar also has been shown to be a candidate for vital sign monitoring applications. The authors in [1] used a FMCW radar with start frequency of 9.6 GHz and the sweeping bandwidth of 800 MHz. It is important to mention that their bandwidth is not wide and it is not too narrow to loose range resolution either. In other words, there is no need for a UWB radar such as [2] for vital signs detection while the more important point is having a higher Doppler detection resolution which is directly related to the sensor operation frequency. In fact, the higher the frequency is the higher resolution Doppler detection is.

Generally, in a FMCW radar a signal whose frequency is varying with the time is sent by a transmitter. The electromagnetic wave travels through the environment with some objects which is reflected to a receiver. A simplified block diagram of the system is shown in Fig. 1. Here, the generator generates a chirp signal with which the output frequency is swept linearly in time. At the receiver, after correlation the intermediate frequency (IF) signal (beat signal) is obtained which contains information about the location and velocity of objects in the scene. We shall discuss the algorithm of heart rate detection in section II. In section III, the measurement results for some experiments in an antenna chamber and in a bedroom will be discussed. Finally, in section V, we will conclude the paper with some remarks.

## II. HEART RATE DETECTION ALGOR ITHM

Fig. 2 shows the signal processing chain used for heart rate detection. The beat signal samples are coming from ADC output. The range FFT is applied over the samples of each chirp. The range tracking unite is responsible for finding a current range bin which contains information about the vital signs. After finding the desired range bin, its phase is stored. After unwrapping the phase, the Doppler FFT applied over the unwrapped phase samples. Furthermore, the block of Doppler samples is filtered by an FIR bandpass filter (BPF) which passes frequencies of 0.8-2 Hz corresponding to heart rates of 48 to 120 beat per minute. The output of BPF is passed through three different algorithms for finding an estimate of heart rate. Here, spectral and temporal and autocorrelation-based algorithms are used. Spectral estimation uses Doppler FFT samples of the desired range phase. Temporal analysis takes the time domain heart waveform and counts the number of peaks in the observation window. Indeed, autocorrelation-based method considers the time difference between the first two peaks in the autocorrelation of the heart waveform. The final rate is the average of the three estimates.

## III. MEASUREMENTS

There are two sets of experiments discussed here. The first set is investigating the sensor accuracy in the range and Doppler while the second set is the actual setup for evaluating the heart rate detection algorithm. In this work, we used mm-wave radar for our measurements. This radar operates at 77 GHz to 81 GHz with parameters listed in TABLE I.

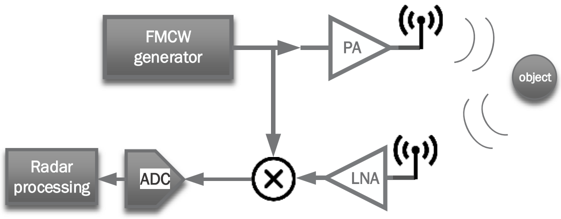


Fig. 1. A general block diagram of a typical FMCW radar

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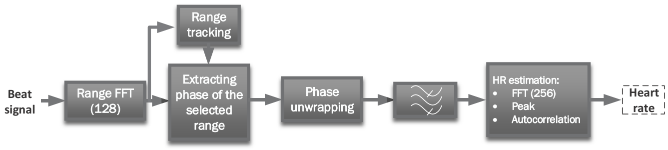


Fig. 2. Heart rate detection signal processing chain

TABLE I. FMCW RADAR PARAMETERS

| **Parameter** | $T_r$ | $T_c$ | **K** | $f_{b,max}$ | **N** | **M** |
|---|---|---|---|---|---|---|
| **Value** | 57 $\mu s$ | 50 ms | 70 $MHz/\mu s$ | 2 MHz | 128 | 256 |

### A. Antenna chamber

In an environment like bedroom, there are so many objects in the scene which are partially reflecting the power of the transmitted chirps. To get rid of all unnecessary reflection, some basic tests were done in an antenna chamber. The radar placed inside of the chamber with a metallic plate in front of it. The time evolution of the range profile as well as the Doppler-range map were considered. In the chamber, the plate can be stationary or non-stationary. If it is still, then ideally the range-slow time map must show a constant peak. In contrast, if it is moving somehow, there should be some peak variations in the map. These expectations are confirmed in Fig. 3. This figure also shows the sensor reliably detected the object in the range for both trials. The basic measurements verified that we could use the radar accurately down to the typical ranges needed for remote heart-rate measurements.

### B. Bedroom

In the second round of experiments, we examined the radar attached to a ceiling above a bed Fig. 4. The patient rested over a bed. A finger sensor from iHealth [3] is connected to his index finger as a reference. We ran both the radar and the sensor, simultaneously, and waited for almost one minute each time. Fig. 5 shows a heart waveform captured by the radar in one trial. The shape of the waveform indicates a similar behavior to electrocardiography (ECG) signal containing a high peak followed by a lower and wider peak corresponding to the well-known R and T waves respectively.

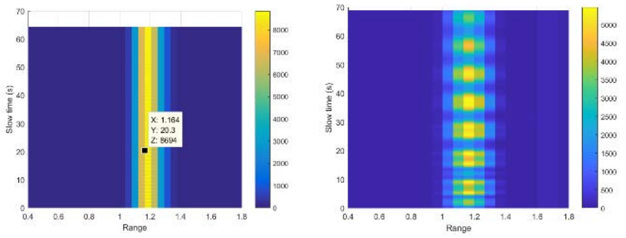


Fig. 3. Range profile time evolution for stationary (left) and rotating (right) plates.

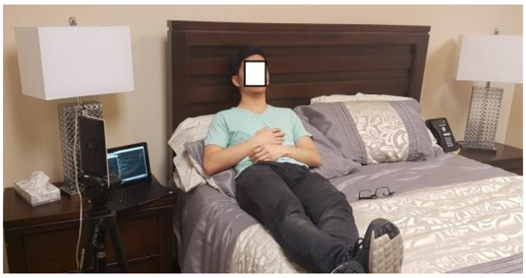

Fig. 4. Patient resting on bed and radar is attached to the ceiling

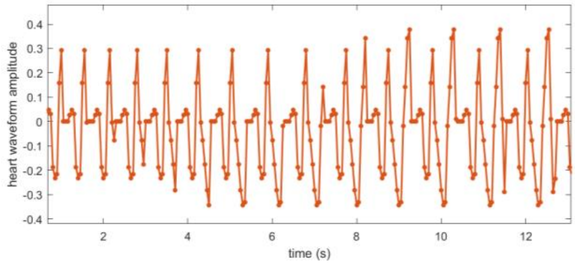


Fig. 5. Heartbeat waveform

Fig. 6. COMPARISON OF THE HEART RATE OBTAINED BY THE RADAR AND THE FINGER SENSOR

| **trial #** | **Radar** | **Finger sensor** |
|---|---|---|
| **1** | 66 | 66 |
| **2** | 74 | 71 |
| **4** | 70 | 69 |
| **6** | 70 | 67 |
| **7** | 67 | 63 |
| **8** | 67 | 71 |
| **9** | 60 | 59 |
| **10** | 73 | 70 |

We ran a set of experiments for ten times each for one minute. The result of the heart rate estimations compared to the wearable finger pulse oximeter system are listed Fig. 6 Actually the second norm of the error is about 7.8 beat per minute which is about 11% of the average heart rate.

## IV. CONCLUSION

In this paper, a heart rate detection algorithm is proposed which utilizes three different approaches for estimating the rate. There were two sets of experiments. The first set was aimed for showing the radar accuracy in the range which was acceptable. By the second round of experiments, the proposed algorithm tested in a bedroom and compared with a reference sensor. This is shown that the radar measures the heart rate within 11% of the actual average rate.

## REFERENCES

[1] L. Anitori, A. de Jong, and F. Nennie, "FMCW radar for life-sign detection," in *2009 IEEE Radar Conference*, 2009, pp. 1–6.

[2] S. Wang *et al.*, "A novel ultra-wideband 80 GHz FMCW radar system for contactless monitoring of vital signs," in *2015 37th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*, 2015, pp. 4978–4981.

[3] https://ihealthlabs.com, "Pulse Oximeter, Blood Oxygen Monitor", 2018. [Online]. Available: https://ihealthlabs.com/fitness-devices/wireless-pulse-oximeter/. [Accessed: 13-April-2018].