Student Design Competition
IEEE IMS 2024 Washington, DC

Radar for Noncontact Vital Sign Sensing

TC28 – Biological Effects and Medical Applications Committee

Introduction:

This SDC aims to introduce students to vital sign sensing radars, which is open to all students registered at an educational institution. With the reference signals, participating teams are required to design, fabricate, and demonstrate a radar system that balances portability (power consumption, weight, and size), performance (accuracy and response time), and potential in practice.

The competition requires to:

- **demonstrate the accuracy of the detection;**
- **show the system power consumption and weight;**
- **demonstrate the potential of the radar system.**

Design Specification and Rules:

Each team has 10 minutes to arrange the setup and calibrate its radar. Thereafter, each team has 15 minutes to complete at least 1-minute measurement to demonstrate the accuracy of the detection. In other words, the best result measured within the competition time can be chosen to evaluate the performance.

The team must demonstrate to the judges that, at least the frequency of the motion is being correctly measured by the radar. Otherwise, the team will be disqualified from the competition.

Due to the signal processing techniques and the subject's random body motion, each team can choose 1-minute radar sensing result to evaluate the performance compared with the reference signals provided by the respiration belt and ECG device. It should be noted that the accuracies of respiration and heartbeat should be provided from the same measurement, and should be consecutive, e.g., 10-70 s or 30-90 s. Each team must prepare the instruments and algorithms to provide the ground truth references of respiration rate variability (RRV) and heart rate variability (HRV), submit the measured accuracies.

Each team must bring their own ground truth (respiration belt and ECG device).

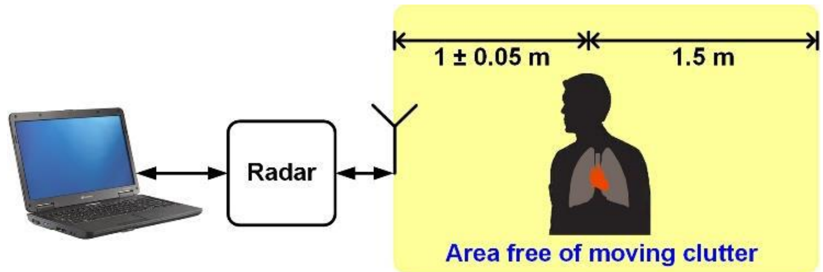

Figure 1. Experimental setup for radar-based vital sign monitoring

Fig. 1 shows the testing and judging environment. The radar sensor needs to detect and measure the cardiopulmonary activities of a seated subject who is breathing normally. Only the fundamental frequencies of respiration and heartbeat need to be detected and measured. During the sensing period, the radar can be located in a range between 0.95 m to 1.05 m from the subject. No moving clutter will be allowed 1.5 m behind the subject in the line-of-sight direction. The team may prepare and use a tripod (not provided by the organizers) to make the radar antenna face the chest of the seated subject.

The potential of the radar system can be shown by demonstrating additional features, e.g., clutter immunity, cost-effectiveness, multiple vital sign sensing capability etc.

Each feature must be demonstrated during the experiment period. The organizers suggest preparing a short presentation (up to 5 minutes) to summarize the potential of the radar, that can be discussed after the experiment period. The DC power consumption and weight of the radar will be measured by calculating the product of the actual supply voltage and current. The power supply model provided by the organization is unknown. If the power supply is not sensitive enough and the team does not provide another power supply to measure the DC power consumption, the score for this section will be 0 points.

A power supply with a single DC voltage output up to 15 V will be provided by the organizers to power up the radar, no battery is allowed on the radar. The DC power consumption will be measured as the product of the actual supply voltage and current. The power consumption must be the same during all the measurements. During the sensing period, a respiration belt and an electrocardiography (ECG) device will be utilized to provide the ground truth of vital signs of the subject.

As seen in Fig. 1, the radar sensor can be connected to a laptop, smart phone, or tablet using a single cable for real-time signal processing. The cable can be used to transmit analog/digital signal through USB/audio port, but no dc power can be transferred from the laptop/smartphone/tablet to power the radar. If USB data acquisition cable (e.g., NI 6008/6009 or FTDI USB to serial converter cable) is used, the power drawn by the unit for data acquisition function will not be counted because of the difficulty in measuring the power. However, it should be noted that the weight of the data acquisition unit will be counted; if two teams have the same score, the team not using USB data acquisition will be ranked higher. Energy harvesting from ambient sources is not allowed. The weight of the radar sensor will be measured as the total weight in the radar system except for the laptop, i.e., the antenna, SMA connectors, SMA cables, radar front-end, ADC (if any) and signal cables will all be counted into the weight of the radar sensor.

Evaluation Process:

The reference signal of respiration is provided by the low-pass filtered result measured by the respiration belt, and the cutoff frequency is set to be 0.5 Hz. With the aid of peak-detection function in MATLAB, the peak-to-peak interval for respiration, *PPI_Rref* can thus be obtained. Similarly, the peak-to-peak interval for heartbeat, *PPI_Href*, can be obtained by the R-R intervals of the ECG waveform. Compared with the results, *PPI_Rradar* and *PPI_Hradar*, measured by the radar with customized algorithms, the average accuracies of respiration and heartbeat, *AA_R* and *AA_H*, are defined as:

$$AA\_R = \frac{\sum_{i}^{N_B-1}\left(1 - \frac{\left|PPI\_R_{ref,i} - PPI\_R_{radar,i}\right|}{PPI\_R_{ref,i}}\right)}{N_B - 1}$$

and

$$AA\_H = \frac{\sum_{j}^{N_H-1}\left(1 - \frac{\left|PPI\_H_{ref,j} - PPI\_H_{radar,j}\right|}{PPI\_H_{ref,j}}\right)}{N_H - 1}$$

where *i* and *j* are respectively the index numbers, NR is the number of measured breaths and NH is the number of measured heartbeats. For example, if the subject exhibit 10 breaths and 90 heartbeats in one minute, the respiration belt and ECG will respectively show 9 *PPI_Rref* and 89 *PPI_Href*.

The score of this competition will be calculated for each team according to Table 1.

DC Power Consumption (P_{DC})		**Weight (W_g)**	
Range	**$Score_{PDC}$**	**Range**	**$Score_{Wg}$**
P_{DC} > 500 mW	5	W_g > 200 g	5
100 mW < P_{DC} < 500 mW	10	100 g < W_g < 200 g	10
10 mW < P_{DC} < 100 mW	15	10 g < W_g < 50 g	15
P_{DC} < 10 mW	20	W_g < 10 g	20
$Score_{Accuracy}$: (AA_R + AA_H)*20			
$Score_{Potential}$: <20			

The total score is given by

$$\mathbf{Score_{Total} = Score_{Accuracy} + Score_{PDC} + Score_{Wg} + Score_{Potential}}$$

How to Participate:

Competing teams will be required to register to the IMS Student Design Competition according to the rules posted on the IMS-2024 homepage.

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