Non-Contact Vital Sign Monitoring using FMCW mmWave Radar

Introduction

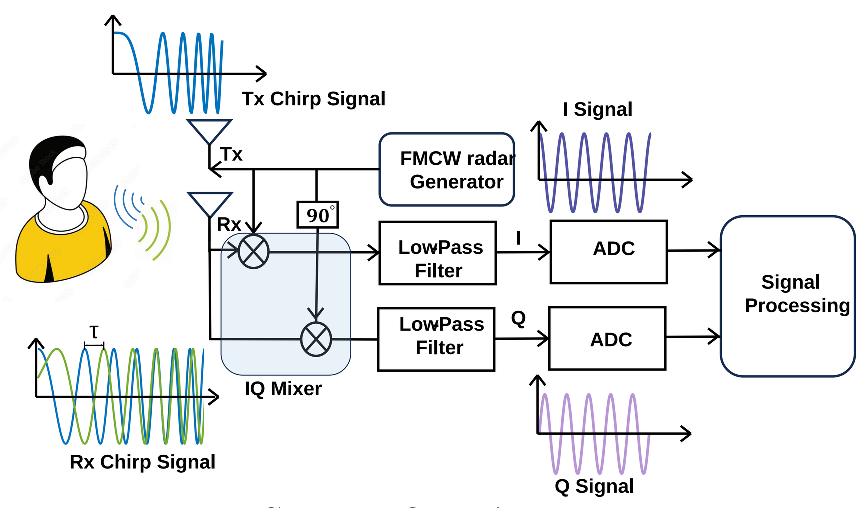
An accurate heart rate (HR) estimation using a radar sensor is challenging in a real-life situation due to interference from unwanted clutter, respiration (RR) harmonics, body movement, and especially variations in the target's position. To overcome these challenges, we propose a novel method based on

- Real-time beam steering to localize the target
- Resonance sparse spectrum decomposition (RSSD) that leverages sub-band energy distribution for optimizing the Q factor
- HUA algorithm for subsequent extraction of HR using harmonics.

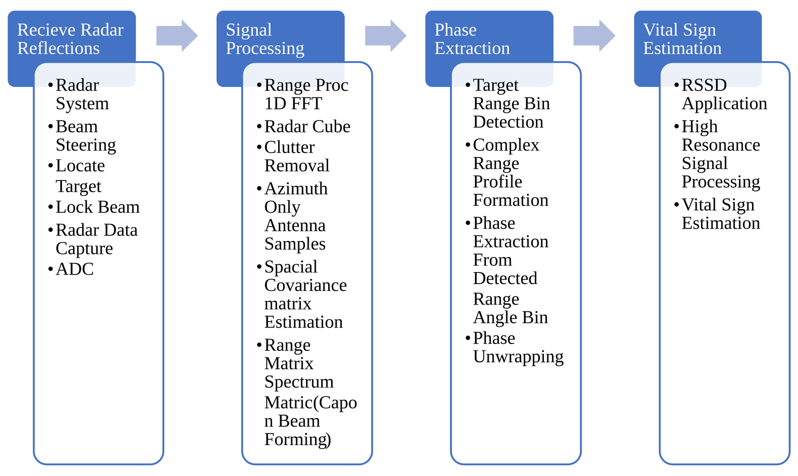
Comprehensive experiments performed under various realistic conditions were performed to demonstrate the consistent HR accuracy of 98.72% up to 4m.

Methodolgy

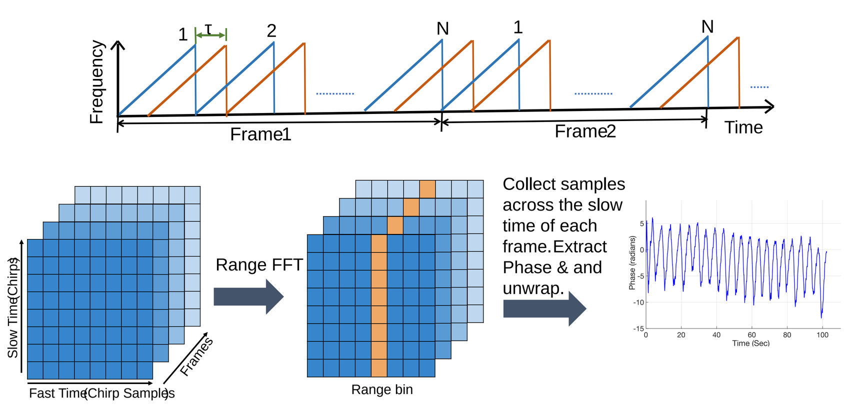
The FMCW radar continuously alters the transmitted signal's frequency using a known rate modulation signal over a set period. The reflected signal is phase modulated by the time varying chest motion proportional to the breathing and cardiac activities.



FMCW radar Operation



Signal Processing chain for Vital Sign Estimation

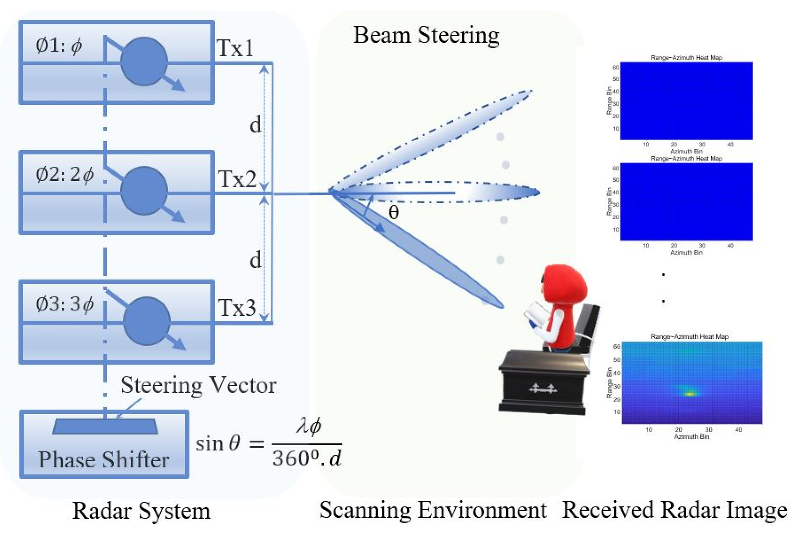


FMCW chirp, radar data cube and Range bins

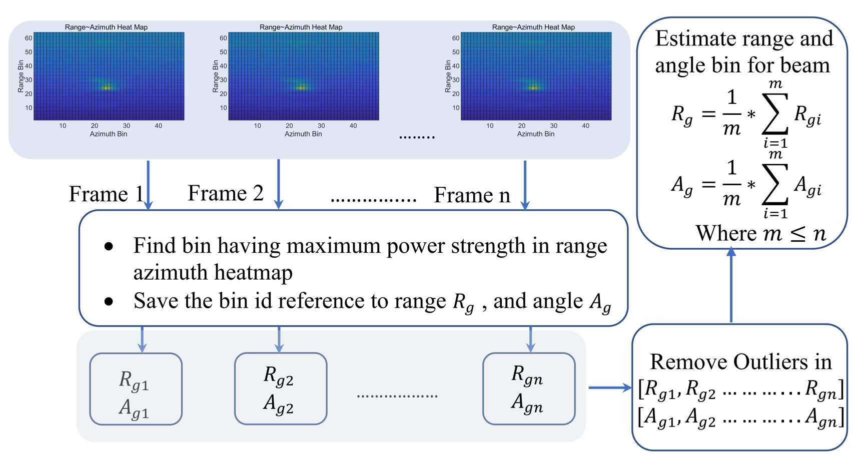
RSSD separates the different resonance components of a given signal and realizes the sparsest representation of each resonance component. The desired optimization problem for estimating coefficient matrixes w1 and w2 under s1 and s2 is find out according to $\underset{W_1,W_2}{argmin}\{\| x - S_1W_1 - S_2W_2\|_2^2 + \lambda_1\|W_1\|_1 + \lambda_2\|W_2\|_2\}$

The RSSD algorithm steps can be summarized in the following:

- The phase signal is input to the algorithm;
- Wavelet bases S1 and S2 (via TQWT) are constructed, suitable Q-factors, Q1and Q2, redundancy factors r1, and r2, decomposition levels J1, and J2, and suitable weight coefficients;
- The optimal coefficient matrixes W1* and W2* are estimated to solve the optimization problem with SALSA;
- Finally, the high and low resonance components are obtained where, $x_1 = S_1W_1^*, x_2 = S_2W_2^*$



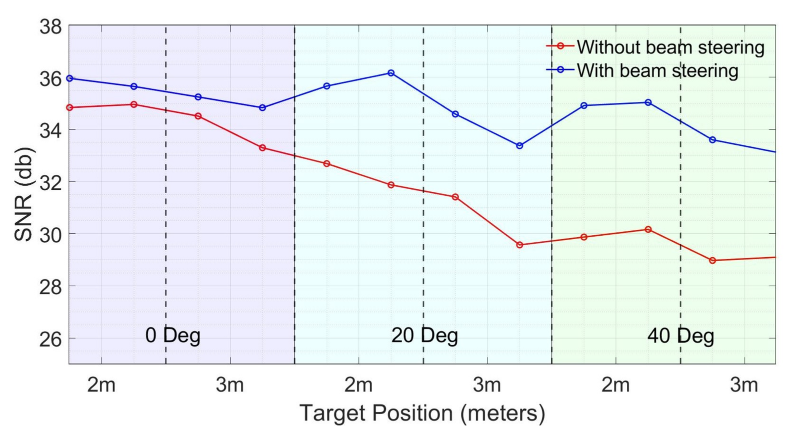
Beam Steering technique used in the experiments using phase shifter



Range Angle Estimation

To steer a beam at an angle θ to the radar, the phase difference of the signal phase shifter can be adjusted using $\sin\theta = \frac{\lambda\phi}{360^0 d}$

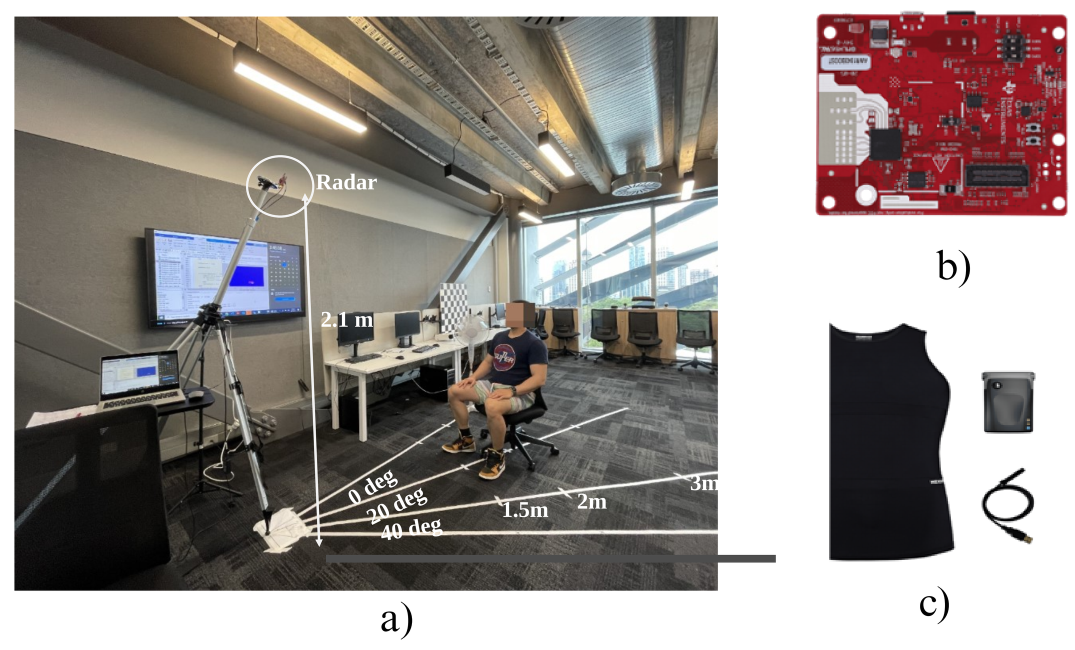
The graph shows without beam steering, the SNR is maximum at zero deg and drops to half for each 20deg increment due to reduced H plane beam coverage. Conversely, employing beam steering a SNR boost of about 4-5 dB at 40deg and 2-3 m is achieved indicating a three-to-fourfold signal strength increase.



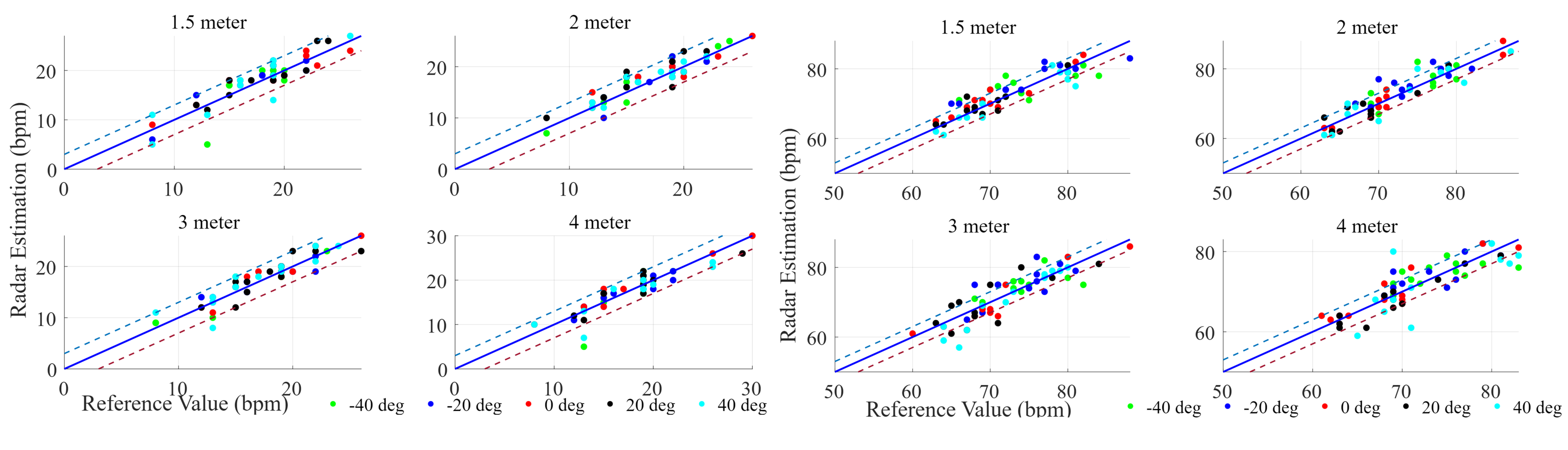
Comparison analysis of SNR with and without Beam Steering at various radar angles

Experiments & Results

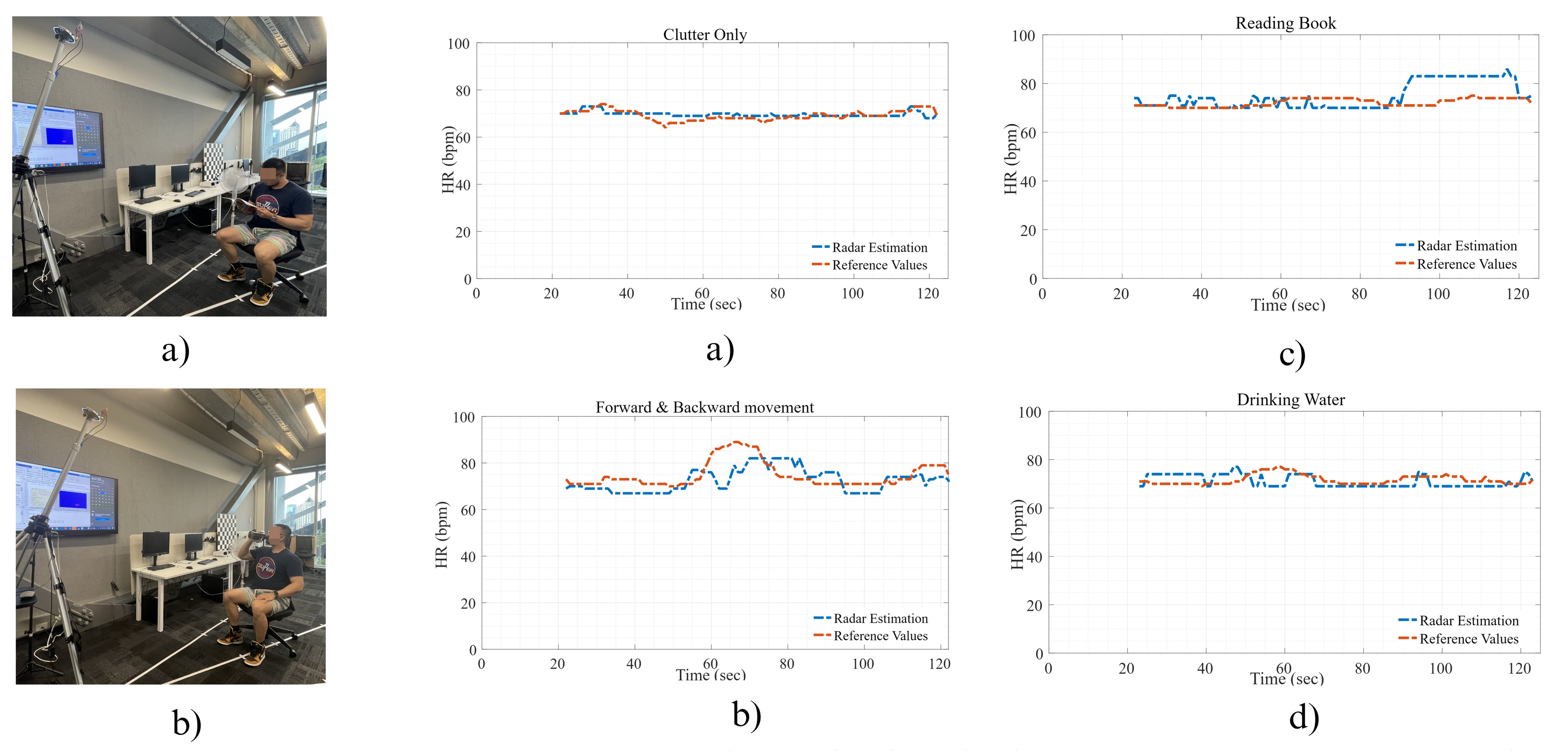
The experimental setup mimics the home environment placing the radar at 2.1m height as shown in Figure. The radar sensor AWR1843 used in the study is an integrated single-chip FMCW radar sensor operating in the 77 to 81 GHz frequency band. A train of chirps is generated with chirp duration time, Tc= 62 µs, the chirp interval idle time = 30 µs, the sawtooth frequency modulation slope S = 60 MHz/µs, and the frame rate Tm = 100 msec.



a) Experiment setup b) AWR1843 EVM and c) Hexoskin device

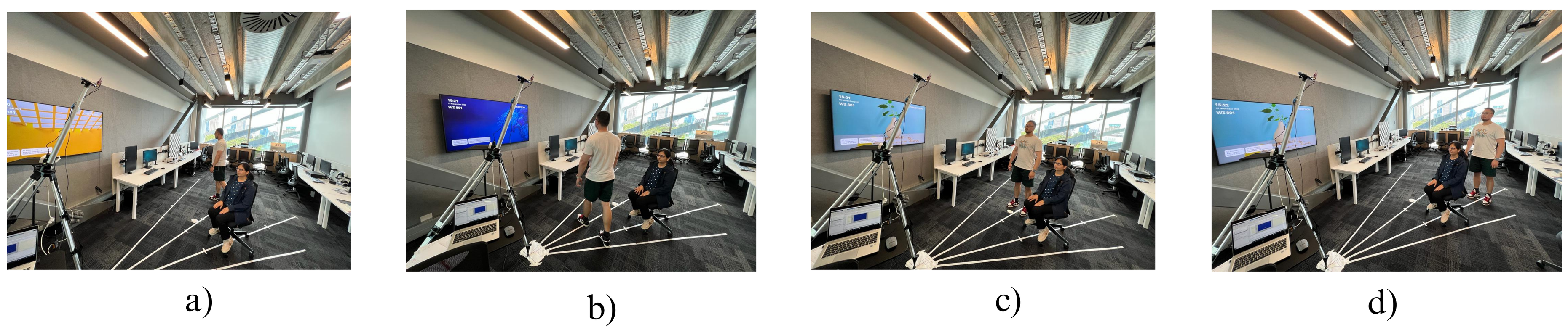


a) Scatter plot showing the relation between RR reference values and radar estimation with R-Squared values 0.77, 0.83, 0.85, 0.813 at 1.5, 2, 3, and 4 m, respectively (b) Scatter plot showing the relation between HR reference values and radar estimation with R-Squared values 0.81, 0.832, 0.743, 0.716 at 1.5, 2, 3, and 4 m, respectively.



Experimental Setup showing different scenarios of Clutter and Body Motion (a) Drinking water (b) Reading.

Beat-to-beat comparison for vital sign estimation under the effect of clutter and body motion (a) Clutter only b) Clutter+Forward/Backward movement (c) Cluter+Reading book and (d) Clutter+Drinking water.



Experimental Setup: another person in the vicinity (a) Crossing from the Back, (b) Crossing from Front, (c) Walking and standing close to the target, and (d) Standing at back.

At all azimuth angles up to a distance of 4m, the difference between the reference and experimental values is well with in 2bpm and exhibits an average accuracy

- RR: 99%
- HR: 98.72%

Notably, the peak performance is observed at 2 m, attaining an accuracy of 99.12%.

Table: Average HR accuracy for complex scenarios

Scenarios	HR Average Accuracy (%)
Clutter Only	99.14
Forward/Backward movement	100.00
Reading	98.51
Drinking Water	99.43
Crossing from Back	100.00
Crossing from Front	99.44
Walking and standing close to target	98.28
Standing at back	96.57

Conclusion

This research paper presents a method for extracting vital heart and breathing signals from noisy radar signals, leveraging the resonance property of these vital signs.

- The RSSD algorithm, integrating optimal Q-factor selection and sub-band energy distribution, is used for phase signal extraction and HR signal decomposition, effectively mitigating random body movement and clutter effects.
- The HUA algorithm suppresses the influence of RR harmonics and intermodulation products on HR.
- The effect of substantial clutter, moderate body movement, body orientation and the presence of another individual in the target's vicinity on HR/RR estimation is studied.