L-17

# A Study on Accelerating Radar Signal Processing for Non-contact Vital Sign Sensing with mm-Wave Wideband MIMO-FMCW Radar

* Haoran Liu[1], Yaokun Hu[2], Takeshi Toda[3]

**Abstract**: This study explores radar signal processing for remote sensing of human vital signs using millimeter-wave wideband multi-input multi-output (MIMO) frequency modulated continuous wave (FMCW) radar technology. We introduce a Visual Studio C# programming scheme that significantly reduces execution time compared to Matlab. Our research highlights the importance of efficient radar signal processing for vital sign monitoring, offering potential benefits in healthcare, biomedical engineering, and remote sensing applications.

## 1. Introduction

We have so far investigated non-contact sensing of vital signs, such as respiration, heart rate, and blood pressure, using millimeter-wave (mm-wave) wideband multi-input multi-output (MIMO) frequency modulated continuous wave (FMCW) radar technology [1-5]. Our MIMO-FMCW rada processing dose not only include complicated radar signal processing (including preprocessing) required for the huge amount of data generated by MIMO channels, but also highly-advanced heart rate estimation algorithms, using multi-branch and multi-chirp. We thus had emploied Matlab, which is powerful tool for the signal processing that includes a lot of array and matrix operations. On the other, we have the MIMO-FMCW radar signal processing implemented with post-processing, that means off-line evaluations. However, we need real-time evaluation for paradigm-shifting from practical to implementation researches.

In the research, we investigate implementation of the real-time MIMO-FMCW radar signal processing with comlicated heart rate estimation algorithms, using Visual Studio C#.

## 2. Hardware Configuration of MIMO-FMCW Radar

The anttena-branch of our used MIMO-FMCW radar module is composed of 3Tx-4Rx. At first, a ramp generator produces frequency-modulated chirp signal. The radar signal is amplified with high power amplifier and transmitted through 3 Tx antennas. Signal reflected from targeted subject skin is received with 4 Rx antenna branches, amplified with low noise amplifiers, intermediate frequency (IF)-signal is extracted by mixing transmitted and received signals, and digital raw data is finally obtained through analog-to-digital converter, in each receive array antenna branches.

## 3. Signal Processing Configuration for SIMO Radar

DC offset, for the IF-signal, is removed in each time window on the raw, the phase is unwrapped after the multiple chirps accumulates, and the chest displacement signal $x(t)$ is finally extracted, in the each receive antenna branch.

Improved complete ensemble empirical mode decomposition with adaptive noise(ICEEMDAN) method, which is frequency analysis in the time domain, is applied for the heart rate frequency extraction, and signal-to-noise ratio (SNR) is calculated. One branch, which has highest SNR, is selected to determine the estimated heart rate frequency, from the four received antenna branches.

## 4. Configuration of Software Implementation

Figure 1 shows the implementation of the FMCW-MIMO rada processing with Visual Studio C#, which is composed of two primary sections, which are “Control Software Section” and “Software Calculation Section.” The Control Software Section (“sample raw”) controls the radar module. The Software Calculation Section is composed of three parts, which are DC compensation, parameters calculator and data processing. Implementaion of the three calculation parts are described as follows.

***DC Compensation***: Crucial for signal preprocessing. It extracts and compensates for any DC offset in the input complex signal data, improving signal quality by minimizing DC component influence, especially beneficial for analyzing the AC portion. In this study, a method employing nonlinear least squares is utilized for estimating the center of the received signal constellation and offsetting the DC component by shifting the estimated center to the origin.

***Parameters Calculator***: Not directly involved in signal processing, this program defines and provides numerical radar system parameter values. These values are valuable for researchers and practical applications, offering insights into system configuration and characteristics.

***Data Processing***: Dedicated to comprehensive radar data analysis, this program conducts preprocessing, including frequency and vibration analysis, and phase accumulation. It results in a time-displacement graph representing vibration data, aiding in characterizing motion or vibration patterns within the radar system, benefiting researchers and analysts.

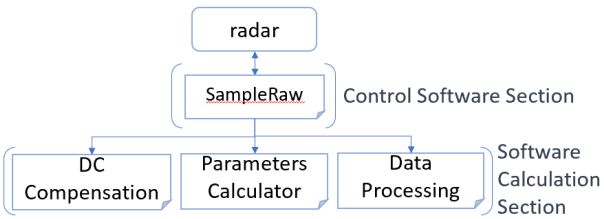


Figure 1 Configuration of software implementation

## Reference

[1] Y. Hu et. al., "Remote Vital Signs Measurement of Indoor Walking Persons Using mm-Wave FMCW Radar," in IEEE Access, vol. 10, pp. 78219-78230, 2022.
[2] X. Peng, et. al., "Design and evaluation of remote tracking heart rate measurement based on millimeter-wave FMCW radar," IEICE Communications Express (ComEX), Apr. 4, 2022.
[3] R. Koyanaka, et., al., "A Study on Pre-Filter Design for Improving Accuracy in Heart Rate Estimation from Backside Using Discrete Wavelet Transform with mm-Wave Radar," IEICE Communications Express (ComEX), Sep. 22, 2021.
[4] Y. Hu et., al, "The Effect of Multi-directional on Remote Heart Rate Measurement Using PA-LI Joint ICEEMDAN Method with mm-Wave FMCW Radar," IEICE Transactions on Communications, Aug. 2, 2021.
[5] Y. Hu et., al., "A novel adaptive range-bin selection method for remote heart-rate measurement of an indoor moving person using mm-wave FMCW radar," IEICE Communications Express (ComEX), Mar. 2021

1：日大理工・学部・電気　2：日大理工・院(後)・電気　3：日大理工・教員・電気