Source 1 - Introduction to Mmwave Sensing: FMCW Radars (Sandeep Rao) [N.D.]

Dr. He provided this source, which is less research and innovation-focused, instead focusing on providing details on introductory processes in Frequency Modulated Continuous Radar (FMCW) function, operation, and signal processing that are necessary when operating such devices. FMCW radars fundamentally work by transmitting out a “chirp”, which is a sinusoid signal whose frequency increases linearly with time, receiving that chirp, and taking the difference between the transmitted and received signals to detect small movements of objects within the radar’s bounds as that difference changes. The simplest FMCW radar will have one TX (transmit) antenna, which sends out the chirp, and one RX (receive) antenna, which receives the reflected chirp. These two chirp signals are sent through a mixer, which takes the difference of the two input signals to output an intermediate frequency (IF) signal. In a more complex situation with multiple potential objects or inputs detected by the radar, a Fast Fourier Transform (FFT), which is a signal processing technique that transforms time domain signals to frequency domain signals, can be done on the IF signal to isolate differing fundamental signals that contribute to the IF output of the radar. Using the FFT to display the IF output signals frequency spectrum will show decibel (dB) spikes in frequency related to the different component signals that make up the IF signal, with the frequency spikes being relative to the distance of those signal sources from the radar.

For processing purposes, the IF signal can be digitized by being run through an Analog-to-Digital Converter (ADC) and any necessary filters, but the sampling rate of said converter must be taken into consideration. When digitizing a signal, an ADC will have a set sampling rate at which it takes points from the “smooth” analog signal, and the given sampling rate of an ADC limits the maximum range of the radar being used based on the rate at which the chirp increases in frequency (also usually a set parameter).

FMCW radars can use these fundamental principles to measure more complex data points, such as the velocity of an object. A signal (in this case, a sinusoidal one) can be represented as the amplitude of the signal multiplied by the sine of the product of the frequency of the signal and a given point in time, plus the "phase" of the signal. The phase refers to the specific position of a signal at a point in time within its cycle, indicating how far the wave has progressed relative to a reference, and is measured in degrees or radians. When an object is displaced a small amount in front of the radar, the phase of the signal changes by a significant amount, even if the frequency of the signal remains the same. Considering this principle, if two consecutive chirps are sent out while an object in the view of the radar is moving, and FFT's are performed on both IF signals that are created from the chirps, the frequency spikes will remain at the same location preserving the ability to distinguish multiple objects, but the phase will differ significantly, corresponding to the motion of the object. Using this principle, you can measure the oscillation of an object by sending out multiple chirps in a "frame" and relating the differing phases of each IF signal to each point in an object's oscillatory movement.

As mentioned earlier, this source serves as an explanation of concepts instead of assisting in the search for a research gap, but the fundamental concepts can be useful in considering device design. Currently, the plan for an original prototype is to use the Texasie Instruments' (TI) AWR1843BOOST Radar, which, in pairing with TI MmWave Studio software and MATLAB, digitizes and preprocesses the signal, but at a point in the development cycle where more custom-designed components would be used, the consideration of ADC and radar specifications are important. The ability to measure the oscillatory movement of an object is critical for device function, as without it, the premise of measuring the respiratory or heart rate is impossible. In addition, the use of the FFT in this device is twofold. For current development, multiple signals sum to affect the FMCW radar output data that need to be processed and separated for the sake of extraction, including but not limited to the rate at which the lungs and diaphragm expand and contract, the rate at which the heart beats, the rate at which your chest and stomach expand and contract, and general outside signal noise. Being able to isolate these different component signals makes them much easier to process. In addition, future development could include the ability to detect biometric data of multiple subjects simultaneously, in which case, FFT could be used to separate the different inputs from multiple objects in the radar's view.

Source 2 - HeRe: Heartbeat Signal Reconstruction for Low-Power Millimeter-Wave Radar Based on Deep Learning (Haili Wang, Fuchuan Du, Hao Zhu, ZhuangZhuang Zhang, Yizhao Wang, Qixin Cao) [April 17th, 2023]

This source attempts to use a neural network to solve the issue of low-powered radars having a worse signal-to-noise ratio by identifying patterns in the signal. The HeRe pipeline is as follows: 1) The reflection of the body is captured from the mmWave data, and the phase of the signal is extracted during data preprocessing. 2) The signal's features are decomposed into a feature matrix for patterns to be detected. 3) FFT is performed to isolate the heart rate. 4) The final heart rate is estimated based on the isolated signal.

The preprocessing of the data mainly consisted of the elimination of static clutter and reflective signals from the walls and floors of the testing facility, as it applied to the feature matrix created, and the restriction of the signal phase between -180 and 180 degrees. This study makes the distinction during heart rate signal reconstruction of treating the signal as a periodic pulse signal, as opposed to a standard sinusoidal signal, as previous studies had. Because of this, the problem is treated as pattern detection as opposed to signal reconstruction, which is done by using a sliding frame fed through a neural detector, labeling the frames as “heartbeat” or “non-heartbeat”, allowing distortion and noise to be eliminated. The pipeline uses a Variational Mode Decomposition (VMD) algorithm, which is useful for analyzing and decomposing nonlinear signals to be used as features within a matrix for the neural detector. After experimentation, a reported 97.5% accuracy was achieved.

This study was limited by the researchers’ ability to mitigate not only general input signal noise but also reflective noise from the confines of the testing area, as well as the other portions of the subject's body. In addition, highly precise frequency estimation remains challenging due to sudden noise inteference from regular bodily function such as shaking or coughing, and to address this, the researchers suggest “correcting” analysis using historical data, showing reliance on past data “norms” to make up for the possible lack of consistency in long term data collection and analysis. This study raises many points and applications of deep learning methods to optimize the process of signal deconstruction and heart/respiratory rate estimation using mmWave data, especially that of low-power commercially available mmWave radar. Ideally, further noise elimination can be done to further attempt to isolate the chest oscillation signal, and safeguards can be placed, either in the recording procedure or in device software, to account for sudden and regular bodily functions, whether that’s in the form of outlier detection/removal, or a certain “allowance” of movements, or a process to automatically correct for these spikes as opposed to doing it manually.

Source 3 - GitHub Repository for Non-Contact Heart Rate Monitoring Using MmWave (can-yesilyurt) [February 27th, 2024]

This source is a public GitHub repository attempting to create an OSX application for Non-Contact Heart Rate Monitoring using a Seeed-Studio 60 GHz mmWave module. The main purpose of this source is to have a reference for the application integration of a mmWave radar and data processing pipeline in a user-ready experience and data-display format. That being said, the module used does all of the processing “under the hood”, so this repository, while being a good reference for app integration, doesn’t serve well as a reference for the data processing algorithm needed to isolate biometric data from the mmWave radar.

Source 4 - GitHub Repository for Mmwave Hrv Sensor (levijpcukett) [February 11th, 2021]

This source is similar to Source 3 in concept, but as it is built as a “lab setup”, it more closely reflects the initial prototyping setup of the current project, in addition to using a more similar sensor and MATLAB for the sake of data processing. This source serves as a good reference for the basis of a data processing and signal extraction algorithm. In similarity to Source 2, the algorithm developed in this repository focuses on heart variability (HRV) in addition to heart and breathing rate, measuring the heart rate as pulse with varying time in between beats, a more accurate model than assuming general sinusoidality of the heart rate signal. For this reason, this repository will be a good reference in tandem with the mathematical models shown in Source 2 when developing the current project’s algorithm. This repository is done entirely within MATLAB and MATLAB App Designer, decreasing general availability and usability for the average person. Ideally, after an initial prototype, this algorithm could be applied to a standalone device, and function through a more separate application, either on a mobile device or computer, to increase access and ease of use.

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