Heart rate and breathing rate detection using wireless signals

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ECE 157B - Final Project Report

Introduction:

Current health monitoring devices, such as finger pulse oximeters and smartwatches, require to install on human bodies which is uncomfortable to be worn all-day around. Wireless based activity recognition is sensitive to arm movements.
In this project, a non-contact health monitoring system that can detect both heart and respiration rates by using wireless sensing is proposed. The system transmits a UWB wireless signals towards a human subject and receives the reflections. Because the amplitudes of the wireless signals reflected by the body vary in patterns from the periodic chest and heart movements, the heart rate and respiration rate can be obtained from the continuously sampled amplitude variations after cleaning any extraneous motions. Even though the amplitudes are influenced by the compound movements of the heart, chest, and even environmental noises, heart and respiration rates can be still extracted and separated because the patterns in amplitude variations, which can be transformed into frequency domains, are robust to the changes of amplitude value. The detection happens in the frequency domain of the amplitude measurements. After reducing noises and excluding unwanted frequencies from the target frequency range, the frequencies of the peak magnitude in the FFT (Fast Fourier Transform) spectrum that shows the periodicity of the time-series measurements correspond to the heart rate or respiration rate. Multiple antenna pairs are used to improve accuracy by capturing . reflections in different directions.

	FMCW	**UWB**
Frequency range	Transmits signal across a short frequency range. But the operating frequency is continuously changed.	Transmits signal across a wider frequency range
Operation Mode	Continuous wave	Pulsed
Range resolution	It has sub cm range resolution with high accuracy	Compared to FMCW, range resolution is worse
Disadvantages	1. Sufficient isolation between Tx/Rx	1. Signal strength used is less; Might

	antennas required because of continuous mode operation. 2. Doppler affects the measurement accuracy	affect accuracy. 2. Interference issues and higher cost

Table 1: Comparison of FMCW vs UWB radar technologies

	WiFi	**Sonar**	**mmWave**
Measurement Range	Medium	High	Low
Range resolution	cm level	meter level	mm level
Operating Frequency Range	2.4 or 5GHz	20kHz to 10MHz	>30GHz
Disadvantages	1. Accuracy is affected due to interference	1. Can be easily interfered with other sound sources. 2. Affected by depth, temperature of the sea.	1. Affected by environment 2. Can't travel long distance due to nature of the mmWave signal

Table 2: Comparison of distance measuring technologies

Background behind heart rate detection:

The signal reflection from the human body is used to measure the heart rate. The phase of this reflected signal is proportional to the distance traveled by the signal. The distance measurement experiment was done in the last report. Also from the below figure we can see variations due to inhaling, exhaling and heart-beats. A person's heart beats cause miniature movements on human body which is captured in those small variations seen in the graph. These small variations are periodic in nature due to breathing and heart rate being periodic activities.

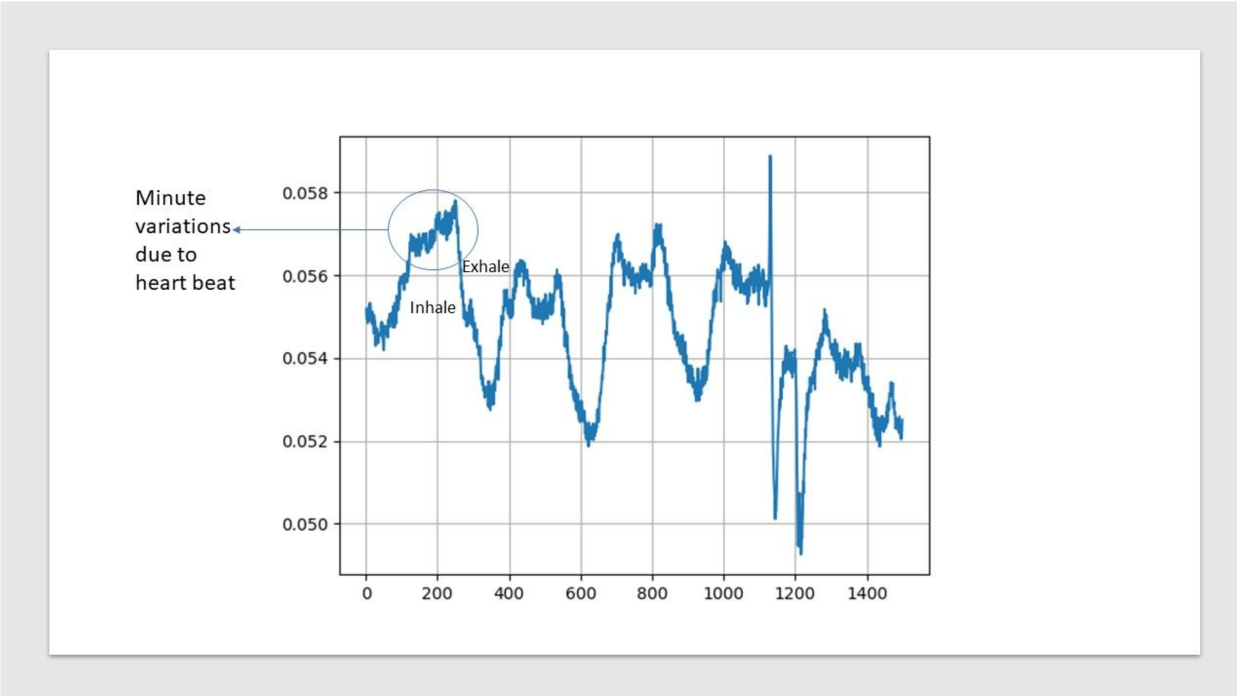

Fig 1: Raw signal plotted on time axis(*X-axis - Samples over time, Y-axis - Distance***)**

By performing an FFT on the distance variations, breathing and heart rate can be detected. Once FFT is performed on the phase of the signal over a period of time, the peak of the signal output gives an estimate of the person's breathing rate.

To obtain a precise measurement, FFT output is filtered to have only peak and its two adjacent bins. This filtering approach eliminates the noise by other human movements. An inverse FFT is performed to convert the signal back to time-domain. By measuring the slope of this time-domain signal, breathing rate can be accurately measured.

Heartbeat are minute variations and its magnitude is very less compared to the breathing signal. This can't be detected using a FFT as the higher amplitude signal masks this minute variations. After FFT is performed over a shorter time on the phase of the reflected signal, a band pass filter is used to get the beats in human heartbeat range. Breathing rate is less than 10 and noise is more than 300. By having the band pass filter, we can measure the heart rate.

To summarize this section:

1. **Removal of Background noise**:
   To remove background noise, samples are collected in the environment over a period of time and average is found Navg. When samples are collected for identifying heart rate, the noise value is subtracted from that. S = S - Navg. This step can be avoided if calibration is done.
2. **Periodicity detection:**
   To detect the periodicity, FFT operation is performed to convert the signals from time domain to frequency domain. This will make the non-periodic signal to have less frequency.

3. **Filtering collected samples:**
   Using a butterworth bandpass filter, filtering is done to remove the samples in unwanted frequency range.
4. **Heart Rate detection:**
   By finding peaks, we can detect the heart rate of the person.

Improving Accuracy Experiments:

- Background noise removal stage helped in improving accuracy
- Walabot has multiple antenna pairs. By using 3 or 4 antenna pairs, we can estimate heart rate in reflected samples from each antenna pair and sum them to avoid any samples missed.
- By superimposing reflected signals in frequency domain, the accuracy can be improved. However, I wasn't able to see any huge improvements or sometimes, the measured heart rate goes down.

Walabot Specifications and APIs used:

Walabot radar uses an array of linearly polarized broadband antennas. It operates in the frequency range of 3.3GHz to 10GHz. It has a range resolution of 0.5cm.

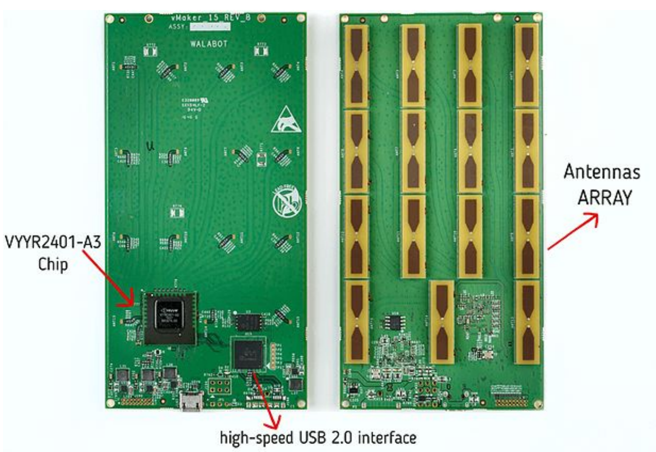

Fig 3: Walabot PCB showing 16 antenna pairs.

<u>Walabot's UWB technology:</u>

UWB radar systems have relatively large bandwidths. In FMCW, the bandwidth is less which increases the spectral density. UWB radar transmit short timed impulse pulses across the entire 3.3 -10.3 GHz frequency spectrum. Since the Walabot has 18 antennas, the resolution of the readings will be increased even the received signal is of lower signal strength.

Walabot supports two scan profiles

1. High resolution scanning with lower capture rate
2. Low resolution scanning with higher capture rate

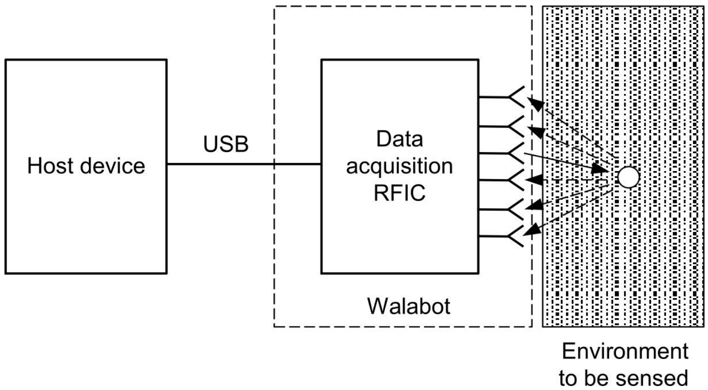

Fig 4: Reflections from the environment is sensed by the antennas and digital samples are provided to the host for processing.

Parameter	Breathing Rate	Heart Rate
API to read signal	GetImageEnergy()	GetSignal()
Arena Parameters	Broader than heart rate wlbt.SetArenaTheta(-0.1, 0.1, 10) wlbt.SetArenaPhi(-0.1, 0.1, 10) wlbt.SetArenaR(20, 150, 2)	Narrower than Breathing rate wlbt.SetArenaTheta(-0.1, 0.1, 10) wlbt.SetArenaPhi(-0.1, 0.1, 10) wlbt.SetArenaR(20, 50/80, 1)
Filter Applied	wlbt.SetDynamicImageFilter(wlbt.FILTER_TYPE_DERIVATIVE)	wlbt.SetDynamicImageFilter(wlbt.FILTER_TYPE_DERIVATIVE)

Table 3: Breathing rate and Heart rate differences in APIs used

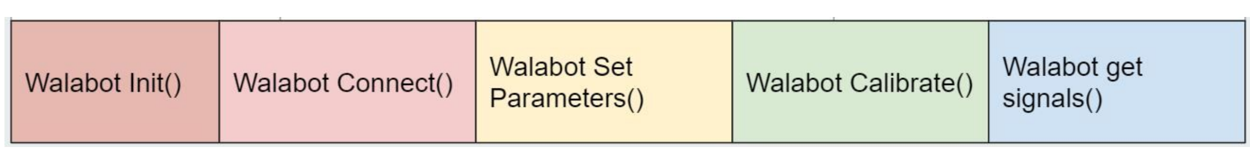

Fig 5: APIs used to configure Walabot and get signals

Walabot sensing reflected paths:

A metallic reflector was used to reflect the signals. In the reflected path, a moving target was introduced to see if the Walabot can detect the range. We noticed the range of the target was quite high than it was supposed to be. This is because of the radio waves travelling the extra distance.

Also this experiment of estimating distance when I faced Walabot sideways was done. This revealed that the MTI filter reduced the accuracy of the distance estimation since the lateral motion of the body is having a low rate compared to when standing straight to the Walabot and breathing. Calibration of the Walabot sensor environment before sensisng would improve the accuracy.

Walabot getting raw ADC signal:

Getting raw ADC signal from the Walabot radar is essential in getting minute variations. This is achieved by using the GetSignal() API. Signal and their times are provided the GetSignal() API. Signal list and Time axis list has 8192 values. Using this, we would be able to perform Breathing detection and other applications. Terminal output is shown below.

```
dinesh-wcsnglab-2@wcsnglab-2:~/Documents$ python raw_adc_read.py

 Antenna Pairs Chosen: AntennaPair(txAntenna=1, rxAntenna=3)
 Signal List Size: 8192      Time Axis list Size:  8192
 Printing 5 samples from this list
 Signal List:  [-0.004304037365348138, -0.012634932263884936, -0.018706330548012164,
-0.021342066802577705]
 Time Axis list:  [9.765625e-12, 1.953125e-11, 2.9296875000000004e-11, 3.90625e-11]
```

Plotting this data using matplotlib is shown below.

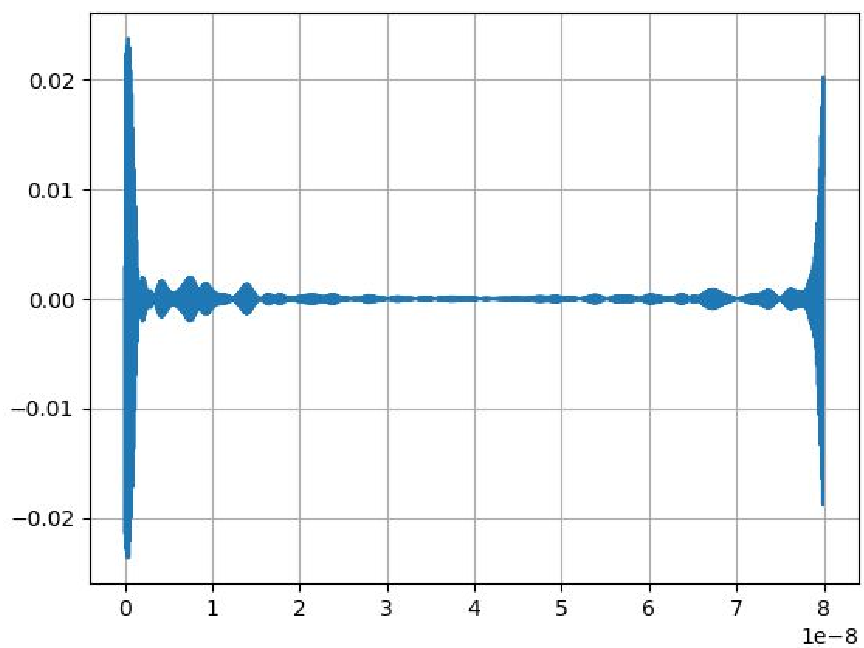

***Fig 6*: Time on x axis and Signal Amplitude on y**

Walabot Get energy API and it’s plot during breathing:

GetImageEnergy() API provides the energy of the reflected signal. Using this, we can detect the breathing rate of the person.

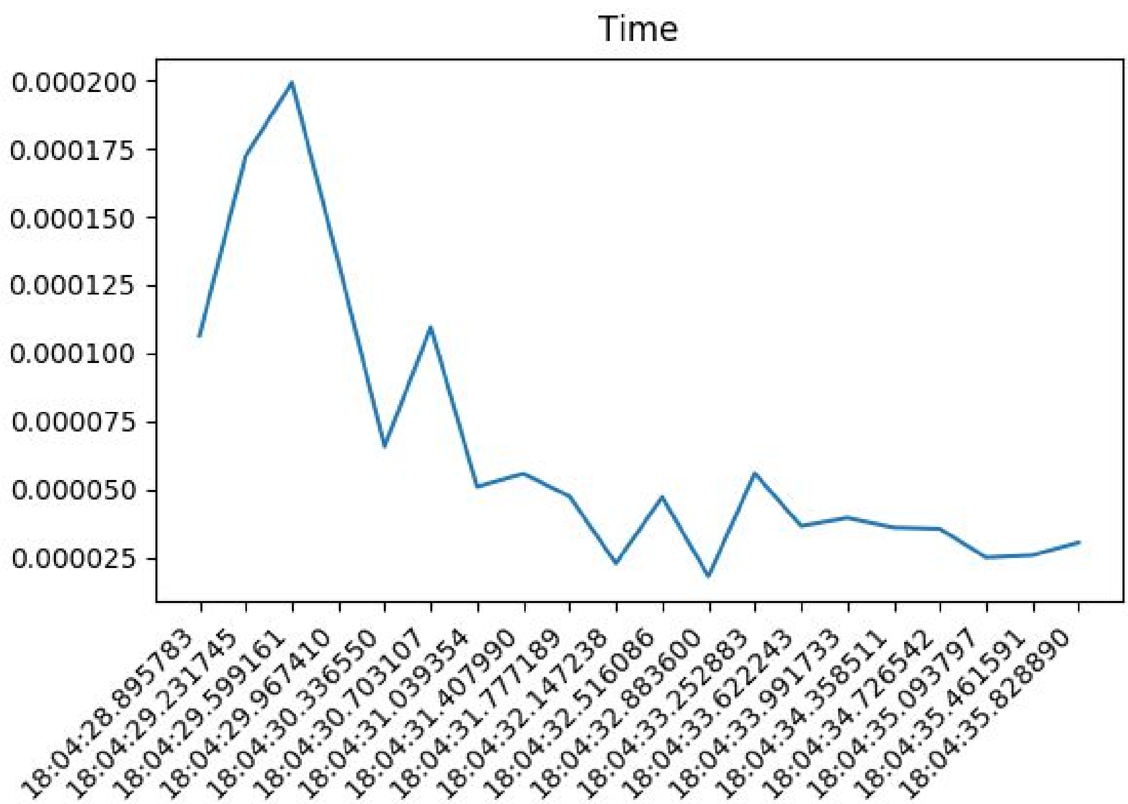

Fig 6: Plot shows the breathing of a person across time

I placed the Walabot horizontally on the table and I moved away. The energy readings reduced to small value (of 10^-5 range). I sat initially close to the Walabot and moved away till 2m(measured approximately ~20cm error might be there). Also changed the arena parameters to increase the range and the maximum obtained was **2m**

Detecting FFT peaks and Heart-rate:

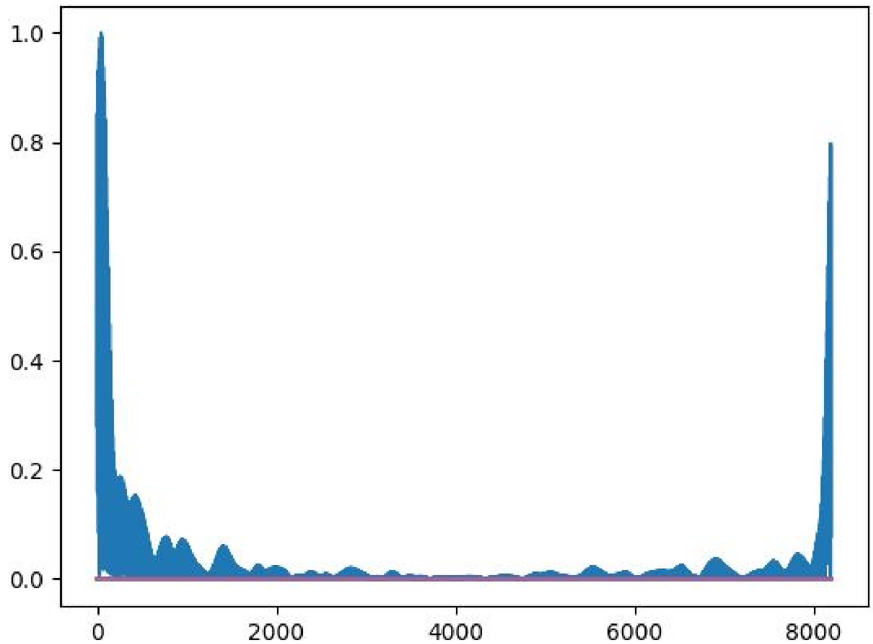

Fig 3: FFT peaks

By using the above method, fft peaks were plotted. When peaks are only identified in the range of 60 to 200, I get 185 as output which is erroneous. We can see this huge peak at the beginning which is the breathing rate. Even the breathing rate value is erroneous(34).

To have better results for I changed the find_peaks function to find_peaks_cwt. In this function, the input vector is smoothened by convolving it for a width. Relative maxima which appear at enough length scales, and with sufficiently high SNR, are accepted.

I didn't implement the regression based approach mentioned in the Vital Radio paper because there was no other motion apart from breathing.