ECE598-HH: Mobile Vital Radio Project Progress Report

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***Abstract*—The intermediate report summarizes our proposal of measuring heartbeat and breathing rate by implementing frequency modulated continuous wave. We start with description of FMCW and proposed Fourier transform (FFT) based phase tracking method. Then we present our obtained experimental data demonstrating the identification of a dynamic object. We conclude the report with a to-do-list.**

I. Introduction

For our project, we propose Mobile Vital Radio (MoViRad), a novel method of measuring physiological signals using a mobile device. We are especially interested in measuring the heartbeat and breathing rate of a person using frequency modulated continuous waves (FMCW). While past work exists that detects the breathing rate through use of a mobile device [1], they were ultimately unable to get down to the fine resolution required to measure heart beats. On the other hand, the heartbeat and breathing rate detection is achieved in Vital-Radio [2] by extracting the heart rate based on ballistocardiography (BCG). BCG refers to body movement that is synchronous with heart beat due to ventricular pump activity; in this case, the movement of interest is the breathing, or chest movement. As a result, we expect to obtain heart beat measurement by observing small fluctuation on top of breathing. Such minute yet periodic movement could be extracted by applying Fourier transform (FFT) of the breathing signal, and identify corresponding peaks in the frequency spectrum as breathing is typically measured of sub-hertz frequency while heart beat should be in the vicinity of tens of hertz. However, Vital-Radio could not be directly applied on top of [1] since the medium is acoustic wave in contrast to RF signal. As a result, the sampling rate required (in other words, the frequency bin resolution of FFT) is not available. In view of the limitation presented by acoustic wave, we propose Mobile Vital Radio (MoViRad) to precisely measure the phase of received FMCW by performing interpolation on individual bins in the obtained FFT.

The rest of the report is organized as follows. Section II illustrates the development of our proposed method by presents a quick overview of FMCW followed by analysis of the FFT interpolation method. Section III presents the experimental data we have obtained so far. Finally, Section IV summarizes our progress and shows the to-do-lists to accomplish the project.

II. Mobile Vital Radio

A. Background: FMCW

During an FMCW transmission, the transmitted waveform, as shown in Fig. 1, sweeps its carrier frequency linearly with respect to time between f_{min} and f_{max}, resulting in a chirp signal being output.

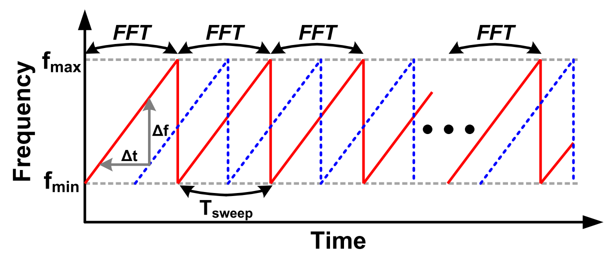

Fig. 1: Illustration of FMCW waveform.

As shown in Fig. 1, for instance, the red line represents the transmitted signal and the blue line represents received signal. The time delay, labeled as Δt in the figure, is proportional related to the slope of the linear sweeping segment of the chirp. In other words, the frequency shift between transmitted and received signal could be accurately extracted from the transmission delay. Denoting the sweeping period of the chirp as T_{sweep}, the frequency offset Δf can be calculated as:

$$\Delta f = \frac{f_{max} - f_{min}}{T_{sweep}} \cdot \Delta t \tag{1}$$

and the delay could be measured as:

$$\Delta t = \frac{2 \cdot d}{v_{wave}} \tag{2}$$

where d denotes the distance between transmitter and the object under test, and v_{wave} is the propagation velocity of the wave.

Consequently, in order to measure minute distance change such as breathing, we could send a signal towards the person so that we could back calculate the periodic chest movement associated with the breathing. Similar to the processing demonstrated in [1], [2], we apply FFT on the received signal and the perform peak search for the breathing signal. Assuming that acoustic wave travels at speed of 340m/sec at room temperature, the accuracy that we are able to achieve is roughly 2cm given that the mobile phone's microphone has a sampling rate of 44.1kHz.

B. FFT Interpolation

While 2cm resolution is adequate for breathing, we are not able to recover heart beat signal which may only cause the chest to move in the order of millimeter. Hence, we proposed a novel interpolation method on the FFT peak search to improve the achievable accuracy. The interpolation of FFT peak is performed as follows:

1) Perform a peak search in the correct "bucket" given a pre-knowledge of the estimated frequency, and assume only one peak resides in the frequency range of interest.
2) Since the peak is very unlikely to fall exactly in one bin, we interpolate the peak and the second largest value to find a precise phase offset using the FFT. Interpolation revolves around the two consecutive FFT samples based on the initial peak search result. Denote the peak index with k, and the next highest peak index with $\mathrm{k}+1$. By taking the ratio of two consecutive samples, we wil find a ratio R:
$$R = \frac{X[k]}{X[k+1]} = \frac{1 - re^{-\frac{j2\pi}{N}}}{1-r} \tag{3}$$
where $\mathrm{r} = \mathrm{e}^{\frac{\mathrm{j}2\pi\delta}{\mathrm{N}}}$ is the frequency shift, and δ is our fine frequency offset. In other words, we can now solve for r now as a function of R, and extract the phase information from that.
3) Use the previously mentioned coarse tracking plus the additional fine tracking to get precise distance measurements

It is worth notice that the proposed interpolation method revolves around the definition of the FFT, and the fine resolution is guaranteed with appropriately selected sweep frequency (f_{min} and f_{max}) of the chirp signal. For this project, we sweep the signal from 10kHz to 20kHz with a sweep time of 50ms, targeting a maximum distance of 2m, we can achieve a distance measurement with a maximum error of 0.25mm. Also, this method could be applied to identify multiple people simultaneously if they are separated sufficiently for our course FFT to resolve (>2cm). In presence of three signals, assuming each 5cm apart distance, we are able to extract three distinct peak from the received signals while still maintaining a maximum error of 7.2mm.

For the above analysis, we have assumed that only one peak reside in the frequency spectrum of interest. However, in practice, it may occur that multiple peaks of comparative power are identified within the same frequency range. Under such condition, our coarse FFT cannot resolve them individually, resulting in large errors for further analysis. For this project, we will be focusing on demonstrating the feasiblity of implementing Vital-Radio idea [2] using mobile phone. So the testing is conducted to ensure only one moving object at presence.

III. Experimental Results

In this section, we presents our experimental results obtained so far. While the ultimate goal is to implement Mobile Vital Radio on cell phone, at the current phase of the project we are transmitting signal using laptop's speaker and receiving signal using cell phone. The FFT is performed using MATLAB by uploading the audio files of transmitted and received signals to the laptop. In order to correctly start the peak search, we need to first run a cross-correlation between the transmission and reception since we are currently employing two different devices. Based on the correlation result, we are able to identify the starting point of our FFT.

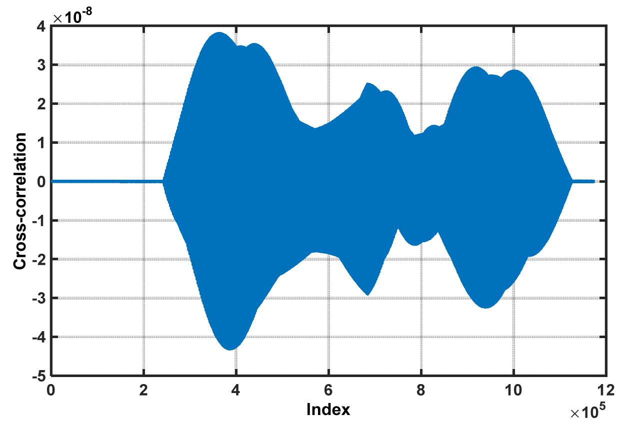

Fig. 2: Cross-correlation between transmitted and received signal of FMCW transmission.

As shown in Fig. 2, the cross-correlation of the two audio files does not show a peak indicating the index shift required corresponding to the distance offset between our position of speaker and microphone. Instead, the obtained cross-correlation actually shows amplitude-modulated waveform, which we believe is caused due to the sampling frequency offset between the two devices. In order to resolve such discrepancy between hardwares, we decide to first design an android application that is able to access both the microphone and speak of the cell phone so that the testing setup could be conducted using cell phone only.

Next, we tested the possibility to identify static and dynamic object (assuming only one at presence) in the environment. For this experiment, we run the peak search and choose the first five peaks identified in the spectrum. As shown in Fig. 3, we are able to correctly identify the movement of the object (data 5 in the plotted figure). Small fluctuations are observed due to the fact that we have to manually press the recording and move away from the cell phone to prevent further disturbance. However, such action may still result in unnecessary noise in the process. We hope to address the issue with the android application.

IV. To Do List

We are able to demonstrate that our algorithm successfully identify dynamic and static objects in the environment within a maximum distance of 2m with respect to the cell phone. As shown in Section III, we plan to work on the following:

1) Design android app to resolve issues caused during the phase of recording itself.

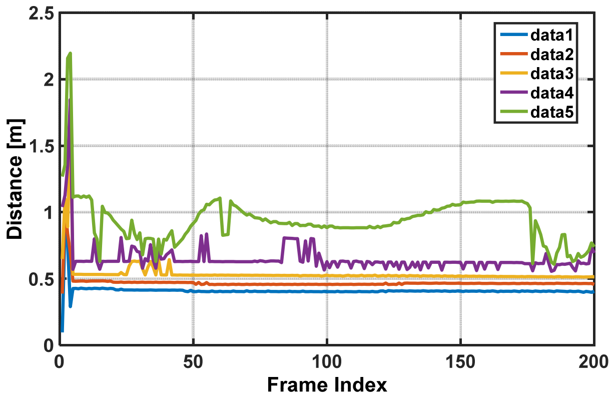

Fig. 3: Path profile demonstrates that we are able to identify static and dynamic object in the environment.

2) More measurements with dynamic objects and move onto capturing the breathing movement.

REFERENCES

[1] R. Nandakumar, S. Gollakota, and N. Watson, "Contactless sleep apnea detection on smartphones," in *Proceedings of the 13th Annual International Conference on Mobile Systems, Applications, and Services*, ser. MobiSys '15. New York, NY, USA: ACM, 2015, pp. 45–57.

[2] F. Adib, H. Mao, Z. Kabelac, D. Katabi, and R. C. Miller, "Smart homes that monitor breathing and heart rate," in *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*, ser. CHI '15. New York, NY, USA: ACM, 2015, pp. 837–846.