

Comprehensive Vital Sign Detection using a Wrist Wearable Nonlinear Target and a 5.8-GHz ISM Band Intermodulation Radar

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Abstract — Nonlinear components can be used to generate third order intermodulation frequencies. Taking advantage of this phenomenon the movement of a nonlinear target can be monitored and distinguished from background clutter. This paper discusses the use of an intermodulation radar, operating in the 5.8-GHz ISM band, and a passive nonlinear tag, located on the wrist, to monitor human vital signs and more specifically to improve remote monitoring of the heart rate. The non-ideal background clutter rejection of an intermodulation radar allowed for the respiration rate to also be monitored. Since the movement of the chest reflects the two individual tones from the transmitter and not the third order intermodulation frequency, for which the receiver is tuned, the respiratory frequency component has a scaled amplitude in comparison to what is seen with the use of a Doppler radar. This prevents the heart rate from being indistinguishable from the harmonics of the respiration.

Index Terms — Intermodulation, nonlinear target, wearable passive tag, vital signs, clutter rejection.

I. INTRODUCTION

Much research has gone into the use of various types of short-range radars to detect human vital signs and for other biomedical applications. This has been achieved with success and various applications have also previously been discussed and implemented, [1].

In existing research, it was shown that when radars are used to monitor vital signs, the movement of the chest caused by respiration is of a much larger amplitude than any movement caused by the heartbeat. This can often cause difficulties for the monitoring of heart rate as the harmonics of the much greater respiration frequency can make it difficult to identify which frequency peak is that of the heartbeat.

In recent years, radars designed to receive frequencies different from those which are transmitted, such as harmonic and intermodulation radars, have become more commonly used to distinguish between a target and background clutter, [2]-[4]. These radars allow for very small movements to be distinguished from a noisy background environment.

Wrist based wearable devices which provide information on health-related parameters, such as heart rate, sleeping patterns and so on, have become increasingly popular in recent times. However, none of these products offer information on respiration without the use of an intrusive chest belt. Respiration is an important parameter for

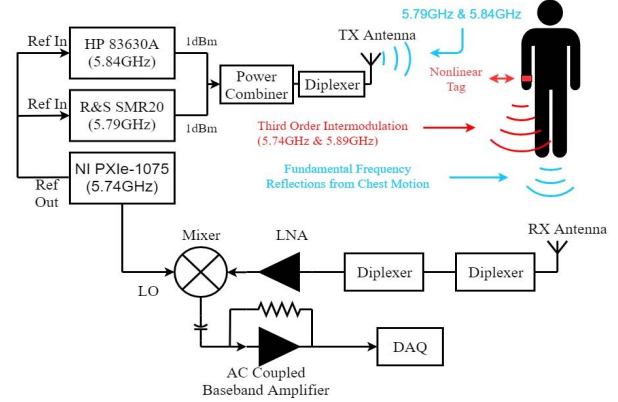


Fig. 1. Block diagram of the intermodulation radar and interaction with human target.

evaluating a person's health and is of particular importance in pediatrics. Respiration rate can also be useful information for people who suffer from sleep apnea, cystic fibrosis and other respiratory related diseases.

With all of the aforementioned in mind, a solution was devised in this paper, taking advantage of the benefits of intermodulation radars and easily distinguishable nonlinear tags. By using a nonlinear target worn over the pulse on the wrist, it was theorized that the heart rate would be seen as a strong frequency component of the radars received signal and that the respiratory frequency component would be seen as a scaled down version. This would allow for the heart rate to be more easily distinguished.

This paper evaluates the results of experiments performed for such a nonlinear tag and intermodulation radar system and a discussion on the performance of this method versus a single tone Doppler frequency for heart rate monitoring is also included. A conclusion is drawn in Section IV.

II. INTERMODULATION RADAR THEORY AND IMPLEMENTATION

The effects of harmonics and intermodulation are often considered to be distortion in a received signal. However, the radar used in this work uses the effects of intermodulation to its advantage to discriminate between the motion of the target and the rest of the environment. In particular, the radar used throughout the experiments conducted was designed to receive the third order intermodulation frequency.

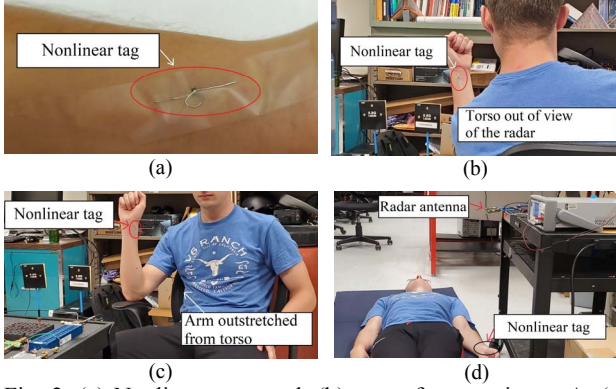


Fig. 2. (a) Nonlinear tag used, (b) setup for experiment A, (c) setup for experiment B, (d) setup for experiment C.

When a nonlinear component is subject to two frequency tones additional tones are generated. For example, if two tones pass through the nonlinear device, one at f_1 and one at f_2 , the additional third order intermodulation frequencies are generated at $2f_1 - f_2$ and at $2f_2 - f_1$. In addition, higher order intermodulation frequencies are generated. In this paper the third order intermodulation frequency of $2f_1 - f_2$ was utilized.

Fig. 1 provides a visual high-level representation of the intermodulation radar used throughout the experiments in this work. Two tones were transmitted simultaneously at 5.79 GHz and at 5.84 GHz. This resulted in third order intermodulation frequencies at 5.74 GHz and 5.89 GHz. Since the intermodulation frequency of $2f_1 - f_2$ was the desired frequency to be received, the local oscillator (LO) frequency of the receiver was set to be 5.74 GHz. A further description of the radar implementation used can be found in [3].

The passive tags used throughout the experiments consisted of a dipole antenna and a Schottky barrier diode, which provided the necessary nonlinearity in the tag, Fig. 2 (a), [4].

III. EXPERIMENTAL RESULTS

Various experiments were conducted to represent different possible positions for which a subject wearing the device could take. These experiments are outlined in this section with a description of the position taken and any other relevant experimental constraints included in each experiment's subsection. All spectrograms depict a typical portion of the relevant experiment's entirety.

A. Tag Performance for Pulse Detection

In order to initially test the performance of the tag, in terms of detecting the heartbeat from the pulse located in the wrist, an experiment was conducted with minimal background clutter within the view of the radar. To achieve

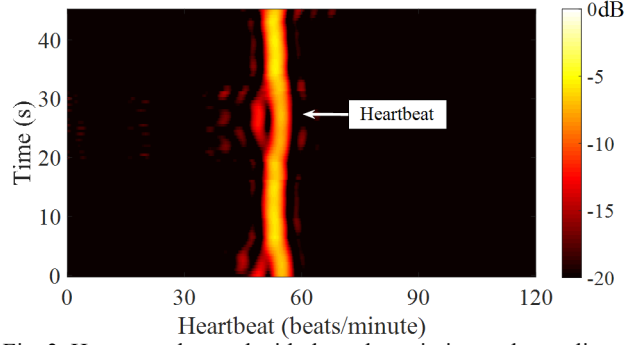


Fig. 3. Heart rate detected with the radar pointing at the nonlinear pulse tag only.

this the subject sat behind the radar antenna with only their arm and the nonlinear target in front of the antenna, as shown in Fig. 2 (b). This was done so that the torso of the human subject was behind the antenna, such that the chest movement did not interfere with the radar signal. The nonlinear target was mounted above the pulse in the wrist. The distance between the radar and the nonlinear target was kept at approximately 0.15 m. A heart rate reference was also used to compare with any results obtained.

The experiment provided promising results, showing that the movement of the target and the performance of the radar and nonlinear target system was sufficient to detect the heartbeat from the pulse in the wrist. Fig. 3 depicts a Short-Term Fourier Transform (STFT) spectrogram for the entire duration of the experiment.

As can be seen from Fig. 3, there is a strong continuous periodic motion found at approximately 54 beats/min or 0.9 Hz. When this was compared to the reference heart rate, it was found that this accurately represented the heart rate of the subject (it should be noted that the subject of this experiment has an athletic background, thus, accounting for the lower than average recorded heart rate).

B. Comprehensive Vital Sign Detection for a Seated Subject

Once it was confirmed that the nonlinear target placed over the pulse was capable of detecting a heartbeat, a second experiment was devised to detect both the heartbeat and the motion of the rib cage caused by breathing. The subject sat facing the radar with their arm raised in a vertical position, Fig. 2 (b). The nonlinear tag was mounted to the wrist in the same fashion as in the first experiment.

Two variants of this experiment were conducted. Following the initial experiment, it was observed that the arm was affected by the motion of the chest due to the upper arm being rested against the subject's torso. The result of this can be seen in Fig. 4. A second experiment, with the arm outstretched and not resting against the torso, was completed with the acquired data providing a more easily

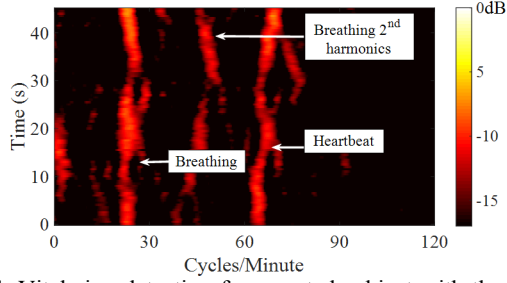


Fig. 4. Vital sign detection for a seated subject with the elbow resting against the torso.

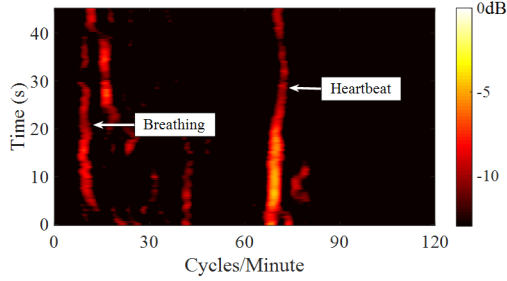


Fig. 5. Vital sign detection for a seated subject with elbow outstretched.

distinguishable heartbeat signal in the resultant spectrogram, Fig. 5.

C. Comprehensive Vital Sign Detection for a Supine Subject

In an attempt to replicate the intended conditions for use, a test was devised where the subject lay in a supine position, as seen in Fig. 2 (d). The distance between the tag and the antennae of the radar was retained at approximately 0.41m. The tag antenna and radar antennae were oriented in a suitable manner to strive for the maximum received signal power. The aim of this experiment was to detect and monitor both the respiration rate and the heart rate of the subject. The subject wore a heart rate detector on their finger in order to supply a reference signal.

The acquired data is depicted in a visual representation in the spectrogram seen in Fig. 6. It was observed that there was a clear periodic frequency component of the signal at approximately 1 Hz (60 cycles/minute), which lies within the expected frequency range of a human heart rate. When the signal's frequency components were compared to the frequency components of the reference heart rate (represented by the green line seen in Fig. 6) it was found that the frequency component at 1 Hz did, in fact, represent the heart rate of the subject.

D. Comparison to Doppler Radar for Vital Sign Detection

Since the heart rate can be detected using a simple Doppler radar, a test was conducted with a Doppler radar under the same conditions as those described in the experiment above, 'Comprehensive Vital Sign Detection

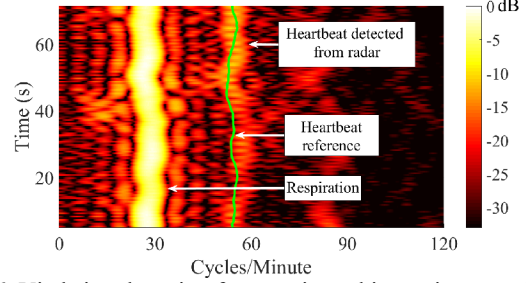


Fig. 6. Vital sign detection for a supine subject using a nonlinear tag and intermodulation radar.

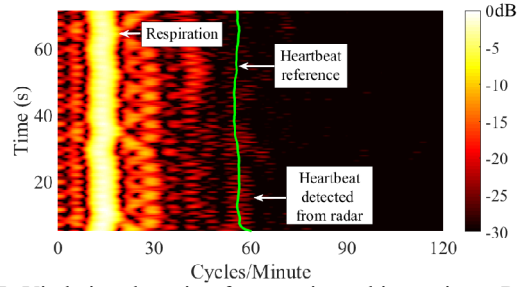


Fig. 7. Vital sign detection for a supine subject using a Doppler radar.

for a Supine Subject'. This provided a means of comparison between both methods of vital sign detection.

By analyzing the spectrograms depicted in Figs. 6 and 7, it can be concluded that the intermodulation radar and nonlinear tag system outperformed the Doppler radar in this scenario. The heart rate is more easily distinguishable in Fig. 6.

IV. CONCLUSION

A passive nonlinear tag and intermodulation radar were used to more accurately detect the heartbeat of a subject, in comparison to a conventional Doppler radar, whilst also using the non-ideal background clutter leakage of the intermodulation radar to monitor the subject's respiration. This method of vital sign monitoring could potentially be used in wearable devices for the fitness consumer market and in the healthcare industry. Future work includes optimizing the design, and thus the performance, of the nonlinear tag to allow for further increased sensitivity in heartbeat detection using the reflected third order intermodulation signal.

ACKNOWLEDGEMENT

The authors wish to acknowledge the support of the Texas Tech University REU program. The authors also wish to acknowledge the National Science Foundation (NSF) for funding support under Grant 1808613 and 1718483.

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