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Non-Contact Cardiopulmonary Sensing with a Baby Monitor

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Abstract— **Cardiopulmonary signals can be detected at a distance using simple Doppler radars operating in CW mode. Tests with and without audio modulation show the feasibility of measurements with this hardware, providing a maximum measured difference to the reference of just 1.6bpm for heart rate. Tests show good correspondence of heart/respiration rate with the reference data.**

I. INTRODUCTION

Remote detection of cardio-pulminary function has been demonstrated [1], [2] using commercial off the shelf hardware. While readily available, bench systems are still expensive and require expert knowledge to setup and use. This paper describes a Doppler radar system capable of cardiopulmonary detection built with low cost hardware. This low cost radar system could be developed into a product useful for large organizations needing many installations in addition to private use.

This system is based on a standard 2.4GHz wireless baby monitor. The baby unit provides the radio signal and a passive sensor node [3] uses this signal and its reflection off the target to generate a doppler output signal.

II. BACKGROUND

A. Goal

The goal of this project is to demonstrate a functional Doppler radar system capable of using low cost hardware to sense the heart rate of a subject. RF signal reflected from the body is phase modulated by chest motion. Phase demodulation can be performed using a simple mixing device that uses part of the Tx signal as the LO. In this experiment, a baby monitor provides both the LO (direct path) and RF signals (reflected from the subject) coupled through the air to the sensor node, and sensor node performs phase demodulation before the signal is digitized for further analysis (heart rate extraction) with software.

B. Common Setup

In all tests, the transmitter and sensor node were located 1m from the sitting subject. The same node and post processing were used, leaving the transmitter as the sole difference. Fig. 2(a) shows the arrangement of the baby monitor, subject, and node. The baby monitor and node were placed in close proximity to each other to provide a strong reference signal for the node to use as a LO.

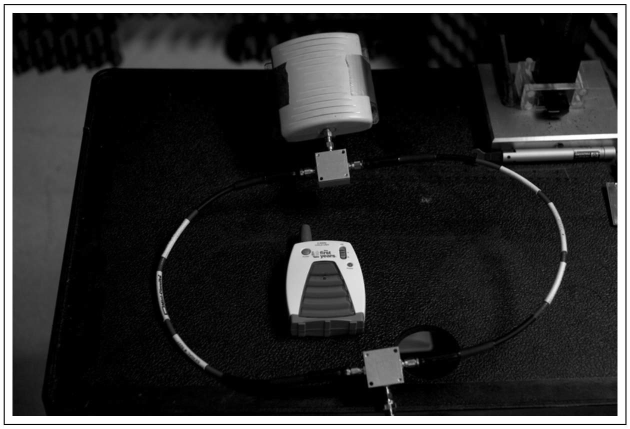
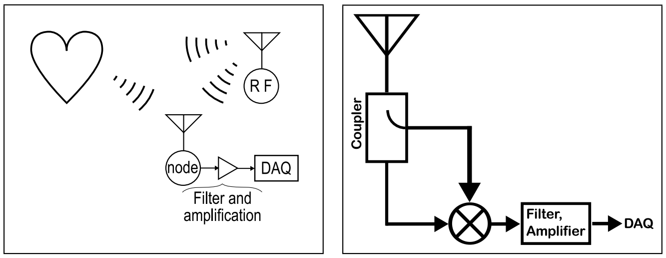


Fig. 1. Baby monitor transmitter and passive receiving node



(a) (b)

Fig. 2. test setup

1) Sensor Node: The sensor node used for receiving and demodulating the radar signal is described in [3]. The diagram in Fig. 2(b) shows the simplicity of the electrical circuit. A 60° Antenna Specialist patch antenna (ASPPT2988) was used in conjunction with the node, composed of a Minicircuits splitter (ZFSC-2-2500) and mixer (ZFM4212).

2) Signal Processing: The signal from the sensor node was passed through a bandpass filter (0.3 - 10 Hz) and amplified (80dB) before digitization with a NI USB-6259.

3) Reference Sensors: For all tests, reference heart and respiratory rates were collected using a finger pulse sensor (UFI 1010) and a chest belt breath sensor (Pneumotrace 1132). These were digitized with the same NI DAQ system in parallel with the radar data.

C. First Test

The first test was conducted with a muted unit - this modification essentially eliminated the audio modulation and allowed for a test similar to the normal Doppler setup. A sensor node [3] was placed near the transmitter with the

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filtered and amplified signal recorded for offline processing by a computer based data acquisition system.

D. Second Test

In another test with the same model baby monitor, a second unit - in its stock configuration provided the RF signal for the Doppler radar system. Audio input for this test was provided in the form of recorded music.

E. Performance Metrics

The performance of the low cost system was determined by checking the maximum difference in beat to beat intervals recorded as well as calculating the PMCC.

III. RESULTS

A. Data

Raw data (shown in Fig. 3), after filtering, was scanned with a moving FFT window to calculate the rates as in [3] to determine the heart and respiration rates. These heart and respiratory rates, both contact (reference) and non-contact (sensor) as a function of time can be seen in Fig. 4. Though the sensor is typically within one beat per minute (bpm) of the reference, the maximum of 1.6bpm is near t=100s. Similar to the heart rate vs. time, respiration rate vs. time is plotted in Fig. 5 and shows the maximum difference between the radar and reference rates of only 0.29 breaths per minute.

B. Analysis

In addition to time plots for comparison between the reference and the radar detected rates, the Pearson product-moment correlation coefficient (PMCC) was calculated for heart and respiratory rates to determine how closely the radar (x) and reference (y) data were correlated [4]. The PMCC between two datasets x and y can be calculated with

$$r_{xy} = \frac{\Sigma(x_i - \mu_x)(y_i - \mu_y)}{(n-1)\sigma_x \sigma_y} \qquad (1)$$

where μ_x is the mean and σ_x is the standard deviation. The PMCC was chosen to provide a numeric indicator for the linear relation between the radar and reference data. These as well as the average ($\Delta_{avg} = n^{-1} \cdot \Sigma|x-y|$) and maximum ($\Delta_{max} = \lceil |x-y| \rceil$) differences are available in Table I. Graphical indicators in the form of XY plots (radar→X-axis, reference→Y-axis) are depicted in Fig. 6.

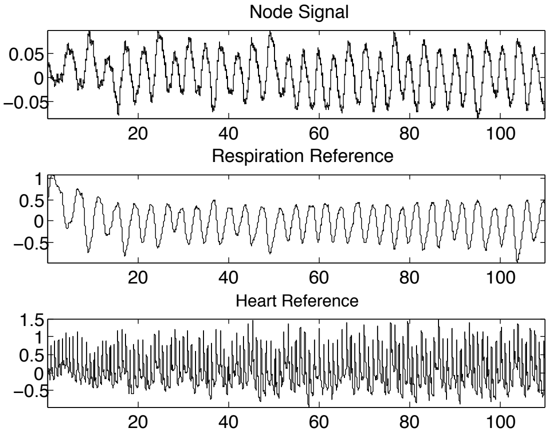


Fig. 3. Data traces before software processing

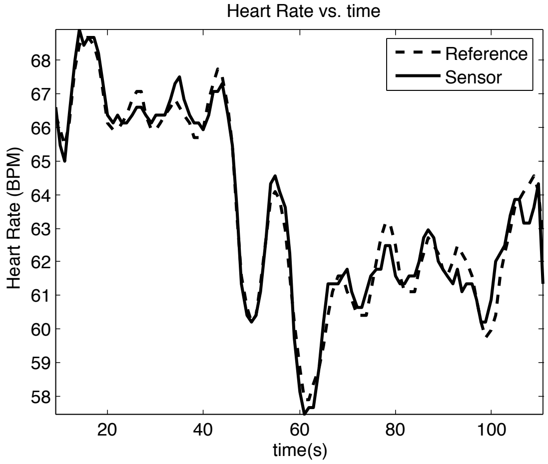


Fig. 4. Reference and radar sensed heart rate

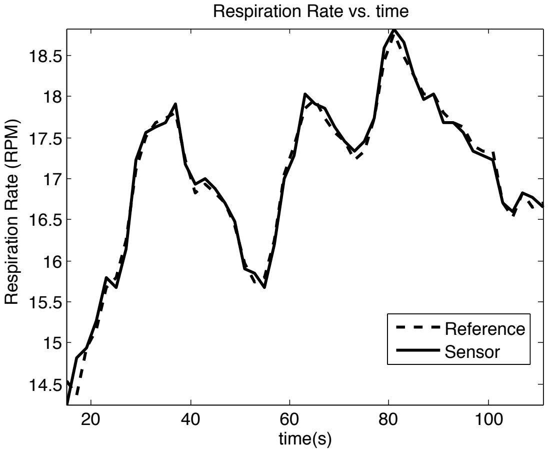


Fig. 5. Reference and radar sensed respiratory rate

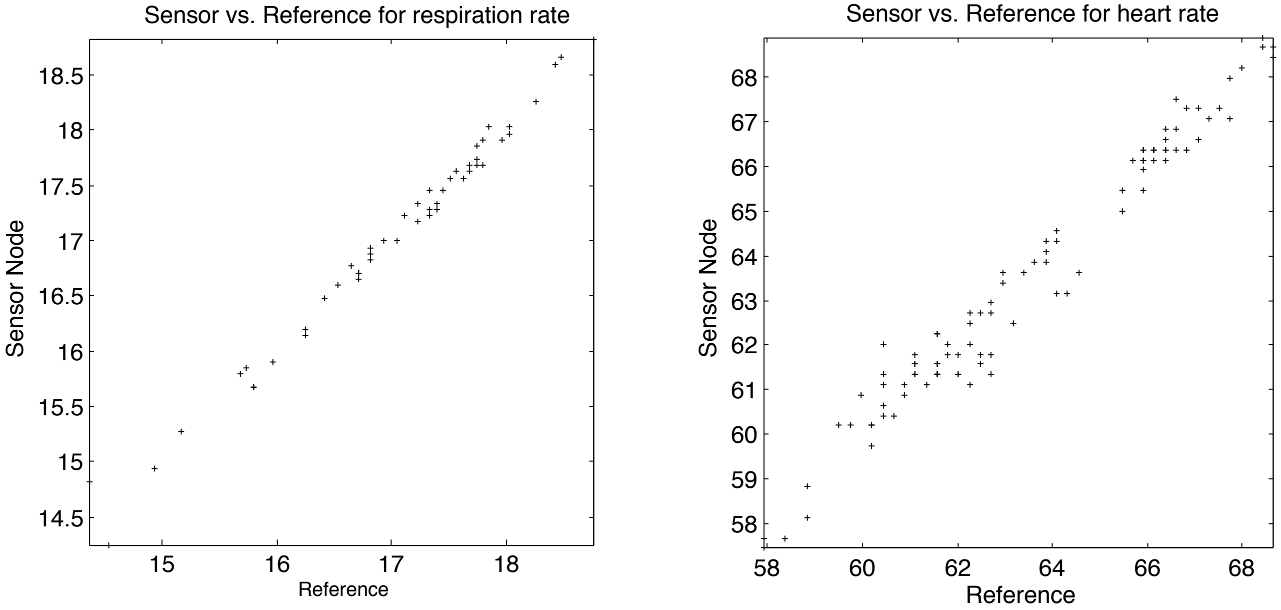
C. Discussion

These results show that inexpensive hardware is capable of operating in the role of an RF generator for a Doppler radar system for biological monitoring. This specific test involved FM transmission of music through the baby monitor while monitoring the heart and respiratory rates.

TABLE I

RADAR TO REFERENCE COMPARISONS

metric	Breath	Heart
Δ_{max}	0.458	1.602
Δ_{avg}	0.085	0.396
$PMCC$	0.994	0.984



(a)

(b)

Fig. 6. Reference vs. Doppler

IV. CONCLUSIONS

A. Conclusions

As demonstrated, a baby monitor based Doppler radar system is feasible and would be able to measure cardio-pulminary function remotely. Building on this system, it may be possible to build the sensor node into the transmitter portion and send the sensed cardio-pulmonary data in the audio band to the parent unit for display or recording.

B. Future Work

In addition to further linear design iterations of this simple prototype, more advanced designs can be also utilised, such as quadrature decoding [2], HRV extraction [5], alarm sensing based on measured cardiopulmonary function, and in some cases piggybacking the Doppler receiver on the "parent" unit .

One such prototype might consist of the radio transmitting half of the baby monitor pair with a pair of sensor nodes able to feed their data to a small custom data processing card in the baby unit. The baby unit could send audio heartbeats to the parent, coded data indicating the baby's health, or an alarm signal whenever an unexpected event occurs. Since radio transmission of audio signals does not adversly affect the operation of this Doppler radar system, the audio heartbeats or the coded data could be sent as a signal in the audio band.

While the current sensor node is significantly larger than a typical baby monitor, future versions could be much smaller, thus enabling a node to be integrated inside a baby monitor (or handheld radio) along with sufficient signal processing capability to detect and analyze heartbeats.

V. ACKNOWLEDGMENTS

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