Poster: Robust Respiration Monitoring using Low-cost Doppler Sensor and Wireless Network

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ABSTRACT

This work proposes a novel respiration monitoring system using Doppler signal from a low-cost motion sensor and received signal strength (RSS) measurements from a wireless network. We present the ambiguity problem of the Doppler monitoring system. We find that RSS from a wireless network is complimentary to Doppler signal, and we propose to integrate Doppler with RSS to make respiration monitoring more robust. Our experimental results show that the respiration rate estimation is more accurate by sensor fusion of these two radio frequency (RF) sensing modalities.

CCS Concepts

•**Computer systems organization** → **Sensor networks;** *Embedded software;* •**Hardware** → *Sensors and actuators;*

Keywords

Doppler, Radio frequency, Wireless network

1. INTRODUCTION

Respiration rate is one of the primary vital signs, and respiration monitoring is important in many aplications such as patient monitoring, elder care, and smart facilities. Previous studies have shown that Doppler motion sensor, ultra-wide band radar, and wireless network can all be used to monitor a person's respiration in a non-contact way. In [1], a low-cost Doppler sensor was modified from a commercial-off-the-shelf (COTS) range-controlled radar sensor, to monitor a person's respiration motion. In [2], received signal strength (RSS) measurements from a wireless network were used to detect human respiration and estimate respiration rate. Further, [3] used wireless frequency and space diversities of a network to monitor respiration of a person with different poses. However, these RF-based methods and systems are evaluated in their own custom and controlled environments, and little research has been performed to compare their performance under the same real-world condition.

MobiCom'16 October 03-07, 2016, New York City, NY, USA

ACM ISBN 978-1-4503-4226-1/16/10.

DOI: http://dx.doi.org/10.1145/2973750.2985282

In this work, we investigate two low-cost RF-based respiration monitoring systems: Doppler sensor and wireless network. We perform human subject experiments at the same environment with the same condition to evaluate their performance. More importantly, we find these two sensing modalities are complimentary, and we propose to use sensor fusion to build a more robust respiration monitoring system. Specifically, we investigate the Doppler system developed in [1] and the wireless network system developed in [3]. We find that in general, the Doppler system outperforms the wireless network system, due to the fact that Doppler signal has finer granularity and higher signal-to-noise ratio. However, in very few cases, the wireless network system is significantly more accurate than the Doppler system. We further investigate these cases, which lead to the finding of an ambiguity problem of the Doppler sensor. This ambiguity problem causes a wrong estimate that is twice the true respiration rate. It happens when respiration motion includes movements from different parts of the body, e.g., the chest and the abdomen. Looking into the Doppler sensing formulation, we argue that the ambiguity problem is caused by the fact that the low-cost Doppler sensor cannot distinguish the direction of the motion, e.g., inhale and exhale motion. We also find that RSS measurements from a wireless network are affected by the multipath effect, but do not suffer from the ambiguity problem. Thus, we propose to use maximum likelihood estimation (MLE) algorithm to estimate respiration rates from Doppler and RSS measurements, and then use a voting scheme to resolve the ambiguity problem to make respiration monitoring more accurate and robust. Our initial experimental results show that the respiration rate estimation error can be reduced to less than one breath per minute by using our sensor fusion approach.

2. SYSTEMS AND METHODS

2.1 Testbed System

Our testbed system includes three components: 1) a Doppler motion sensor with a directional antenna; 2) a wireless network of four nodes and a basestation to collect all pairwise RSS measurements; and 3) a spirometer to measure the airflow rate of respiration as the ground-truth. The Doppler sensor is modified from a commercial range-controlled radar, originally designed for home security. The Doppler sensor operates at the 5.8 GHz industrial, scientific and medical (ISM) band [1]. The wireless network is composed of TI CC2531 USB dongles, which operate at the 2.4 GHz ISM band. In this work, four wireless nodes are programmed

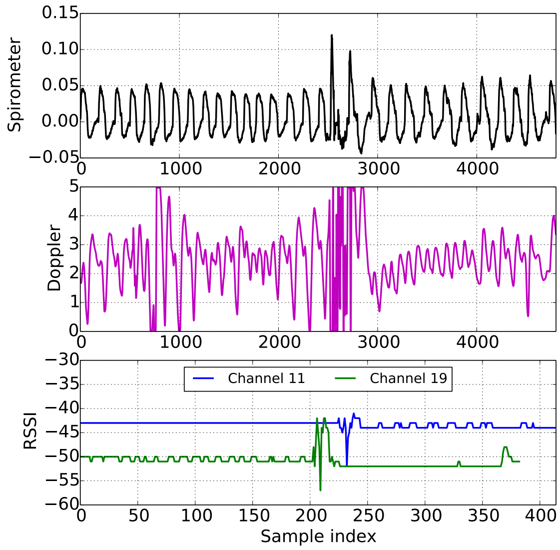

Figure 1: Experimental data from spirometer, Doppler, and RSS on two channels. Doppler signal has finer granularity, but suffers from the ambiguity problem; while RSS has lower resolution, without the ambiguity problem.

with a time division multiple access (TDMA) network protocol to measure RSS from multiple channels [3]. We show data recorded by the spirometer, Doppler sensor and wireless network in Figure 1.

2.2 Methods

The details of the two RF sensing methods: Doppler and wireless network, can be found from [1] and [3], respectively. Here we show the ambiguity problem of the Doppler sensor and our sensor fusion approach to solving this problem.

2.3 Ambiguity problem

From Figure 1, we see that the Doppler signal has finer granularity, compared to the RSS measurements. At the beginning of the experiment, there is a primary peak with a secondary peak in the Doppler signal for each respiration motion. For certain respiration, the two peaks are almost equivalent, making two periods corresponding to one respiration motion. For the second half experiment after the person turns his body, the Doppler signal shows two periods corresponding to one single respiration period for seven times. That is, the Doppler-based MLE solution is doubled the true respiration rate. We notice that this ambiguity problem happens when there are respiration movements from two parts of the human body, for example, the chest motion and the abdomen motion. Since the Doppler frequency shift measured by the Doppler sensor is the absolute difference between two frequencies, the Doppler sensor cannot distinguish the direction of the motion, e.g., inhale and exhale motion. If the chest moves upwards while the abdomen moves downwards, there will be a phase difference of 180 degrees between these two components, thus two periods will correspond to one respiration, causing the ambiguity problem. However, the wireless network sensing system uses RSS measurements, which are affected by the multipath effect, but not sensitive to the Doppler effect. Thus RSS measurements are complimentary to Doppler signal, and can be used to resolve the ambiguity problem for Doppler sensor.

2.4 Sensor fusion with voting scheme

Now we propose to combine Doppler and RSS measurements with a voting scheme. Since the Doppler signal has a finer granularity and higher SNR in general, we propose to use the Doppler as the primary sensor, and use RSS to deal with the ambiguity problem. We first estimate the respiration rates from Doppler and RSS measurements: $\hat{F}_{Doppler}$, $\hat{F}_{Network}$. Then if $\frac{\hat{F}_{Doppler}}{\hat{F}_{Network}} \sim 2$, we detect the ambiguity problem happens, and we use the RSS estimate as the final estimate $\hat{F} = \hat{F}_{Network}$. If we do not detect the ambiguity problem, we use the Doppler estimate $\hat{F} = \hat{F}_{Doppler}$ instead. Here we use the fact that the ratio of $\hat{F}_{Doppler}$ to $\hat{F}_{Network}$ is approximately equal to two, for detecting the Doppler's ambiguity problem. We can also define a range of values close to two, to include estimation errors from RSS and Doppler. The specific range will be determined by the noise characteristics and the performance of the estimation algorithms.

3. EXPERIMENTS AND FUTURE WORK

We perform human subject experiments at an indoor mock hospital environment. We deploy the Doppler sensor above a bed on the ceiling, with the directional antenna facing down towards the bed. We also deploy four wireless nodes CC2531 USB dongles powered by battery packs on the bed frames. During the experiments, we ask the human subject to lie on bed and wear a disposable mask so that we can use a spirometer to record the airflow data as the ground truth. In one experiment, we ask the person to turn his body from facing upwards at the beginning to his right side after one minute, and then keep the same posture for the rest of the test. The spirometer, Doppler and RSS data are shown in Figure 1. Note that the body turning motion causes high variations in both Doppler signal and RSS measurements. The spirometer data show that the person breathes 30 times during the two minutes time period: 17 times before the turning, 2 times during the turning, and 11 times after the turning. The RSS on channel 19 is able to capture the 17 respiration motion before the turning, while the RSS on channel 11 is not sensitive to the respiration motion. For this particular experiment, the Doppler system has an absolute error greater than five BPM due to the ambiguity problem.

We use experimental data to show that these two sensors are complimentary for respiration monitoring. We propose a loosely-coupled sensor fusion approach to integrate RSS with Doppler. We plan to perform more human subject experiments and also investigate other sensor fusion methods in the future.

4. REFERENCES

[1] C. Graichen, et. al. Unobtrusive vital signs monitoring with range-controlled radar. In *IEEE SPMB*, pages 1–6, Dec 2012.

[2] N. Patwari, et. al. Monitoring breathing via signal strength in wireless networks. *IEEE Transactions on Mobile Computing*, 13(8):1774–1786, August 2014.

[3] Y. Zhao, et. al. Respiration monitoring using a wireless network with space and frequency diversities. In *IEEE ICCE*, pages 474–477, Jan 2016.