EasySense: Contact-less physiological sensing in the mobile environment using compressive RF probes

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Motivation

Long-term monitoring of physiology at large-scale can help determine potential causes and early biomarkers of fatal diseases of slow accumulation such as cancer and heart diseases that are major causes of mortality.

Physiological monitoring today, however, requires sensors attached to the body surface such as electrodes for ECG and EMG. The burden associated with the use of wearable sensors in daily life especially for long-term usage is a major roadblock to the widespread adoption of mobile health, especially among patients.

In this project we aim to develop and evaluate a mobile device that can provide physiological measurements without body contact in both lab and field environments.

Project Aims

- Develop theory and reference designs for UWB radar sensing with compressive sampling
- Investigate compressive subspace estimation and cancellation methods for canceling motion artifacts using data obtained from accelerometers and gyroscopes
- Integrate radar sensor with digital backend and low power radio transceiver for mobile phone integration.
- Implementation of firmware (compressive sampling, processing, and wireless communication) and mobile phone software (data collection, storage and visualization).
- Conduct a user study with 20 subjects in the lab environment under a rigorously validated stress and exercise protocol to validate EasySense with validated physiological sensing devices.

System Concept

RF Doppler sensors for vital signal monitoring have been developed previously. However these systems are typically narrowband and have no spatial resolution. As a result these sensors are unable to decouple the movement of limbs and sensors from that of heart and lung. We adopt a MIMO UWB sensing architecture, that can integrate information spatially-temporally to identify and track weak physiological signals of interest.

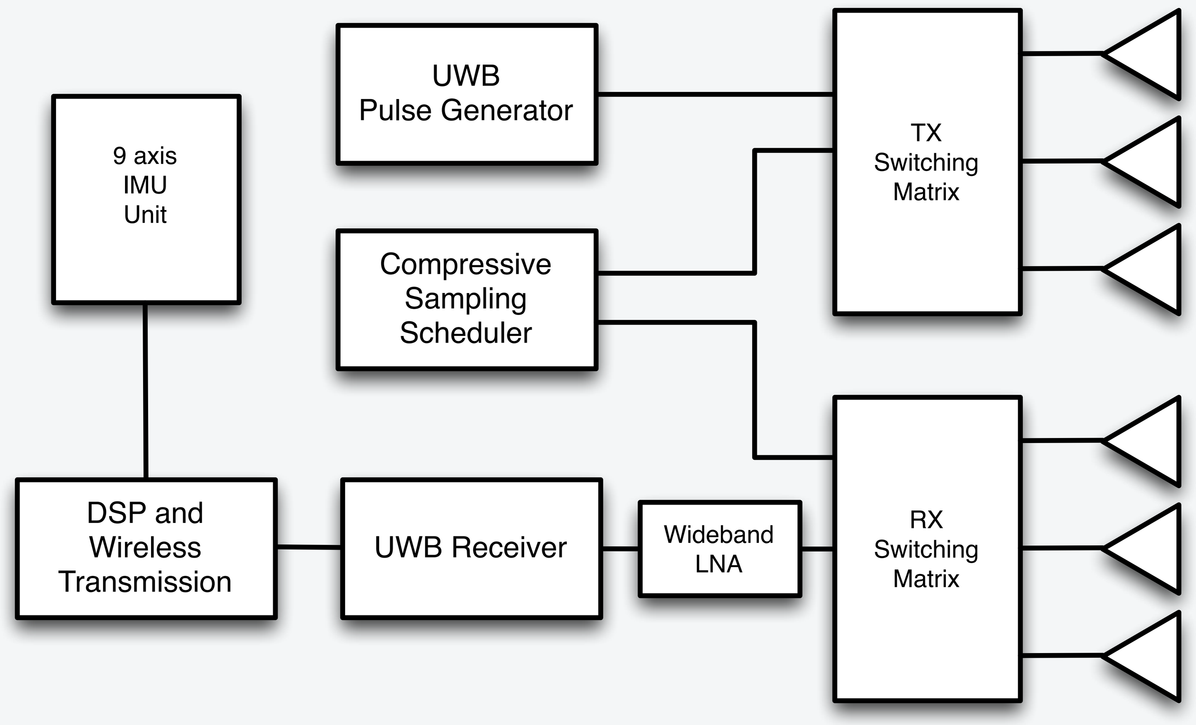
We integrate a MIMO switching matrix for compressed sampling using a single receiver to identify and separate signal sources due to physiological processes and background clutter, motion artifacts. The dynamic sensing problem can be expressed as:

$$\boldsymbol{y}(t) = \boldsymbol{A}(\phi, r)(\boldsymbol{x}_D(t) + \boldsymbol{x}_I(t)) + \boldsymbol{n}(t).$$

This model allows the support sets of the signals and the amplitudes of the active coefficients to vary smoothly in time. If the interference subspace can be estimated then compressed recovery can be applied as:

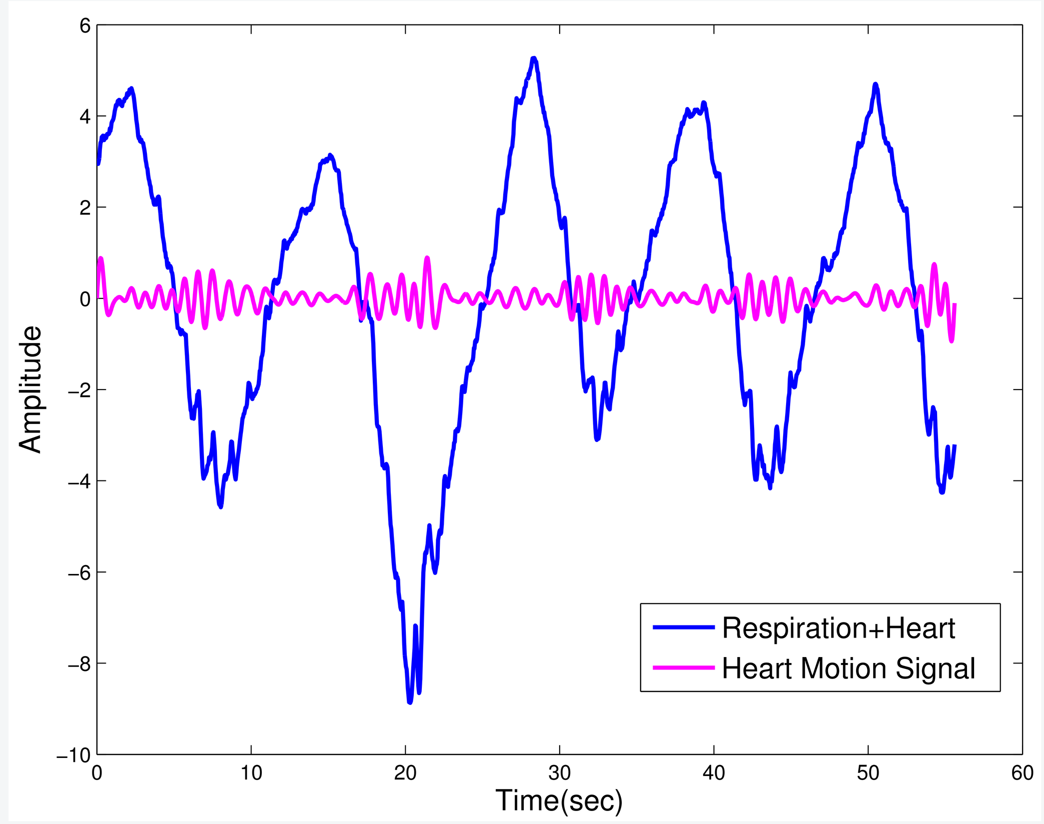
$$(I - \Phi_I \Phi_I^H)y = (I - \Phi_I \Phi_I^H)A\boldsymbol{x}_D + \tilde{n}$$

In practice, the interference subspace $\mathcal{R}(\Phi_I)$ is not known a priori. We propose the integrate 3D axis accelerometers and 3D gyro measurements from the strap to estimate the inference subspace due to sensor motion artifacts.



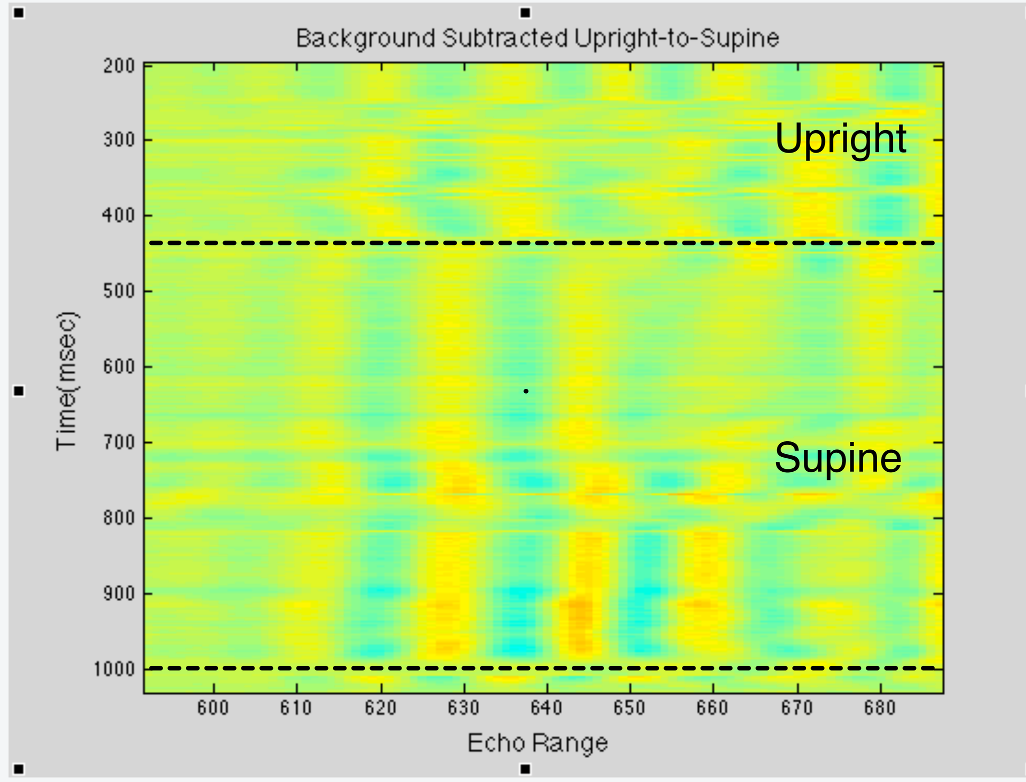
Smart Health Application 1(Cardio-respiratory Monitoring)

RF frequencies penetrate all skin,fat, muscle tissue that makes up the human body. Each interface causes a different reflection. The movement of the reflection points can be tracked since it causes the phase of the reflected wave to change. Separating sources of motion in space, however, requires high resolution bandwidth, since the major return from air-to-skin interface at the chest wall is only few centimeters away from the heart. We have conducted stationary 0.45-3.55 GHz UWB measurements. Switching matrix was used to estimate and subtract the clutter subspace components due to direct leakage between transmitter and receiver.



Smart Health Application 2 (Monitoring of Lung Water)

Careful monitoring of fluid status in chronic heart failure patients can provide an early warning of decompensation and reduce the number of heart-failure related hospitalizations. A major unresolved challenge in reducing the number of HF hospitalizations is our inability to timely predict episodes of worsening HF, using either patient self-monitoring or remote monitoring of symptoms and daily weight. EasySense measures attenuation and time-delay of UWB waves as they travel through the body at the lung level. The attenuation and the time-delay increase as the amount of fluid in the lungs change, enabling EasySense to estimate the changes in the fluid level.



Future Work

We finished the second iteration of our design spiral, further integrating system components into a compact prototype form to be shared with the partner institutions for testing and validation. We have successfully demonstrated the system concept for stationary subjects. We will develop and test adaptive interference estimation and cancellation algorithms for monitoring subjects in motion. We plan to conduct two user studies: 1) A study with 20 subjects in the lab environment under a rigorously validated stress protocol to validate EasySense with validated physiological sensing devices. 2) A pilot study with 10 CHF patients visiting OSU Medical Center due to congestion, to assess concordance of EasySense measurements with fluid change measured during the patients' hospital stay.

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