Compressive Sensing Based Approach for Through-Wall Detection of Human Respiratory Rate: Performance Analysis

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Non-invasive detection of human vital signs such as the respiratory rate, heartbeat, etc. is important for both commercial and military applications. Some examples are disaster rescue services, health monitoring, homeland security, and urban warfare. Different radar systems have been considered for these applications. These mainly fall under three categories: continuous wave (CW) Doppler radar, UWB radar, and stepped-frequency (SF) CW radar. While the SFCW radar systems have advantages over both CW and UWB radar systems, they typically suffer from long data acquisition time, which can lead to aliasing while capturing scattered signals.

In this paper, we investigate a compressive sensing (CS) framework for the SFCW radar to detect human respiratory rates through-the-wall. The conventional SFCW radar sequentially transmits a set of continuous wave signals whose frequencies are increased by a fixed frequency increment to realize a large effective bandwidth. An antenna is used to receive the echoes from the scene. By utilizing the inverse Fourier transform of the frequency domain signal returns, one can determine the ranges from the radar to the targets. Fourier transform is then applied to extract the Doppler frequency shift due to motion during the human respiration. The emerging compressive sensing techniques are employed to compress both measurement frequencies and slow-time samples to resolve range profiles and respiratory patterns, enabling a significant decrease in data acquisition time, and reducing the amount of data to be processed.

Experiments are performed through simulations with multiple subjects behind the wall. It is shown that the proposed CS approach can successfully detect respiratory signatures of stationary subjects using less random measurements. However, the compressive sensing methods can only work effectively when the signal is super sparse, since the number of measurements increases linearly with the sparsity level of the target space. Hence, an analysis of the performance of the CS-based approach with respect to the target space sparsity is investigated. Moreover, scenarios where the subjects are in the near zone of each other are also investigated. When the subjects are close together, near interference due to mutual coupling does exist. Hence, a respiratory pattern of one subject can contribute to respiratory patterns of other subjects, which results in higher order harmonies in the frequency spectrum of each respiratory pattern.