Comparison of Radar Architectures Integrated in Wireless Sensor Network for Vital Signs and Human Being Detection

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STATING THE PROBLEM

The global population and the elderly population (65 years or older) in the world have been steadily increasing. This situation has resulted in a growing need for healthcare approaches that emphasize routine long-term monitoring. For this reason, contactless life detection is widely used in rescue service and remote medicine which has attracted a lot of attentions from all around the world. The micro-vibration activities of the biological human system, including heartbeat and respiration, can be detected to identify the life targets. The sensing of biomedical parameters can be made contactless, or remotely, by adopting radar techniques [1],[2],[3]. Utilizing the difference between biological and the static targets, namely the micro-doppler activities, enables to detect the life targets. The principle is that the mechanical movements of heart and lungs involve a periodic movement of the chest wall in the order of millimeters. The Doppler shifts caused by the chest wall displacement can principally be detected and in this way heart beat and respiration rate can be measured. Also the knowledge of speed and position are important parameters to monitor.

One of the largest obstacles is the accuracy of the weak signal reflected off the chest wall. Moreover, the received signals may be strongly disturbed by the influence of random body movements (i.e., movements of arms and legs, walking), which may be several orders of magnitude larger than the pulmonary activity and the heart movement. The received signal also gets more difficult to be analyzed in case multiple persons are present and due to clutter reflection as well. In order to resolve these problems and to increase the accuracy, radars may be connected together by a Wireless Sensor Network, meaning that each sensor node acts as radar next to the wireless communications capability. By combining the measured information of the various radar nodes, it is expected that a better estimate about the target (chest displacement, position, …) can be obtained. Using more than one radar implicitly assumes that the cost, and therefore the complexity, of the radar architecture and the feasibility of integration into the wireless network should be taken in account as well. For these reasons, the radar must be an optimized solution both at the signal and sensor constellation level, meeting conflicting boundary conditions (positioning, speed detection, accuracy, energy efficiency, costs…).

Three different set-ups have been evaluated, namely CW (Continuous-Wave) Radar, UWB IR (Ultra-Wide-Band Impulse-Radio) Radar, and SFCW (Stepped-Frequency-Continuous-Wave) Radar, in order to extract the micro-doppler frequency of the biological target. The results have been validated by simulation and experimental results. These radars can be easily integrated in a Wireless Sensor Network where by our evaluation criteria Zigbee is currently the optimal wireless technology for the communication part.

COMPARISON OF RADAR ARCHITECTURES

Due to its narrowband nature, a pure CW radar is not able to determine absolute distances, while it can measure the target’s velocity without ambiguity. In that way, a phase-shifted signal proportional to the chest-wall position that contains information about movement due to heartbeat and respiration can be detected [1]. The biggest problem of such kind of architecture is linked to its nature of constantly transmitting and receiving, which results in the inability to separate reflections temporally. A portion of the transmitted signal leaks from the transmitter to the receiver, either through coupling between the transmit and receive circuit, or directly through the antenna(s). Additionally, clutter reflects part of the signal and its noise sidebands back to the receiver, adding to the signal power at the frequency due to leakage. These unwanted signals result in a dc offset and low-frequency noise.

Unlike the CW Radar, both UWB-IR Radar and SFCW Radar present an ultra-wideband nature [2],[3]. This nature involves high range resolution and has many advantages in radar techniques:

1. ability to resolve closely spaced targets in range;
2. improvement in range accuracy;
3. reduction of the amount of clutter within the resolution cell;
4. reduction of multipath;
5. high-resolution range profiles;
6. aid in target classification;
7. increase the signal-to-clutter ratio.

Due to these features, both UWB-IR Radar and SFCW Radar represent the best candidates for our application. In this paper we compare these two types of radar having in mind the objective of vital sign detection, positioning and speed detection. To do this we consider a particular application in which a person (target) is free to move in a hallway. Accuracy, costs and complexity of the radar architecture play important roles.

In order to compare the two radar types, the same specifications and conditions have been used. It means that the two set-ups have the same bandwidth and central frequency. Both simulations and experimental results demonstrate that either UWB Radar technologies are able to detect vital signs and track persons (position and speed). Figure 1 and Figure 2 show respectively the detected position and the respiration rate of a person by SFCW Radar. Moreover both architectures are easily integrable in Wireless Sensor Network by Zigbee technology. As mentioned before, cost and architecture complexity represent important parameters to take into account. For these reasons, and considering our particular application, the SFCW Radar represents the best solution. The system is shown in Figure 3.

A step-frequency radar, in fact, has a narrow instantaneous bandwidth (corresponding to individual pulse) and attains a large effective bandwidth sequentially over many pulses in the processor. As the result, the hardware requirements become less stringent. Lower-speed ADCs and lower-level processors can be used. Moreover, the receiver bandwidth is smaller, resulting in lower noise bandwidth and higher signal-to-noise ratio. As compared with UWB-IR waveforms, frequency step waveforms require lower AD conversion sampling rates, low peak power sources, and slower computers to process smaller sets of data. In fact, to sample with good accuracy a UWB-IR pulse we need at least ten sampling points per pulse while in SFCW Radar we need to acquire one sample every time interval corresponding to each frequency. The latter time interval is many orders smaller than the sampling time of the UWB-IR Radar. Another important advantage of SFCW Radar is the rejection of multiple time around clutter. In fact, due to different frequencies of successive pulses, multiple times around clutter from ambiguous range will come at frequencies other than the one from the target area.

CONCLUSION

In summary, SFCW Radar provides the range resolution of wideband systems with the advantages of narrowband systems. This involves a cost effective and an attractive technique to detect vital signs and to track persons. Moreover, it can be easily integrated in Wireless

Sensor Network where currently Zigbee represents the most optimal wireless communication technology.

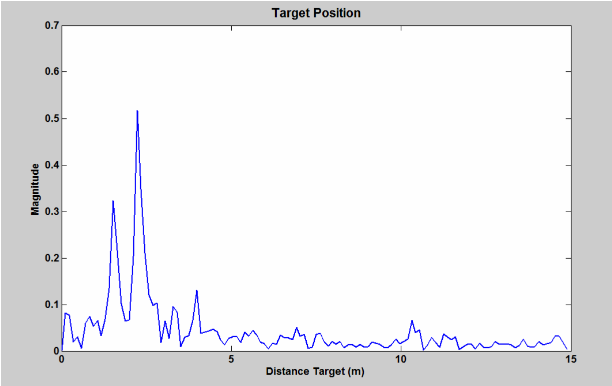

Figure 1: Range profile of target.

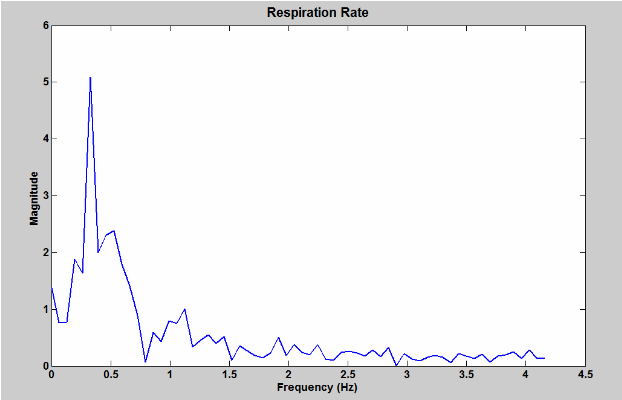

Figure 2: Respiration rate.

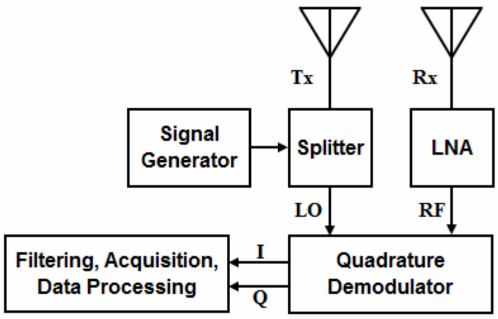

Figure 3: SFCW Radar system

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