Through-the-Wall Doppler-based Human Sensing

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***Abstract*— We present a low-cost Doppler-based system that enables human sensing and localization behind walls. In contrast to conventional through-the-wall radar systems, the proposed platform transmits low-power, band-limited signal (comparable to Wifi signal) using an off-the-shelf Software Defined Radio (SDR). Experiments have demonstrated its ability to detect human presence, classify 11 different human motions and localize moving persons with a high degree of accuracy, all under through-the-wall scenarios.**

Keywords*— *Through-wall radar, Doppler detection, motion classificaiton, software defined radio, deep learning

I. INTRODUCTION

In recent years, there has been a growing interest in detecting and localizing people in buildings, particularly in hostile scenarios [1][2], which enables law enforcement to infer the intentions of malicious individuals and make appropriate decisions. Our proposed system, which transmits RF signals and analyzes their reflections off the moving persons, is a reliable and affordable non-cooperative sensing solution that works even through opaque materials such as walls. In this abstract, we introduce the design and implementation of the proposed system, as well as its effectiveness in human sensing and localization.

II. THROUGH-WALL HUMAN SENSING SYSTEM

A. SDR-based Hardware and Experiment Setup

The through-wall motion sensing system operates on a National Instruments USRP-2954 SDR device which is used both as a transmitter and a receiver. The signal of choice is a CW WiFi-like orthogonal frequency-division multiplexing (OFDM) signal with 30MHz bandwidth, transmitted at an Effective Radiated Power (ERP) of approximately 10dBm with a carrier frequency at 5.4GHz. The setup is illustrated in Figure 1.

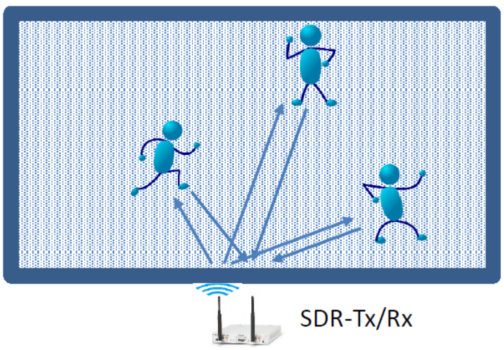

Fig. 1. Experimental setup schematic layout.

B. Signal Processing Techniques

The signal processing scheme of the system is summarized in Fig.2. Firstly, strong multipath interferences and leakage from the transmitter are removed from the received signal. The system reference signal is derived from a loop-back signal tapped from the output of the transmit channel. After cancellation, matched filtering and Doppler processing is performed.

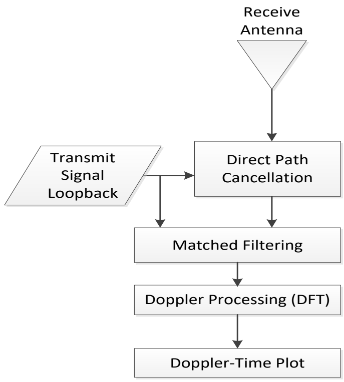

Fig. 2. Signal Processing flowchart for through-wall human sensing.

Due to the limited bandwidth of the system, the range resolution (5 meters for 30MHz bandwidth) is too coarse to be used to sense human motions. The Doppler-Time map which reveals the motion dynamics in its micro-Doppler signature, as shown in Figure 3, has sufficient sensitivity to detect fine movements such as hand and finger movements while typing.

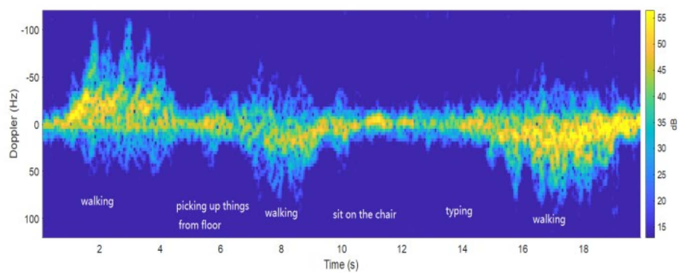

Fig. 3. Doppler-Time Map of a serial of human motions.

C. Deep Learning

To achieve human sensing with Doppler maps, we adopted a Deep Learning method. Unlike shallow learning methods (SVMs, Random Forest, etc.) that using handcrafted features, Deep Learning methods can automatically extract high-level, complex representations from the input data through a hierarchical learning structure and thus is more likely to provide a better solution when provided with a sufficiently large amount of training data. As Doppler measurements are sequential with temporal information for different activities, we employed a model of bi-directional LSTM, i.e., BLSTM [3], which consists of a forward and a backward process for feature learning. It can take both past and future information into consideration when determining the current hidden state of the LSTM.

D. Dual-Frequency Ranging and DOA

A dual-frequency continuous wave target ranging technique was adopted, where the phase difference between the Doppler cells across different carrier frequency corresponds to a given range of a target [4]. The technique was adopted but modified to perform ranging on a wideband signal. Bandpass filtering is applied on different sections of the received signal to obtain two receive signals of differing center frequency. The signals are processed independently with the standard radar processing method described earlier to obtain two Doppler-time plots. The phase difference of the corresponding Doppler cells corresponds to a given range of the target as described in [4].

III. Experimental Results

A. Motion Classification

The motion classification results of 11 daily office activities are show in Figure 4. It is found that that all motions are recognized fairly accurately, even for small motions like head motions and typing.

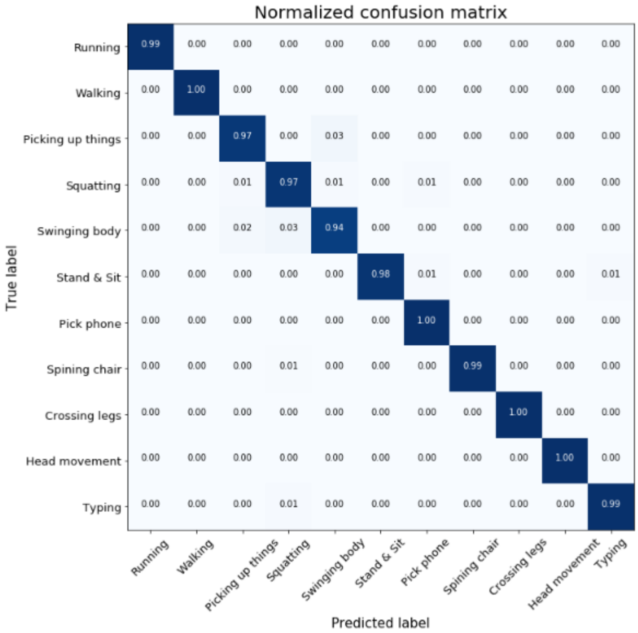

Fig. 4. Confusion matrix of motion classification

B. Localization and multi-target sensing

While a single receive antenna has proven to be good for motion sensing, it can be replaced with a receiving array to handle situations with multiple targets and localize one or more targets. We dealt with individual target by estimating its DOA and then performed dual-frequency ranging on the dual band signals that beamformed at the estimated DOA. The localization of the target is then achieved by combining the DOA and ranging estimates.

The localization result of multiple simultaneous moving targets in a room (8.3m(L)×8m(W)) is shown in Fig. 5, where the SDR sensing platform was placed outside of the room. The lower-left target performed a swinging body motion while the upper-right target performed sitting and standing movement simultaneously, whose true locations are indicated by bold red crosses. The estimated locations of two persons are shown with time (for a 10sec duration) in different color, which suggest that the system is able to localize the two targets with a fairly good accuracy.

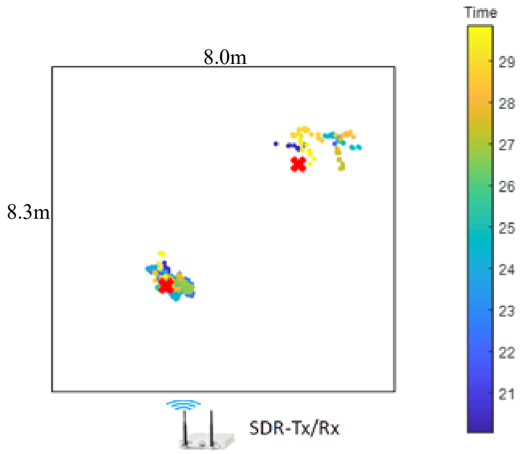

Fig. 5. Localization of 2 persons performing motions simultaneously

IV. Conclusion

Through-the-wall human sensing and localization with a WiFi-like signal is investigated in this paper. It is demonstrated that a simple SDR-based system is capable of sensing human motions and localizing one or more target(s) through a brick wall with high precision.

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