An Experimental Study on the Feasibility of Fall Prevention using a Wearable K-band FMCW Radar

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***Abstract*—Falling, which will cause serious physiological and psychological injuries, is a common health problem for senior people all around the world. Currently, with the increasing demands for fall detection and prevention, a large numbers of systems are developed and tested using different technologies. For all-time prevention of falls in daily life, an experimental study on a novel fall prevention system using wearable FMCW radar is presented in this paper. A wearable radar prototype was built, and attached to the front of a subject's shoe to detect any potential obstacle on the walking path. Experiment results are analyzed to demonstrate the feasibility of fall prevention using wearable radar.**

Keywords—health, fall prevention, FMCW radar, wearable

I. Introduction

Falling is a major health problem for senior people. It is reported that most of the hip fractures and traumatic brain injuries are caused by fall incidents [1]. This situation has resulted in an increasing demand for fall detection/prevention systems. Currently, depth camera and inertia measurement unit (IMU) are two popular solutions. Camera sensors and IMUs are utilized to capture the gait parameters of a subject, the risk of fall can be evaluated and alerted when the gait parameters of the subject becomes abnormal [2] [3]. However, IMU based systems rely on the predefined gait data in the database, camera-based systems have challenges in operational range, image processing and present privacy concerns.

A large number of radar-based fall detection systems have been developed as well. In [4], a continuous-wave radar was used to monitor the speed of a subject, signals were transmitted to a base station for data processing, algorithms were applied to distinguish fall incidents from normal activities. In our previous work, we also investigated fall detection using wearable Doppler radar [5]. However, despite the accuracy of these systems, very few radar-based systems placed emphasis on fall prevention. Considering the serious consequences that may be caused by fall incidents, preventing a fall before it happens deserves more attention. Therefore, this paper presents an experimental study of the feasibility of fall prevention using wearable radio frequency devices. In the experiment, a frequency-modulated continuous-wave (FMCW) radar is mounted in front of a subject's shoe to detect the distance information between the radar and surrounding objects. A wearable FMCW radar was built, attached to the shoes of walking subjects, and tested. Experiment results are analyzed to demonstrate the feasibility of fall prevention using wearable radar systems.

This work was supported by the NSF under grant ECCS-1254838 and the NSFC under grant 61528104.

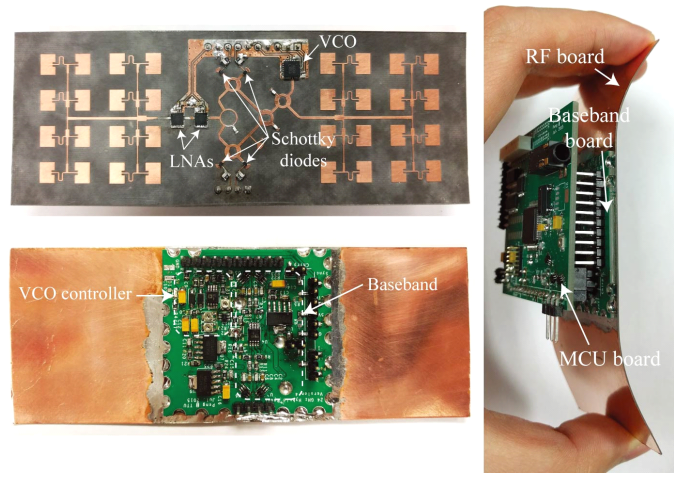

Fig. 1. Photos of the wearable K-band FMCW radar

II. Fall Prevention Theory

A concept study on an all-time fall prevention system named as iPrevent was presented in our previous work [6]. In the proposed method, a complete normal human walking cycle can be divided into different phases as shown in Fig. 3 (a). An FMCW radar is proposed to be attached to a subject's shoe. During the movement of the subject, if an obstacle is located in front of the shoe, the obstacle will be detected by the radar. Therefore, fall prevention can be realized by constantly measuring the distance information between the radar and surrounding environment.

It should be noted that due to the position change of the subject's foot in different walking phases, radar-measured feature will vary as a function of time. In practice, since the radar sensor to be used may have a lower limit on the detectable range due to TX-to-RX leakage, objects that are too close to the radar sensor may not be detected.

III. Experiment

In order to experimentally demonstrate the proposed fall prevention method, a K-band wearable FMCW radar is developed as shown in Fig. 1. This wearable FMCW radar has an RF board, a baseband board and a MCU board. The RF board was fabricated on a Rogers RT/duroid 5880 substrate with a thickness of 0.254 mm, and includes a pair of 4 × 4 patch arrays, a six-port down-converter, two LNAs and a VCO. The baseband board with the VCO controller and the baseband

Fig. 2. Experiment setup with radar attached to the front of the shoe

circuit is soldered on the back of the RF board. A “sawtooth” voltage generated by the VCO controller was used to control the free-running VCO to transmit the frequency-modulated RF signal. An interface to laptop soundcards and smartphones was integrated on the MCU board for data acquisition.

Experiment was implemented in a department building. The K-band FMCW radar was mounted in front of a subject's shoe as shown in Fig. 2. A small cookie box serving as an obstacle was placed 5 meters away in front of the subject's shoe. The subject was asked to walk towards the obstacle at a relatively low speed. The radar transceiver uses a 4×4 antenna array. The baseband signal is fed into the laptop through audio jack and digitized by the laptop soundcard with 192 KHz sampling rate and 16-bit resolution. After FFT algorithm, signals are normalized with respect to the maximum power level.

A typical experiment result is shown in Fig. 3. (b). The spectrum clearly presents that the obstacle located in the walking path was detected by the radar sensor during walking phase 2, phase 3 and phase 4. Between phase 2 and phase 3, as the subject’s foot gradually moved toward the obstacle, a smooth distance decrease was captured. In phase 1, radar was facing the ground when the subject lifted his foot, thus the obstacle was out of the radar scanning range, and resulted in a gap in the spectrum. As a result, the obstacle was detected as a fragmented distance reduction in the experiment. Measurement result matches the prediction in [6]. However, as shown in the spectrum, ground was not detected during the entire movement. This is because when the subject performs a normal walking, the distance between the ground and the radar is too small, which makes the corresponding low beat frequency filtered by the ac-coupled capacitors. It should be noted that a patch antenna array with less elements may also work, and the smaller size will make the radar sensor easier to be mounted on the subject’s shoe.

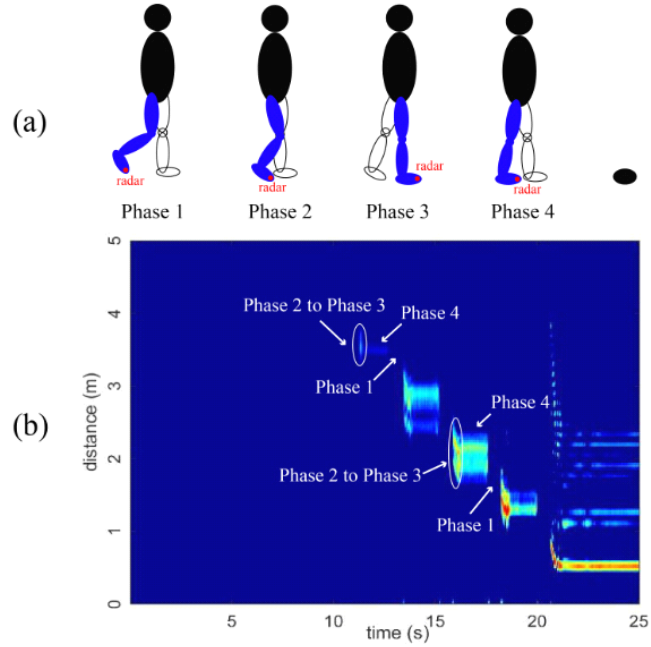

Fig. 3. (a) Four phases of a complete walking cycle (b) Experiment result of the fall prevention system

IV. Conclusion

A wearable radar-based all-time fall prevention system is proposed, implemented and tested. The radar is attached to the front of a subject's shoe to detect surrounding obstacles in front of the shoe. Measurement result shows that obstacles can be easily captured by the radar once it enters the radar detection range. Experiment result demonstrated the feasibility of fall prevention using wearable radar sensor. Future work will be focused on robust radar signal processing and feature extraction under various environments, further reduction of the device size, and the design of an integrated system with onboard signal processing and automatic warning of potential falls.

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