iPrevent: A novel wearable radio frequency range detector for fall prevention

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Abstract:
Falling is a serious and costly health problem for senior people. It is reported that one out of three senior people around the world falls every year. As a result, a large number of fall detection and fall prevention systems are developed. In existing technologies, camera-based and inertial measurement unit-based are two dominant methods for fall prevention. Considerable radar-based researches were carried out as well, however, most of them were focused on fall detection. Therefore, this paper presents a theoretical study on a novel all-time fall prevention system using on-shoe K-band frequency-modulaed continuous-wave(FMCW) radar, which is capable of detecting the absolute distance between the radar and the obstacles in front of the shoe. The concept of fall prevention is illustrated, and a FMCW radar prototype is tested to demonstrate the feasibility of radio frequency range detector for fall prevention.

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Contents

SECTION I. Introduction

Falling poses serious risks for senior people all around the world. According to the report from Centers for Disease Control and Prevention(CDC), millions of senior people aged over 65 falls every year. One fifth of falling causes serous injuries such as hip fractures, broken bones and traumatic brain damages [1]. On the other hand, smart phones have become an indispensable part of people's daily life. Playing a smart phone while walking on the street is a common phenomenon. Such distraction on the street is dangerous and virtually increases the risk of falls. As a result, preventing a fall before it happens has become an important task, and has attracted considerable research interests from both industry and academia.

In existing technologies, depth camera-based systems is a popular solution for fall detection/prevention [2]. Camera sensor was mounted in a room to track the motion of subjects. Algorithms were developed to extract the person from the background and capture the gait parameters. The risk of fall can be assessed by comparing the captured gait parameters with normal gait parameters for a person with normal activities. However, the camera was usually mounted at a fixed location. Therefore, all-time tracking of a moving person was diffcult. In addition, cameras present significant privacy concerns.

Inertial measurement unit (IMU)-based system is another popular method for fall detection [3]. Some of IMU-based systems also offer the capability to alert a possible fall before it happens. IMU built-in smart phone were placed at different position on a subject's body to capture the gait parameters such as limb acceleration. The risk of fall was assessed by analyzing the gait and posture of the person. However, a problem of IMU-based system is that it strongly depends on predefined gait data in the database, thus it is hard to cover all cases of fall events. On the other hand, a common problem of camera-based and IMU-based fall prevention systems is that fall can only be pre-alerted when the gait parameters of a person becomes abnormal, which means an unfavorable object/event already changed the status of the body. Considering the fact that a fall always happen in a brief moment, if the gait or body posture is already changed, it might be too late for a person to take any action to prevent a fall from happening.

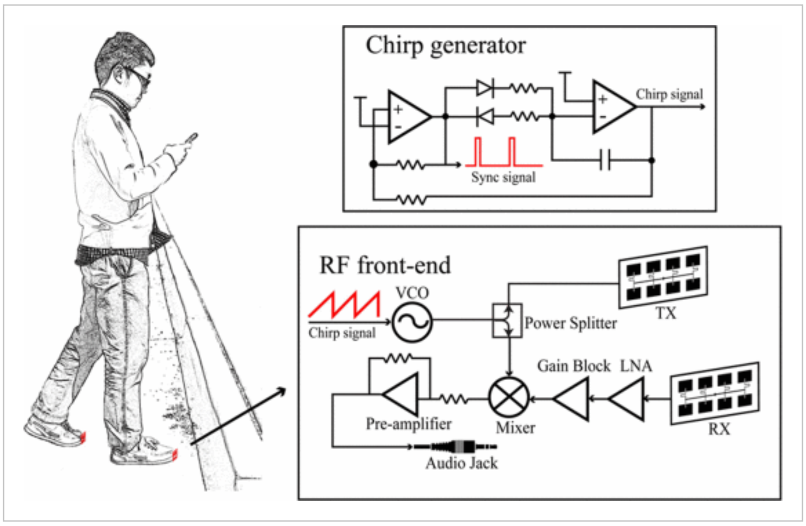

Fig. 1.
Using on-shoe FMCW radar for fall prevention.

As one of the most promising technology in next decades, wireless healthcare devices have been gaining interests. Many systems are developed for non-contact human vital sign detection and wireless indoor positioning [4]–[5][6]. Among them radar-based researches were carried out using Doppler radar and stepped-frequency continuous-wave(SFCW) radar for fall detection [7] [8]. Various algorithms were developed to extract Doppler signature when a fall happens. In our previous work, we also proved the feasibility of using wearable K-band Doppler radar for fall detection by monitoring the subject's gait parameters in different scenarios [9]. However, to the authors' knowledge, very few research placed emphasis on fall prevention.

This paper presents a concept study on a novel fall pre-vention system named as iPrevent, which uses two wearable K-band frequency-modulated continuous-wave(FMCW) radar sensors mounted on shoes. One radar is attached to the front of a person's shoe to detect the absolute distance between the radar and the objects in front of the shoe. The other radar is placed at the bottom of the shoe to detect the vertical distance between the ground and the shoe. Detailed fall prevention procedure is discussed, followed by experiment result using a K-band FMCW prototype radar.

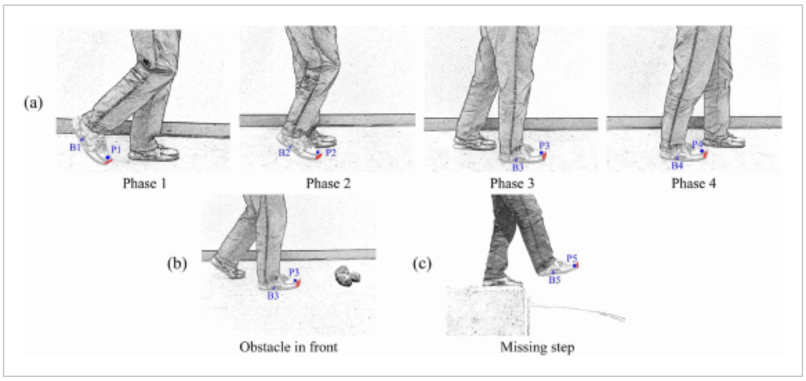

Fig. 2.
(a) Four phases of a complete walking cycle during a normal walk (b) walking with obstacles in front (c) walking with a potential missing step

SECTION II. Fall Prevention Theory

A. Operation Principle of FMCW Radar

Fig. 1 shows the block diagram of the FMCW radar that is propose for fall prevention. The chirp generator is capable of generating linear chirp signal, which is fed into the voltage controlled oscillator (VCO). Therefore, the transmitted signal is a sequence of linear chirp signal as well. The signal reflected from the target has a time delay with a round-trip travelling time behind the transmitted signal. The mixing of the received signal and the transmitted signal produces the so called beat frequency, which is proportional to the target distance as:

$$d=\frac{\tau\cdot c}{2}=\frac{f_b\cdot T}{BW}\cdot\frac{c}{2} \tag{1}$$

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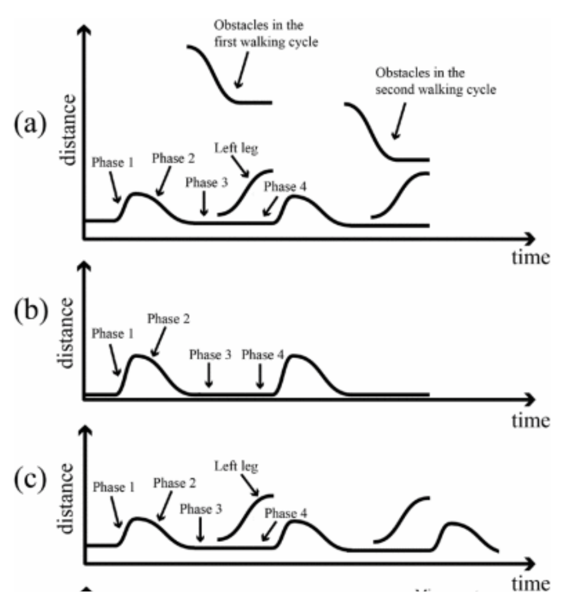
where d is the distance, τ is the round-trip travelling time, c is the speed of light, T is the time span of linear chirp signal and BW is the bandwidth of the transmitted signal.

B. Fall Prevention Concepts

To illustrate the proposed fall prevention method, a complete walking cycle of a normal person is divided into four phases as shown in Fig. 2. (a). The positions of the two radar are labeled as P ‘ and B. Each phase corresponds to a different posture. When the human subject lift the right leg in phase 1, a sudden distance increase will be measured by two radar sensors as both of them move away from the ground rapidly. During phase 2, P1 and B1 gradually approach P2 and B2 at a regular speed, corresponding to a smooth distance decrease in Fig. 3. When the right foot lands on the ground in phase 3, due to the directivity of antenna, it is reasonable to predict that the ground will still be detected by the front radar at a short distance. Meanwhile, the distance measured by the bottom radar will be close to zero as it the foot touches the ground. In Phase 4, while the measurement of the bottom radar is not influenced, a distance increase will be detected by the front radar when the left leg passes the right leg. Finally, the movement transits into the next cycle.

Tripping over obstacles and missing steps are two primary factors causing falls. Fig. 2. (b) shows a case that an obstacle is located in front of a person. Compared with the normal walking scenario analyzed above, the measurement of two radar sensors will have the same spectrum characteristic in the first two phases. However, once obstacles appear in the radar detection range in phase 3 and phase 4, the distance between the front radar and the obstacle can be easily captured as a fragmented distance decrease shown in Fig. 3. (a), because the front radar is pointing at the front direction in these two phases. However, since the bottom radar is always facing the ground during the entire movement, the measured distance information will not be influenced.

Fig. 2. (c) depicts another dangerous case that a person steps on the edge of a street, falling is likely to happen if this person misses the next step. In this case, the distance information captured by the front radar will have similar characteristic during the entire movement, as nothing is located in front of the person. However, when this person is about to miss the next step, the bottom radar will detect a rapid distance increase, which happens when the radar detection area suddenly changes from the edge of the street to the ground. This sudden distance increase is presented in Fig. 3. (d).



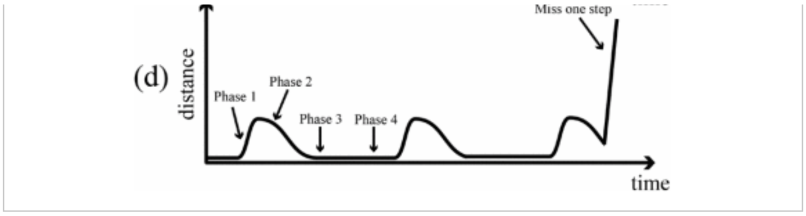


Fig. 3.
Predicted measurements of the (a) front radar and (b) bottom radar with an obstacle in front. Predicted measurements of the (c) front radar and (d) bottom radar with a potential missing step.

As analyzed above, each scenario has its unique features. Certain algorithms can be developed to extract these features so that normal walking and risky cases can be distinguished and alerted. Therefore, fall prevention is realized by constantly measuring the distance information between surrounding objects and the subject's feet. It should be noted that the radar detection range can be controlled in a short distance to avoid undesirable clutter signals. For a typical moving speed of seniors from 0.3 m/s to 0.8m/s 1 meters is considered to be a reasonable detecting range.

SECTION III.
Experiment

A K-band FMCW radar prototype is tested to evaluate its range accuracy for fall prevention. The frequency of the transmitted signal linearly increases from 23.79 GHz to 24.35 GHz (BW=560MHz) within a time span of 14.05ms. The radar transceiver uses a 2×4 patch antenna array, which has 45-degree horizontal and 38-degree vertical full beam width. The chirp generator of the radar system is capable of generating another square wave, which is synchronized with the chirp signal and can be used to extract each chirp response in the output data, achieving coherent detection. After FFT algorithm, the peak frequency is used to calculate the distance.

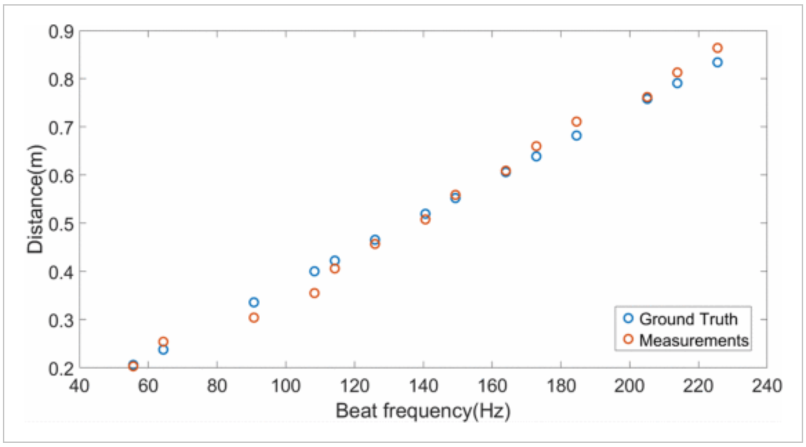


Fig. 4.
Comparison of the results measured by a K-band FMCW radar and the ground truth.

A plate hosted by a cart was used as the target. The distance between the radar and the target was increased from 20.32 cm to 86.36 cm with a step size of 5.08 cm. Experiment result is shown in Fig. 4. The radar-measured distances are compared with the ground truth to evaluate the range detection accuracy. It turns out the average error is 1.76 cm, while the worst-case error is 4.5 cm.

SECTION IV.
Conclusion

The concept and an ab-initio study on a novel wearable radar-based fall prevention system have been presented. A prototype FMCW radar was tested. The measurement result shows a high range detection accuracy with an average error of 1.76 cm. Future work will be focused on the experiment design and system tests using the proposed method.

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Keywords

IEEE Keywords
Radar detection, Radar measurements, Legged locomotion, K-band, Doppler radar, Chirp

INSPEC: Controlled Indexing
gait analysis, biomedical measurement, CW radar, FM radar

INSPEC: Non-Controlled Indexing
inertial measurement unit-based system, iPrevent, wearable radiofrequency range detector, health problem, fall detection, camera-based measurement, all-time fall prevention, on-shoe K-band frequency-modulaed continuous-wave radar, FMCW radar prototype

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