Indoor Position Tracking using Onboard K -band Doppler Radar and Digital Gyroscope

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Abstract—This project presents a indoor position tracking system for multiple applications. The proposed tracking system combines a digital gyroscope and an onboard K-band Doppler radar to simultaneously detect the Doppler frequency and the direction information. Trajectory can be reconstructed based on the received signal. By comparing with the ground truth, the accuracy of the system was found to be high with less than 3 inches average error. Besides, the tracking system has the potential to operate in frequency-modulated continuous-wave (FMCW) mode, which makes 2D mapping possible.

I. INTRODUCTION

For these decades, higher demands on radar wireless system led to a rapid growth of radar technology. Indoor positioning, motion/gesture identification and human vital signals detection are of great interest in health care, energy control, and even entertainment industries. Currently, two main methods for detecting human vital sign and motion are Doppler radar and ultra-wideband(UWB) radar. In order to detect absolute distance of the targets, researchers developed Stepped-frequency continuous-wave (SFCW) and frequency-modulated continuous-wave (FMCW) radar [1][2]. However, precisely localization requires radar to operate at very high frequency with a large transmitted bandwidth to get higher resolution, thus this two kinds of radar systems are usually used to detect large movement. In our project, we developed a novel position and trajectory tracking method of using a K -band Doppler radar and a digital gyroscope. Moreover, we compared the measurement result with ground truth to evaluate the accuracy of the system.

II. THEORY OF TRAJECTORY TRACKING

In our preliminary study, a manually-operated cart was used in the experiment as shown in Fig. 2. Two K -band Doppler radar were mounted on the cart to simultaneously detect the displacement at $x-$ and $y-$ axis. Trajectory can be reconstructed based on the captured Doppler information. The experiment was performed in the hallway of the department. However, despite the high accuracy of the system, two radars need to have fixed orientation during the movement, which means the cart can not have rotational movement. In order to solve this problem, a digital gyroscope was applied in our system.

The block diagram and principle of the improved tracking system is shown in Fig. 2. To realize all-time tracking, the gyroscope and the radar were mounted on the helmet so that they can constantly detect the Doppler shift and direction change in human movement. The radar transceiver operates at the frequency of 24.125 GHz. At receiver chain, the received signal is successively amplified by a low noise amplifier (LNA) and a gain block to maintain a satisfactory SNR before fed into mixer. After the signal is digitized by the ADC, the received *I /Q* signal at baseband can be used to obtain the motion signal *x(t)* of the person. The corresponding Doppler frequency is calculated as $\Delta f = 2vf/c$, where v is the velocity, f is the transceiver carrier frequency and c is the speed of light. During the movement of the person, the displacement at x— and y— axes are:

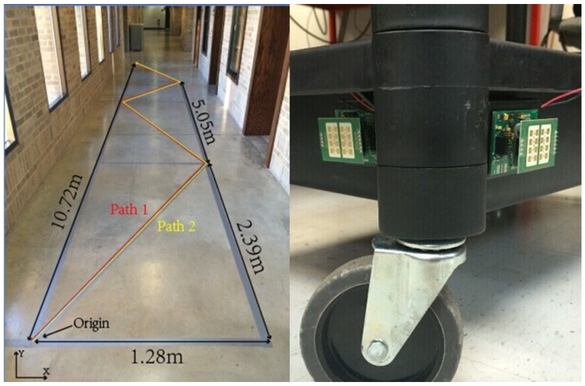

Fig. 1. Tested trajectory, ground truth and radar placement in the preliminary study.

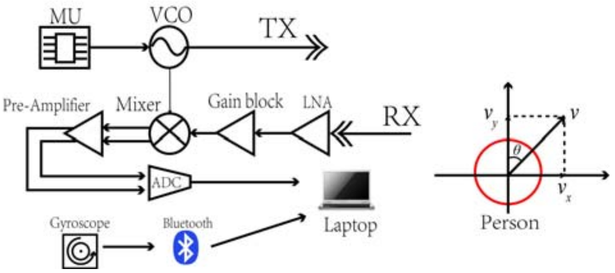

Fig. 2. General scenario of position tracking in a room using onboard K -band radar.

$$D_x = \int_0^t v_x(t)\,dt = \int_0^t \left(\frac{\Delta f(t)\times c}{2f}\cdot\sin\theta\right)dt \qquad (1)$$

$$D_y = \int_0^t v_y(t)\,dt = \int_0^t \left(\frac{\Delta f(t)\times c}{2f}\cdot\cos\theta\right)dt \qquad (2)$$

The trajectory can be tracked by comparing the displacement at two axes and the initial position. Except for the basic radar structure, we also embedded a microcontroller in the radar system. The microcontroller is capable of generating linear chirp signal to make the system work as a frequency-modulated continuous-wave(FMCW) radar, which can detect the absolute distance. Therefore, if we program the microcon

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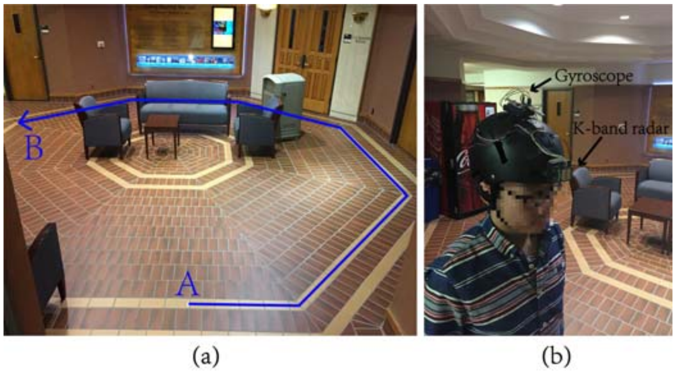

Fig. 3. (a) Surrounding environment of the experiment location (b) Experiment setup [3].

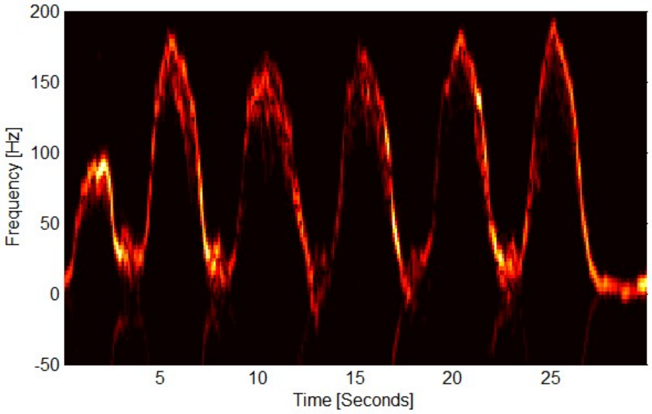

Fig. 4. Doppler spectrum measured by K -band radar for the entire movement [3].

troller properly to make it work in interferometry mode and FMCW mode, 2-D mapping becomes possible.

III. EXPERIMENT

Experiment was implemented in the department building. Fig. 3. (a) shows the surrounding environment of the experiment location. The blue solid line represents the tested trajectory. The person wearing the helmet started at point A, and moved along the wall towards point B. During the experiment, the person was asked to stop at each turning corner. Therefore, the entire movement can be divided into six segments. In order to transfer the gyroscope data to laptop wirelessly, we embedded a bluetooth module in our system.

Fig. 4 is the measured Doppler spectrum at baseband. The spectrum shows a periodic frequency change for six segments, which indicates the person stopped at each corner. The peak frequency of first segment is smaller than others, this is because the distance of the first segment is much shorter than other segments, the person has to decrease his speed before it reaches regular level. To evaluate the accuracy, we compared the measured trajectory with the ground truth and found that the average error is 7.1 cm, the worst-case error is 16 cm. It should be noted that the accumulated error of gyroscope will seriously affect the measured result. To mitigate this problem, we propose to incorporate another digital accelerometer in the system and make them calibrate each other.

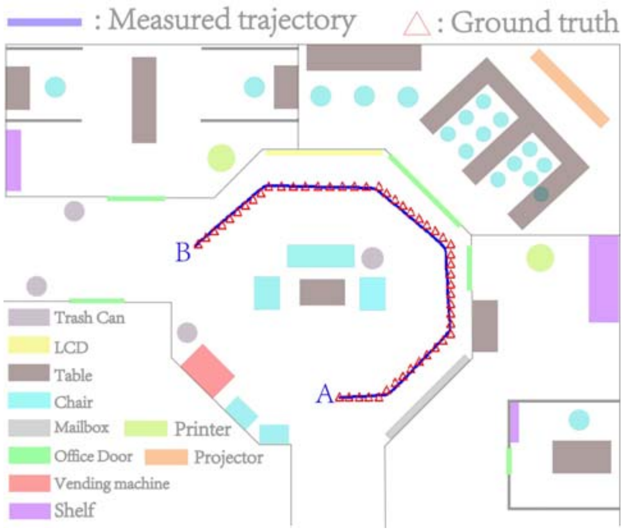

Fig. 5. Surrounding environment of the experiment location and measured result [3].

IV. CONCLUSION

A position tracking system was developed and tested in this project. The measured human moving speed and direction information were combined together to reconstruct the trajectory. The measurement result has high accuracy with an average error of 7.1 cm, which shows the feasibility for indoor localization using the onboard radar and digital gyroscope. The project is still woking in progress to incorporate the FMCW operation.

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REFERENCES

[1] M. Mercuri, D. Schreurs, and P. Leroux, "SFCW microwave radar for indoor detection," IEEE Radio and Wireless Week, January 15-18, 2012.

[2] S. Scheiblhofer, S. Schuster, and A. Stelzer, "High-speed FMCW radar frequency synthesizer with DDS based linearization," IEEE Microw. Wireless Compon. Lett, vol. 17, no. 5, pp. 397399, May, 2007.

[3] Y.Tang, C.Li, "Wearable Indoor Position Tracking using Onboard K - band Doppler Radar and Digital Gyroscope," IEEE MTT-S International Microwave Workshop Series on RF and Wireless Technologies for Biomedical and Healthcare Applications(IMWS-Bio), Taibei, September 21-23, 2015.