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Three-Dimensional Positioning Method of Indoor Personnel Based on Millimeter Wave Radar Sensor

Chao Wang, Zuxue Xia, Wenhai Xia, Rui Wang, Jiayuan Hu, Rui Cheng

***Abstract*—**Aiming at the application of indoor personnel positioning under smog conditions, this paper proposes a 3D positioning method based on the IWR1443 millimeter wave radar sensor. The problem that millimeter-wave radar cannot effectively form contours in 3D point cloud imaging is solved. The results show that the method can effectively achieve indoor positioning and scene construction, and the maximum positioning error of the system is 0.130 m.

***Keywords*—**Indoor Positioning, Millimeter Wave Radar, IWR1443 Sensor, Point Cloud Imaging.

I. Introduction

At present, the emergency situation on the floor and inside the house needs to be built to be able to visualize the system for better rescue. Traditional indoor 3D positioning technologies mainly include infrared sensors [1], image analysis, computer vision positioning and imaging technology [2], etc. However, the positioning system based on infrared technology is greatly affected by heat sources, which makes it difficult to distinguish targets. Although the positioning system based on image technology can realize 3D personnel position tracking and human posture recognition, its disadvantage is that it cannot pass through the smoke.

Frequency Modulated Continuous Wave (FM-CW) has been widely concerned in the application of indoor personnel positioning because of its transmission and strong anti-interference [3]. The research team of Alex Shoykhetbrod designed an indoor 3D imaging system based on FM-CW [4], [5], its operating frequency is 57-63 GHz, but the system integration is not high enough and the resolution is 0.22 m. In recent years, with the popularization of autonomous driving technology, Infineon, Freescale, Texas Instruments, STMicroelectronics and other companies have successively launched millimeter-wave radar sensors [6], which can significantly reduce the complexity and cost of system implementation. The transmission signal in the millimeter wave band also makes it more accurate. Therefore, how to apply these commercial automotive radar sensor chips to indoor personnel imaging deserves further in-depth research and discussion.

In order to solve the above problems, this paper implements a 3D positioning method for indoor personnel based on Texas Instruments' (TI) IWR1443 millimeter-wave sensor combined with a two-dimensional rotating turntable. The millimeter wave imaging system sends the signal through the transmitting antenna, and then uses the receiving antenna to collect the echo data after being reflected by the target object. After the echo signal is amplified and demodulated, it is converted into a digital signal through analog-to-digital (AD) sampling, and stored in the computer. Appropriate imaging algorithms process the echo data combined with the data of the two-dimensional rotating turntable, and finally realize the reconstruction of the target scene.

II. System Structures

The connection relationship of the three-dimensional imaging system for indoor personnel positioning based on the IWR1443 evaluation board is shown in Fig. 1. The evaluation board and the two-dimensional turntable are directly connected to the PC through the serial port.

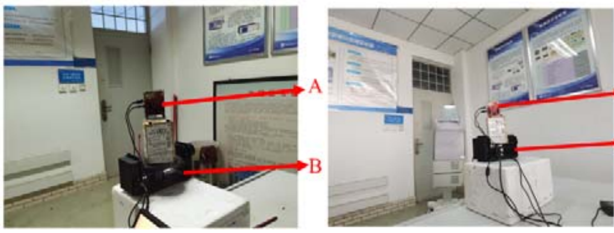


Fig. 1 Construction diagram of experimental system

The hardware A used in this paper is the IWR1443 device, which is an integrated single-chip millimeter-wave sensor based on FM-CW radar technology capable of operating in the 76~81 GHz frequency band, with continuous chirp pulses up to 4 GHz. It mainly consists of three subsystems: radio frequency (RF)/analog subsystem, signal processing subsystem and master subsystem. The RF/analog subsystem includes RF and analog circuits: three signal transmitters, four signal receivers, crystal oscillators, temperature sensors, synthesizers, power amplifiers (PA), low noise amplifiers (LNA), mixers, IF amplifiers and analog-to-digital converters (ADCs). The signal processing subsystem includes the digital front end, the ramp generator, and an internal processor that handles the application programming interface (API) received from the master subsystem and controls and configures the front end and the ramp generator. The processor under this subsystem is controlled by TI programming and cannot be controlled by the user. The master subsystem includes a user-programmable

Chao Wang, Zuxue Xia*, Rui Wang, Jiayuan Hu and and Rui Cheng are with School of Information Engineering, Southwest University of Science and Technology University, Mianyang 621010, China (e-mail: wangchao@mails.swust.edu.cn; zuxue_xia@swust.edu.cn; jyren@fudan.edu.cn; ruiwang@mails.swust.edu.cn).

Xia Wenhai is with Zhejiang Lierda Internet of Things Technology Co., Ltd.Yuhang District, Hangzhou 311100, China. (e-mail: xiawh@lierda.com).

industrial-grade Cortex-R4F ARM processor with a clock frequency of 200 MHz. Through the API that has been defined by TI, developers can easily program and control it. The processor is mainly assisted by the radar hardware accelerator (HWA) for signal processing, and can control the transmission and reception of the radar front-end, and is used to schedule the overall operation of the mission control device.

The hardware B used in this paper is a two-dimensional rotary turntable, a high-precision rotary turntable that can rotate horizontally and vertically. It has two interfaces, a 12V power supply interface and a USB2.0 square interface for data transmission.

III. Radar Signal Processing Flow

The indoor radar positioning system studied in this paper is shown in Fig. 2.

The IWR1443 is directly used as the RF front-end of the radar. The collected data are processed by 1D-FFT and 2D-FFT in the radar HWA through MATLAB in the personal computer (PC), and complete the processing and storage of the echo data, and finally the angular dimension processing and the construction of three-dimensional coordinates are sequentially performed on the echo data of all acquisition points.

A. Detection of Echo Signals and Extraction of Coordinates

In order to further find the coordinates of the detection target, it is necessary to detect the phase difference ω carrying the bearing information. Perform angle FFT on the echo signals on the 8 virtual RX antennas to obtain the distance and azimuth coordinates of the target, and then extract the coordinates (x, y) of multiple peak targets, as shown in Fig. 3.

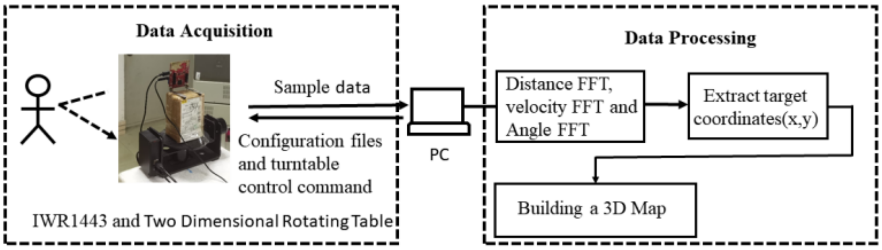


Fig. 2 Indoor personnel positioning system and radar signal processing flow

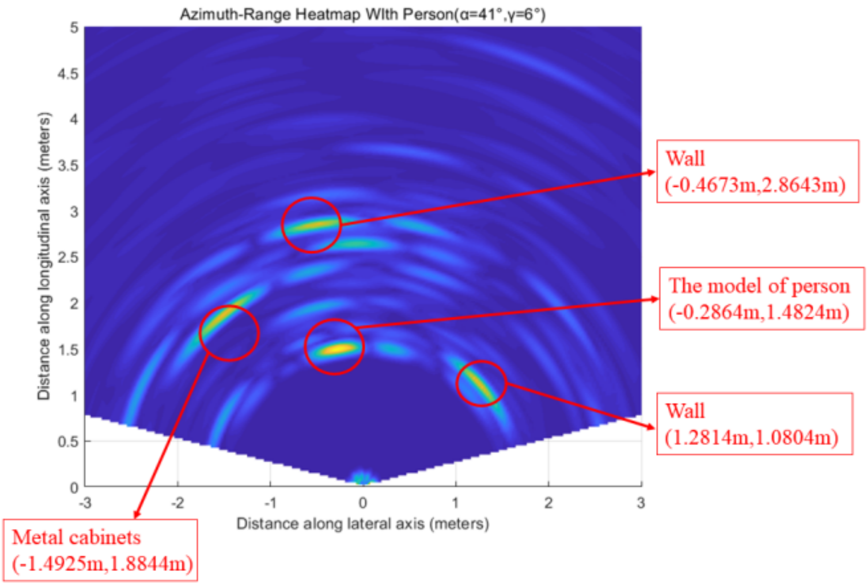
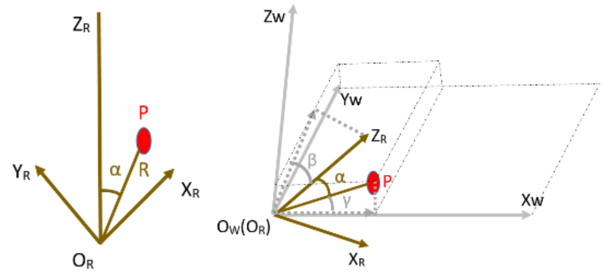


Fig. 3 Heat map of azimuth and range

Fig. 3 is the heat map of the distance and azimuth of the manned model with the two-dimensional turntable turned 41° to the right in the horizontal direction and 6° in the vertical direction. It has multiple target coordinate positions, and the specific values are shown in the figure. After simple coordinate conversion, it is obtained that the detection target person is 1.510 m away from the radar, and the angle with the propagation direction is -10.935°.

B. 3D Coordinate System Construction

The millimeter-wave radar is installed on the central axis of the two-dimensional rotating turntable. The key to the construction of the three-dimensional coordinate system is to establish the relationship between the millimeter-wave coordinate system and the world coordinate system. The world coordinate system in this paper is the coordinate system in which the radar coordinate system is at 0 degrees in the horizontal direction and the antenna is at 0 degrees in the vertical direction. The millimeter-wave radar coordinate system is XRORYR, and ZR is the beam direction; the three-dimensional world coordinate system is OW -XWYWZW, OROW are the origin of the two coordinate systems respectively. The positional relationship diagram is shown in Fig. 4.



(a) (b)

Fig. 4 Coordinate system position diagram: Location map of radar coordinate system (a), Location map of world coordinate system and radar coordinate system (b)

Fig. 4 (a) is the definition of the radar coordinate system, where point P is the point scanned by the radar, expressed as the angle α of the measured target in the radar coordinate system, and the relative distance is R. Fig. 4 (b) shows the conversion relationship between the millimeter-wave radar coordinate system and the world coordinate system, β is the angle at which the two-dimensional turntable rotates in the horizontal direction, and γ is the rotation of the two-dimensional turntable in the vertical direction. After a simple mathematical conversion, we can get 3D point cloud image required.

IV. Experimental Verification and Performance Analysis

A. Echo Signal Acquisition

The experiment is carried out in a corner of the laboratory with a height of 2.7 meters. Considering that the design uses the two-dimensional plane coordinates of the radar combined with the data of the two-dimensional rotating turntable to form a three-dimensional point cloud image, the IWR1443 is configured as 2 transmitters and 4 receivers. The antenna height is set to 1.2 m. The overall software system runs on the MATLAB platform, and takes MATLAB as the center to realize the transceiver, storage and motor drive control of radar signals. Due to the limitation of experimental conditions, it is not convenient for us to measure the speed in the experiment, so our next experiment mainly analyzes the distance measurement, and the data acquisition process is shown in Fig. 5.

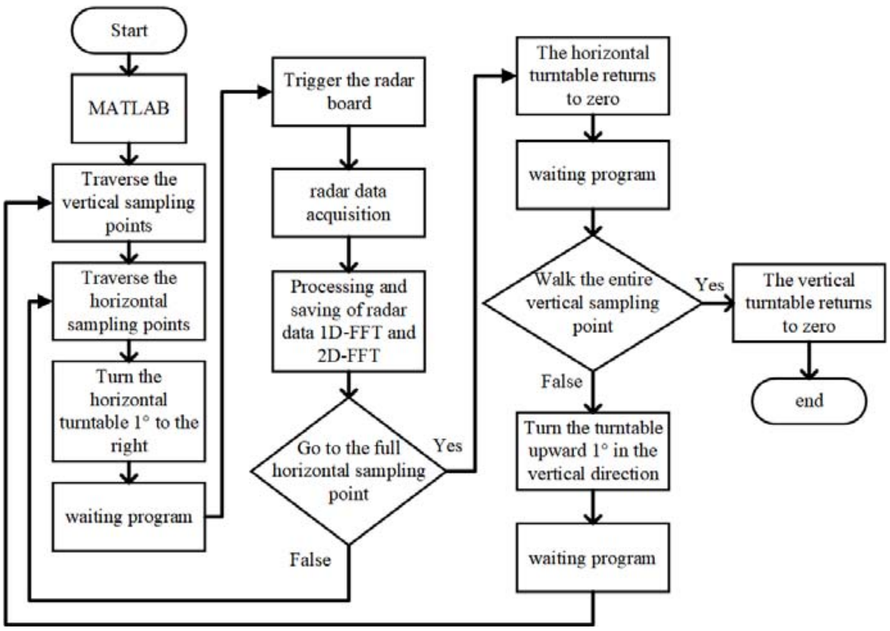


Fig. 5 Data acquisition flow chart

Fig. 6 shows the processed 3D point cloud of the 2700 echo data collected by the process of Fig. 5. In Fig. 6, the position of the target person can be clearly identified in the world coordinate system (WCS), which is located at 1.5 meters from the radar, and the distance of the left and right walls from the radar can also be measured. The next step is to calibrate the build system and processing algorithms for errors.

B. Experimental Results and Performance Analysis

Considering the complexity of the experimental environment, the system first measures the positions of the leftmost B and rightmost C of antenna A and the model person relative to wall D, as shown in Fig. 7 (a). X measures the distance of the right wall perpendicular to the door, Y measures the distance of the wall parallel to the door, and Z measures the distance from the ground. Finally, the actual measured distance between the turntable and the model person at different azimuth and pitch angles is given by conversion in Fig. 7 (b).

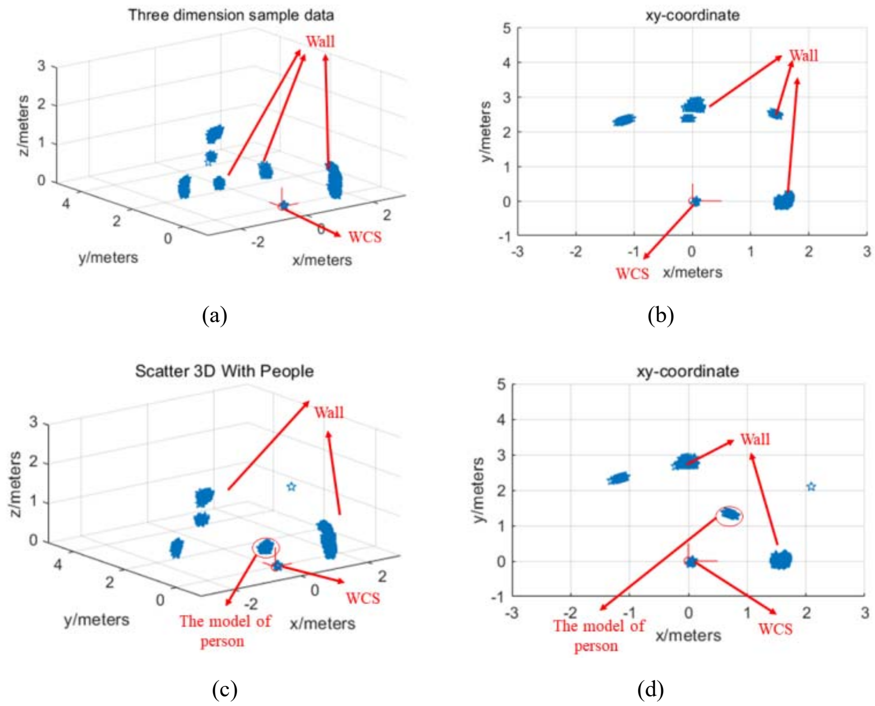


Fig. 6 Comparison of 3D images with and without human models: (a) 3D drawing without human model; (b) x-y view without human model; (c) 3D drawing with a character model; (d) x-y view with a character model

Fig. 7 (a) Distance calibration diagram

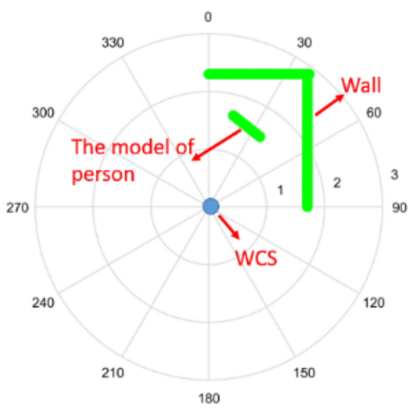


Fig. 7 (b) Measured calibration PPI diagram

Table I is the comparison data table between the distance of the character model measured by the radar and the measured distance of the character model at a certain azimuth and pitch angle of the two-dimensional turntable. It can be seen that the target distance measured by the IWR1443 sensor is consistent with the actual measurement result, and the source of the error is the turntable error. Although the experimental test conditions are simple in the research process of this paper, the distance error of the target object obtained after conversion of the measured data of the distance azimuth heat map and the measured target object are both less than 0.130 mm, the measurement accuracy is very high, and the results are completely obtained. Accurate target-person coordinates verify the effectiveness and accuracy of the proposed 3D imaging system scheme.

TABLE I
COMPARISON BETWEEN RADAR DATA AND MEASURED RESULTS

The turntable rotates β (°) horizontally and γ (°) vertically.	β=5° γ=2°	β=15° γ=3°	β=25° γ=4°	β=35° γ=5°	β=45° γ=6°
Range azimuth heat map measurement result distance (m)	1.5161	1.5098	1.5076	1.5161	\
Actual measured distance (m)	\	1.64	1.54	1.50	\
Residual (m)	\	0.1302	0.0324	0.0161	\

The positioning accuracy of the method adopted in this paper is compared with that of other positioning systems, as shown in Table II. As can be seen from Table II, compared with the Zigbee-based system proposed in literature [7] and the infrared system proposed in literature [8], the positioning error of the system in this paper is smaller and the accuracy is higher, and the positioning accuracy of the method adopted in this paper is slightly higher than that of WiTrack [9], which also uses FM-CW technology.

TABLE II
PRECISION COMPARISON BETWEEN THE PROPOSED SYSTEM AND OTHER SYSTEMS

System	Technology	Positional Accuracy (m)
Zigbee indoor positioning system [7]	Zigbee+Inertial	0.22
Infrared positioning system [8]	Infrared + fingerprint	0.3
WiTrack [9]	FM-CW	0.177
In this paper	FM-CW	0.130

Note: The error of this system is the max value of the error in Table I.

V. CONCLUSION

This paper proposes a 3D positioning method for indoor personnel based on the IWR1443 radar sensor combined with a two-dimensional rotating turntable, and presents the implementation scheme of radar signal processing, which solves the problem that millimeter-wave radar cannot effectively form contours in three-dimensional point cloud imaging. A 3D map is constructed by collecting echo data at different azimuth angles. Compared with the measured and calibrated PPI map, the system positioning error is 0.130 m, which can effectively distinguish and accurately locate the indoor human body. It has certain application prospects.

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Chao Wang received the B.S. degree in electronic information engineering from the Yangtze Normal University, Chongqing, China, in 2019. He is currently pursuing the M.S. degree with School of Information Engineering, Southwest University of Science and Technology (SWUST), His research interest includes Microwave and millimeter-wave circuits and radar systems.

Zuxue Xia received the Ph.D. degree in electromagnetic field and microwave from the University of Science and Technology of China. He is currently with the Southwest University of Science and Technology. He has long been involved in the research of microwave and millimeter-wave circuits, antenna, electromagnetic compatibility and radar systems.

Wenhai Xia received the B.S. degree in electronic science and technology from Southwest Jiaotong University in 2015. He is currently working in Zhejiang Lierda Internet of Things Technology Co., Ltd., and has long been engaged in the research and development of communication components and systems related to the power Internet of Things.