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Pedestrian Trajectory based Calibration for Multi-Radar Network

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***Abstract*—In recent years, using *radio frequency* (RF) signal for pedestrian localization and tracking has aroused great interest of researchers due to its property of privacy protection. With the high spatial resolution, *millimeter wave* (mmWave) becomes one of the most promising RF technologies in human sensing tasks. Existing mmWave-based localization and tracking approaches can achieve decimeter-level accuracy. However, it's still extremely challenging to locate and track multiple pedestrians in a complex indoor environment due to target occlusion and multipath effect. To overcome these challenges, it is an opportunity to leverage multiple mmWave radars to form a multi-radar network that monitors pedestrians from different perspectives. In this poster, we address one of the fundamental challenges of building one multi-radar network: *How to calibrate the perspectives of different mmWave radars before fusing their data*. To reduce the overhead and improve the efficiency, we propose a multi-radar calibration method that determines the position relationship of different radars by tracking the pedestrian trajectory. Our evaluation shows that the proposed method can achieve the average error of ($8.7cm$, $8.5cm$) in 2D position and $0.79°$ in angle.**

***Index Terms*—Wireless Sensing, Millimeter Wave, Calibration**

I. INTRODUCTION

With the rapid development of IoT applications, e.g., smart home and smart supermarket, the indoor location and trajectory of pedestrians provide essential information in these applications. Most of the existing solutions are based on cameras and the computer vision technique to monitor pedestrians. These approaches, however, introduce heavy privacy issues and may suffer from poor lighting conditions.

In the past decade, many works have focused on using RF signals for indoor pedestrian localization and tracking, which avoids invading user privacy and being limited by lighting conditions. WiFi signal is most popular in this task [1]. However, most of these solutions are incapable in the multi-person scenario. Recently, using mmWave signals in wireless sensing has become an emerging research direction. Compared with traditional WiFi, the mmWave frequency band has a wider bandwidth and thus can achieve a higher range resolution in sensing tasks. Meanwhile, mmWave devices can integrate small-size large-scale phased arrays that can transmit highly-directional beam due to the short wavelength.

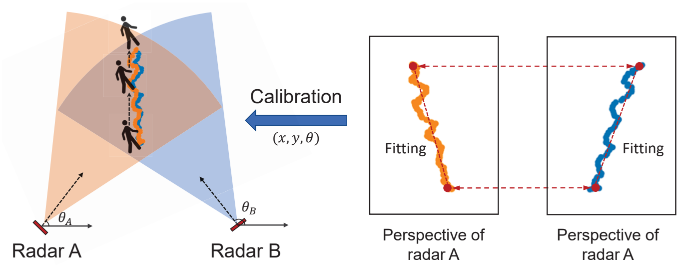

Fig. 1. Radar Calibration with Pedestrian Trajectory

Localizing and tracking multiple people with mmWave signals has been studied in the prior work [2] [3]. Although these works achieve a great step forward, they usually work in a simple and clear environment. It's still very challenging to locate and track multiple pedestrians in a complex indoor environment due to target occlusion and multipath effect. Inspired by the multi-camera network in urban video surveillance systems, we try to deploy multiple mmWave radars in the indoor environment to form a multi-radar network. The multi-radar network is expected to monitor pedestrians from different perspectives, which reduces the impact of occlusion.

When building a multi-radar system, one of the fundamental challenges is *How to calibrate the perspectives of different mmWave radars before fusing their data*. To address this challenge, we propose a multi-radar calibration method by tracking the pedestrian trajectory. Since mmWave radar is more sensitive to moving objects rather than static ones, we leverage the coherence among the trajectories of a walking person in different radar's perspectives for the calibration. By analyzing the relationship among these trajectories, we can determine the position relationship among mmWave radars. Our evaluation shows that the proposed method can achieve the average calibration error of ($8.7cm$, $8.5cm$) in 2D position and 0.79° in angle.

II. SYSTEM DESIGN

A. System Overview

Our system consists of the following four components:

- **Point Cloud Generation.** First, we use a commercial mmWave FMCW radar for the point cloud generation.
- **Point Cloud Clustering.** Second, for the generated point cloud, we cluster them to detect walking pedestrians.

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- **Pedestrian Tracking.** Then, we apply a tracking algorithm to obtain their moving trajectories.
- **Radar Calibration.** Finally, we perform the radar calibration according to the coherence among these trajectories.

B. Point Cloud Generation

The mmWave radar transmits *frequency-modulated continuous-wave* (FMCW) signals for range and velocity estimation. Meanwhile, mmWave radar usually has multiple transmit and receive antennas that can perform beamforming to obtain targets' angle information. From the range and angle information, we can compute the point cloud of the scene. In addition, we perform the static-cluster removal to filter out the reflection points from static objects in the environment.

C. Point Cloud Clustering

For the generated point cloud, we apply the *DBSCAN* algorithm to merge the points together based on their space density to identify the individual pedestrian target. We then take the centroid of each cluster as the position of the target.

D. Tracking

After obtaining the target positions in each frame, we use the *Kalman Filter* for continuous tracking in a frame sequence.

E. Radar Calibration

In our scenario, to obtain multiple perspectives, we need to make radars have different orientations, so we focus on the rotation θ of different radars on the horizontal plane. At the same time, because the radars we use obtain the 2D position of the targets, we also need to know the position (x, y) of radars in the 2D world-coordinate system. Therefore, in Radar Calibration, we need to calibrate three parameters (x, y, θ).

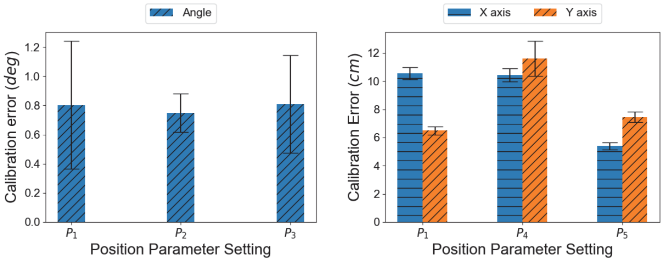
To achieve this goal, we let a single pedestrian walk along a straight line freely. His/her moving trajectory can be obtained with the prior tracking step. Then, we take the coordinate system of one of the radars as a reference. By comparing the trajectories from other radars with it, we can finally obtain the radars' position parameters.

Since the trajectory might be disturbed by noise and error, we cannot compare them directly. So we propose to fit the trajectories to straight line equations. In this way we obtain the slopes of these line equations. Assuming that the slopes of the trajectory fitting equation of two radars are k_i and k_j respectively, the difference of orientation angles between the two radars can be computed as $\Delta\theta = \arctan(k_i) - \arctan(k_j)$. And we further calculate the position difference between the starting points of the two trajectories as the position difference between the two radars.

After obtaining the position parameters of the radars, we can transfer the point clouds from different radars into the same perspective.

III. PERFORMANCE EVALUATION

Hardware Setup: We use two commercial mmWave radar TI IWR1642, which can operate from 77GHz to 81GHz. The two radars are deployed 130cm above the ground.



(a) Accuracy of angle calibration (b) Accuracy of position calibration

Fig. 2. Accuracy of Calibration in different parameter setting

Evaluation: We set the position parameters (x, y, θ) of two radars, denoted as R_A, R_B, as following:

- $P_1 : A_1(-0.9m, 0m, 90°), B_1(0.9m, 0m, 90°)$;
- $P_2 : A_2(-0.9m, 0m, 75°), B_2(0.9m, 0m, 105°)$;
- $P_3 : A_3(-0.9m, 0m, 60°), B_3(0.9m, 0m, 120°)$;
- $P_4 : A_4(-0.9m, 0m, 90°), B_4(0.9m, 0.9m, 90°)$;
- $P_5 : A_5(-0.9m, 0.9m, 90°), B_5(0m, 0m, 90°)$;

We examine the calibration procedure with 3 participants, the heights of which range from 165cm to 180cm. The result is shown in Fig. 2. When the two radars are deployed towards different directions, our method achieves average orientation angle errors as $0.80°$, $0.75°$, and $0.81°$ respectively. At different locations, the average position errors of our method are $(10.5cm, 6.5cm)$, $(10.4cm, 11.6cm)$, $(5.4cm, 7.5cm)$ respectively. The result shows that our method has a good performance in angle calibration, while it can also calibrate different radars in 2D position.

IV. CONCLUSION

In this poster, we propose a method to calibrate the position parameters of mmWave radars in a multi-radar system. We leverage the trajectory of a person walking in a straight line to determine the position relationship between different radars. The experiment result shows that our method's average calibration error is $(8.7cm, 8.5cm, 0.79°)$ in X-coordinate, Y-coordinate, and orientation angle, respectively.

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