CM-002

A Field People Counting Test Using Millimeter Wave Radar in the Restaurant

Shenglei Li† Reiko Hishiyama†

1. Introduction

As a well-known key to preventing the spread of the COVID-19 is knowing where the crowd is and avoiding from it [1]. The automatic system detecting, visualizing and the sharing the indoor crowd information has attracted more and more attentions. Meanwhile, as the expectation for the future smart city, people also have more requirements for a future smart space services basing on this kind of automatic system knowing how many people there is and who they are. For instance, buildings and appliances can know multiple people's location and provide the bespoke heating and lighting service [2]. Firstly, it is necessary to propose a good user acceptance method to know how many people in the smart space.

In the past years, device-based and vision-based automatic people detecting and counting methods has been well developed and became widely used. Especially device-based method has been the most common method for automatic detecting, counting and identification in the past years [3]. Via the smart device, such as smartphone, smartwatch and smart tag, the device-based system could count users by detecting and counting those smart devices. However, there is an obvious limitation that users and their smart device need to be always together, which is almost not possible. As a result, there is a strong requirement of device-free method to covering more scenarios in smart space.

To answer this requirement, many device-free methods have been proposed and rapidly developed in recent years. As an application of computer vision, which is very well developed and widely used in past years, the vision-based method could detect and count the users by recognizing people's body and face [4]. In this category, the vision-based method could provide a high accuracy of people counting result, if taken a clear view of the user's body or face. However, there is a concern that the camera contained system has a lower user's acceptance and may be intrusive in people's home and commercial area [5]. On the other hand, the vision-based method is limited by the clear view from the camera which could be easily affect by the environment, such as the rain, fog, smoke, dust, darkness and other problems in the potential emergence situation like fire, earthquake etc. In the future smart city planning, it is necessary to propose the smart devices in the future wireless network system to have such a capacity to be functional under these environmental limitations.

By contrast, the radio frequency technology might be less intrusive and have a better user's acceptation not only in people's home and commercial area, but also in the area emphasized privacy like fitting room, etc. However, the conventional radio frequency identification system (RFID) usually is a device-based system consisted of tags (transmitters/responders) and readers (transmitters/ receivers) [6], [7]. Different from the conventional RFID, the mmWave radar is a transceiver only requiring a single device for tracking and identification [8]. By receiving and analyzing the reflection from the obstacles like human and furniture, the MMWave radar is capable to provide a high precise range measurement [9]. Moreover, there are some researchers documented that mmWave radar could be wall penetrated under some conditions like thickness and material of the wall, frequency of the mmWave radar and etc. [10]. By this characteristic, it could be possible to setting the mmWave based people counting system under the wall finishes or cover by furniture, which should be helpful for people to accept it in the commercial area and etc.

In this paper, there is a field people counting test carried out using our people counting system based on the millimeter wave (mmWave) radar to detecting and counting people in a restaurant at Tokyo. By this field test, our system has been evaluated and demonstrated as 2 scenarios as people walking case and overall case (walking, standing and sitting), resulted an accuracy of 80.00% (walking case) and 63.74% (overall case) from dozens of people in 273 times of people counting. It is necessary to mention that this test is carried out under a real commercial situation, which is a lunch time from 11:30 to 13:30 at the soba restaurant in front of Shin-okubo station, which is a railway station on Yamanote Line in Shinjuku, Tokyo.

In addition, it is the first version of our future wireless network project to make a better interaction for smart city. Hence, there are many problems needed to be solved in our future work, such as the accuracy improvement for the standing and sitting cases and etc., which are found and listed in the result section of this paper.

There are two main contributions contained in this paper as the follows:

First, there is a mmWave-radar-based people detecting and counting system proposed. It is capable to providing a visualized information of the crowd information of the indoor environment in multi-person scenarios.

† Graduate School of Creative Science and Engineering, Waseda University

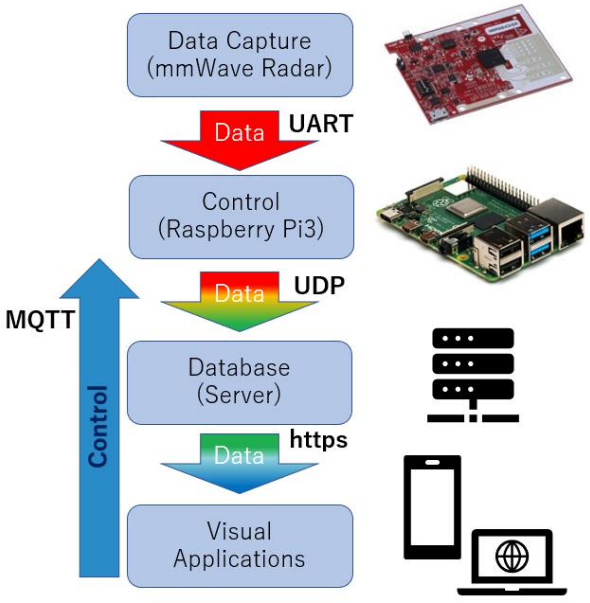

Figure 1. System Overview

Second, this people counting system has been evaluated and demonstrated the capability of people detecting and counting under a real case of commercial situation, resulted an accuracy of 80.00% for the walking case and 63.74% for the overall case (walking, standing and sitting).

2. People counting system design

In this project, the people counting system mainly contents a data capture (mmWave radar), a controller (Raspberry Pi3), a database (AWS Server[1]) and visual applications (in this paper is a laptop installed the application) shown as Figure.1. The mmWave radar is a low-cost, easy-to-use and commercial-off-the-shelf mmWave radar from Texas Instruments (TI)[2]. It is a single chip solution running in the 60- to 64-GHz band and controlled by the application through the Raspberry Pi 3[3].

In this field test, since the cloud computation part is on developing and the internet issue of the restaurant, the data capture from mmWave radar has been calculated on the PC directly. In the future, our computation part would be moved to Cloud Servers to reducing the computing resource needed for the visual application on PC and mobiles.

There is a brief introduction about each component of our people counting system as follows:

A) Data Capture. In this part, it is only contained a single mmWave chip (IWR6843ISK)[4] from TI. It is operating at 60GHz to 64GHz and powered and controlled by the Raspberry Pi3 (Control part).

[1] https://aws.amazon.com/
[2] https://www.ti.com/
[3] https://www.raspberrypi.org/
[4] https://www.ti.com/tool/IWR6843ISK

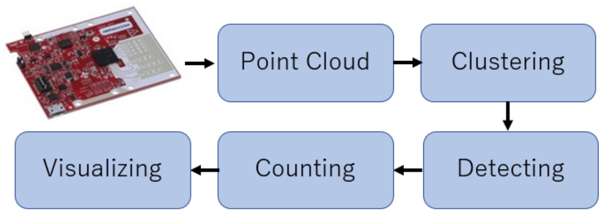

Figure 2. Frame work of data process

B) Control. This part contains a Raspberry Pi3 (1.4GHz, 32GB RAM). It connects to mmWave radar with a micro-USB and power by an external power supply rated at 5V dc, and a minimum current of 2.5Amp. It is capable to remote control the mmWave radar by the wireless network, which is connecting with our Database through the OpenVPN built on the AWS EC2.

C) Database. Via the OpenVPN built on the AWS EC2, it allows us to control the on/off of the mmWave radar and transmit the data to our PC visual application.

D) Visual Application. This part is based on the TI's mmWave industrial toolbox 4.0.0. It is capable to visualizing the cloud point capture from mmWave radar and clustering the detected people and counting them. The frame work of data process is shown as Figure.2.

3. Experiment and evaluation

3.1. Experiment Setup

To evaluate the performance and make a better understanding of our people counting system, there is a field experiment set up and carried out with 2 real indoor scenarios at a soba restaurant near to Waseda University Nishi-Waseda campus. The mmWave radar data is captured by TI IWR6843ISK. The IWR6843ISK radar sensor includes a FMCW radar has up to 4GHz bandwidth from 60GHz to 64GHz, with 4 receivers and 3 transmitters [11]. It outputs a data frame work containing the point cloud of every detected obstacle. This point cloud is a summary of the detect obstacles. With a proper filter, it could be possible to detecting the target people and counting them.

There are various modes and settings are available such as short-range, mid-range, and long-range. Considering the size of experiment area shown as Figure 3, which contains the main room of the soba restaurant and the pathway to kitchen, the indoor detecting and counting range has been opted as 6 m to maximizing the resolution and view field. For the data capture site, the mmWave radar was fixed on a tripod and elevated to a height at 1.7m with 10 degrees slope from the vertical direction, shown as Figure 4.

In this field test, the mmWave is directly control by the application on the laptop due to our cloud computation server is still on developing and the internet issue of the

Figure 3. Experiment area in the restaurant

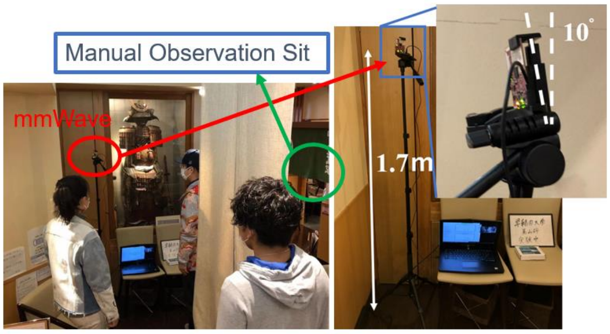

Figure 4. MMWave position and Manual observation position

restaurant. As mentioned in the previous section, there is a lower user's acceptance and more concerns for the camera contained system. The owner of the restaurant, who has given us lots of help, shows a strong concern that whether the customer would feel interrupt if there is camera or a person sitting here to watching them when they are eating. Due to this reason, our evaluating system have to be changed only shooting floor and feet of the customer and staff. In addition, since there are many obstacles troubling to shoot the floor and feet, we decide to add a manual recording of the ground truth value which is the actual movement and number of people walking through the experiment area. Our sit has been placed at the side room next to the Cashier shown as the green circle in Figure 4.

3.2. Experiment Procedure

Due to the COVID-19 counter measure avoiding from crowd, the main room of this restaurant only containing 20 sits during the lunch time shown as Figure 3. There are 5 staffs in the restaurant, so the maximum number of people at the same time in this field test would be 25.

Firstly, there is an initializing test has been carried out before the restaurant open to make sure the system is functional. After that, this field test has been carried out from 11:30 to 13:30 to detecting and counting how many people in the restaurant.

The mmWave radar would capture and output the point cloud data of the detected obstacles to the algorithm in real time. Shown as Figure. 5, once people coming into the experiment area, algorithm would filter out the point cloud of the potential targets (people).

After the potential targets move around for a very short time, the algorithm would confirm these are people. Meanwhile, the detected people would be marked by

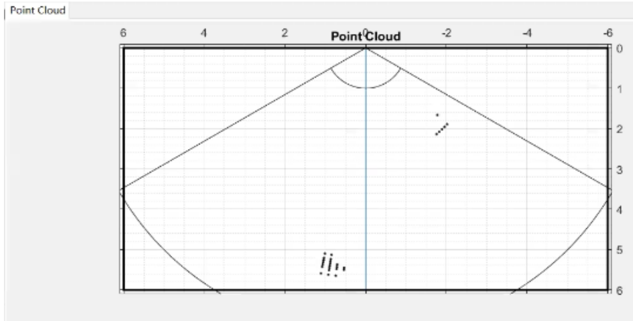

Figure 5. Point cloud

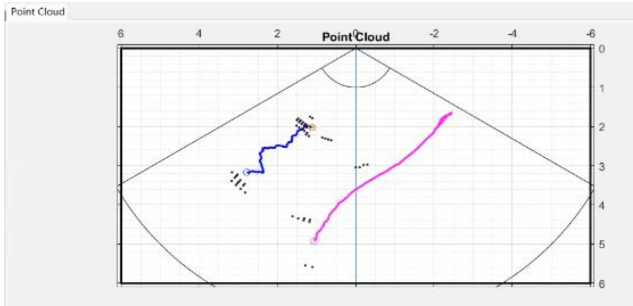

Figure 6. Point cloud and People's track

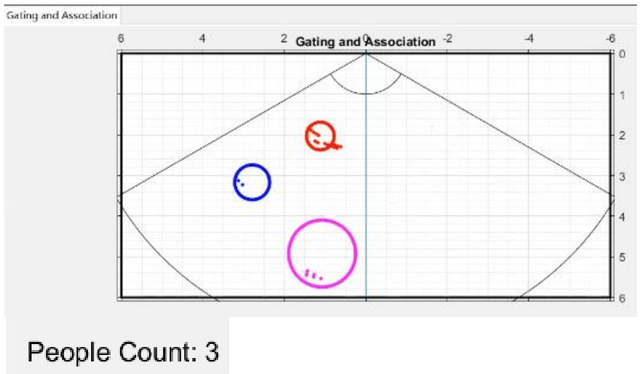

Figure 7. People counting

circles with various colour in the gating and association figure and their track would be shown with the same colour as their circle simultaneously (Figure 6 and Figure 7). Then, the number of the detected people would be counted and shown as Figure 7.

3.3. Evaluation

To evaluate the people detecting and counting accuracy of mmWave radar, there is a reference group to compare. Due to the lower user's acceptance and more concerns of a camera in the restaurant, this reference group is made by the manual recording plus the video shooting on the floor and people's feet.

In this result section, the accuracy of our people counting system are 80.00% for the walking case and 63.74% for the overall case, including walking, standing and sitting. This performance is obtained in the complex real restaurant case that people would randomly stand

Table 1. Test result of people counting

	People status	Ground Truth	Detected	Accuracy
Walking case	Walking	215	172	80.00%
Overall case	Walking, standing, sitting	271	174	63.74%

up and sit down and walk around. Hence, there is some compromise in the overall case result which would describe in the following sections.

Note that the accuracy of overall case in this study would be substantial influenced by the time period counting the difficult-detected targets which is people standing and sitting for over minutes. Currently, it is very difficult to recognize the people who keep standing and sitting for over minutes since the mmWave radar would detect them as the static point could and filter them out. Furthermore, since the point cloud obtained by mmWave could be sparse which might be significantly disturbing human detecting and tracking [8], [12].

In this paper, the undetected people who keeps standing and sitting would be counted only once until there is any other one else has been detected and counted by this system. In another word, the real accuracy of the detecting and counting accuracy for the standing and sitting people could be lower than this experiment result. It is difficult to decide a fixed time period to record the undetected people since the customer in the real case would randomly move. The details of the test results are shown as Table.1.

4. Conclusion

In this paper, there is a field people counting test carried out by using the millimeter wave FMCW radar in a restaurant at Tokyo. In this proposed people detecting and counting system, the real time sparse point cloud data of the indoor environment would be captured by the commercial-off-the-shelf millimeter wave radar (TI's IWR6843ISK). Then the proposed system would extract the point cloud representing the potential targets (people) and tracking them. After confirming the detected people, people would be counted and recorded in the system. By this field test, the results show that the proposed system providing an accuracy of 80.00% for the walking people and 63.74% for the overall case (walking, standing and sitting) with a total number of 271 times of people counting. It also shows the potential ability of tracking the people and the possibility to knowing the distance of everyone in the future. Besides, the result of the overall case also shows that there is improvement required for detecting the static people in the restaurant and other indoor environment. There would be a multi-radar solution or a dynamic radar setting solution preposed in this project in the future.

On the other hand, it also shows a substantial gap of the user's acceptance between camera contained system and the FMCW radar contained system like the millimeter wave FMCW radar system proposed in this paper. We envision that FMCW radar-based system like the proposed people detecting and counting system would be a promising solution for the future smart space and future wireless network. Moreover, we will keep optimized the not only the algorithm, but also other physical way to improve the accuracy of this proposed people detecting and counting system.

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