A Parking Monitoring System Using FMCW Radars

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Abstract— **Parking monitoring systems provide the availability and statistics of parking space in an indoor or outdoor parking lot. Image recognition-based parking monitoring systems are popular since their strong link to billing systems. With privacy concern, those camera-based systems are not suitable for parking spaces monitoring. Hence, the radar-based parking monitoring system is built in this study. By combining the TI 77GHz FMCW radar, Raspberry PI (RPI) single board computer, and image-based auto-labeling service, an automatic radar heatmap collector is constructed in the data collection phase. Those long term collected data is then employed to train and a CNN-based model is developed. Due to the coupling effects of radar signals on two adjacent parking space, the availability of six adjacent parking spaces is defined to be the parking status and denoted by a 6-digit binary code. The trained mode is then ported to several GPU-based edge computing platforms to infer the parking status. The main advantages of radar-based parking monitoring system are excellent inference results in dimmed environment, privacy-protected and lightweight computing load. Even the on-device inference using RPI platform gives a prompt response with very satisfied results.**

I. INTRODUCTION

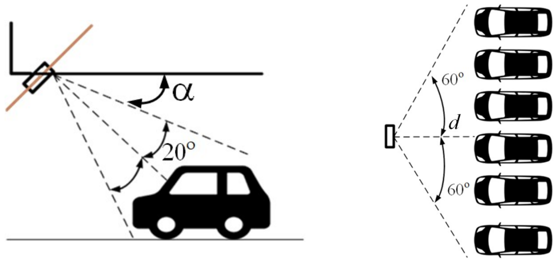
Finding a parking space in a metropolitan or city is always an annoying to drivers. The parking management system (PMS) provides a solution to this issue. The PMS is usually consist of two major components, the parking space monitoring system (PSMS) and the billing system (BS). Several detection sensors have been applied to detect the vacancy of a parking space. Those detection sensors can be divided into visual-based and non-visual based schemes [1]. The former scheme employs video camera and detects if the parking space is vacancy via image processing or artificial intelligent (AI) techniques. Hence, a powerful or GPU-enabled computing units is required to fulfill the image detection. By the way, the environment of the parking space can affect the captured imaged dramatically. The common network architecture in this scheme is usually centralized. That is, the front-end IP cameras send their captured image back to a main computer which performs all the computing and detection. The sensors in the latter scheme could be ultrasonic sensors, infrared sensors, radars, or laser scanner. The ultrasonic and infrared sensors are short distance and ultra-narrow beamwidth devices. On the contrary, the radar and laser scanner have the enough coverage range for parking space monitoring. However, the laser scanner usually needs a rotator to accomplish the angle scanning, consumes much more power, and is usually expensive. Hence, the radar is the best sensor for parking space detection front-end device for non-visual-based method.

Due to the spatial resolution in millimeter and angel scanning requirements, the frequency-modulated continuous wave (FMCW) millimeter wave (mmWave) radars with beam-scanning are employed for parking space detection[2][3]. For parking space detection, the output signals of the FMCW radars or the specific aperture radar (SAR) data from those output can be employed to detect the vacancy of the parking space. Since the SAR radar is usually for high resolution construction of objects or geometry in remote sensing application. Hence it required complicate SAR algorithm to fulfill the object 3D building. However, the raw output or heatmap from a FMCW radar provides sufficient information to discriminate if the parking space is occupied. Hence, a 77GHz FMCW radar with digital beamforming is employed to construct the smart front-end device for parking space detection in this study.

In order to collect the radar heatmap, a FMCW radar heatmap collection system is first established and described in section II. Followed by the radar heatmap-based parking space detection. The conclusions are then draw at the end of this paper.

II. A FMCW RADAR HEATMAP COLLECTION SYSTEM

In this section, an radar heatmap collecting system is constructed by integrating the TI 77GHz FMCW radar[4], Raspberry PI (RPI) single board computer[5], and an IP camera which provides the ground truth for manual labeling of received heatmap. For the installation of the FMCW radar in the monitored parking space, the azimuth and elevation radiation scanning angles are 120 and 40 degrees, respectively, as shown in Fig.1. The angle of depression, α, and projected horizontal distance, d, between the phase center of radar and nearest parking space should be adjusted according to the physical structure of the deployed spaces. The system and network architecture of the proposed FMCW radar heatmap collection system is shown in Fig.2. The system mainly consists of the front-end devices and back-end data storage server. The front-end device collects the radar heatmap data (RHD) and captured image from IP CAM and sends these data back to the back-end sever for further processing via Internet. These two components are detailed in next sections.



(a) Side view (b) Top view

Fig. 1. The installation of the FMCW radar for parking space monitoring.

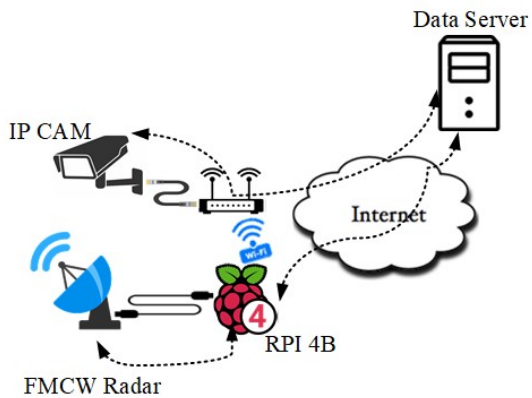


Fig. 2 The system and network architecture of the FMCW radar heatmap data collection system.

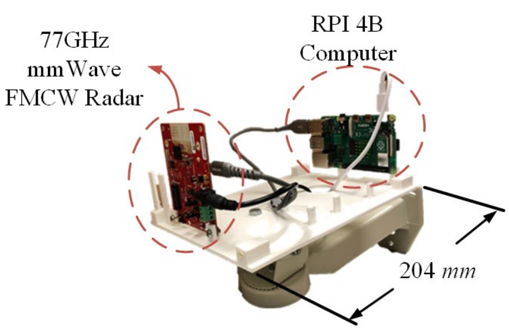


Fig. 3. The FMCW radar and a single board computer.

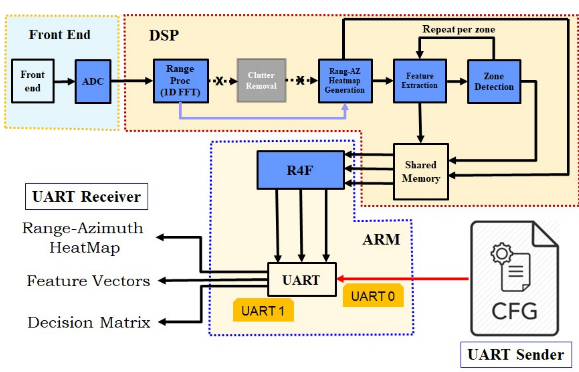


Fig. 4. The components of the modified firmware in the TI AWR1843.

A. *The Front-end Device*

The front-end device consists of a mmWave radar, a IP CAM, and a RPI 4B computer which functions as a data gateway. The captured image from the IP CAM and radar data packet are transferred to the back-end server.

The radars by Texas Instrumentals (TI) need a firmware to work and the firmware written may be different for different applications. In this study, the firmware of the mmWave FMCW radar in Fig. 3, is a modified vehicle occupancy detection (VOD) program from the automotive toolbox 2.2.0 provided by TI's mmWave sensors software development kit (SDK)[6]. Most firmware provided by TI include the static clutter removal module which removes the point cloud by the static objects and hence is insensitive to static objects. However, detecting the parked automobile is the main purpose of our study. Hence, the clutter removal function in the original VOD is disabled as shown in Fig.4. The configuration of the mmWave radar is another key issues that make radar work properly for the specified application. After the time-consuming and tedious on-site tests, a custom radar configuration (CFG) is finalized according to requirements of the detection range and reasonable signal sensitivity.

The FMCW radar is then connected to a RPI 4B computer using the USB connection which is decomposed into two serial connections viewed by the computer running Linux OS. To redirect the radar data packet from the FMCW radar to back-end server, a serial-to-TCP bridge program [7] is implemented on the RPI 4B computer. This program sends each packet from radar back to server and these packets are processed in the server.

B. *The Back-end Storage Server*

Since the front-end device is designed to be a data collector and gateway, most data processing are actually perform on the back-end server. Three major tasks are implemented on this server: radar heatmap parsing, image captured from IP CAM, and data storage.

The VOD packet is in TLV (Type, Length, Value) format. Also, in the incoming packet, there is a set of binary magic words which identify the start of the TLV. Therefore, a Python-based program is established to parse the radar heatmap array from the incoming radar packet. A radar heatmap is a *64×48* integer array in polar coordinate with ADC values from 0 to *65536* (2^{16}). Along the radius axis, r-axis, the maximum distance is divided by *64* and the angle by *48* from -60° to 60° for the azimuth axis. This integer heatmap array is called RHD to discriminate from the radar heatmap image (RHI), a 2D image calculated from the RHD. In this study, the RHD is shown to provide the enough information for parking space vacancy detection. The RHI requires not only conversion from RHD but also usually have to include the environment factors to render more clear images.

In the front-end, another data is the captured images with 640×360 resolution from IP CAM. This image provides the ground truth for the parking space status and the information to label the RHD. This image capture function is implemented by using the openCV package for Python. The main program parses the radar heatmps first, averages specific number of heatmap, captured the images from IP CAM and stores both data on the storage space with the timestamp naming style.

III. Parking Space Detection Using the FMCW Radar Heatmap

The radar heatmap data of six adjacent parking areas covered by effective radar radiation is chose to be the data for parking space detection. The convolutional neural network (CNN)[8] is employed to detect the target parking space status.

To detect the availability of the target parking space, it is a waste of computing resource to employ the six 64x48 heatmap arrays returned by the FMCW radar as the input data for CNN-based model training and inference. Hence, the corners of the parking spaces are first defined by indicating the return spots by corner reflectors in the rendered heatmap image of the on-site measurements. The zones in heatmap image is then defined by numbers 53, 54, 55, 56, 57, and 58 for parking spaces and -1, -2, -3, and -4 for non-parking space in Fig. 5. After review of many heapmap images of several on-site measurements, the region of interest (ROI) is then defined. The ROIs of the measured heatmap array is then chose to be the inputs of the proposal CNN-based model. In this study, two parking space scenarios, basement parking and off-road parking, are measured using the radar heatmap collection system. The status of the target parking space in each ROI is labeled by using a 6-bit binary number. For example, the 000000 denotes no any cars in the ROI and 100000 represents the only no. 58 is occupied and others are in ROI are empty.

For the proposed CNN-based model in Fig. 6, there are three convolution layers, two subsampling layers, and two dense layers in the proposed CNN-based model for parking space monitoring. This model is employed in both the basement and outdoor off-road parking space monitoring. The sizes of ROI of each scenarios are 26×39 and 23×39, respectively. Different sizes of ROI for different parking scenarios is a key point in this study. The ROI auto-finding algorithm becomes an interesting topic for the further study since it seems not too difficult to define the ROI from a RHD.

The dimensions of the feature maps in each layer and number of neuros after the flatten layer can be calculated using the following equations (1) to (4),

$$W_{C1} = W_i - (nK_{C1} - 1) \quad (1a)$$
$$L_{C1} = L_i - (nK_{C1} - 1) \quad (1b)$$

$$W_{Sk} = floor(W_{Ck}/2), \quad k = 1, 2 \quad (2a)$$
$$L_{Sk} = floor(L_{Ck}/2), \quad k = 1, 2 \quad (2b)$$

$$W_{Ck} = W_{S(k-1)} - (nK_{Ck} - 1), \quad k = 2, 3 \quad (3a)$$
$$L_{Sk} = L_{Sk} - (nK_{Ck} - 1), \quad k = 2, 3 \quad (3b)$$

$$n_{N1} = n_{C3} W_{C3} L_{C3} \quad (4)$$

where most variables in those equations can be found in Fig. 12 and the nK_{Ck} is the dimension of kernel in layer C_k. For basement parking, the input data is a 26x39 integer array where W_i=26 and L_i=39 and other parameters are listed in Table I. Table II lists the parameters of off-road parking detection.

There are total 12800 (200x64) heatmaps in CSV format for the model training, validation, and testing with the ratio: 60%, 20%, and 20%. The accuracy and loss for the training and validation is shown in Fig. 7. It is observed that both curve sets get cross at about 5 epochs and slightly separate before 50 epochs. The accuracies of training and validation is very close to each other; hence, the proposed model is accepted. The accuracy and loss of the testing are 97% and 0.134, respectively.

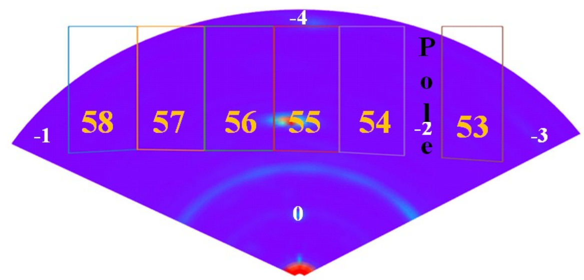


Fig. 5. Zone definition. The number 53 to 58 are the parking spaces and -4 to 0 are non-target areas.

Table I. Parameters in CNN-Based Model for Basement Parking

W_{C1}	L_{C1}	W_{S1}	L_{S1}	W_{C2}	L_{C2}
22	35	11	17	9	15
W_{S2}	L_{S2}	n_{C3}	W_{C2}	L_{C2}	n_{N1}
4	7	**256**	2	5	**2560**

Table II. Parameters in CNN-Based Model for Off-road Parking

W_{C1}	L_{C1}	W_{S1}	L_{S1}	W_{C2}	L_{C2}
18	34	9	17	7	15
W_{S2}	L_{S2}	n_{C3}	W_{C2}	L_{C2}	n_{N1}
3	7	**128**	1	5	**640**

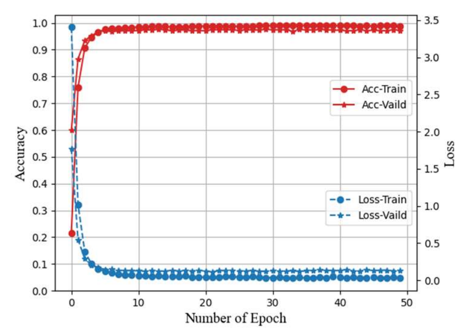


Fig. 7 Accuracy and loss of the proposed CNN-based model for basement parking space monitoring.

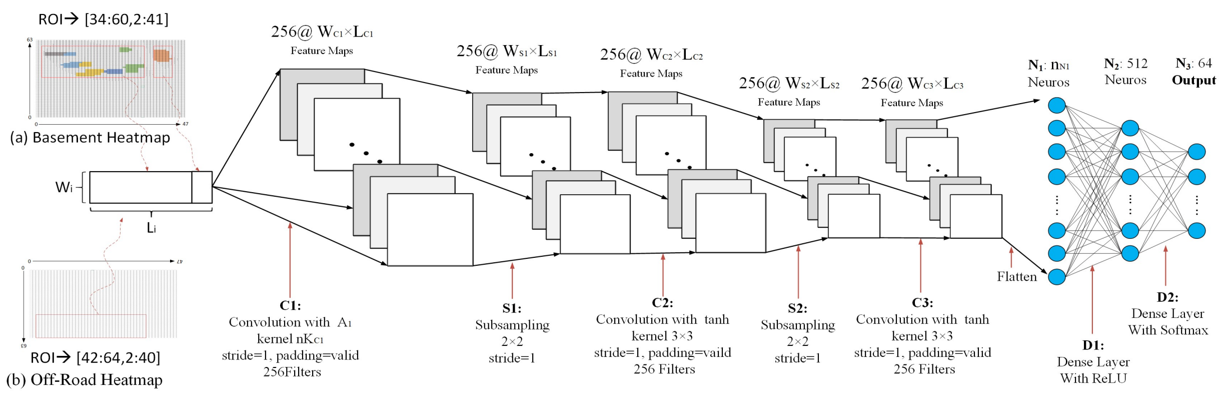


Fig. 6 The input data and the proposed CNN-based Model.

IV. Conclusions

A radar heatmap collection system is built in this study. This system can collect the heatmaps for any parking space or lots continuously and store data automatically. In the meantime, a simple CNN-based model to detect the status of the adjacent parking space is constructed and the performance and accuracy is excellent. This model is not a complicated and don't consume too much computing power. It would be suitable for inferring the status of parking space on the edge device either with or without AI accelerated hardware. The above issues will be verified and studied in the near future. Also, the ROI auto-finding algorithm is an interesting topic to be studied. Moreover, the proposed model will be applied to other parking space scenarios to check if this model can be a general model for parking space monitoring using the FMCW radars.

Acknowledgment

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