Design of Intelligent Pedestrian and Vehicle Guidance System for Zebra Crossing Based on Millimeter Wave Radar

Peng Guo\textsuperscript{1,4}, Hong Xiang\textsuperscript{2}, Shengguang Wu\textsuperscript{3}, Tian Pu\textsuperscript{1} and Dongyang Chen\textsuperscript{3}

\textsuperscript{1}Chongqing Vocational College of Economics and Trade, No. 1785, north section of Wuling Avenue, Qianjiang District, Chongqing, China.
\textsuperscript{2}Hangzhou innovation Institute, Beihang University, No.18 Chuanghui street, Binjiang District, Hangzhou, Zhejiang Province, China.
\textsuperscript{3}Chongqing Jianshe Industry (Group) Co.,Ltd, No.1 Jianshe Avenue, Huaxi Industrial Park, Banan District, Chongqing, China.
\textsuperscript{4}Author to whom correspondence should be addressed. No. 555, Wenhui Road, Qianjiang District, Chongqing, China.
\textsuperscript{5}E-mail: 278906067@qq.com, abc33021126@126.com

Abstract. In order to protect the life safety of the pedestrian and strengthen the intelligent management of urban traffic, this paper's proposes is a set of low-cost and easy-to-install intelligent transportation pedestrian and vehicle guidance system. The system can be applied to the non-crossroads zebra crossing. On the premise of ensuring the safety of crossing pedestrians, it would reduce the waiting time of vehicles when there are no pedestrians or scattered pedestrians passing by, to improve the vehicle traffic rates and avoid the traffic accidents about people and vehicles snatch the right of way, so as to effectively guide pedestrians and vehicles to pass. The system uses STM32L431RCT6 microcontroller as the main control chip, uses millimeter wave radar technology to monitor the number of pedestrians in front of the zebra crossing, intelligently controls the time of pedestrian passing, and coordinate the traffic lights on both sides of the road for countdown display by Lora, and switches the traffic status of vehicles and pedestrians, for realize the function of traffic command. At the same time, the system will automatically upload the number of pedestrian to OneNET, providing access and management interface for superior applications, so that the transportation department can master the travel rules, and provides travel data for the construction of smart city. The system also can receive data returned from OneNET, and flexibly control the time of pedestrian passing at that moment.

1. Foreword

Withing the rapid development of modern transportation and automobile industry, Road traffic crashes represent the eighth leading cause of death globally now. According to the "Global Status Report on Road Safety 2018", They claim more than 1.35 million lives each year and cause up to 50 million injuries\cite{1}. At the same time, road safety accidents also become the first cause of casualties in China. It can be seen that road traffic safety accidents are a huge burden for social development. In order to solve this problem, on May 2011, the United Nations officially launched the "Decade of Action for Road Safety 2011–2020 ". China also joined the "Road Safety in 10 Countries "project (RS-10) in 2010, to save lives by providing evidence for stronger road safety interventions around the world\cite{2}. With the implementation of the road traffic safety law of the people's Republic of China on May 1, 2004, the traffic safety work in China has gradually shown its effectiveness. In 2001-2002, there were more than 700 thousands traffic accidents in China and 660 thousands in 2003. However, since the
implementation of the traffic safety law in 2004, the number of traffic accidents has been decreased year by year. By 2011, the number of traffic accidents has dropped to 210 thousands, with casualties and direct property damage. The loss is also reduced, which shows that the level of road traffic safety in China is gradually improving. However, with the rapid development of economy, the number of cars would be increased greatly. How to reduce the rate of traffic accidents effectively is still a major problem in China's road traffic safety[3].

According to statistics, 22% of the people who died by the road traffic accidents are pedestrians every year[2]. In addition to some pedestrian violations, it is mainly due to the lack of safety protection of crosswalks. In view of this problem, domestic and foreign countries have successively carried out research on Intelligent zebra crossing to realize the intelligent adjustment of traffic light timing. The sensors used to detect the vehicles or pedestrians mainly include pressure sensors, image sensors, infrared sensors, etc[4], but there are always some shortcomings in the practical application of these sensors. If the pressure sensor needs to be re constructed on the existing road surface, and a large number of pressure sensors are laid to sense pedestrians, the system is complex and the cost is high. Considering from the construction period, the amount of work is large, and the traffic cannot be improved in a short time, so it is difficult to achieve a wide range of popularization. The image sensor, namely the camera, uses the optical imaging principle to obtain the scene picture, After image processing to extract the number of pedestrians data, but the system is complex, greatly affected by the weather and environmental changes, especially with the reduction of light intensity, it will greatly affect the accuracy of its detection; infrared sensor is to use the emitted infrared ray to reflect back after encountering obstacles, so as to perceive pedestrians, its system structure is simple, but cannot achieve accurate recognition.

Millimeter wave radar sensors can also be used to detect pedestrians. Millimeter wave refers to the electromagnetic wave in the frequency domain of 30-300GHz. The wavelength is 1-10mm, which is between microwave and centimeter wave. Therefore, millimeter wave has both the advantages of these two kinds of spectrum and has its own unique properties.

1) Compared with centimeter waveguide seeker, millimeter waveguide seeker has the characteristics of small volume, light weight and high spatial resolution;
2) Compared with infrared and laser seeker, millimeter waveguide seeker has strong ability to penetrate fog, smoke and dust, and has a long transmission distance, which has the characteristics of all-weather and all-weather;
3) Millimeter wave radar has stable performance and is not interfered by the shape and color of the target object. It can make up for the application scenarios of other sensors such as infrared, laser, ultrasonic, camera and so on;
4) Millimeter wave radar can distinguish and recognize small targets and multiple targets at the same time.

In view of many advantages, this paper’s proposes is a zebra crossing intelligent pedestrian and vehicle guidance system based on millimeter wave radar. It has high precision, high sensitivity, and can realize "all-weather, all day" work. It is used to detect the pedestrians in front of the crosswalk and adjust the timing of traffic lights intelligently. On the premise of ensuring the safety of passing pedestrians, it can also reduce the number of vehicles in the absence of pedestrians or scattered pedestrians. The waiting time can improve the traffic rate of vehicles, avoid the phenomenon of people and vehicles seizing the right of way, so as to effectively guide pedestrians and vehicles to pass.

2. System Scheme
In order to protect the life safety of the people and strengthen the intelligent management of urban traffic, traffic command should be set up at key intersections and nonintersections with large pedestrian flow to guide pedestrians and vehicles to pass safely. The guidance system of intelligent pedestrian vehicle proposed in this paper is composed of MCU module, radar module, wireless communication module, traffic control lamp and power module, as shown in Figure 1. The system adopts for separate structure, which can be placed on both sides of the zebra crossing, with the left side as the main control. It has the functions of pedestrian number detection, pedestrian passing time calculation, system in-line wireless communication, system external NB-IoT, and traffic control lamp
control. The right side is auxiliary control, with pedestrian number detection, system internal wireless communication and traffic control lamp control functions.

![System composition diagram](image)

**Figure 1.** System composition diagram

3. System Design

3.1. Radar Module

The core chip of the module is x1642bigabl, which is a millimeter wave radar sensor working in 76-81 Ghz frequency band. It adopts FMCW system, and comprehensively uses MIMO, beamforming, group tracking and machine learning target type recognition technology. It can accurately identify the pedestrian track and detect the number of insiders in the waiting area. The data is provided to the MCU module to calculate the pedestrian passing time.

![Schematic diagram of radar detection](image)

**Figure 2.** Schematic diagram of radar detection.

The module is connected with MCU by TTL interface. The detection distance is 15 meters, the range resolution is 0.12 meters, the speed resolution is 0.12 meters per second, and the number of...
objects can be detected is 70 person, which can meet the needs of pedestrian detection in a large range. The schematic diagram of radar detection is shown in the figure 2.

3.2. Wireless Communication Module
Considering that the laying of wired equipment needs to destroy the road surface, in order to reduce the construction, the system selects wireless communication module to exchange data between the system internal and the external NB-IoT.

The module consists of two parts: one part is the system internal Lora wireless module, as shown in Figure 3. Lora is a low-power LAN Wireless Standard created by Semtech company, which can realize the unification of low-power consumption and long-distance. The system uses the module to conduct wireless communication to coordinate the separation systems on both sides of the zebra crossing, and synchronize the number of pedestrians and the countdown data of traffic control module. The data exchanged in the system include:

1. The command of starting the countdown of vehicle passing;
2. The vehicle duration;
3. The command of inquiring about the number of pedestrians in waiting area;
4. The number of pedestrians in waiting area;
5. The command of starting the countdown of pedestrian passage;
6. The pedestrian duration;

The second is the system external NB-IoT module, as shown in Figure 4. Through this module, the system uploads the pedestrian number data to OneNET, or receives the remote traffic control instructions and data issued by OneNET. OneNET is the PAAS open platform of NB-IoT built by China Mobile. As the center of equipment connection and data, OneNET can adapt to various sensor networks and communication networks. The data exchanged between the system and the external NB-IoT include:

1. The number of pedestrians crossing the road at this time;
2. The pedestrian duration received from NB-IoT;

The above two communication modules are connected with MCU through UART interface to realize transparent data transmission.

3.3. MCU Module
The main control chip is STM32L431RCT6 single chip microcomputer, with the main frequency of 80MHz. It supports SPI, I2C, UART and other protocols, which is convenient for communication with other modules and can meet the requirements of real-time control.

The system plans a pedestrian waiting at the area on both sides of the zebra crossing to detect the number of pedestrians, and the default initial state is the state of guiding vehicles. When the pedestrian enters the waiting area and is ready to cross the zebra crossing, the millimeter wave radar will detect and recognize this behavior and transmit the information to the single chip microcomputer, which
receives the trigger signal and controls the traffic control light to display the countdown of vehicle passing. Before the end of the countdown, the vehicle can continue to pass. At the end of the countdown, the single-chip microcomputer controls the traffic control light to display the yellow warning status of the vehicle. The single-chip computer will query the radar module and the auxiliary control system on the other side actively again. At this time, the accurate number of people in the waiting area will be calculated according to the number of people, and the traffic control light will be controlled to display the countdown of vehicle prohibition and coordinate the road surface. At the same time, the single chip microcomputer also uploads the pedestrian quantity data to the OneNET through the NB-IoT module, so that the traffic department can master the pedestrian travel situation and provide data for the construction of smart city. Under certain circumstances, the system can also receive the data from the NB-IoT, and directly control the countdown display of the traffic command module according to the traffic needs of the road section.

It should be noted that the interval between the two cycles should not be less than 2 minutes, so that pedestrians can concentrate on crossing the zebra crossing and reduce scattered traffic, resulting in long waiting time of vehicles.

3.3.1. Pedestrian travel time calculation
The time for pedestrians to cross the zebra crossing is related to the width of the road, the speed of pedestrians and the number of pedestrians, which can be calculated according to the following formula:

$$ t = \frac{3.5k}{v} + \frac{m+n}{s} $$

- k: Take 2 for two lanes and 4 for four lanes. The width of general lane is 3.5m;
- v: Pedestrian walking speed, taking into account the elderly and children, is taken as 1mps;
- m: Number of pedestrians on the left side of zebra crossing;
- n: The number of pedestrians on the right side of the zebra crossing;
- s: Safety factor, take 5.

Assuming that eight people need to cross the two lane zebra crossing, the travel time is calculated to be 8.6 seconds and rounded to 9 seconds.

3.3.2. The working state of the system and the work flow of single chip microcomputer
The working state of the system is shown in the figure 5, and the workflow of the main control MCU and auxiliary control MCU are shown in figure 6 and figure 7.

![Figure 5. The working state of the system](image-url)
4. Experimental Result

4.1. Mainboard
As the core of the whole system, the core control board is independently developed and consists of single-chip microcomputer module, radar module and wireless communication module. The physical object is shown in Figure 8.

**Figure 6.** Workflow of Main control MCU.

**Figure 7.** Workflow of Auxiliary control MCU.

**Figure 8.** Mainboard.
4.2. Number of Pedestrians Identification Results
The pedestrian detection experiment of radar module is shown in the figure 9.

![Figure 9. Pedestrian detection test.](image)

4.3. NB-IoT Datas
The data uploaded by the system to the OneNET is shown in Figure 10.

![Figure 10. Pedestrian data flow on OneNET](image)

5. Conclusion
The intelligent pedestrian and vehicle guidance system proposed in this paper adopts a separate structure, for which is light and portable. It is suitable for non-intersection zebra crossing, and it is easy to be modified on the existing road signs, poles and other infrastructure. It is suitable for the majority of small and medium-sized cities. It is widely used. Starting from low-cost, it does not need to reconstruct the pavement. It uses millimeter wave radar to detect the number of pedestrians through wireless communication. Adjust the traffic lights on both sides of the zebra crossing to display synchronously, and switch the traffic status of vehicles and pedestrians, so as to realize the function of traffic command. The system can not only ensure the safety of pedestrians, but also reduce the waiting time of vehicles when there is no passing pedestrian, and improve the traffic rate of vehicles, thus
avoiding the phenomenon of snatching the right of way between vehicles and pedestrians when there is no traffic light command, and can effectively guide the vehicles and pedestrians at the zebra crossing to pass smoothly.

The system also has the NB-IoT access and management interface, which can be used by the transportation department to master the travel rules, provide travel data for the construction of smart city, or flexibly control the passage time of this section in this period according to the calculation results returned from the cloud.

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