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Research on live detection technology in wireless charging of electric vehicles based on milli-meter wave radar

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Abstract. Recently, milli-meter wave radar has been recognized as efficient solution that has the capacity to contribute to live detection in wireless charging of electric vehicles. We discuss the importance of the live detection in wireless charging of electric vehicles and traditional solution like infrared sensor, ultrasonic detector and camera. This article proposes to apply milli-meter-wave radar to improve the reliability and accuracy of live detection. At the end of the article, the software and hardware design ideas of the scheme are proposed. It can effectively solve the safety and reliability problems in the existing electric vehicle wireless charging scenarios. At the same time, it can eliminate people's concerns about the safety of wireless charging technology and lay a good foundation for the promotion and further research of electric vehicle wireless charging technology.

Keywords: Electric vehicles, live detection, milli-meter wave radar, wireless charging, infrared sensor, ultrasonic detector, camera.

1. Introduction

Electric vehicles have the advantages of zero emission, low noise, and low cost. They are the choice for green travel and have been vigorously promoted in countries around the world. Wireless charging technology can get rid of the shackles of wires and plug-in interfaces, and solve the problems of traditional wired charging, such as inconvenient operation, easy aging and damage, leakage and short circuit in humid environment, high maintenance cost, and unsightly appearance.

Wireless charging is more convenient, safe, and reliable than wire charging. It has more advantages, and it conforms to the development trend of electric and intelligent vehicles in the future, and will become an important development direction of new energy vehicle charging technology. Wireless charging technology is an important power supply method for electric vehicles in the future. There is a high-frequency magnetic field area between the transmitting and receiving coils of the wireless charging system for electric vehicles, and there will inevitably be liveness intervening in this area, such as humans and animals. Electromagnetic radiation from high-power electric vehicle wireless charging systems may have health effects on nearby humans. Exposure to electromagnetic radiation exceeding safety standards will have adverse effects on bodily functions and irreversible harm, resulting in increased probability of cell cancerous lesions, degeneration of physiological functions and other problems [1]. In order to ensure human safety, the Society of Automotive Engineers (SAE) has formulated the SAE J2954 wireless charging standard, which clarifies the safety standards for the human body in the electromagnetic exposure environment. A live detection system that complies with the SAE J2954 standard should have the following functions: When a living body appears in the detection area, the wireless charging system should immediately reduce the transmission power so as to control the electromagnetic exposure within the standard range [2]. Therefore, how to accurately and effectively realize live detection is an indispensable key technology for the wireless charging system of electric vehicles.

Milli-meter-wave radar is a new type of detection method, which has many advantages such as long coverage (up to 160 meters), not affected by rain and fog weather, and can work around the clock. It has great potential for live detection. This paper will analyze the advantages of the sensor in the situation of wireless charging of electric vehicles systems from the theoretical level. We will discuss the composition the composition of wireless charging of electric vehicles systems, analyze the principles and applicable scenarios of other sensors like infrared sensor, optical camera and ultrasonic sensor. We will study the circuit characteristics of the combination of milli-meter-wave radar and wireless charging vehicles, analyze the possible solutions for the establishment of radar systems, analyze the optimal placement position and direction of the radar, analyze the simplest architecture of the system, and verify the detection accuracy of live targets under real-time movement, to achieve the matching of system parameters with the best monitoring points, and achieve accuracy under the tracking of multiple targets and multiple actions.

2. Literature Review

2.1. Research status of live detection

The first patent application related to living body recognition in China was in 2001. As of 2014, Chinese living body recognition technology has been in a stage of slow development, and the number of patent applications is not large. At this stage, Chinese living body recognition is still in its infancy [3].

The current live detection technology mainly focuses on identity confirmation and recognition, mostly using face information recognition, iris recognition, etc. A small number of vehicle-mounted liven detection technologies are only limited to in-vehicle live detection, and almost no live body outside the car or even on the road is involved [4].

2.2. The principle and application of traditional sensor

Traditional detection methods include infrared sensors, ultrasonic radar, and cameras. Infrared sensors fail when the object to be measured is a black body, and cannot work in high temperature situation, and the detection distance can only reach 10 meters. The disadvantage of ultrasonic radar is that the distance is very short, the maximum distance is 5 meters. And ultrasonic radar is easily disturbed by weather factors when using it. It is very difficult for the camera to obtain accurate three-dimensional information, and it is relatively limited by ambient light. Millimeter-wave radar is a new type of detection method, which has many advantages such as long coverage (up to 160 meters), not affected by rain and fog weather, and can work around the clock. It has great potential for live detection.

2.3. The development of milli-meter wave radar

Europe first carried out extensive research on vehicle radar. In 2003, the 77 GHz vehicle radar developed by Bosch was officially commercialized. Since 2013, it is planned to gradually adjust the use frequency of vehicle radar from the 24 GHz frequency band to the 79 GHz frequency band [5]. Japan's vehicle radar research work was carried out relatively early, and companies such as Honda, Toyota and Mitsubishi have successively carried out the development of vehicle radar [6]. The development of the vehicle radar industry in the United States is later than that in Europe, but driven by its related manufacturing industry, the vehicle radar industry has developed rapidly and is now at the leading level in the world. In 1992, Ford and Eaton jointly developed the VORAD safety system. The radar system uses a single beam method to achieve forward detection and early warning functions. It is installed on public buses as a rear-mounted system, reducing the accident rate of buses by nearly 30%. Currently, the system is still widely used, operating at 24.725 GHz and capable of detecting up to 20 targets within 106m.

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3. Discussion

3.1. Disadvantages of the traditional wireless charging of electric vehicles solution for live detection

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3.1.1. Infrared sensor. The biggest disadvantage of infrared sensors in the live detection process of wireless charging of electric vehicles is that they are easily affected by high temperature. Any object with a temperature higher than absolute zero (-273.15 °C) will spontaneously radiate infrared energy outward [7]. The higher the temperature of the object, the stronger the energy radiated outward. According to Kirchhoff's law of thermal radiation, the radiation energy of an object is:

$$M(T_{obj}) = \sigma\xi T_{obj}^4 \tag{1}$$

where M is the radiation energy of the object, σ is the Stephen-Boltzmann constant, ε is the emissivity of the surface of the object, and Tobj is the temperature of the object. The temperature measurement principle of the thermopile infrared sensor basically satisfies the formula (3-1)

The human body mainly radiates infrared rays with a wavelength of 9-10 μm [8], and the infrared rays in this wavelength range will not be absorbed by the air. According to the above-mentioned law, it can be known that the surface temperature of the human body can be known by knowing the emissivity of the skin on the surface of the human body and the energy radiated from the measured part, thereby realizing the live detection.

The thermopile infrared sensor detects the radiant energy of the object through the hot end, and the cold end detects the ambient temperature inside the sensor. The output voltage signal U is obtained by combining the difference between the two. Therefore, the output characteristic formula of the thermopile infrared sensor is:

$$U = K\xi(T_{obj}^{4-\delta} - T_{amb}^{4-\delta}) \tag{2}$$

where K is the total factor of the infrared sensor, δ is the undetermined factor. According to formula (3-2), when there is a temperature difference between the working ambient temperature and the internal ambient temperature of the infrared sensor, heat exchange will occur. A large amount of heat exchange will lead to thermal shock, which affects the measurement of ambient temperature at the cold end and makes it impossible to accurately measure the temperature of the object. Generally speaking, infrared sensors cannot work properly when the ambient temperature is higher than 40 degrees. In addition, the detection distance of infrared sensors is affected by environmental conditions such as rain, fog, dust, pollution, etc. It cannot penetrate ceramic plastics. Therefore, the use of infrared sensors in the field of wireless charging of electric vehicles has certain limitations.

3.1.2. Ultrasonic detector. The biggest problem of ultrasonic detector is that it will be affected by complex noise. Ultrasonic detector detects the target by emitting ultrasonic waves with characteristic frequency, and record the time it takes to emit ultrasonic waves of characteristic frequency and receive ultrasonic waves of reflected characteristic frequency, thereby obtaining the distance. Ultrasonic sensors generally have a short operating distance. Its common effective detection distance is between 5-10m, while the detection distance of milli-meter waves can reach 100m. At the same time, the detection performance will be disturbed by smoke, dust and raindrops. Its anti-interference ability is weak, any acoustic noise may interfere with the output of the sensor. When two ultrasonic sensors of the same frequency are placed together, acoustic crosstalk will occur. The complex sound sources in the electric vehicles parking lot will affect the detection of ultrasonic radar.

3.1.3. Camera. The camera loses its live detection function when there is insufficient light. A camera is a device that uses the principle of optical imaging to form an image and uses a negative to record the image. It is an optical device used for photography. The shortcomings of the camera are obvious:

1. The acquired information is complex and inconvenient to process.
2. It is seriously affected by light, weather and occlusion.
3. Although stereo vision can obtain rough distance information, the accuracy, speed, stability and scope of application are far inferior to milli-meter wave radar.

3.2. Principles and advantages of milli-meter wave radar

Millimeter wave radar originated from military radar. The earliest application of radar was in the military. The principle is to send a signal with a frequency that gradually increases over time through the transmitter. When the signal encounters an object, it will be reflected back, and its delay is twice the distance/speed of light value. There is a frequency difference between the returned waveform and the sent waveform. This frequency difference has a linear relationship with the time delay. By subtracting these two frequencies, the difference frequency (beat frequency) of the two frequencies can be obtained. From this, the distance of the object to the radar can be calculated.

Milli-meter-wave wavelengths are between 1 and 10 mm, and the corresponding frequency range is 30 to 300 GHz. Milli-meter-wave radar transmits frequency-modulated continuous waves (triangular waves) through the antenna, receives the reflected signal from the target, mixes the IF signal with the transmission frequency of this frequency, and processes the IF signal to obtain the target distance and speed information. On this basis, not only the existence of the measured target can be known, but also precise information such as the position, direction, distance and speed of the target can be calculated.

We will use the micro-Doppler effect to extract low-frequency life signals, distinguish living and non-living bodies in a non-contact way, and use the hardware circuit, core algorithm, and software embedded system of milli-meter-wave radar to solve the problem of live detection during the wireless charging of electric vehicles.

3.3. Construction of software and hardware platform

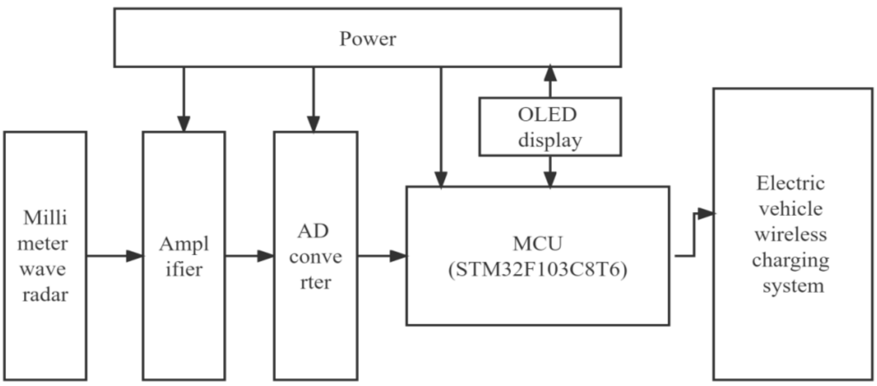

Figure 1. The block diagram of milli-meter wave radar detection system.

The hardware system framework of milli-meter-wave radar live detection is shown in Figure 1. The power supply module provides a stable voltage for each module. The milli-meter-wave radar senses the distance and speed of the target and converts it into an electrical signal for output. The AD (Analogue-to-digital) conversion module realizes the conversion of the analog signal to the digital signal, and then converts the analog signal to the digital signal. The data is transmitted to the MCU (Micro controller Unit) for processing, and finally the MCU makes the electric power adjustment decision for wireless charging of electric vehicles system.

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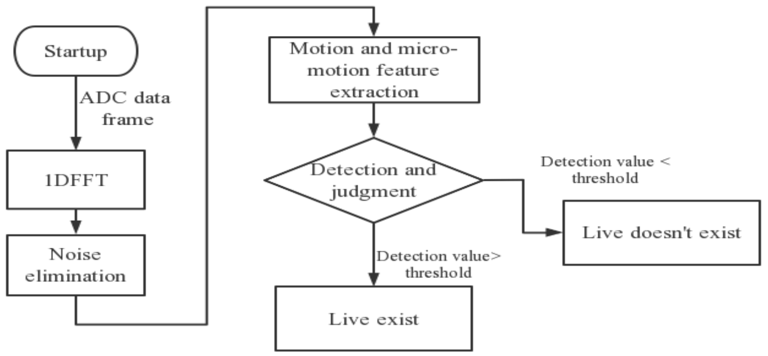

Figure 2. Algorithm Framework of Live Detection.

At the software level, we perform windowing and 1DFFT processing on the signal of each channel, and perform noise processing on the signal after distance FFT processing, so as to achieve the purpose of eliminating noise signals that generate stationary clutter. Motion and micro-motion features are extracted by Doppler and micro-Doppler effects respectively [9], so as to design a living body detection algorithm (the flowchart is shown in Figure 2).

The expected function of this device：when a living body enters the electromagnetic exposure area, the wireless charging power is automatically reduced to ensure that the electromagnetic exposure is within a safe range. When the living body leaves the electromagnetic exposure area, the wireless charging resumes to work at rated power.

4. Conclusions

From the perspective of safety and reliability, this paper creatively applies milli-meter-wave radar to the live detection scene of wireless charging of electric vehicles, which can effectively solve the safety and reliability problems in the existing wireless charging scene of electric vehicles, and can eliminate people's concern about wireless charging. We discuss the advantages and disadvantages of traditional sensors, and summarize the advantages of milli-meter-wave radar in this field by comparing different sensors.

There are some limitations to this study, which could lead to further studies and recommendations for future directions. At present, we have built a system framework at the theoretical level, but there is not enough experimental data to verify the feasibility of the scheme. Future research will be carried out in software and hardware to improve the accuracy and timeliness of live detection.

This paper will lay a good foundation for the promotion and further in-depth research of wireless charging technology for electric vehicles. Wireless charging technology makes charging of new energy vehicles more convenient and faster, which facilitates people's travel and ensures people's safety. The wireless charging technology has broad prospects. As a supporting tool for wireless charging technology, this technical solution has the same market potential and economic value.

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