Pedestrian detection in automated vehicles using ultrasonic and passive infrared sensors

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Abstract— **Pedestrian safety is one of the important issues of traffic safety in urban areas. The application of various technologies in vehicles provides enormous opportunities to reduce accidents in which pedestrians are most often injured. The development of intelligent pedestrian recognition systems can be divided into two directions. Development of hardware part related to different types of sensors, and development of software part based on artificial neural networks. The paper analyzes various technologies used in pedestrian detection in automated vehicles with an emphasis on hardware development. A system based on two types of sensors, ultrasonic sensor and passive infrared, is proposed. Aspects of the application of such sensors with possibilities of implementation in complex computer vision systems are analyzed.**

Keywords-Automated Vehicle; Pedestrian Detection; Ultrasonic Sensor; Passive Infrared Sensor;

I. Introduction

Pedestrian safety is a primary traffic issue in an urban environment. A special problem of pedestrian detection occurs in densely populated urban areas where public bus transport of passengers takes place. This problem is especially pronounced with bus drivers who have a problem visually following all events around the bus, especially with a high concentration of passengers and surrounding pedestrians. The mentioned problem is the accidental movement of pedestrians without predefined rules, which is reflected in the crossing of streets at unmarked pedestrian crossings, a longitudinal crossing of streets, sudden and without clear signals of intent to cross, and more. Combined with a cluttered background and a range of visibilities under various weather and roadway conditions, the solution for a reliable and accurate means of identifying pedestrians requires sophisticated configurations and extensive experimental evaluation.

To solve the mentioned problem, various projects have been launched, the most important of which are the collision detection system (CWS) project in public bus transport, to help drivers in detecting and preventing accidents. The main steps included in the development of pedestrian detection and accident prevention systems include pedestrian detection, pedestrian monitoring, hazard assessment, and vehicle warning or stopping.

Detection involves the identification or measurement of a pedestrian object. On the other hand, tracking involves the detection and tracking of an object over time, movement. The hazard assessment determines the proximity and relative movements between the target and the subject. Depending on the applied sensor techniques and working environment conditions, a certain degree of success in hazard detection, monitoring and assessment will be achieved. The task of detecting pedestrians can be very challenging in conditions of poor visibility, at night, when the weather is foggy, rainy, snow, and other aggravating factors. Pedestrian detection poses several challenges to the system. First of all, it is necessary to distinguish the human body from other movable and immovable objects. This is a common problem for all types of sensors whose work is based on different technologies, ultrasound, electromagnetic waves, infrared light, and more. Based on such an analysis, it is possible to conclude that it is necessary to select different sensor technologies in the pedestrian detection system that will complement each other and eliminate the weaknesses of certain technologies. The main emphasis of the research is on the development of a low cost sensor system intended for the detection of pedestrians in traffic, based on the Arduino UNO device with a satisfactory accuracy class.

II. Related Work

Various technologies can be used in a pedestrian detection system. Sensors based on the piezo effect can be used by placing them in pedestrian crossings and by detecting pressure and sending a certain voltage signal when pedestrians appear at the crossing. There are systems based on piezo sensors that detect pedestrians standing at marked pedestrian crossings PUFFIN (Pedestrian User-Friendly Intelligent Crossing), and PUSSYCATS (Pedestrian Urban Safety System and Comfort at Traffic Signals) [1]. Another type of sensor suitable for detecting pedestrian objects is the ultrasonic sensor. When a pedestrian passes by the vehicle, the transmitted signal is reflected to the receiver. There are two types of ultrasonic sensors.

Pulsed ultrasonic sensors measure the distance of a pedestrian or his presence. The second type of ultrasonic sensor sends a continuous ultrasonic signal of a certain frequency and uses the Doppler effect to detect the movement of the object and its speed [2]. Ultrasonic sensors can detect pedestrian objects up to 20m away. This type of sensor also has a few drawbacks. The first drawback is the mounting position which must be on the front and rear of the vehicle with a certain mounting angle. The sensor covers a certain angle, so for complete coverage of the vehicle's environment, it is necessary to install several sensors in different locations on the vehicle. Another bad feature of these sensors is that they are sensitive to different types of clothing worn by pedestrians.

The reflected signal from pedestrians may differ depending on the material of the clothes worn by the detected pedestrians. Clothes made of natural materials have a higher power of absorbing the ultrasonic signal than clothes made of artificial materials.In general, ultrasonic sensors are also affected by weather conditions, so this should be taken into account in the construction of pedestrian detection systems [3]. In addition to the above types of sensors, microwave radars are widely used in pedestrian detection, which works on a similar principle as ultrasonic sensors. This type of sensor bases its work on the analysis of the reflected signal and its analysis. In addition to detecting an object, it is possible to detect the speed at which the object is moving. A new approach to pedestrian detection is discussed in [3], where the authors perform pedestrian detection based on a detailed analysis of the obtained ultrasonic signal. It was determined that the analysis of the spectrum of the reflected ultrasonic signal makes it possible to determine the type of detected object, ie. whether it is a human or some other object.

In [4], the authors have a different approach to the pedestrian detection system. The use of FIR cameras with ZnS lenses is analyzed, which gives a thermo-image of the observed object as an output. The downside of such a system is its high cost. The proposed system was tested in conditions of poor visibility and bad weather and gave satisfactory results. The authors in [5] analyze the influence of weather conditions on FIR sensors in pedestrian detection, where the authors gave a new perspective on the use of the Denoising Convolutional Neural Network (DnCNN) method by merging data sets for FIR, HAZ, and SCUT into one data set. Based on testing with this data set, better detection accuracy was achieved compared to the classical method for 9.8 mAP (mean Average Precision). For pedestrian detection in [6], a multispectral method was analyzed that eliminates problems in pedestrian detection using visible spectrum cameras. It is known that thermal cameras work with a different range of signal spectra, and their sensitivity to weather conditions and low light is lower compared to cameras for the visible spectrum. The synergy of both types of cameras achieves higher detection accuracy in conditions of poor visibility and bad weather conditions.

In addition to the above sensors for the successful detection of pedestrians, various methods are used that more or less give satisfactory results. In [7], the authors analyze the possibilities of using infrared cameras in order to accurately detect pedestrians in traffic. The authors use four different data sets and integrate different algorithms. The degree of accuracy, ie mAP, was raised by 5.22 %. A good feature of such systems based on IR signals is that they give better results at night compared to systems based on other types of technologies.The widely used sensor technology is based on microwave radars. Doppler radars can identify pedestrians moving at a speed faster than a threshold speed. On the other hand, long-range radars at frequencies of 77 GHz based on frequency modulated continuous wave (FMCW) technology is widely used [2]. Recently, radars based on Ultra wideband (UWB) technology have been used. This type of radar provides detailed information on the position of the detected object at 10-15 cm.

In addition to microwave sensors, laser scanners are also used for detection purposes. They work on the principle of laser emission of an infrared light pulse. Measuring the time since the arrival of the reflected wave is information about the distance of the detected object-pedestrian. Scanning of the reflected wave is achieved with the help of a rotating prism, so it is possible to cover a complete area of 360^0. Exceptional accuracy and excellent resolution of the obtained images put this type of sensor at the top of used sensors for object detection. Each of these technologies has its pros and cons. Therefore, the fusion of all these technologies is widely used in the automotive industry, which eliminates the disadvantages of certain technologies. Based on the conducted analysis, it is possible to conclude that for short distances it is best to use sensors based on ultrasonic technology (parking, reversing, pedestrian detection up to 50 cm, etc.). For longer distances, up to 20 m, it is convenient to use short-range radar (SRR), which operates at a frequency of 24 GHz. For longer distances, up to 120 m, long-range radar (LiDAR), whose operation is based on the 77 GHz frequency range, has shown excellent properties. Computer vision, based on cameras for visible light, can be used at medium distances of 0-80 m, and the use of cameras based on in frared light for night driving.

III. METHODS

The basic idea of the research is based on the analysis and proposal of a cheap solution of a complex sensor system based on Arduino microcontroller technology and related sensors. Based on a detailed analysis of the technologies used, it can be seen that modern solutions are based on very complex and expensive technologies that are difficult to access in less developed countries. To keep pace with the times, the idea of using cheap solutions with satisfactory results that these solutions can provide was imposed. The Arduino UNO microcontroller assembly can be equipped with different types of sensors to provide a low-cost, efficient sensor assembly for pedestrian object detection. Two technologies on which the operation of the sensor is based, based on ultrasound and based on infrared waves, have been selected as the starting point for the design of the sensor assembly.

The HC-SR04 type sensors were selected for this purpose. The HC-SR04 ultrasonic sensor uses sonar to determine the distance to an object. This sensor reads from 2 cm to with an accuracy of 0.3 cm, which is good for most projects. In addition, this particular module comes with ultrasonic transmitter and receiver modules. The ultrasound transmitter (trig pin) emits a high-frequency sound (40 kHz). The sound travels through the air. If it finds an object, it bounces back to the module. The ultrasound receiver (echo pin) receives the reflected sound (echo). The time between the transmission and reception of the signal allows us to calculate the distance to an object. This is possible because we know the sound's velocity in the air. The distance to the pedestrian facility is calculated according to the formula:

$$D = \frac{v_s \cdot t}{2}\left[m\right] \quad (1)$$

where: v_s the speed of sound in the air at a temperature of 20^0 C is 343 m/s, t measured time, D distance to the detected object.

Figure 1. shows the principle of operation of the HC-SR04 ultrasonic sensor.

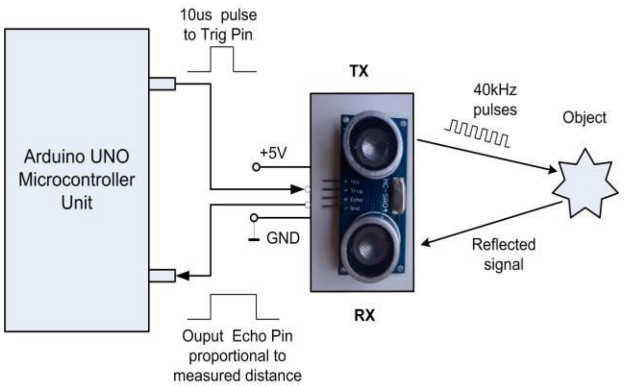

Figure 1. Ultrasonic sensor HC-SR04

For distance measurements up to 15 cm with an error of less than 1.5 %, the distance between the transmitting and receiving part of the ultrasonic sensor must be taken into account.

Figure 2. shows the situation when measuring the distance to the object that is closer than 15 cm.

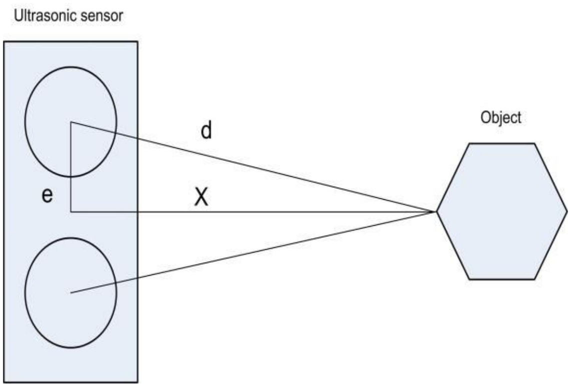

Figure 2. Correcting the distance

The following form is used to calculate the corrected distance:

$$x = \sqrt{d^2 - e^2} \quad (2)$$

where: d is the measured distance, x is the correct distance, e is the correction factor ~ 2.5 cm.

A PIR (Passive Infrared) sensor was used to detect the presence of pedestrian movement. This type of sensor can detect the presence of pedestrians at a distance of up to 7 m with a coverage angle of 120^0. It is one of the sensors for detecting objects at short and medium distances. Figure 3. shows the principle of operation of the PIR sensor.

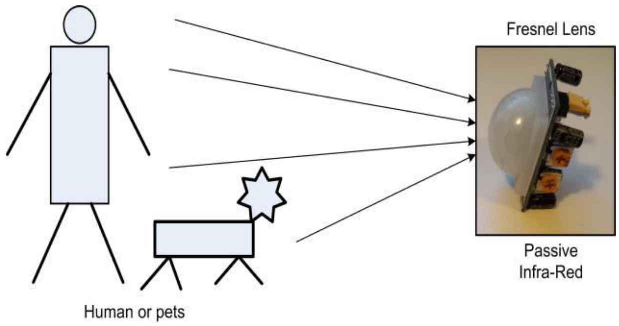

Figure 3. Principle of operation of PIR sensor

In presence of human IR radiations, the sensor detects the radiations and converts it directly to electrical pulses, which are fed to the inverter circuit. Based on the information about the change in the thermal radiation of the body, it is possible to detect the presence and movement of the observed object.

IV. RESULTS

A sensor system consisting of two ultrasonic sensors and one PIR sensor has been proposed for pedestrian detection. Ultrasonic sensors provide information on the distance of the observed object while the PIR sensor provides information on the presence of a human or animal. On the other hand, the PIR sensor also provides useful data on the movement of the observed object. The system uses an Arduino UNO microcontroller device and a speaker assembly with an amplifier, which serves as an audible signal for pedestrian detection. The display was also used as a pointing device showing the distance to the detected pedestrian object. The sensors are mounted at a height of 50 cm. In addition to the hardware part for the operation of the system, the appropriate software has been designed. The software was developed in Arduino IDE 2.0.0.-beta12. environment. Of the specialized files, the LiquidCrystal library was used to communicate with the LCD screen. For the needs of experimental research, scripts were developed for collecting information from the used sensors, and the collected data were sent to a computer. For further research, the development of new software based on artificial neural networks is planned in order to increase the accuracy of detection. Figure 4. shows the appearance and components of the sensor system.

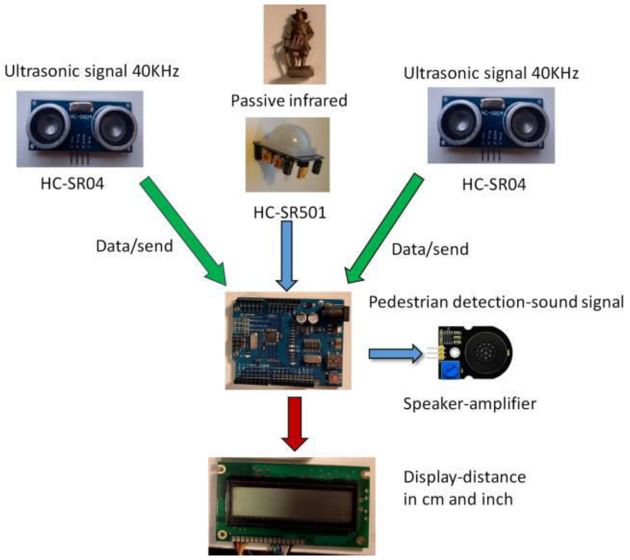

Figure 4. Sensor system with ultrasonic and PIR sensors

The system was tested in laboratory conditions, where human of different bodies were grouped into two different classes as models [8]. The research was performed in accordance with the Ethical Regulations at the Faculty of Transport and Traffic Engineering Doboj, University of East Sarajevo. The first class consisted of human up to 120 cm tall (children), and the second was over 120 cm (adults) [8]. Fifty measurements were performed, and the obtained results are shown in Table I.

TABLE I. MEASURE RESULTS

No. of class	Detection accuracy for different distances		
	Up to 50cm	**50cm-1m**	**1m-4m**
Class 1	**94.3%**	**95.3%**	**95.7%**
Class 2	**96.1%**	**97.4%**	**97.7%**

It is evident from the obtained results in the table that the detection accuracy is high in both cases, for both classes of samples. The application of the proposed type of sensor system can be in less critical applications where 100% accuracy is not required.

V. DISCUSSION

The paper analyzes the sensors used in practice for pedestrian detection and automatic response. The application of intelligent systems for the detection of movements, persons, objects is a very important segment of the development of autonomous vehicles and intelligent robots. It can be seen that this is a very demanding and complex problem. The basic idea of the research is the analysis of the possibilities of applying available sensor technologies in the process of object-person detection and the development and implementation of low cost sensor solutions based on these technologies.

It is evident from the research that the technologies used provide relatively good results so that they can be used in less demanding security applications. It is also evident that the use of these technologies in cooperation with other types of technologies such as microwave radars, thermal imaging cameras, cameras for the visible part of the spectrum. The LiDARs and others can provide excellent results in the problem of pedestrian detection where safety requirements are at a very high level.

VI. CONCLUSIONS

The conducted research represents the first phase in the development of sensor systems for the detection of human objects and the recognition of these objects. The obtained results show that the implemented sensor system provides a satisfactory level of accuracy in less demanding applications. The maximum measuring range of the sensor is 4.5 m, which is one of the shortcomings of the sensor system. Another drawback is the small PIR sensor coverage angle of 120^0. Future research will focus on finding the optimal positions of implemented sensors in the sensor system, and the development of software based on artificial neural networks to increase the accuracy of detection. In the next phase of the research, it is necessary to include microwave radars and LiDARs, which would represent one whole and a complete sensor system.

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