IJEEC

International Journal of Electrical Engineering and Computing
Vol. 6, No. 2 (2022)

Short Report
UDC 621.397:004.42
DOI 10.7251/IJEEC2202085S

Subsystem With Ultrasonic and Passive Infrared Sensors for Pedestrian Detection

Aleksandar Stjepanović, Zoran Ćurguz, Miroslav Kostadinović, Gordana Jotanović, Mirko Stojčić, Goran Kuzmić

University of East Sarajevo, Faculty of Transport and Traffic Engineering, Doboj, Bosnia and Herzegovina

aleksandar.stjepanovic@sf.ues.rs.ba, zoran.curguz@sf.ues.rs.ba, miroslav.kostadinovic@sf.ues.rs.ba, gordana.jotanovic@sf.ues.rs.ba, mirko.stojcic@sf.ues.rs.ba, goran.kuzmic@sf.ues.rs.ba

Abstract— **Despite the rapid development of technologies for the detection of pedestrians in traffic, there are still significant problems with automated vehicle management systems. Often these problems are caused by different external conditions, weather disasters, different light levels, day and night, and more. All these factors can affect the incorrect assessment of the system and the performed detection of the pedestrian object. Pedestrian fatalities have risen recently, even as vehicles are equipped with sophisticated avoidance technology. Vehicle-based sensors can fail to identify pedestrians especially when those pedestrians are small, too far or too close to the vehicle, or partially occluded by nearby objects. Pedestrians have variable physical characteristics and appear in a variety of environments with different background features. The paper analyzes the possibilities and problems that arise in the detection and recognition of pedestrians. 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 and machine learning techniques. The paper analyzes various technologies used in pedestrian detection in automated vehicles with an emphasis on hardware development. A low-cost 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. The most common classes of sensors presently used in automated driving applications include visible-light cameras (VLC), light detection, and ranging (LiDAR).**

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 is the collision detection system (CWS) project in public bus transport, to help drivers in detecting and preventing accidents.

Most new vehicles sold in 2020 had, as a standard or optional feature, Advanced Driver Assistance Systems (ADAS) equipped with Pedestrian Automatic Emergency Braking (PAEB). These systems with automatic braking functionality have the potential to prevent or reduce the severity of collisions resulting in property damage, personal injury, and/or death. Current pedestrian detection systems will warn the driver through an audible, visual, or haptic alert when it determines a significant collision risk exists. Drivers need to understand the capabilities of any (ADAS) present in their vehicle.

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, and movement. 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.

The hazard assessment determines the proximity and relative movements between the target and the subject. Depending on the applied sensor techniques and working environment

This paper is a revised and expanded version of the paper presented at the XXI International Symposium INFOTEH-JAHORINA 2022 conditions, a certain degree of success in hazard detection, monitoring and assessment will be achieved. Depending on the sensor suite, the system can monitor a field of view several meters in front of the vehicle. Inputs from the different type of sensors are fed into a central processing unit that classifies objects based on their speed relative to the vehicle and their size.

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. For this purpose, it is convenient to use artificial neural networks, and machine learning techniques, which based on a large set of data, can distinguish movable from immovable objects. In addition to the visual detection of pedestrians, which is performed by visible-light cameras (VLC) sensor, it is necessary to process the obtained and extract the necessary data from the image (presence of pedestrians).

Different types of sensors are used to detect pedestrians in automated vehicles, most commonly based on visible light cameras, thermal cameras, and laser distance measuring devices with LiDARs and microwave radars. Each of the mentioned sensors has certain good and bad sides which is the integration of all the mentioned ones give acceptably good results. Visible-ray cameras (VLC) are widely used in the applications of detecting different objects and vehicles, but it is difficult for VLC to detect pedestrians at night when they are not illuminated and they can mistake the shadows of pedestrians for the pedestrians themselves. Another problem of pedestrian detection with VLC has been considered a vital one in the domain of Computer Vision and Pattern Recognition. It is formulated as the problem of detecting and tracking pedestrians in images or videos.

In contrast, since far-infrared light (FIR) cameras produce images by detecting the heat objects emit, this type of camera can be used even in the dark of night. An FIR based camera uses far-infrared light waves to detect differences in heat (thermal radiation) naturally emitted by objects and converts this data into an image. As well as capturing the temperature of an object or material, a FIR camera captures an object's emissivity—how effectively it emits heat. Far infrared light cameras can also take images even when water drops or snowflakes adhere to the lens; in various other adverse environments as well, they offer promise as pedestrian detection tools.

A radio detection and ranging (Radar) system generates radiation within the microwave region of the electromagnetic (EM) spectrum, and radar waves are reflected by solid objects back to the sensor. Based on the characteristics of the reflected signal, object attributes such as position, distance, velocity, and shape may be determined. Advantages of radar for automotive applications include functionality through most weather conditions such as rain, snow, and fog; radar is also unaffected by ambient lighting conditions. A radar has a lower resolution than LiDAR and is not effective at discerning object detail. For this reason, driver-assistance and autonomous vehicle systems typically include image sensors in conjunction with radar.

A Light Detection and Ranging (LiDAR) sensors measure the distance to objects by emitting infrared radiation and evaluating the reflected energy. LiDAR can also measure object velocity and create high-resolution maps of the environment. LiDAR can also measure object velocity and create high-resolution maps of the environment. These sensors systems are somewhat sensitive to precipitation and fog. The other potential limitation to LiDAR is its tendency to be blinded by direct sunlight.

This is a common problem for all types of sensors whose work is based on different technologies, including 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. These systems must provide satisfactory detection accuracy with an acceptable cost of installation. 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]. A very interesting system that does not invade privacy, because it does not record images or video and sound, but counts human steps. In [2], the authors analyze the possibility of using the piezo effect to detect the presence of a pedestrian and these movements. 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 the receiver. There are two types of ultrasonic sensors. Pulsed ultrasonic sensors measure the distance of a pedestrian or 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 20 m 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 [4], 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, i.e. whether it is a human or some other object. In paper [5] authors propose an alternative approach to detect traffic participants using cost-effective arrayed ultrasonic sensors. Candidate features were extracted from the collected episodes of pedestrians, cyclists, and vehicles. The importance of this work is reflected in the use of ultrasonic sensors that are not sensitive to the lack of light, which is especially important in the evening hours. The application of cameras for pedestrian detection in night conditions has certain limitations and cannot be used for reliable detection in conditions of poor visibility. Results showed an overall detection accuracy of 86%, with the correct detection rate of pedestrians, cyclists, and vehicles around 85.7%, 76.7%, and 93.1%, respectively. The detection accuracy varies across object types and is the highest for vehicles and lower for pedestrians and cyclists.

In [6], 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 [6] 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 [7], 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 [8], the authors analyze the possibilities of using infrared cameras 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 [3]. 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 [9], the visual detection system of human has been studied, and tried to propose a backbone architecture based on that. The advantage of proposed model is that it can be applied to most of the existing architectures with some negligible manipulations. Authors in [10] study how deep learning approaches solve the safety problems in the interaction between autonomous vehicles and pedestrians. The proposed algorithm can provide an accuracy of 81.98%, and can significantly reduce the data transmission delay. In [11], authors review the principles of four novel image sensors:ninfrared cameras, range-gated cameras, polarization cameras, and event cameras. In [12], the authors analyzed, on a small model of an autonomous vehicle, the possibilities of using ultrasonic sensors for object detection in low visibility conditions. An Arduino UNO device was also used to control and manage the operation of the sensors. In addition to ultrasonic sensors, the authors also used infrared sensors for traffic lane detection and traffic sign detection.

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 infrared light for night driving.

III. METHODS

The basic idea of the research is based on the analysis and proposal of a cheap solution for 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. Arduino Uno is a microcontroller board based on the ATmega328P and it has 14 digital input/output pins, a 16 MHz ceramic resonator, a USB connection, a power jack, ICSP header, and a reset button. This is a open-source electronics platform based on easy-to-use hardware and software. Two technologies on which the operation of the sensor is based, on ultrasonic, and on infrared waves, have been selected as the starting point for the design of the sensor assembly.

Ultrasonic sensors are generally used for a short distance around a vehicle and these sensors are cheaper than other ADAS sensors [13]. The HC-SR04 type sensors were selected for this purpose. This ultrasonic sensor uses sonar to determine the distance to an object. Sensors generate high-frequency sound waves of 40 kHz and evaluate the echo which is received back by the sensor. Sensors calculate the time interval between sending the signal and receiving the echo to determine the distance to an object.

For the proposed sensor system selected an ultrasonic sensor type HC-SR04. The HC-SR04 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:

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

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.

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

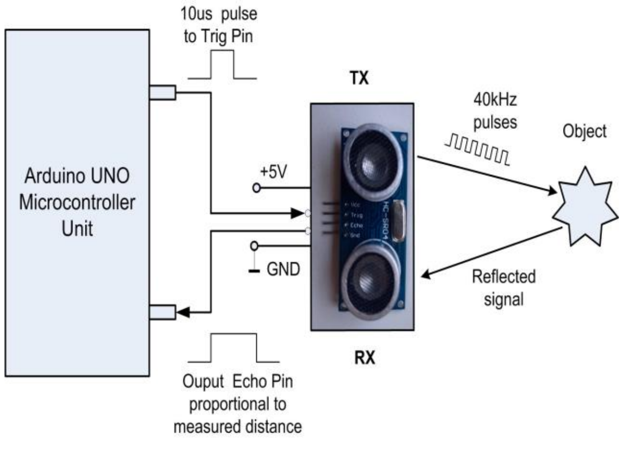

Figure 1. Ultrasonic sensor HC-SR04

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.

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

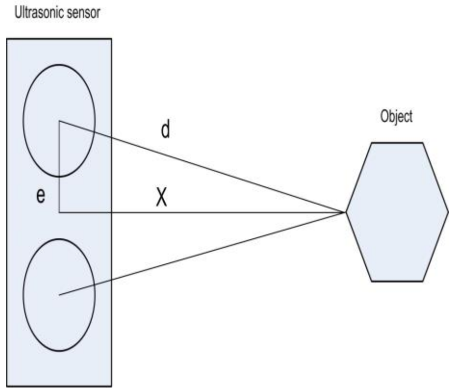

Figure 2. Correcting the distance

The following form is used to calculate the corrected distance:

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

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 [14, 15]. 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. Most PIR sensors have a 3-pin connection at the side or bottom. One pin will be ground, another will be signal and the last pin will be power. It is one of the sensors for detecting objects at short and medium distances. The motion can be detected by checking for a high signal on a single I/O pin. Once the sensor warms up the output will remain low until there is motion, at which time the output will swing high for a couple of seconds, then return low.

Fig. 3. shows the principle of operation of the PIR sensor.

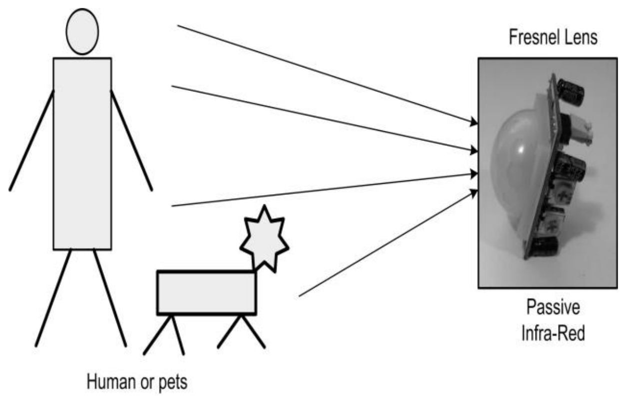

Figure 3. Principle of operation of PIR sensor

The PIR sensor itself has two slots in it, each slot is made of a special material that is sensitive to IR. If the sensor is idle, both slots detect the same amount of IR, the ambient amount radiated from the room or outdoors [14, 15]. In presence of human IR radiations, the sensor detects the radiations and converts them 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 [9]. 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 to show 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 and machine learning tecniques is planned to increase the accuracy of detection. Fig. 4. shows the appearance and components of the sensor system.

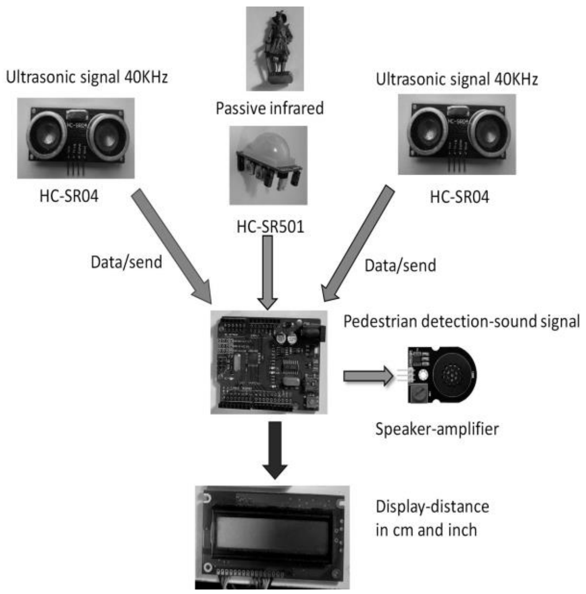

Figure 4. Sensor system with ultrasonic and PIR sensors

The system was tested in laboratory conditions, where humans of different bodies were grouped into two different classes as models [16]. The first class consisted of humans up to 120 cm tall (children), and the second was over 120 cm (adults) [16]. Fifty measurements were performed, and the obtained results are shown in Table I. The system was tested in laboratory conditions, where human of different bodies were grouped into two different classes as models [16]. The research was performed by following per the Ethical Regulations at the Faculty of Transport and Traffic Engineering Doboj, University of East Sarajevo. The first class consisted of humans up to 120 cm tall (children), and the second was over 120 cm (adults) [16]. Fifty measurements were performed, and the obtained results are shown in Table I.

TABLE I. ACCURACY DETECTION RESULTS

No. of class	Detection accuracy for different distances		
	Up to 50 cm	**50 cm-1 m**	**1 m-4 m**
Class 1	**94.3%**	**95.3%**	**95.7%**
Class 2	**96.1%**	**97.4%**	**97.7%**
Object	**Pedestrians**	**Cyclists**	**Vehicles**
Literature [5]	**85.7%**	**76.7%**	**93.1%**

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. As additional research, it can carry out extensive measurements that will include different situations from real life. By taking a sufficient number of measurements, it is possible to train an artificial neural network that would provide information on object detection based on new input data. The assumption is that this method would achieve better detection accuracy with fewer false outputs.

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, and 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. Comparing the corresponding results from the literature, 85.7% [5], with the results obtained in the research (96.1%-97.7%), it is evident that the use of ultrasonic sensors in combination with PIR sensors provides good detection accuracy. In [12] paper, are presented a model of such a car that can perform multiple functions such as detecting obstacles, taking sharp bends and turns, overtaking, following traffic signals and, turning its lights on under low light conditions. In the paper [12], the authors did not analyze the accuracy of the detection, but they provided and elaborated the complete system of the autonomous vehicle. On the other hand, the emphasis of the research presented in this paper is on the construction of a cheap and reliable snowmaking system with an acceptable level of detection accuracy. It is also evident that the use of these technologies in cooperation with other types of technologies such as microwave radars, thermal imaging cameras, and 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. On the other hand, the proposed system has certain limitations, which are reflected in the optimal choice of the location of the sensor on the vehicle. The second limitation refers to the way the system is tested, which was performed in laboratory conditions, and the obtained results do not take into account the real driving conditions (influence of weather conditions, snow, rain). It can be concluded that the accuracy of detection in real conditions where the sensors would be mounted on the vehicle would deviate from the obtained laboratory results.

VI. CONCLUSIONS

The problem of pedestrian detection is very complex problem. A special segment is the development of a quality multifunctional sensor with excellent detection characteristics in low visibility conditions, severe weather conditions, rain, snow, and fog. On the other hand, due to the wide commercial use, the proposed sensor system must be economically affordable. In addition to creating a quality sensor system, it is necessary to build software tools for pattern recognition, thermal image analysis, and software development for extraction of hidden knowledge in a huge database of collected data from the field. Recently, the techniques of machine learning and deep learning methodologies, convolutional neural networks (CNN), have been particularly prominent in this.

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.

ACKNOWLEDGMENTS

This work was created as a result of research for the project, "New technologies for the detection of pedestrians in autonomous vehicles", co-financed by the Ministry of Scientific and Technological Development, Higher Education and Information Society, Republika Srpska.

REFERENCES

[1] SRF Consulting Group, Inc. “Bicycle and Pedestrian Detection”, Minnesota DOT research report, 2003.

[2] Yang Yu, Xiangju Qin, Shabir Hussain, Weiyan Hou andTorben Weis, “Pedestrian Counting Based on Piezoelectric Vibration Sensor”, MDPI, Applied Sciences, Special Issue Artificial Intelligence and Complex System, https://doi.org/10.3390/app12041920, February 2022.

[3] “NIT Phase II: Evaluation of Non-Intrusive Technologies for Traffic Detection”, Minnesota DOT research report, SRF No. 3683, 2002.

[4] Andreas H Pech, Peter M. Nauth, Robert Michalik, “A new Approach for Pedestrian Detection in Vehicles by Ultrasonic Signal Analysis”, IEEE EUROCON 2019 -18th International Conference on Smart Technologies, 1-4 July, 2019.

[5] Guofa Li, Shengbo Eben Li, Ruobing Zou, Yuan Liao, Bo Cheng, “Detection of road traffic participants using cost-effective arrayed ultrasonic sensors in low-speed traffic situations”, Mechanical Systems and Signal Processing, Volume 132, 1 October 2019, Pages 535-545.

[6] Hiroaki Saito, Takeshi Hagihara, Kenichi Hatanaka and Takanori Sawai, “Development of Pedestrian Detection System Using Far-Infrared Ray Camera”, Sei technical review, ·Number 66, April 2008.

[7] Paulius Tumas, Arturas Serackis, and Adam Nowosielski, “Augmentation of Severe Weather Impact to Far-Infrared Sensor Images to Improve Pedestrian Detection System”, MDPI, Electronics, 10, 934, 2021.

[8] Jorg Wagner, Volker Fischer, Michael Herman and Sven Behnke, “Multispectral Pedestrian Detection using Deep Fusion Convolutional Neural Networks”, In Proceedings of 24th European Symposium on Artificial Neural Networks, Computational Intelligence and Machine Learning (ESANN), Bruges, Belgium, April 2016.

[9] Mahmoud Saeidi, Abouzar Arabsorkhi, “A novel backbone architecture for pedestrian detection based on the human visual system”, The Visual Computer, Springer Link, 10.1007/s00371-021-02280-6, 2021.

[10] ZijiangZhu, Zhenlong Hu, Weihuang Dai, Hang Chen, Zhihan Lv, “Deep learning for autonomous vehicle and pedestrian interaction safety”, Saefty Science, Elsevier, Volume 145, https://doi.org/10.1016/j.ssci.2021.105479, January 2022.

[11] You Li, Julien Moreau, Javier Ibanez-Guzman, “Unconventional Visual Sensors for Autonomous Vehicles”, https://arxiv.org/pdf/2205.09383.pdf, 2022.

[12] Ayesha Iqbal, Syed Shaheryar Ahmed, Muhammad Danish Tauqeer, Ali Sultan, Syed Yasir Abbas, “Design of Multifunctional Autonomous Carusing Ultrasonic and Infrared Sensors”, 2017 International Symposium on Wireless Systems and Networks (ISWSN), 19-22 November, DOI: 10.1109/ISWSN.2017.8250023, 2017.

[13] Mutinda Mutava Gabriel, Kamweru Paul Kuria, “Arduino Uno, Ultrasonic Sensor HC-SR04 Motion Detector with Display of Distance in the LCD”, International Journal of Engineering Research & Technology (IJERT), ISSN: 2278-0181, Vol. 9 Issue 05, May-2020.

[14] Shengzhe Wang, Bo Wang, Shifeng Wang, “Feature Channel Expansion and Background Suppression as the Enhancement for Infrared Pedestrian Detection”, MDPI, Sensors, 20, 5128; doi:10.3390/s20185128, 2020.

[15] Gerardine Anne J. Anson, Kiel Cedrick T. Huplo, Mark Anthony V. Marin, James Andrei, C. Rivera, Mark Vincent M. Pinili, Dr. Eric B. Blancaflor, “TAOAID: Pedestrian Assistance Using Car Motion Detection System”, Proceedings of the 4th African International Conference on Industrial Engineering and Operations Management Nsukka, Nigeria, April 5-7, 2022.

[16] Luciano Spinello, Kai O. Arras, Rudolph Triebel, Roland Siegwart, “A Layered Approach to People Detection in 3D Range Data”, Proceedings of the Twenty-Fourth AAAI Conference on Artificial Intelligence (AAAI-10), July 11–15, 2010.

PhD Aleksandar Stjepanovic, was born on October 5, 1970. in Doboj. He completed his basic studies in 1996 in Banja Luka at the Faculty of Electrical Engineering. At the Faculty of Electrical Engineering in Banja Luka in 2010, he received MSc degree. Doctoral dissertation titled "Multimedia Applications with Multimodal Interactions of Intelligent Transport Systems and Spatial Information Infrast-ructure" earned in 2015 at the Faculty of Transport and Traffic Engineering Doboj. His research interests include solar energy, fuel cells,telecommunications, multimedia, intelligent transportation systems and electric vehicles.

PhD Zoran Ćurguz was born on May 20, 1971. in Sanski Most. In 2000 he graduated from the Faculty of Natural Sciences and Mathematics in Banja Luka, majoring in Physics. Since 2006, he has been employed at the Faculty of Transport and Traffic Engineering in Doboj, University of East Sarajevo. He received his master's degree in 2009 from the Technical Faculty "Mihajlo Pupin" in Zrenjanin, University of Novi Sad. He obtained his doctorate in physical sciences in 2014 at the Faculty of Natural Sciences and Mathematics in Kragujevac. In 2019, he was elected associate professor at the Faculty of Transport and Traffic Engineering in Doboj, Narrow Scientific Field - Nuclear Physics.

PhD Miroslav Kostadinovic received the B.Sc., M.Sc. and Ph.D. degree in Automation and Electronics from the Faculty of Electrical Engineering, University of East Sarajevo, East Sarajevo, Bosnia and Herzegovina in 2005, 2010 and 2015 respectively. He has 5 years (2010-2015) of working experience in industry, including the positions: Sales manager "Adriatic Automation" doo, Teslic. Adriatic Automation is Bosnia and Herzegovina's leading supplier of Process Automation and Control equipment. He works as a Associate Professor at the Faculty of Traffic and Transport Engineering, University of East Sarajevo. He has been the Vice Dean for Teaching at the Faculty of Traffic and Transport Engineering since 2015. His teaching interests are in communication systems, information and coding theory, discrete stochastic signal processing and wireless sensor and computer networks. His research interests are in the areas of wireless sensor networks, fieldbuses and industrial communication networks, building and home network systems, networked automation and control systems.

Ph.D. Gordana Jotanovic defended dissertation of thesis in 2016 and obtained the title of Doctor of Technical Sciences in the field of Information Technology, narrow scientific field of Artificial Intelligence at the University of Novi Sad, Technical Faculty "Mihajlo Pupin" in Zrenjanin, Serbia. Currently employed as an Associate Professor at the University of East Sarajevo, Faculty of Transport and Traffic Engineering, Doboj, Bosnia, and Herzegovina. Gordana Jotanovic is the Head of the Department of Information-communication Systems in Traffic and the Quality Assurance Coordinator at the Faculty of Transport and Traffic Engineering in Doboj. Current research interests are the Internet of Things (IoT), the application of IoT in transport and traffic, Fog computing, wireless communications, machine learning, and engineering education. Also, Gordana Jotanovic is the author and co-author of many papers. Also, a member is of the European Innovation Alliance (EAI), and participated in several program/management/organizing committees of international conferences.

PhD Mirko Stojčić was born on May 18, 1989. in Doboj, BiH. After graduating from the High School of Traffic and Electrical Engineering, he enrolled in the first cycle studies at the University of East Sarajevo, Faculty of Transport and Traffic Engineering Doboj, study module telecommunications. After graduating in 2012, he enrolled in the second cycle studies and obtained his master's degree in 2014. Since 2017, he has been employed at the Faculty of Transport and Traffic Engineering in Doboj. In 2021, by defending his doctoral dissertation, he acquired the title of Doctor of Traffic Sciences, and is currently working as an assistant professor at the Faculty of Transport and Traffic Engineering in Doboj.

PhD Goran Kuzmić was born on September 7, 1973 in Doboj, Bosnia and Herzegovina. He finished elementary school and high school in Doboj. Technical Faculty "Mihajlo Pupin", Zrenjanin enrolls in computer science in 1995, where he graduated in 2001. He enrolled in postgraduate studies at the Faculty of Transportation in Doboj in 2009 and received his master's degree in 2012. Since 2005, he has been employed at the Faculty of Transport and Traffic Engineering in Doboj as an assistant, senior assistant, and after his doctorate in 2022 as an assistant professor.