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Conference Paper · September 2024

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https://doi.org/10.5281/zenodo.14054137

The use of Digital development board for development of ultrasonic radar system for short distance detection in a 360-degree

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***Abstract* — This scientific paper discusses the application of single-board computers in performing various projects focusing on the practical development of an ultrasonic radar system for detecting objects at short distances in a 360-degree radius using the digital development electronic board Arduino Mega 2560. This platform contributes to the development of electronic technology, microcomputers and microprocessors and their application for educational purposes. The development of the ultrasonic radar system for the detection of objects at short distances in a 360-degree radius was carried out by programming the ultrasonic radar system using the tools Arduino IDE and Processing PDE.**

***Keywords* — Ultrasonic Radar System, 360-degree radius, digital development electronic board, Arduino Mega 2560, Arduino IDE, Processing PDE**

I. Introduction

The topic of this scientific paper has a wide application in the field of digital electronics, information of communication technologies (ICT) and Integrated Control and Monitoring System (ICMS) as important scientific branches in the digital world. At the same time within the framework of programming and the use of algorithms which are key elements in the course of the development of the practical part within the scientific paper, i.e. the creation of an ultrasonic radar system for the detection of objects at short distances in a 360-degree radius using the Arduino Mega 2560 digital development electronic board. The scientific paper shows the importance of the application of single-board computers in various educational processes and areas that are key factors for development and scientific advancements in technology today. Through the practical development of the Ultrasonic Radar System for the detection of objects at short Distances in a 360-degree radius (furthermore: URSAD), in this paper is showed the way to successfully connect the Arduino Mega 2560 digital development electronic board (programmed with the Arduino IDE tool) with a personal computer using a program made with the Processing PDE software. It allows to finally display on the computer screen the presence of a certain object detected by the short-range object detection ultrasonic radar system in a 360-degree radius. The ability to program and display on a computer screen is made possible by the integration of the Arduino Mega 2560 digital development electronic board with the digital electronic platform, specifically the Arduino IDE and Processing PDE.

II. Single Board Computers

A single-board computer is a device or digital component that contains only the most necessary circuitry needed to operate as a machine. These boards, or single-board computers, are often shipped without cases and other accessories to keep the selling price low. A single-board computer is also called a digital development electronic board or a development board because they can be programmed and connected to various digital electronic platforms that allow the construction of various systems or devices that develop the scientific branch itself as a scientific discipline in today's digital science. The most important component, the heart of a single-board computer, is the microprocessor. A microprocessor is a unit that has several General-Purpose Input/Output (GPIO) ports that can be used for different digital applications, platforms, and can be programmed to work in a certain way. There are many manufacturers of microprocessors available in the market and each manufacturer and brand has its own main purpose and purpose with which they differ in selling price, capabilities, features that offer users opportunities to use them for making and experimenting with various projects and scientific experiments from different disciplines and fields [6-9], and [15].

Today's single-board computers are supported by a large Internet community around the world, where hobbyists and professionals share projects, scientific experiments, scientific journals and papers, and help each other solve various problems encountered during their construction, projects or scientific experiments. The large community is also an important factor when it comes to educational purposes. Information and data are easy and most likely someone has already done a similar thing, which can be a source of inspiration. Very often source code is provided (open source), which makes it easy for anyone interested to start a project or a particular experiment.

Depending on the application, different board specifications are required. Some boards, or digital development boards, are designed as multimedia players and therefore need a microprocessor that can handle video and audio acceleration. Another popular single board computer is the Arduino digital development board [13]. It was started as a school project with the main goal of developing a cheap solution that could be learning programming and electronics. This approach was quickly liked by amateurs and researchers who found large areas of use, which contributed to the development of the community around the platform. The Arduino digital development electronic board is designed to be programmed within their own integrated development environment (IDE – Integrated Development Environment) and uses the C++ programming language as a simple learning language for students in the educational process. It also could expand with compatible shields. A shield is a complete add-on circuit that can be placed directly on the Arduino board and can be programmed and used with various applications. Such an example is a shield for network communication between controllers (CAN BUS – Controller Area Network) which enables the Arduino protocol and the Servo Motor Shield which makes the Arduino capable of controlling servo motors. Arduino is a popular open access platform with various variants, including the Arduino Nano, the smallest board with low power consumption, ideal for low-power applications and ideal for those requiring minimal expandability. The Arduino Uno digital development board is one popular development board in the Arduino family of digital development boards. There are several different types of integrated protocols, but there is no video output as a standard option. It is often used as a prototype for projects and products before the board is scaled down and adapted to the application [2], [3], [9], [15].

The Arduino Corporation initiated a collaboration with companies compatible for designing and developing digital boards and developed a new board, that is, a digital electronic development board called the Arduino Galileo. The Arduino Galileo digital development board has been launched as an Internet of Things (IoT) development board and has a more powerful processor than its predecessor and can run a Linux operating system. It has the same physical form factor as the Arduino Uno digital development board, which means it can be used with most existing shields and code with minor modifications [9], [12], [15], [16].

The Arduino digital development circuit board was a turning point for the concept of single-board computers as we know them today. It has received a lot of support from the online community and has shown to be beneficial in a wide range of applications, including autonomous vehicles, robotic arms, smart home appliances, Internet of Things projects, weather stations, air quality monitoring, wearable technology, STEM learning kits, surveillance systems, object detection, and ultrasonic radar. Thanks to open source, various versions have been developed and extended to different application areas. There are several development boards available in the market with different specifications and vendors. This has also led microprocessor manufacturers to add more features to the processor itself [9], [10], [11], [15], [17], [18], [19].

III. SYSTEM MODEL OF ARDUINO MEGA 2560 DIGITAL DEVELOPMENT ELECTRONIC BOARD

Arduino Mega 2560 represents a platform based on the Atmel ATMega 2560 microcontroller. In addition to the microcontroller, it also contains several elements and components necessary for its proper operation. Programming and communication with the computer are done using a USB port. It is compatible with several other Arduino boards and with the Duemilanove and Diecimila platforms. The Arduino Mega 2560 digital development electronic board, unlike other Arduino boards, has more inputs to which sensors can be connected [4], [13], [15], [20], [21], [22], [23].
The operating voltage that can enable this microcontroller through a pin, as with most Arduino boards, is 5 V. The limit value of the input voltage has a range from 6 to 20 V, and the recommended voltage at which this microcontroller works is from 7 to 12 V. There are 54 digital input/output pins, 14 of which support pulse-width modulation. It also has 16 analog inputs and a 16 MHz crystal oscillator. It can be powered by a USB port or an external source [3], [4], [13], [15].

IV. DIGITAL ELECTRONIC COMPONENTS AND PARTS FOR THE PRACTICAL FRAMEWORK

In this section are shown all the digital electronic components and parts that were used for the practical part of URSAD for object detection in short range in a 360-degree radius (see Tab. 1).

TABLE 1: Used digital electronic components and parts for the practical part [15]

Components	Name of components
	Arduino Mega 2560
	USB cable
	Breadboard
	Jumping Wires
	Servo Motor
	Ultrasonic Sensor HC-SR04
	Ultrasonic Sensor HC-SR04

V. ALGORITHMS FOR FUNCTIONS IN THE INTEGRATED AND PROCESSING DEVELOPMENT ENVIRONMENT

The code in the Arduino IDE integrated development environment is done with a combination of the C and C++ programming languages. As already mentioned earlier in this paper, the code of the integrated development environment consists of two main functions void setup() and void loop() [1], [15], [18], [19], [20]. In the Fig. 1 is depicted the algorithm for the functionality of the servo motor, which allows to rotate from 0 to 360 degrees and with that the ultrasonic sensors placed on the servo motor can detect the objects in the range of 40 cm and in a 360-degree radius by appearing the detected objects in the screen of the laptop. In Fig. 2 is shown the algorithm for the function calculateDistance() that is used in the code, which precisely gives the mathematical equation of the way of measuring the distance of the object.

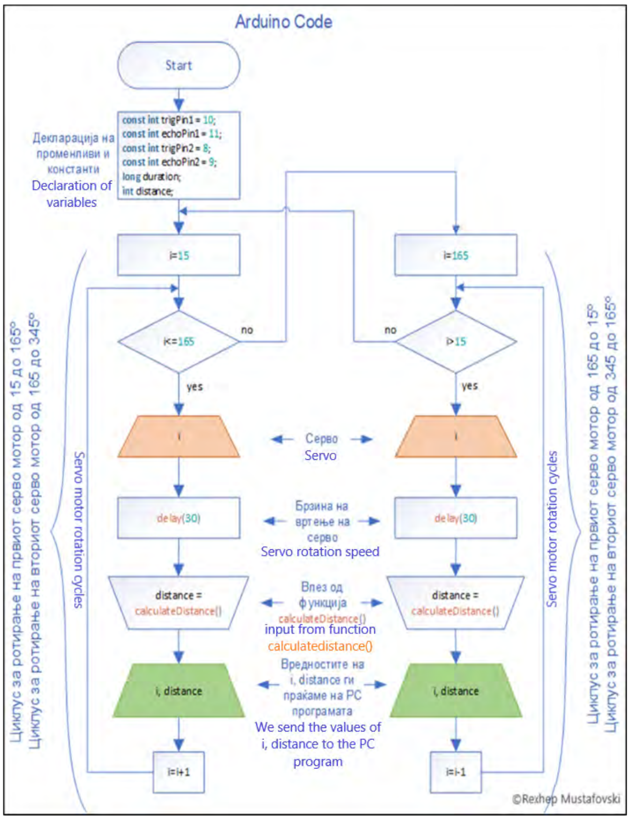

Figure 1: Algorithm for void setup() and void loop() functions for URSAD in a 360 degree radius [15]

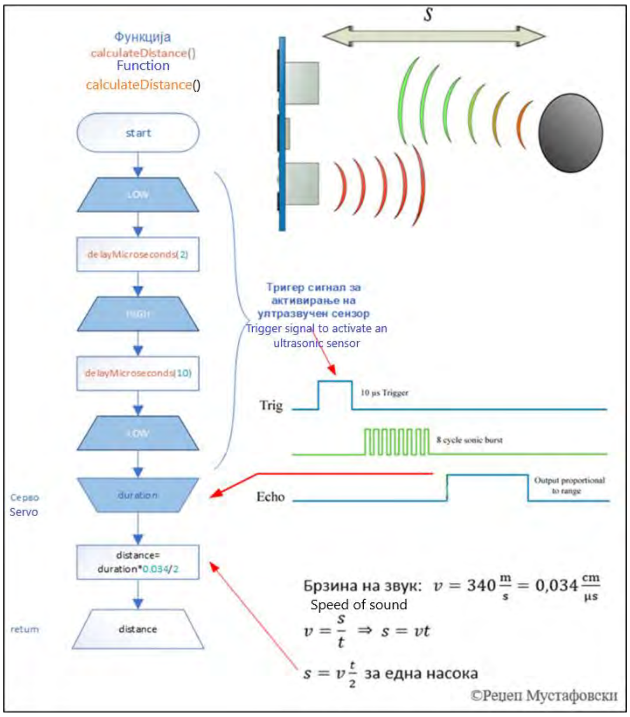

Figure 2: Algorithm for the calculateDistance process for URSAD in a 360 degree radius [15]

Figure 3 illustrates the algorithm written in Processing code within the Processing Development Environment for URSAD in a 360-degree radius. This code facilitates the creation of the URSAD display and enables the visualization of potential detected objects on the PC screen.

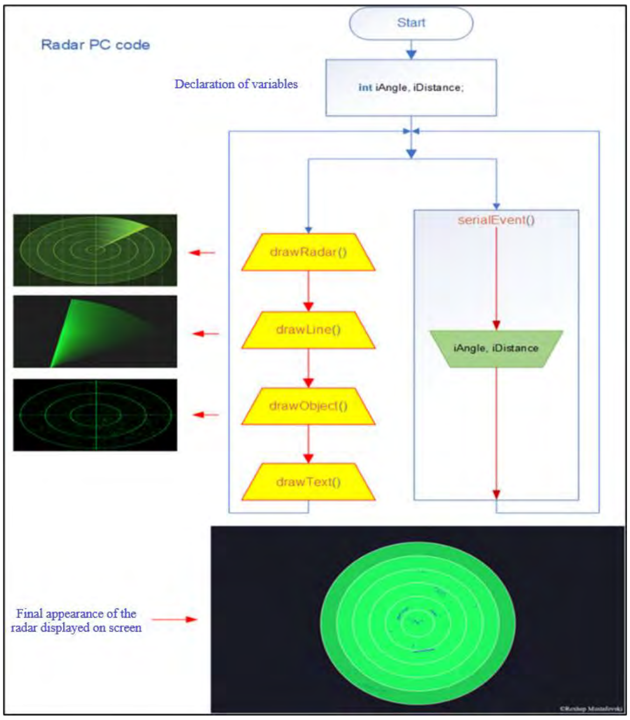

Figure 3: Algorithm for Processing's code for URSAD in a 360 degree radius [15]

VI. PRACTICAL APPEARANCE AND CONNECTION OF THE URSAD IN A 360 DEGREE RADIUS

From the information presented thus far, we've developed a conceptual understanding of the ultrasonic radar in a 360-degree radius potential appearance and functionality. This section will specifically show the appearance of the URSAD in a 360-degree radius and its function through pictures.

Through the graphic display shown in Fig. 4, a visual representation of what the URSAD in a 360-degree radius looks like in reality is obtained. The difference is that the ultrasonic sensor itself is attached to the servo motor.

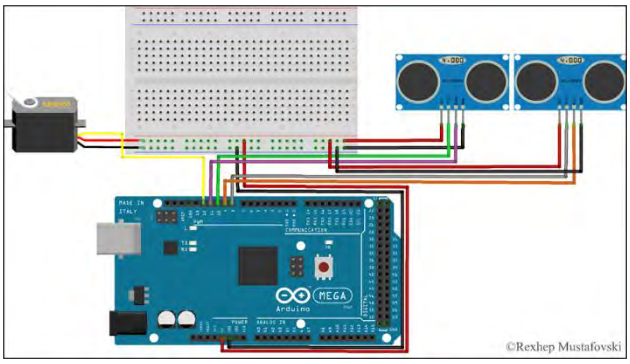

Figure 4: Connecting the components of the URSAD in a 360 degree radius

The Fig. 4 presents the connection of different colored wires, usually the black wire is used to connect the common end or the minus, the red wire is used to connect the positive pole of the power supply, while the rest of the wires can be chosen as desired. What is important when connecting the rest of the parts and the various wires is visibility during the connection. Transparency in connectivity allows for easier inspection of connected elements [15].
The Processing program created in the processing development environment plots the URSAD in a 360-degree radius surface based on the information and display of the detected target. The developed URSAD for the detection of objects at short distances in a 360-degree radius as part of this paper in our laboratory is shown in Fig. 5.

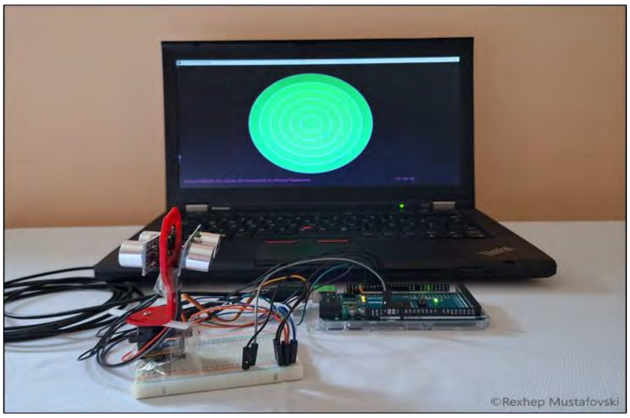

Figure 5: The realistic appearance of the radar system for detecting objects at short distances in a 360-degree radius

VII. LIMITATIONS AND CHALLENGES OF THE SYSTEM

While developing the ultrasonic radar system for object detection at short ranges based on the Arduino platform that has demonstrated promising results for object detection, several limitations and challenges emerged during the implementation and development process. In the future work of this paper will be given some steps to enhance the system's performance and reliability and implement in the future similar or enhanced radar systems for object detections in different situations. The several limitations and challenges faced during the implementation of this system were:

1. Sensor Accuracy and Range: Ultrasonic sensors, despite being inexpensive and simple to use, have certain performance restrictions and difficulties that may arise when incorporating them. The range of detection is constrained between a few centimeters and 1 meter, preventing the system from being used for long-distance object detection and monitoring. Moreover, the sensors' precision is reduced in varying conditions like uneven surfaces or terrains, very cold or hot temperatures, or when faced with dust, fog, or other environmental obstacles. These elements can lead to incorrect or unsuitable distance measurements, especially in outdoor settings [20], [21].
2. Angular Resolution: The system's angular resolution is restricted by the servo motor that rotates the ultrasonic sensor. The accuracy of object recognition relies on the velocity and increment of the motor's turning. Decreasing the size of steps results in greater detail, however, this also leads to longer scan times and causes delays in real-time tasks. In high-stakes situations, like obstacle detection for self-driving cars, this delay can create major obstacles [22], [23].
3. Arduino Processing Limitations: The Arduino Mega 2560 platform is adequate for simple control functions, but it has limited processing capabilities and memory. These limitations are evident when attempting to oversee numerous sensors, process extensive datasets, or conduct intricate signal processing. More complex functions, like running real-time filters or intricate decision-making algorithms, would need stronger microcontrollers or external processing units to ensure high performance and effectiveness [23].
4. Power consumption: The presence of numerous sensors, a servo motor, and wireless modules leads to higher energy usage, particularly during continuous system operation. This restriction is particularly important for portable apps or devices running on batteries. Optimizing power efficiency or integrating power-saving modes is vital for prolonging the operational lifespan of these systems [23].
5. System scalability: The current system can only scale up to the processing capabilities of the Arduino platform and the mechanical restrictions of the servo motor. Expanding the radar's coverage area or including additional sensors

would necessitate a complete overhaul of both the hardware and software [23].

VIII. Results and Analysis

This part of the paper will show and explain the practically performed tests in laboratory conditions that show the functionality, accuracy and precision of the systems, specifically the 180 and 360 degree object detection system.

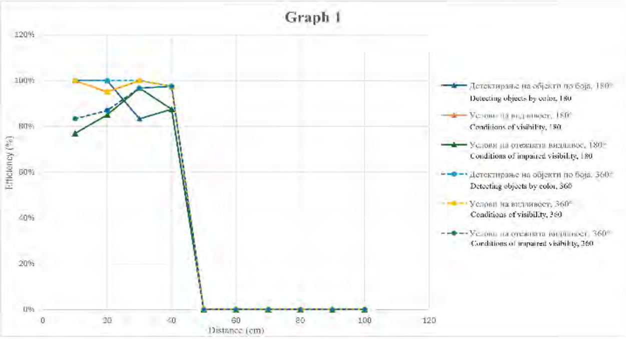

Figure 6: Perfomed test for detection of objects by color, visibility conditions and conditions of difficult visibility

Figure 6 shows the performed tests for the ultrasonic radar system for the detection of objects at short distances for 180 and 360 degrees, namely: detection of objects by color, visibility conditions and conditions of difficult visibility. According to the presented results for the same tests, we can notice that the ultrasonic radar system for detecting objects at short distances for 360 degrees has better results compared to the 180 degree system up to 40 centimeters of the total capabilities of the ultrasonic sensor itself.

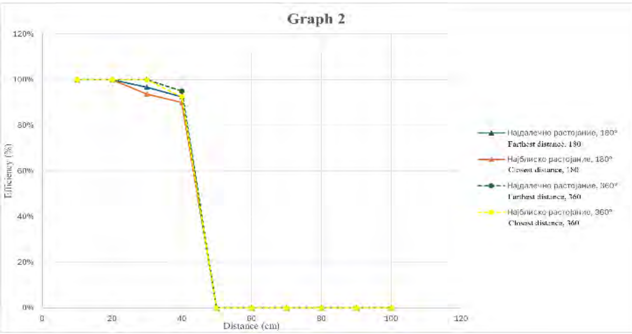

Figure 7: Perfomed test for farthest distance and closest distance

Figure 7 shows the farthest distance and closest distance tests performed for the 180 and 360 degree system. According to the results shown in the table comparing the two systems, we can notice that the 360 degree system at a distance of 20 to 40 centimeters has better results than the 180 degree system by a few percent, which makes the system itself functional and display better performance than the 180 degree object detection system.

IX. Conclusion

The paper presents several achievements with the application of digital development electronic boards or single board computers. Their application in many other different scientific fields and branches or combination with new codes or models allows controlling, operating and giving instructions to many digital development electronic boards and digital components to build different systems with specific functions and capabilities.

In the overall work of this scientific paper, the flexibility, characteristics and possibilities of digital development electronic boards, their open code, and their application for various scientific fields, through which their unlimited connection and combination with other digital development electronic boards, components, software, and computers are shown. These digital development electronic boards, i.e. single-board computers, have a price that is accessible to everyone, offer advanced features, while being simple and can be used by students in the educational process, for various other scientific projects and experiments in other scientific fields and disciplines. Digital electronic boards can be used in the educational process and the study process, which are an important factor for the development of education itself and can also be used in the industry to carry out various processes with which they save certain human and time resources. In contrast to the 180 degree system, the 360 degree system provides many unexpected results in terms of object detection in a variety of conditions, with better detection accuracy and full coverage of 360 degrees compared to 180 degrees, which solves many issues in comparison to various 180 degree systems. This thesis aimed to illustrate the improvements and accuracy of the 360-degree system in comparison to the 180-degree system. Additionally, more data volume and component cost compared to a 180-degree build-up system. With the help of this system, we can help the community develop even more accurate systems in the future that can monitor and recognize objects in a variety of settings with high precision and at a lower cost.

The URSAD in a 360-degree radius system detects nearby objects and connects with the Arduino Mega 2560 board through the Arduino IDE and Processing PDE. The goal of the project was to showcase and represent the most recent system that has been proposed. This system is capable of accurately detecting and monitoring objects in 360-degrees, and it can gather a wealth of data regarding the objects' angles and distances. It also covers the entire 360-degree sector, and, in comparison to the 180-degree system, it has significantly more advancements and developments in its component parts, code, and system integration. The configuration shows cases for object detection on a computer screen by utilizing data gathered from the Arduino Mega 2560 hardware, summarizing the accomplishment achieved with the short-range ultrasonic radar system for object detection in a 360-degree radius.

Also, the URSAD in a 360-degree radius system demonstrates promising potential in short-range object detection, showcasing a practical fusion of hardware and software capabilities to enable precise and efficient identification of nearby objects, marking a significant stride in innovative technological advancements.

The presented results of the practical tests clearly show the performance of the Arduino Mega 2560 digital development electronic board, as well as the capabilities of the ultrasonic sensors, so that in the future, different sensors and digital components can be used to increase the system's performance in object detection, under different conditions.

The authors firmly believe that numerous strategic breakthroughs centered on improving techniques and system design will lead to improvements in ultrasonic radar systems for 360-degree object detection. The goals of these initiatives are increased accuracy, improved results, and general system development.

X. FUTURE WORK

To enhance the Arduino Mega 2560 ultrasonic radar system for short-distance object detection in a 360-degree radius, we should consider these future steps [19], [15]:

1. Enhance Detection Accuracy: Refine radar sensitivity and signal processing for more accurate object detection.
2. Expand Object Recognition: Develop algorithms for recognizing specific objects detected by the radar.
3. Optimize Hardware Setup: Streamline connections and components for better efficiency and reduced size if applicable.
4. Implement Range Adjustment: Enable adjustable range settings for versatile detection capabilities.
5. Enable Remote Monitoring: Investigate ways to monitor detections remotely, possibly via wireless connectivity.
6. Develop User Interface: Design a user-friendly interface for intuitive system control and data visualization.
7. Test and Validate: Conduct thorough testing under various conditions to validate and refine the system's performance.

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