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An Advanced Air Defence System Prototype using Arduino UNO

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***Abstract*—An Advanced Air Defence System is mandatory to ensure the safety of our country. Our proof-of-concept Air Defence System, comprises of Arduino UNO, two Servo Motors- one for horizontal sweeping and another for vertical sweeping, and an HC-SRO4 Ultrasonic Sensor to detect an object within the threshold distance. When connected to a power source, for every ten-degree increment in motion of the horizontal Servo-Motor, a top to bottom, 180-degree vertical sweeping is done for effective tracking. Once an object is within the threshold distance of the sensor, the HC-SRO4 Ultrasonic Sensor locks on to that object and an LED or a Laser Diode continuously turns on and off simulating the launching of a projectile. This process continues until the object is out of the threshold range of the sensor. In real life, since fighter planes are capable of travelling at supersonic speeds, enemy tracking using Ultrasonic Sensors is almost futile. Hence, Infrared Enemy Detection and Tracking Methods are more commonly used as active search systems like radar, must emit electronic signals that tip off the enemy to its presence and they have the capability to detect enemy aircrafts at a range of about 200-600 km. In the future, further enhancements can be done by AI Integration (for example: IRST Systems) to identify and track enemy aircrafts, analyse patterns, etc.**

***Index Terms*— Air Defence System, Arduino, Ultrasonic Sensor, Servo-Motors, Lasers, Convex Lens.**

I. INTRODUCTION

It is critical and vital to have an Advanced Air Defence System to effectively locate and track enemies, so that the threat is eliminated as fast as possible. It must be able to search each and every direction to detect any incoming enemy drones or aircrafts. Our proof of concept "Advanced Air Defence System" project provides an effective method to detect obstacles which are within the set threshold range of the HC-SRO4 Ultrasonic Sensor. At the heart of this system lies the Arduino UNO, a commonly used microcontroller known for its versatility and reliability in electronic circuits. This project harnesses the properties of Arduino and HC-SRO4 Ultrasonic Sensor to create a simple yet efficient defence system.

An Ultrasonic Sensor normally has a transducer which convert sound energy into electrical energy and electrical energy into sound energy. They are utilized for estimating object position and direction, crash evasion framework, observation framework and so on. It also solves the issue of straight estimation, as it permits the client to get non-contact estimations in this manner and thus, distance among object and its speed and so forth can be effectively estimated.

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II. Related Works

Air Defence Systems are vital in prevention against enemy aircraft attacks and drone attacks. It normally comprises of sensors used for effective tracking of enemy aircrafts and drones such as IR Sensors which has a very large range of up to 600km, identification and trajectory prediction systems. According to a survey by Seong-Joon Park et al.(2021)[1], the system requirements for an anti-drone system are as follows: The physical components such as motors, batteries, and internal hardware radiate significant amount of heat, which can be recognized by thermal cameras. Many studies have proposed detecting target drones by their heat signatures. Thermal detection has advantages in terms of weather resilience, identification availability, and lower cost than radar-based systems. However, the practical detection range (51 m) is considerably shorter than most other approaches, hence enhancing granularity of detection scheme or improving resolution of thermal imaging camera are major challenges. Thus, ultrasonic sensors are used as they have a range of up to several meters as compared to thermal sensors and GSM modules, which provide real-time location tracking and communication via SMS if the bag moves outside a designated area. A microcontroller coordinates all the components, ensuring smooth operation.

System portability is critical, as defending an area against unauthorized or illegal drones can vary depending on space and time. Immediate anti-drone deployment can be accomplished with mobilized detection, identification, and neutralization components, which require lightweight equipment and competent wireless networks.

However, to build a cost-effective Air Defence System, especially for proof-of-concept models, Arduino is used, due to its low cost and flexibility making it useful for prototyping and educational purposes. Ahman Emmanuel Onoja et al. (2017) [2] stated that the advantage of using Arduino is drastic reduction in power consumption and allow the designers to have access to a wide range of online communities of Arduino programmers and open-source reusable code.

Vittorio Ugo Castrillo et al. (2022)[3] stated that the efficiency and optimization of an air defence system is crucial be- cause a large area should be effectively covered and available resources are optimized. The selection of the technologies that best complement each other is also important to optimize the level of situational awareness with respect to the complexity and cost of the system, considering the specific requirements (i.e., range, accuracy, etc.) of the application. As mentioned before, our proof-of-concept Air Defence System comprises of two servo motors (one for horizontal sweeping and another for vertical sweeping) where the base connected to the horizontal servo-motor moves 180 degrees in clockwise and counter- clockwise directions in steps of around 20 degrees at a time, after a 180 degree top-to-bottom vertical sweeping is done. This ensures that the entire area is scanned for enemy drone detection.

Dragana Mitrovic´ et al.(2018) [4] pointed out a limitation in Arduino modules, which is, when defining the Arduino concept and developing the appropriate IDE software, no direct support is provided for working in the multitasking environment. With this in mind, one of the important challenges, in the further development and application of the Arduino concept, was finding the possibility that devices based on the Arduino module work in multitasking mode. While designing a complex system such as an Air Defence System using Arduino modules, they are limited by factors such as processing speed and memory limitations. That is why modules such as ESP-32 are a better fit due to its low processing power and it runs at 240MHz unlike Arduino which runs at 12MHz. It also has a PCB antenna which allows us to perform Wi-Fi and Bluetooth operations and it also has much better security features. In our proof-of-concept air defence system project, we are implementing an Arduino UNO board which costs around Rs.249, which is cheaper than a 38 pin ESP-32 module which costs around Rs.433. However, for a better performance, it is recommended that an ESP-32 module needs to be implemented. Include automatic security measures like alarms when the bag is moved beyond a set distance, making the bag more secure and user-friendly [3].

Varun Suthar et al.(2020)[5] developed a project about boosting the security at military installations by interfacing PIR sensors and ultrasonic sensors to effectively monitor the perimeter for any unauthorized movement or controlled airspace incursion activities inclusive of drone and other airborne threats. In addition, a threat detection system is further fortified by the incorporation of unmanned ground vehicle (UGV) fitted with missile armament to autonomously eliminate threats that have been identified. Moreover, there is real time monitoring and fast reaction mechanism thanks to the incorporation of IoT that employs the use of Arduino UNO and Nano for sensor communication. However, even with the resilient provisions of the project, there still exists an issue in terms of control due to complication associated with combining features such as machine learning and missile systems, IoT systems among others. Such complication could also imply that the system will be unwieldy in operation as well as continuous maintenance within real time scenarios. Consequently, the project, albeit with good prospects, has the issue of scalability and deployment. One of the possible areas of

development in the future would include making the system less complex by redesigning some of its major parts in order to make it more efficient.

Prachi Gupta et al. (2022)[6] created a radar unit with the help of an ultrasonic sensor to identify and follow the moving objects in a particular area. The whole system is operated on Arduino, which is responsible for the processing of the signal from the sensors. This arrangement allows both detection and avoidance, and can therefore be employed for several defence uses. The project brings out the application of a radar like configuration using inexpensive ultrasonic sensors and an Arduino to achieve real-time object tracking. However, the limited range of the ultrasonic sensor, proved to be a drawback, making the system less effective in a long-range object detection system. This drawback indicates a possible emergence of the need to employ more sophisticated sensors like LIDAR or RADAR in order to increase the range of the system and enhance performance

The work presented by Daniel Michalski and Pawel Bernat (2019)[7] proposes an Internet of Things based surveillance system where ultrasonic sensors are used for the detection and monitoring of objects overtime intervals and within a certain distance. The ultrasonic sensors act as a pair working in a circular manner to allow for the occurrence of any threat in more than one zone in real-time status, whereas the IoT integration allows for the data and images to be captured to be viewed over the net from any station. The project employs the Arduino Uno and Nano boards for collecting the sensor data and interaction with the IoT platform, creating a connected system which intensifies its deterrent and surveillance activities. Even if the project is found to be useful, it suffers from the obstruction of ultrasonic sensors limitations and network induced data lag during data transfer. It is also noted that intelligence focused on security is not only important but an integral part of modern defence systems due to the fact that such systems can leverage on the net for enhanced communication and communication. Improvement of improvement of the system by eliminating the challenges posed by sensor range and network capabilities will greatly improve the system's efficiency and reliability.

The research of D. R. P. Rajarathnam et al. (2019) is centred on an enhanced defence mechanism employing Arduino Uno, an ultrasonic sensor, a servo motor, and a missile launcher [8]. In this system, the ultrasonic sensor is crucial in determining the presence of obstacles whereby it sends series of ultrasonic signals and measures the distance to an object by calculating the time taken for the reflected signals to return. The processed data is then supplied to the Arduino Uno, which determines the location of the object, and the servo motor in turn positioned the missile launcher at the appropriate angle. After this, once the target has been acquired the Arduino gives the command to the missile launcher to shoot. In this system detection, targeting and firing are all integrated and happen live, thereby showcasing targeting of an object in real-time. There is however a shortcoming in the project which is the range of the ultrasonic sensor, which will limit the ability of the system to detect objects at longer distances. Sensor range enhancement would therefore positively impact the performance of the defence mechanisms using the system. In conclusion, for practical implementations, we can make the structure more stable, and adopt a more efficient scanning method. Ultrasonic Sensors can be replaced or combined with the sensors of very large range such as Infrared Sensors to drastically increase the range of detection and detect the enemy

We referred to the works of Pallavi Deshpande et al. (2024) to guide the structure, format, and flow of this paper for conference publication. While their studies informed our organizational approach, no direct content or references were used, ensuring the originality of this work [10-11].

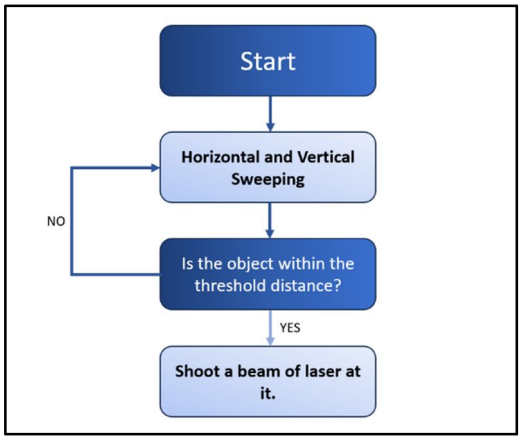

Figure 1: Flowchart of working of our proof-of-concept prototype

III. METHODOLOGY

The flowchart in Fig. 1 shows the working of our proof- of-concept model. First, the Horizontal Servo Motor Rotates the base from 0 to 180 degrees, and the Vertical Servo Motor rotates the base containing the laser diodes and the HC-SRO4 Ultrasonic Sensor. The process continues until it detects an obstacle within the set threshold distance of the sensor. Once, an object is detected, it will lock on to that object and pulses of laser will be shot at that object until is out of the threshold range, and the sweeping process starts again.

A. List of Components

Our proof-of-concept Air Defence System comprises of the following components:

Arduino UNO

Arduino UNO (Fig. 2) is a microcontroller that can be programmed using Arduino IDE. It has a 0.5kB bootloader which allows the program to be integrated into the circuit and it operates on the frequency of about 12MHz. The purpose of Arduino UNO in our prototype is to integrate the code, programmed for horizontal and vertical sweeping of servo-motors, measuring distances and turning on laser diodes on object detection, into the board to perform the above said function. We have used the transmission speed of 9600 baud for normal operation of components.[2]

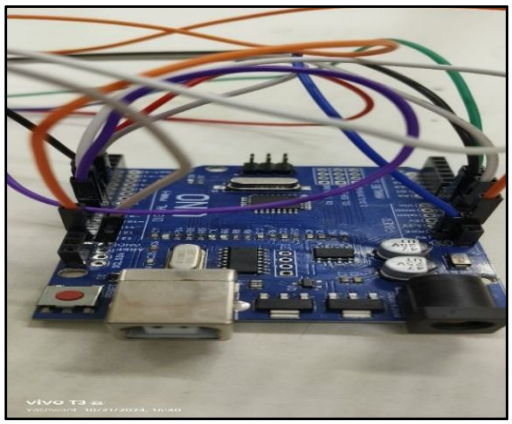

Figure 2: Arduino UNO

HC-SRO4 Ultrasonic Sensor

The HC-SR04 Ultrasonic Sensor (Fig. 3) is a 4-pin module with the following pins: 1) VCC, 2) Trigger Pin, 3) Echo Pin, and 4) Ground (GND). This sensor is widely used in applications requiring distance measurement or object detection. The module has two eyes- like projections in the front, which function as the transmitter and receiver. The sensor operates on the principle that the transmitter emits an ultrasonic wave with a frequency of 40 kHz. When this wave encounters an object, it is reflected toward the sensor, where it is detected by the Ultrasonic receiver module. For longer ranges, infrared sensors are used as a substitute. The purpose of this sensor in our prototype is to measure how far the object is and detects whether the object is within the set threshold distance [2].

Figure 3: HC-SRO4 Ultrasonic Sensor

180 Degree Rotating Servo Motors

A Servo Motor (Fig. 4) is a rotary actuator or linear actuator which allows precise control of angular or linear position, velocity and acceleration. It consists of a suitable motor coupled to a sensor for position feedback [2, 6]. The purpose of the servo-motors in our project is to enable horizontal and vertical sweeping. We have placed a horizontal servo-motor under a base for horizontal rotation and provided another base for the vertical servo motor, thus facilitating vertical sweeping. For every 20- degree shift in the horizontal servo-motor in counter-clockwise direction, the vertical servo motor performs an entire 180- degree scan. This process continues until the horizontal servo motor covers the 180-degree angle, and then, the same process occurs, with horizontal servo-motor rotating in clockwise direction.

Figure 4: Horizontal and Vertical Servo-Motors

Laser Diodes

The term"LASER" stand for Light Amplification by Stimulated Emission of Radiation. The device which emits coherent light though a stimulated emission process is known as a Laser Diode(Fig. 5). The operation of a laser diode is similar to that of an LED, but with a key difference: it creates lasing conditions at the diode's junction when driven with electrical current. When an excited electron collides with a photon with same energy as the energy difference between its excited state and a lower state, it can be stimulated to emit another photon with identical properties. This leads to the amplification of light and the creation of a coherent beam. The purpose of implementing the laser diodes in our prototype is to simulate or indicate that the missile rounds are fired. In our setup, 21 laser diodes are arranged in groups of seven, with three rows.

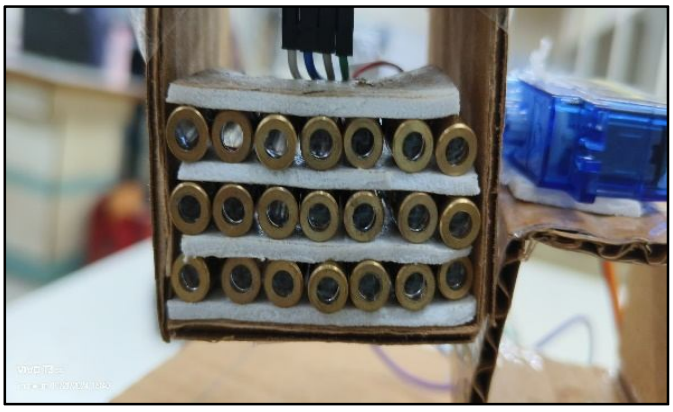

Figure 5: Laser Diodes

Convex Lens

The proof-of-concept can be modified by using a convex lens, which is a converging lens. It is a lens that is thicker at the centre than at the edges. This is because it converges light rays by bending them inward towards a point, which is called the focal point. The purpose of the convex lens is to focus the beams of 21 laser diodes on a single point increasing its effectiveness, producing enough power to blow a balloon.

Figure.6: Convex Lens

B. Circuit Diagram

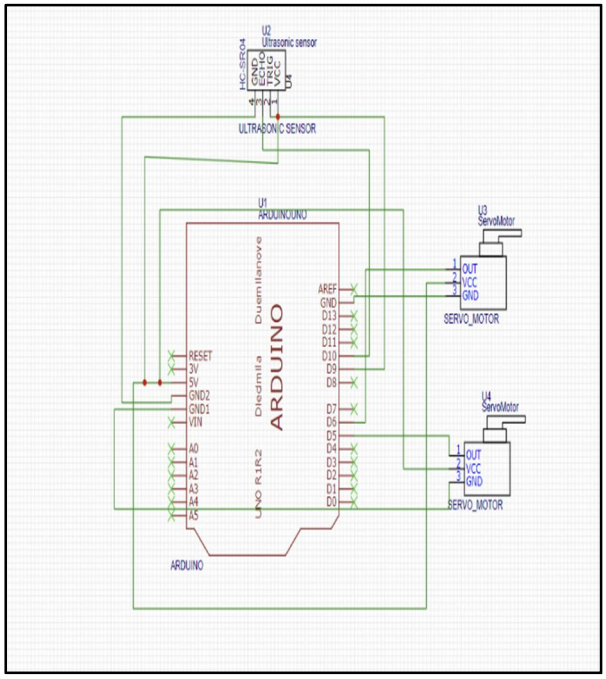

Figure.7: Circuit Diagram of our Proof-of-Concept Air Defence System

C. Model of our Proof-of-Concept Prototype

We designed a model for our proof-of-concept Air Defence System, and placed a Servo Motor underneath the base for horizontal sweeping, and another servo motor on a different elevated base to turn the Sensor along with 25 Laser Diodes up and down, thus enabling vertical sweeping, as shown in Fig. 8.

Figure.8: Model of our proof-of-concept Air Defence System

IV. Results

After connecting the Arduino to the laptop or a power source, both the horizontal and vertical servo motors are set to 0 degrees during the setup process as shown if Fig. 9. Then, the horizontal and vertical sweeping process starts and it continues till and object is detected.

Figure. 9: Before Object Detection

Once an object within the threshold range is detected, the sensor will lock on to that object and a beam of laser will be fired at it, as shown in Fig. 10, simulating or indicating that the missiles rounds have been fired.

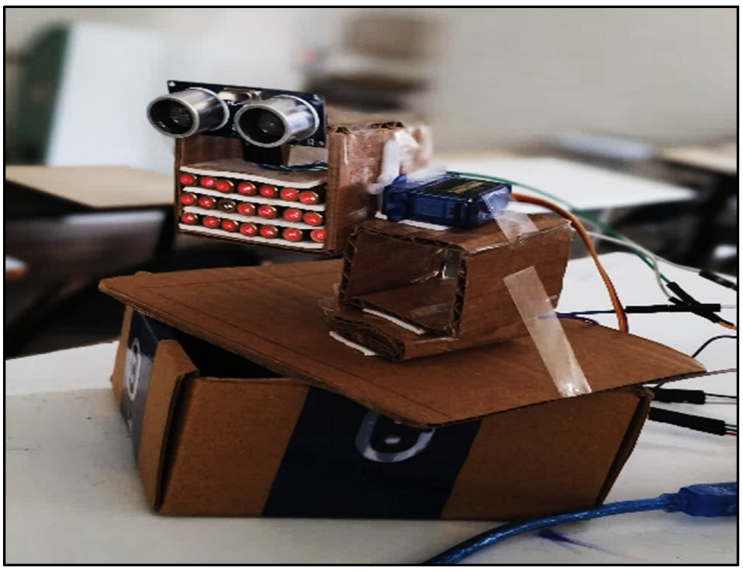

Figure. 10: After Object Detection

V. Discussions, Limitations And Future Scope

This project can also be modified by adding a GSM Module which gives the status of the target. By connecting a wireless camera to the system, we can see the surrounding area from our computers only by using GPRS and GPS System[9].

In the "Air Defence System Using Arduino UNO project", we had to face many issues that affected our prototype's performance and reliability. One problem was the improper laser alignment, which led to the lasers not striking objects. The shaking cardboard platform used for the foundation of the structure also added difficulties to the system's efficiency and didn't create a consistent ground for the components. Moreover, we had problems with loose connections that led to erratic sensor readings and problematic laser activation. Sometimes,

the ultrasonic sensor malfunctioned and produced errant distance measurements, which decreased the efficiency of the overall detection system. Also, the load on the vertical and horizontal servo motors was higher than desired because of this, causing strain and decreasing their responsiveness in terms of movement. These spot areas indicate further refinement along with implementing some robust solutions to make the system much more efficient.

Ultrasonic sensors can only be used for hunting down drones and is inefficient in taking down enemy aircrafts as they have the capability to travel at supersonic speeds, due to which measuring distances using these sensors are difficult. This can be solved by replacing ultrasonic sensors with Infrared Sensors.

- By replacing ultrasonic sensors with Infrared Sensors a very long range (about 200 to 600km) can be achieved unlike Ultrasonic Sensor which has a range of u to several metres.
- AI algorithms would be implemented in the IR Air Defence Systems for efficient tracking and reducing workload for humans and also predict potential enemies' trajectories, thus optimizing defensive responses.
- IR Sensors can be miniaturized into wider range of aerial defence platforms such as UAVs and ground-based systems.

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