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# Webcam-Guided Rover Control for Medical Waste Transport

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***Abstract*— This research study aims to address the health risks posed by improper medical waste management by implementing an innovative solution: a webcam-guided rover control for medical waste transport. It is a robot that can be programmed to communicate with MATLAB over Wi-Fi to carry out different tasks. The rover autonomously navigates along the predefined paths, utilizing image processing to identify and collect medical waste. This approach eliminates the need of human intervention, thus reducing the risk of infections associated with manual waste handling. The rover hardware components incorporates Arduino Nano 33 IoT, Arduino Nano Motor Carrier, DC motor with encoder, Servo motor, Fork lifting ,Wheels, Webcam and Ultrasonic Sensor.**

***Keywords*— *Medical waste, Fork lifting, Webcam, Image processing, Arduino Nano 33 IoT, MATLAB.***

## I. Introduction

In India, hospitals and healthcare facilities generate a significant amount of waste, but its disposal is often neglected. This negligence leads to improper dumping and mixing of hospital waste with domestic waste, causing various hazards. Mishandling of infectious and hazardous hospital waste can result in serious health issues for waste collectors and the environment, and it can spread communicable diseases. Hospital waste is categorized into infectious and non-infectious types. Infectious waste includes human tissue, bodily fluids, and contaminated items like sharp objects, which pose risks of diseases such as AIDS/HIV and hepatitis B and C. Non-infectious waste includes laborator 4. A comparative analysis of the proposed model and existing techniques can be included for better validation. y waste and materials from surgeries and autopsies.

So proper management of medical waste should be done and as per the Hindustan times 5.2 million people die every day globally due to medical waste [1]. Waste generated is too much to handle and highest waste generated states in India from June (2020-2021).Among all the states Maharashtra is the highest waste generating state with 8,315tonnes in India as per the Times of India [2].

To avoid human intervention in medical waste management, a Webcam-Guided Rover with a Forklifting Mechanism has been designed. [3]. For the transport of medical waste it is a programmable robot to perform operations using an image processing algorithm. The Rover is built using an Arduino Nano 33 IoT, the Arduino Nano Motor Carrier, two DC motors with encoders and a micro-servo motor. A color-coded sticker has been installed on top of the rover to act as a marker, aiding the image processing algorithm that uses a webcam to detect the robot's location and orientation.

It is designed using a Arduino Nano 33 IoT, powered by an ARM Cortex M0+ microcontroller, is a robust and versatile board designed for makers and engineering students working on robotics and IoT projects. It offers a powerful, cost-effective solution with built-in Wi-Fi, a crypto-chip for secure communications, and configurable low power consumption for long-term operation. Its compact size, integrated wireless connectivity, and enhanced security features make it a standout choice, surpassing older boards like the Arduino Uno and other platforms that require additional components to match its functionality.

## II. Literature Survey

Stephina R, Sushmitha S ,Thanmaya H K, Thejaswini Y N , Smt. Asha M [4] proposed an Automated Guided Vehicle uses smart dustbins. When the dustbin is filled IR sensor detects the and as soon as the trash gets filled ,the robot comes near bin in a predefined path by identifying the colour of the bin using colour sensor collect the waste from dustbins and dumps the waste in the destination point and it will be moving back to the start point. Drawback is human interaction is required in loading waste.

Pneumatic tubes [5] are a type of transportation system that uses compressed air to move objects through a network of tubes. These pneumatic tube systems are used to deliver drug, liquid waste. The pneumatic tubes connect all the wards by this waste is transported from different areas of hospital to a central disposal location safely. These tubes transport waste quickly from one place to another place without any human involvement. Drawback is that implementation cost is high ,can't transport all kind of waste.

Brindha S, Praveen V ,Rajkumar S, Ramya V, Sangeetha V [6] proposed conveyor belt system. The conveyor belt system activates when waste enters, turning on the belt motor along with all microcontrollers, motors, and sensors. An inductive proximity sensor tests whether the waste is metallic. If it detects metal, the conveyor belt stops, and a motor pushes the metal waste into a designated bin. For non-metallic waste, a moisture sensor determines if it is wet or dry. If the waste has moisture, it is classified as wet waste, the belt stops, and another motor directs it to a wet waste bin. Dry waste continues on the conveyor to its bin. The system's drawback is that it requires some human involvement for monitoring and occasional intervention.

Transportation vehicles [7] will include GPS for movement tracking and will feature separate compartments for the driver/staff and for color-coded biomedical waste containers. The waste compartment will be designed to prevent liquid leaks and will have tiered storage, lighting, and smooth, easy-to-clean surfaces for efficient disinfection. It will have convenient openings for loading waste containers and will display the Bio-Hazard symbol. Additionally, the driver will possess valid transport authority registration and an up-to-date pollution control certificate. The vehicles will be regularly inspected to ensure compliance with health and safety regulations, maintaining the highest standards of operation. Training sessions will be provided to drivers and staff to handle biomedical waste safely and effectively, minimizing risks and ensuring proper waste management. Drawback is human intervention is required.

Samreen Amir, Adnan Waqar, Maryam Ajmal, Mariam Majeed, Hafsa Haseeb, and Hasan Mehmood [8] proposed a Gesture Control Automobile Model, which is a rover that navigates using human gestures and voice commands. Equipped with a kinetic optical sensor, it facilitates human-robot interaction, offering an intuitive, robust, and engaging experience. The rover can control various operations, including acceleration, braking, steering, and media volume. The drawback of model is it suffer from inaccuracies in gesture or voice recognition in noisy or complex environments, potentially compromising safety and precision during tasks such as transporting medical waste.

Shreyansh Kumar Jain, Mittapalli Monish, Neeraj Gupta, Shivam Kumar Raj, and Karpagavalli Subramanian [9] introduced Robot Arm for garbage disposal in hospital environments. This robot requires specific data to identify and collect particular objects. For instance, if programmed to detect items such as syringes, mayo scissors, masks, and gloves, it can accurately identify these objects in the waste and ensure their safe transport. A drawback of the Robot Arm for garbage disposal is its reliance on predefined data, limiting its ability to adapt to unprogrammed or unexpected waste items, which could reduce its overall efficiency in dynamic hospital environments.

Chapala Sara Grace, M. Sreeja, and M. Deepika [10] in biomedical waste management by minimizing human exposure to potentially dangerous materials. Its automated systems for disinfecting, sterilizing, and grinding waste are designed to streamline waste handling processes and enhance safety. The robot’s user-friendly design and cost-effectiveness make it an accessible solution for various healthcare facilities, ensuring efficient and hygienic waste management while r educing labour and operational costs. A drawback of the automated biomedical waste management system is that it may require significant maintenance and technical support, which could offset its cost-effectiveness and accessibility for some healthcare facilities.

By addressing the limitations of earlier solutions, this rover provides a more efficient and effective approach to ensuring safe waste disposal. Arduino Nano 33 IoT for power efficiency, image processing for waste detection, and complete autonomy in waste transport makes this rover a superior solution. It not only reduces the risks associated with human intervention but also ensures a reliable, accurate, and scalable approach to managing medical waste in healthcare environments compared to above solutions.

## III. Proposed System

In this study a webcam guided rover control for medical waste transport is presented to address the health issues posed by improper medical waste. Our innovative approach integrates cutting- edge technologies and strategic methods to provide a holistic solution for overcoming challenges in medical waste management. The incorporation of all components onto an Arduino Nano 33 IoT Board not only ensures cost-effectiveness but also facilitates seamless interaction. The Block diagram of Webcam-Guided Rover is shown in Fig.1.

### *A. Block diagram of Webcam-Guided Rover*

The block diagram of rover includes Arduino Nano 33 IoT, Arduino Nano Motor Carrier, DC Motor with Encoder, Servo Motor, Fork Lifting ,Wheels, Webcam and Ultrasonic Sensor.

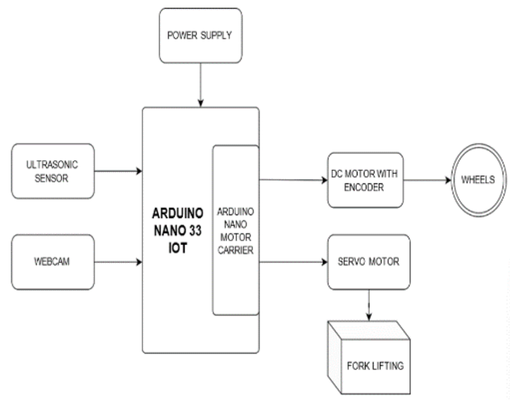


Fig. 1. Block Diagram of Webcam-Guided Rover

### *B. Hardware*

The hardware design is shown in Fig.2. A brief description about the hardware used is given below. The process is carried out by connecting all the hardware components such as Arduino Nano 33 IoT , Arduino Nano Motor Carrier, two DC Motors with Encoder, Servo Motor, Webcam, Ultrasonic Sensor and a power supply of 3.6V Lithum battery for the working of rover [11].

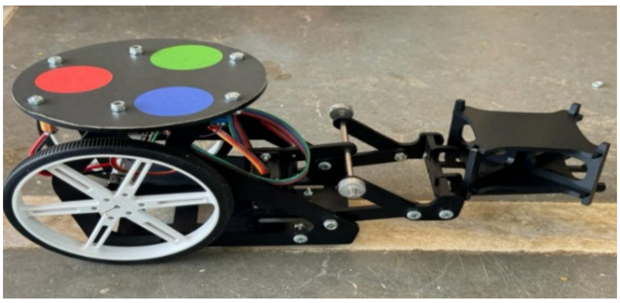

Fig. 2. Webcam Guided Rover with Forklifting Mechanism

*1) Arduino Nano 33 IoT:* The Arduino Nano 33 IoT, illustrated in Fig. 3, comes with 19 digital pins (D2-D21) and 8 analog pins (A0-A7). The analog pins can handle voltages ranging from 0 to 3.3 volts, whereas the digital pins operate at binary levels of 0 or 3.3 volts. Additionally, pins D14-D21 and A0-A7 can serve as General Purpose Input/Output (GPIO) pins, supporting both analog and digital functions. The board is also equipped with an IMU, which measures orientation, shocks, vibration, acceleration, and rotation speed.

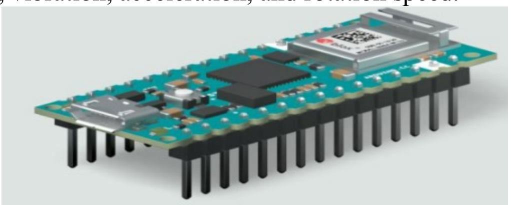

Fig. 3. Arduino Nano 33 IoT

*2) Arduino Nano Motor Carrier:*The Arduino Nano Motor Carrier used is shown in Fig.4, is an add-on board that controls servo, DC, and stepper motors. It plugs into the Arduino Nano 33 IoT and facilitates connections for motors and sensors via 3-pin male headers. It includes 4 analog connectors for sensors linked to analog pins A2, A3, A6, and A7, and has terminals M1, M2, M3, and M4 for motor connections with positive and negative terminals.

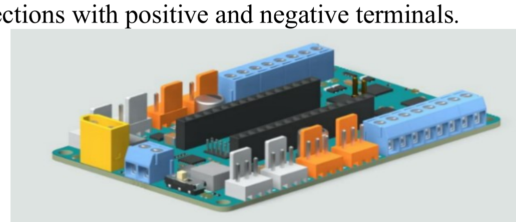

Fig. 4. Arduino Nano Motor Carrier

*3) Servo motor:*Servo motor shown in Fig.5 are actuators that provide precise control of position (angle) or angular velocity via a microcontroller. They include an internal control circuit, which can be either analog or digital. With a range of 0 to 180 degrees, servo motor is used for applications like forklifting.

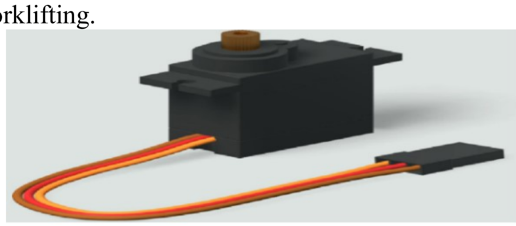

Fig. 5. Servo motor

*4) DC Motor:* The DC motor is illustrated in Fig. 6, is micro DC motors with a gearbox (100:1). The two DC geared motors were used to move the wheels of the rover, and to drive the rover forwards and backwards. It works with a speed of 320 RPM and with a Gear Ratio 100:1.

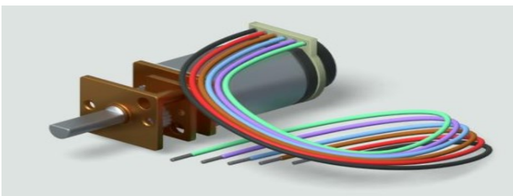

Fig. 6. DC Motor with Encoder

*5) Webcam:*The webcam shown in Fig.7 is a USB digital camera that converts optical images into electrical signals in real-time. In our study, it will capture images for image recognition algorithms and track the movement of devices in control experiments.

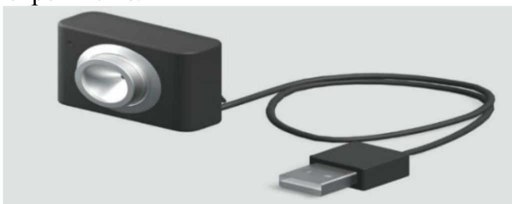

Fig. 7. Webcam

*6) Lithum Batteries:* A 3.6V lithium battery is used as the power supply for the rover, providing the necessary energy for its operations. This battery ensures reliable power delivery to various components of the rover, including the motors and electronics is shown in Fig.8.

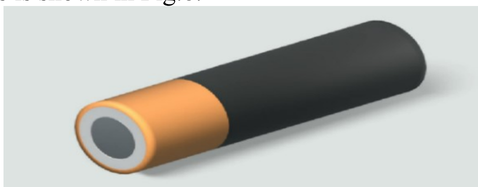

Fig. 8. Lithum battery

*7) Ultrasonic Senosr:*Ultrasonic sensors shown in Fig.9 help rover by using sound waves to find obstacles and measure distances. They let the rover see what's in its path, helping it avoid bumping into things or falling off edges. This sensor also help the rover map its surroundings and make sure it can move safely and accurately. They are especially useful for tasks like docking or approaching objects, making them crucial for the rover's operation.


Fig. 9. Ultrasonic Sensor

## IV. IMPLEMENTATION

The process is carried out by connecting Arduino Nano 33 IoT to Arduino Nano Motor Carrier. The Arduino Nano Motor Carrier is used as a support for Arduino Nano 33 IoT for connecting different type of sensors and motors. Here we have connected two DC motors with encoder for the Arduino Nano Motor Carrier for rotating the wheels and a Servo motor for the purpose of forklifting and a Ultrasonic Sensor for obstacle detection. Webcam is used for detection of path and a power supply of 3.6V is connected to the Arduino Nano Motor Carrier for the working of rover. After the hardware components like Arduino Nano 33 Encoder, Servo Motor, Fork Lifting, Wheels, Webcam were assembled.

To control the rover, MATLAB was installed and downloaded additional libraries namely

- MATLAB support package for Arduino hardware
- Simulink Support package for Arduino hardware

- MATLAB support package for USB webcam
- Arduino_Enginerring_Kit_Project_Files_Rev_2

Connected individual component and tested it with characteristics of rover to check program whether each individual part is working or not. It is observed that all components are working properly. Since when built-in led in characteristics of rover is turned on the Arduino IoT board is working properly in the same way the DC motors, servo motors and Arduino Nano Motor Carrier were controlled using characteristics of rover is shown in Fig.10.

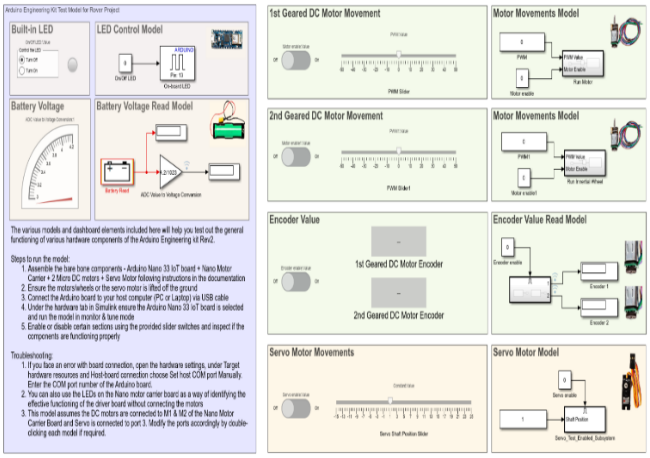


Fig. 10. Characteristics of Rover

After successfully completing testing of individual components, the rover's kinematic equation was simulated using (3). (1) gives the rate of rotation; (2) gives velocity. For the rover to move in a straight line, circle, or other desired paths, it is necessary to calculate rotational speeds ($\omega_l$, $\omega_r$) for the desired rate of rotation ($\omega$) and velocity ($v$).

$$\omega = \frac{v_r + v_l}{L} \tag{1}$$

$$v = \frac{v_r - v_l}{L} \tag{2}$$

$$\begin{bmatrix} \omega_l \\ \omega_r \end{bmatrix} = \frac{1}{r} \cdot \begin{bmatrix} 1 & \frac{-L}{2} \\ 1 & \frac{L}{2} \end{bmatrix} \cdot \begin{bmatrix} v \\ \omega \end{bmatrix} \tag{3}$$

Where

L= Distance between the wheels

r = Radius of rotation

$\omega$= Rate of rotation

$v$ = Forward velocity

$\omega_r$= Rotational speed of right wheel

$\omega_l$= Rotational speed of left wheel

$v_r$ = Right wheel velocity

$v_l$ = left wheel velocities

ICC = Instantaneous centre of Curvature

TS= Sampling time

The rover model that describes the kinematics of this system given in (3) is implemented in Simulink program angular speed for left and right wheel is shown in Fig.11 .

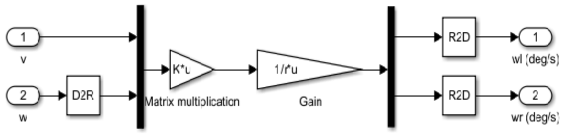


Fig. 11. angular speed for left and right wheels

Then, simulated the rover's motion. In the previous section, Simulink is used to implement basic kinematic equations of rover but the model did not consider the location of the Rover in real-world coordinates. The location (x ,y) and the heading ($\theta$) of the Rover in an X-Y coordinate system can be described using the following equations (4) gives angle of rotation; (5) gives distance along x-axis; (6) gives distance along y-axis .

$$\int \theta(t) = \int \omega(t).dt \tag{4}$$

$$\int x(t) = \int v(t).cos\theta.dt \tag{5}$$

$$\int y(t) = \int v(t).sin\theta.dt \tag{6}$$

Where

$\theta$ = Angle of rotation

X=Distance covered along x-axis

Y=Distance covered along y-axis

These equations are calculated using the below Simulink called vehicle kinematics as shown in the below Fig.12.

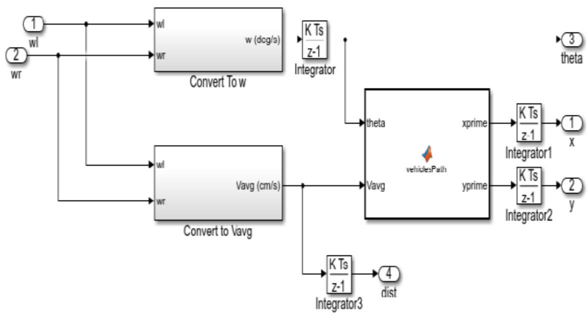


Fig. 12. Vechicle kinematics model

Model parameters of webcam controlled rover provided by the Arduino Engineering project Kit Rev2 are shown in Table I [12].

TABLE I. MODEL PARAMETERS

| Parameter | Value |
|---|---|
| L | 8.5 cm |
| r | 4.5 cm |
| TS | 0.01 sec |
| $v$ | 10 cm/s |
| $\omega$ | 0 deg/s |
| $\omega_r$ | 127.3 deg/s |
| $\omega_l$ | 127.3 deg/s |
| $\theta$ | 360 degrees |
| X | 50 cm |
| Y | 70 cm |

After, simulating the rover's motion run the Encoder simulation to observe the path of the rover. The Encoder simulation is shown in Fig.13.

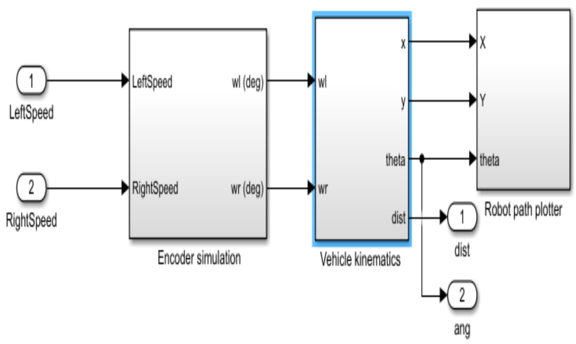


Fig. 13. Encoder Simulation

The output for the Encoder simulation is shown below in Fig.13.It is observed at rover moved 50 cm along x-axis and 70cm along y-axis in 5sec and the turned 360 degrees per 5 sec as shown in Fig.14.

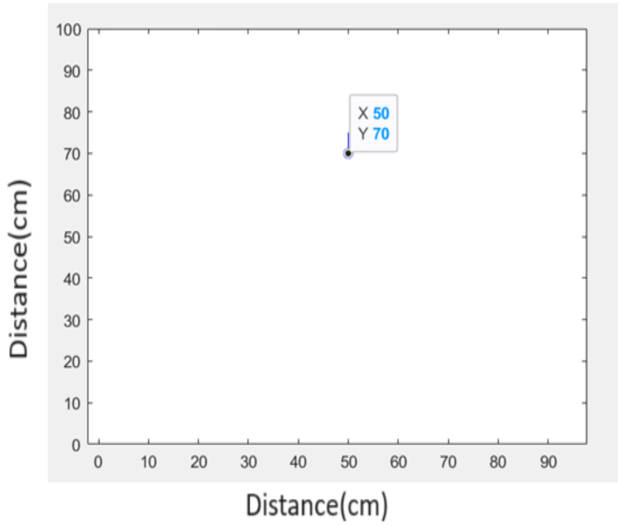


Fig. 14. Robot path plotter

Rover is controlled using open loop control it is implemented using Simulink rover open loop control shown in Fig.15 and observed outputs by changing the proportional gain, integral values which are not accurate.

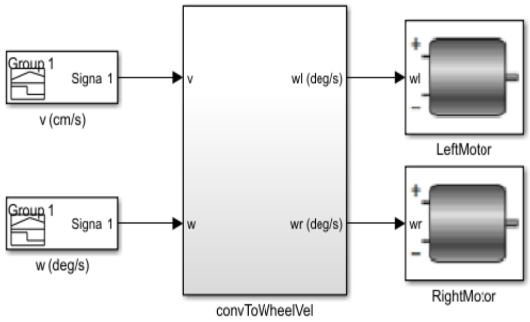


Fig. 15. Rover Open loop Control

Closed loop control is used since outputs from the open loop control were not accurate. In closed loop control accurate outputs were observed by changing P, I values in trial and error method..

Then, created Arena with width of 420 mm and height of 594 mm in white chart as shown in Fig.16.

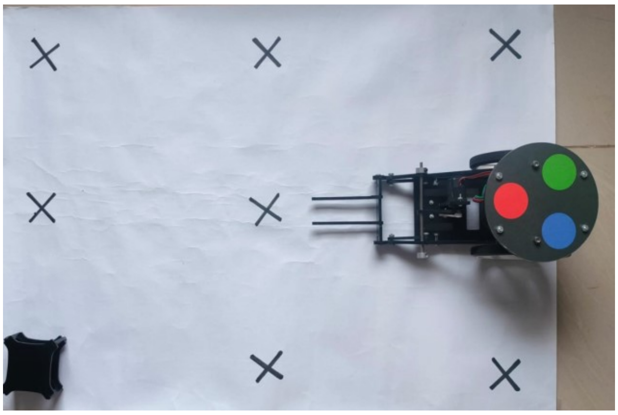

Fig. 16. Top view of arena

After,creating arena rover position is calibrated by placing in different positions like Left, Right, Top and Bottom as shown in Fig.17,18.

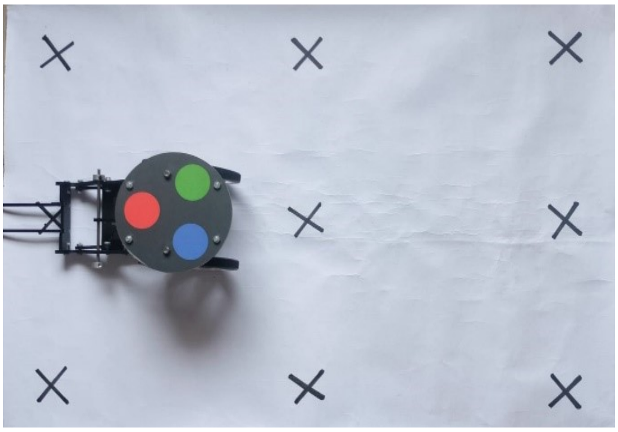

Fig. 17. Rover located at top of the arena

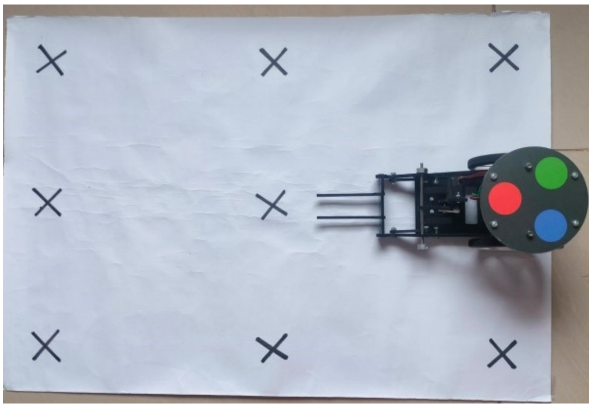

Fig. 18. Rover located at Bottom of the arena

The image processing starts by calibration, where images of the Rover at the arena's edges (TOP, BOTTOM, LEFT, RIGHT) are captured. This helps adjust for depth perception and convert pixel data into real-world measurements. The Rover is recognized by detecting its red, green, and blue markers using colour thresholding. Noise is removed through morphological operations. The centroids of the markers (cR, cG, cB) are calculated, and the Rover's centre (cPlate) is determined from these points. The Rover's heading is found by measuring the angle between the red marker and the centre. The algorithm gives the Rover's position and heading, which are shown on the image, along with the target object.

## V. Experimental Results

The implementation of the closed loop control system significantly improved the accuracy of the webcam-guided rover for medical waste transport compared to the open loop control. With a position rise time of 5 seconds and a settling time of 7.5 seconds, and an angle rise time of 5.5 seconds and settling time of 7 seconds, the system demonstrates quick and stable responses. These metrics show that the rover can adjust its position and orientation efficiently, making it more reliable for precise tasks like medical waste transport. Position closed loop control is shown in Fig.19 and Fig.20 shows angle closed loop control and respective outputs were shown in Fig.21 and Fig.22.

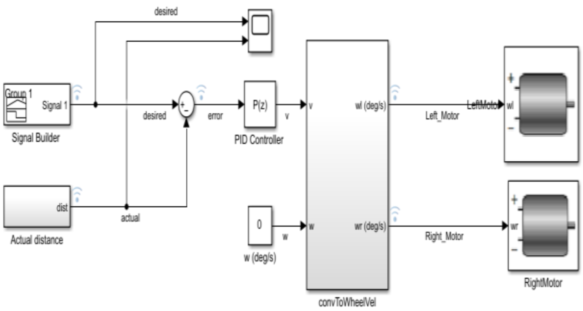


Fig. 19. Position Closed loop control

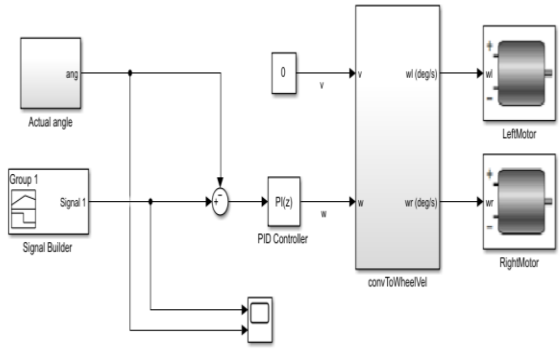


Fig. 20. Angle Closed loop Control

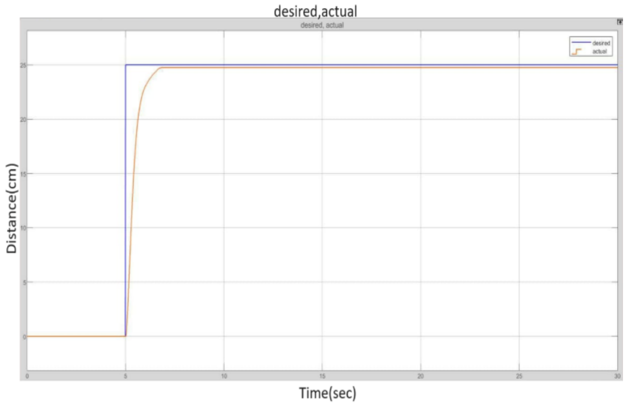


Fig. 21. Response of the rover position (cm)

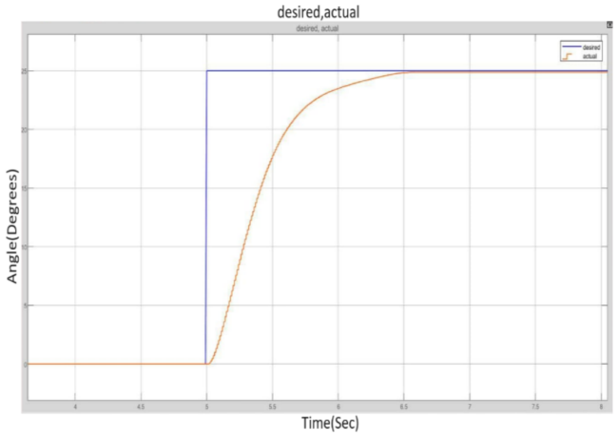


Fig. 22. Response of the rover angle (degrees)

## VI. Conclusion

In conclusion, the implementation of a webcam-guided rover with a forklift mechanism, offers a promising solution to the challenges posed by improper medical waste management. By autonomously navigating predefined paths and utilizing image processing for waste identification and collection, this innovative approach reduces the need for human intervention, thereby minimizing the associated health risks and enhancing operational efficiency. The integration of advanced technologies, such as Arduino Nano 33 IoT microcontroller, webcam, servo motor, and DC motors with encoders, provides a robust platform for developing a cost-effective and low-power solution. The Arduino Nano 33 IoT board's versatility and capabilities make it suitable for various robotics and IoT projects, while the Arduino Nano Motor

Carrier simplifies the connection of motors and sensors, enhancing the rover's functionality. Through the proposed system, hospitals and healthcare facilities can effectively manage medical waste, segregating infectious and non-infectious waste and minimizing the risk of disease transmission. Overall, the webcam-guided rover with a forklift mechanism represents a significant step towards achieving safer and more efficient medical waste management practices, contributing to public health and environmental sustainability. With further research and development, this system has the potential to be scaled up and adapted for use in various healthcare settings, ultimately benefiting communities worldwide.

## VII. Future Scope

The webcam-guided rover equipped with a forklift mechanism can be significantly enhanced for more efficient and effective medical waste management in healthcare. By incorporating Simultaneous Localization and Mapping (SLAM) techniques, the rover's navigation capabilities will improve, allowing for better environmental mapping and path planning. Additionally, integrating advanced sensors such as LiDAR, ultrasonic sensors, and inertial measurement units (IMUs) will enhance the rover's perception and obstacle avoidance abilities. Implementing real-time monitoring of waste collection status and environmental conditions will provide continuous feedback to the reinforcement learning system. These enhancements will collectively optimize the rover's performance, ensuring safer and more efficient medical waste management practices in healthcare settings.

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