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Development of an Autonomous Waste Handling Robotic System for Hospital Wards

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Abstract

The healthcare industry has grown substantially in recent years, increasing medical waste generation. This upsurge poses a unique challenge to effective waste handling, particularly within hospital wards. Manual handling of medical waste has been associated with inefficiencies, jeopardizing the safety of patients, staff, and visitors. This study introduces the development of an autonomous waste-handling robotized system that automates waste-handling processes and optimizes overall efficiencies To address these challenges. This system employed two controllers that synergize ultrasonic sensors and servomotors for automated lid control and waste container monitoring. A notification system with colour-coded Light Emitting Diodes (LEDs) indicates the present status of the waste container and, consequently, reduces the need for human intervention. The system also uses Infrared proximity sensors integrated with motor drivers to control the robot's navigation, featuring a mechanism that enables climbing obstacles. The system design includes generating mathematical models of mechanical and electrical components to ensure structural integrity and efficient performance. The fabrication phase translates the theoretical design into a physical system considering material selection, assembly processes, and compliance with healthcare regulations. The electrical circuit design guides the selection of motors, batteries, and sensors, ensuring effective performance and power efficiency. These approaches position the adaptable mobile robotic system to contribute to sustainable waste management that promotes improved operational efficiency, increased safety for healthcare workers, and a positive environmental impact.

Keywords

Hospital Ward, Modelling, Robotics System, Sensor, Servo Motor Waste Handling,

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1. Introduction

Hospital ward waste, such as the byproduct of patient care and medical procedures, poses a unique challenge due to its diverse and potentially hazardous nature. However, dustbins are placed strategically on the floor of the hospital wards for waste collection without any smart disposal mechanism. Hence, handling this waste is time-consuming, dangerous, and infectious as it exposes personnel or workers to medical and bio-hazardous waste (Baskoro *et al.*, 2020). The collected hospital ward waste should not be kept for more than a day to help the hospital provide a clean environment for the patients, staff, and visitors. Thus, there's a need to ensure regular and safe disposal of ward waste (Stephina *et al*., 2020). Traditionally, handling these hospital wards' waste has been a labour-intensive process that poses various challenges, especially infection control and the overall efficiency of hospital operations (Bandaso & Ayuningtyas, 2019). These conventional waste handling practices employed in hospitals rely wholly on human labour and involve waste collected with a waste bin or container. Then, manual segregation categorises the waste into various streams: general, biohazard, hazardous, pharmaceutical, and recyclable. Waste carts are often used to transport this waste to a central collection point before disposal. Waste management practices must be effective, safe, and environmentally sustainable to prevent unintentional exposure to this waste when carrying out management processes. The inability of workers to perform these waste management procedures consistently due to their demanding and repetitive nature could result in management error, creating a toxic environment for patients, staff members, or visitors (Sreejith *et al*., 2019). The major goals of biomedical waste management are to minimise disease transmission from one patient to another, from patients to hospital workers, and from the worker to patients or visitors, as well as to prevent injury to hospital workers and waste handling staff employees. This helps prevent exposure to the harmful effects of the bio-hazardous and hazardous wastes generated throughout the hospital (Mathusuthan & Vasanthiny, 2017).

Employing mobile robotic systems equipped with sensors, actuators, and robust navigation algorithm capabilities can be deployed in hospitals to handle waste more effectively (Sutar et al., 2020). Mobile robotic systems have the potential to play pivotal roles in the improvement of safe and efficient waste-handling systems in hospitals (Kyrarini *et al*., 2021).

Exploring technologically innovative solutions such as the robotic system curbs this limitation and more that could happen from these manual practices. It helps improve waste management efficiency, safety, and environmental sustainability. A robotic system in waste handling introduces several benefits and advantages to its practices. A robotic system brings automation to the waste handling processes, reducing the reliance on human labour and enhancing the operations involved. The robot autonomously navigates the hospital wards, stops waste collection, and transports the waste to a designated location for its disposal. These overall operations save time, minimize risk, and make the utilization of human resources available. Several efforts have been made in the past to provide solutions to the problem of the manual waste-handling process, including the study by Agasali (2019).

In the same light, Oltean (2019) introduced a study on a Mobile Robot Platform that used an Arduino Uno and Raspberry Pi for Autonomous Navigation. The study provided a mathematical model for waste container capacity management, which can help organizations analyse idle capacity and design strategies for maximizing value. Specific details about the implementation and validation of the mathematical model were not included.

In contribution to the developments made by researchers to the autonomous waste handling by robotics systems for hospital wards, (Ignisha *et al.*, 2019) developed a robotic dustbin with wheeled mobility that used IR sensors and ultrasonic sensors to detect and collect waste, then a WIFI module to send notifications when the waste bin is full to enable prompt disposal. The deficiency that came from the robot is implementing the system in different types of environments. The robot can only transverse on a one-level floor only. Wang *et al.*, (2019) proposed a study that integrates computer vision technology and path planning algorithm to enhance the capabilities of a construction waste handling robot. This study focuses specifically on the recycling of nails and screws, and it is unclear if the robot can handle other types of waste.

Stephina *et al.* (2020) developed a smart waste disposal robotic system used in hospitals. The robotic system is a fully automated smart waste disposal system that reduces the need for human intervention and makes the waste disposal process more efficient. However, the requirement for well-structured hardware may increase the cost of installation. Their development improves over previous waste disposal systems and has potential for future enhancements. Remell (2021) also published a study on a mathematical model of a two-wheeled robot. This paper shows the mathematical model of a generic two-wheeled robot, including kinematic and dynamic equations. The published paper does not present experimental validation or testing of mathematical models. Control development, experimental validation, and testing of the mathematical model are some of the areas that can be studied.

In other developments, Kayani et al. (2022) designed a Smart Bin using Internet of Things technology to promote cleanliness and reduce human interactions and efforts in waste collection. They highlighted challenges like cost and infrastructure for continuous usage as part of the system's limitations. Das et al. (2023) also designed an Autonomous Robot for Municipal Waste Collection. The waste detection model of the system used TensorFlow and Python, which were built with a waste collection mechanism to detect and collect plastic waste very fast. The limitations associated with this system include the slow processing of images due to insufficient CPU power. Jain et al. (2023) proposed an articulated robot arm for garbage disposal in a hospital environment. They designed a 3D-printed robotic arm model with 6 degrees of freedom (DOF) and successfully integrated it with servo motors. Their design did not delve into the real-time object detection capabilities of the AI system used with the robot and its potential application in image processing and object detection. The study did not discuss the use of path planning and wheels for the movement of the robotic arm, which could improve its mobility and navigation capabilities.

The literature reviewed so far reveals several existing systems on waste handling, the inadequacies, and setbacks that need further improvements with the advent of this robotic system. This research adopts a robotic waste handling system that carries out waste collection, transportation, and disposal. It also incorporates a robust mechanical structure that improves the existing mobility mechanisms for different waste robotic systems, which aims to increase waste collection efficiency within an operation time.

2. Methodology

Waste-handling robots in different designs are already in existence, but this design focuses on carrying out waste collection, disposal, and transportation with obstacle climbing and inclination movement abilities.

In Figure 1, the robotic system used two controllers, the Atmega 328 and Atmega 328P microcontroller boards, to control the system's overall operations. Controller 2 controls the infrared proximity sensors and motor drivers for opening the waste bin and closes for dumping activities to be completed. The lithium battery with nominal voltage of 12.8V, charge voltage 14.4V to 14.6V, cold cranking amps / peak discharge (5 Sec) 4500A, continuous charge / discharge rate 200A, and capacity (amp hours) 450AH; IR proximity(LM393) and ultrasonic sensors(HC-SR04) with working voltage of 3.3 5vdc,operating voltage/current of 3.3V-5V/23-43mA, detecting range of 2-30cm and working voltage of 5V, measuring distance 2 to 40cm, input/output pine of 4 and operating current of 15mA specifications respectively. Whereas a 6W servomotor is adopted for the design.

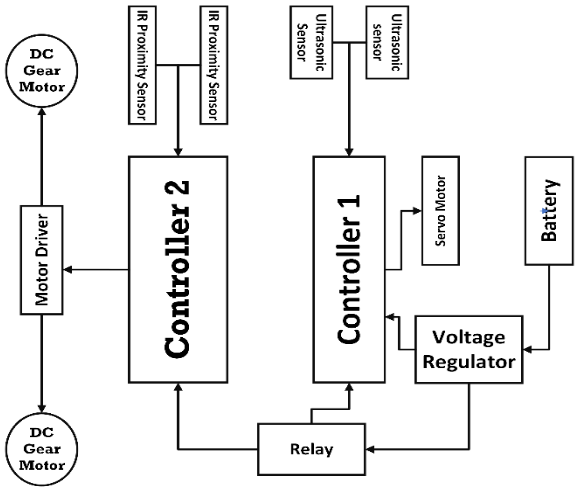

Figure 1: Block diagram of the waste handling robotic system

These components enabled the robotic system to navigate a hospital ward autonomously using a tracked line. The infrared proximity sensors use infrared light to detect track lines, and the controller decodes these inputs from the waste handlers and then initiates precise motor control, steering the robot on its path for collection through the activities of the motor drivers.

Controller 1 manages the automatic operation of the waste container lid. It controls the ultrasonic sensors and servo motor action of opening and closing the bin for the waste to be dumped. The ultrasonic sensors detect the presence of waste from the handlers, enabling the robot to approach and interact with waste intelligently. The servo motor controls the automated opening and closing of the waste container lid, ensuring seamless waste collection. Both controllers were interconnected to a relay switch to ensure a synchronized operation. Additionally, a voltage regulator stabilizes the power supply from the system's power source.

The design is modelled in two ways: the mechanical model and the electrical model.

2.1 Mechanical Model of the Waste Handling Robotic System

This section presents the Mechanical Model of the Waste Handling Robotic System

2.1.1 Model of the waste handling robotic skeletal frame

Figure 2 depicts the skeletal side view of the mechanical system for the waste handling robotic system and the mathematical representations.

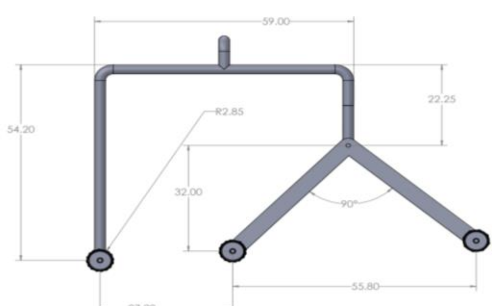

Figure 2: Side view of the robot chassis

The wheel diameter of the robotic system was determined from the relationship in (1).

$$tan\theta = \frac{d}{h} \tag{1}$$

Where d = diameter of the wheel in m, h = height of one step of the obstacles in m, $\theta =$ inclination angle.

$d = h \times tan\theta$

$d = 0.15 \times tan\,(35°)$

$d = 0.20\ m$

The wheelbase of the robotic system (L);

$$D = \frac{h}{tan\theta} \tag{2}$$

Where D = horizontal distance, h = step height,

θ = inclination angle = $\frac{0.15}{tan35°}$

D = 0.26m

The wheelbase should be greater than the horizontal distance to ensure stability. Therefore,

$$L = D \times (1 + safety\ margin) \tag{3}$$

$$L = 0.26 \times (1 + 0.10) = 0.29m$$

Track width of the robotic system (W);

$$W = \frac{L}{2} \tag{4}$$

$$W = \frac{0.29}{2} = 0.125m$$

Wheel velocity of the robotic system (V);

$$V_{max} = \frac{rpm \times \pi \times 2r}{60} \tag{5}$$

$$V_{max} = \frac{100 \times 3.142 \times 2 \times 0.1}{60} 1.05\ m/s$$

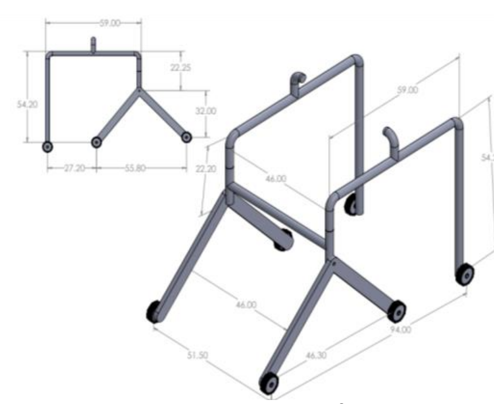

Figure 3: Isometric diagram of robot chassis

The motor torque of the robotic system, T is obtained using (6);

$$T = M(a + g \times sin\theta)r \tag{6}$$

Where: M = mass of the robot, a = acceleration,
g = acceleration due to gravity, r = radius of the wheel

T = 15 (0.21 + 9.81×sin35) 0.1
T = 8.62Nm
Total Torque, T_{max} = 8.62×6 = 51.73Nm

The total gear ratio, GR is obtained using (7)

$$GR = Gearbox\ reduction\ ratio\ \times\ wheel\ diameter \quad (7)$$
$$= 10\ \times\ 0.2 = 2$$

Similarly, the traction force, FT is computed using (8);

$$Ft = \frac{T \times GR}{Dw} \quad (8)$$

$$= \frac{8.62 \times 2}{0.2} = 86.2N$$

2.1.2 Kinematics of the Mobile Robot

In terms of a mobile robot, kinematics is the basic study of the motion of robots without considering the force that causes the motion. There is no direct way to predict a mobile robot's position instantaneously. Instead, the motion of the robot must be integrated over time. Additionally, due to some factors such as slippage and rolling constraints of each wheel, it is an extremely challenging task to determine precisely the position of a mobile robot as it moves from one place to another.

According to Figure 2, the robot is modelled as a rigid body on a wheel operating on a horizontal plane. The total dimensionality of the mobility of this robot chassis on the plane is three: two for the position in the plane and one for the orientation along the vertical axis, which is orthogonal to the plane. However, the joints, degrees of freedom, and internal joints of the robot are ignored in this case.

In order to determine the robot's position on the plane, the relationship between the global reference frame on the plane and the local reference frame of the robot is established, as shown in Figure 4.

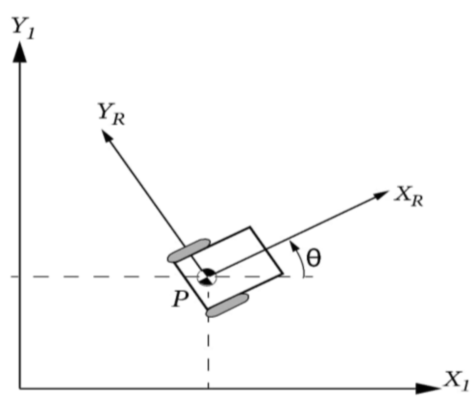

Figure 4: Waste robot modelled according to position on local frame in reference to the global frame.

Let $\{X_1, Y_1\}$ = Axes of the global reference of the plane from an origin 0. Let $\{X_r, Y_r\}$ = Axes of the local reference, which signifies the robot's position from a reference point P.
Coordinate (x, y) = Coordinate of the position of point P on the plane.
θ = Angular difference between the global and reference frame. Hence, the pose of the robot can be described by ζ_1 as expressed in (9).

$$\zeta_1 = \begin{bmatrix} x \\ y \\ \theta \end{bmatrix} \quad (9)$$

Assuming the robot is posing to rotate along the Y-Axis on the global frame. According to the Denavit-Hertenberg transformation method, the rotational matrix can be represented as R(θ) represented in (10),

$$\mathrm{R}(\theta) = \begin{bmatrix} \cos\theta & \sin\theta & 0 \\ -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (10)$$

Assuming $\theta = \frac{\pi}{2}$;

R(θ) = R $(\frac{\pi}{2})$….(11)
Thus,

$$R(\theta) = R\left(\frac{\pi}{2}\right) = \begin{bmatrix} 0 & 1 & 0 \\ -1 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (11)$$

The mapping of the motion of the global reference to the motion of the local reference can be denoted as ζ_r, as shown in (12)

$$\zeta_r = \zeta_1 R(\theta) \quad (12)$$

Therefore,

$$\zeta_r = \zeta_1 R\left(\frac{\pi}{2}\right)$$

Given some velocities $(\dot{x}, \dot{y}, \dot{\theta})$, the components of motion along the x-axis and y-axis can be denoted as $X_R\ and\ Y_R$ respectively. Due to the specific angle of the robot, $X_R = \dot{y}\ and\ Y_R = -\dot{x}$. So, the velocity equation becomes (13)

$$\dot{\zeta_R} = \mathrm{R}\left(\frac{\pi}{2}\right) = \begin{bmatrix} 0 & 1 & 0 \\ -1 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (13a)$$

$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} \dot{y} \\ -\dot{x} \\ \dot{\theta} \end{bmatrix} \quad (13b)$$

2.1.3 Forward Kinematic Models

This mobile robot consists of six wheels with two pairs paired in parallel, though independently driven. A sample of two differential drive wheels is considered in this case. The sample considered consists of two wheels, each with diameter d, given a point p centred at an angle between the two wheels. Each wheel is connected through a link at even a distance from point P. Given d, l and the spinning speed of each wheel, $\varphi_1\ and\ \varphi_2$, a forward kinematic model is generated to predict the overall speed of the robot in the global reference frame:

$$\dot{\zeta_1} = \begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix} = f(l, d, \theta, \dot{\varphi_1}, \dot{\varphi_2}) \quad (14)$$

The rotational velocity (ω) of the right wheel at point P moving along the arc of the circle of radius 2l can be computed as:

$$\omega_1 = \frac{r\dot{\varphi}_1}{2l} \quad (15)$$

Similarly, the velocity of the left wheel can be computed as:

$$\omega_2 = \frac{-r\dot{\varphi}_2}{2l} \tag{16}$$

A combination of these effects yields a kinematic model for the differential-drive waste robot, and this is computed as:

$$\dot{\zeta}_1 = R(\theta)^{-1}\begin{bmatrix} \frac{r\dot{\varphi}_1}{2l} + \frac{r\dot{\varphi}_1}{2l} \\ 0 \\ \frac{r\dot{\varphi}_1}{2l} + \frac{-r\dot{\varphi}_1}{2l} \end{bmatrix} \tag{17}$$

2.1.4 Model of the Waste Handling Robotic Container

The Solid Works simulation platform was utilised to create a model of the autonomous waste-handling robotic system, as shown in Figures 4, 5, 6, and 7. Also, a virtual hospital ward environment closely resembles reality for the virtual simulation of the system. This computer-generated environment allowed a thorough examination of the robot's capabilities by imitating real-world circumstances. The simulation accurately reproduces the robot's actions, such as navigating the hospital environment following a line and handling waste, thereby providing valuable insights. The control algorithms of the robot underwent validation within the simulation. The simulation aligns with expected behaviours in the real world, effectively demonstrating the accuracy and efficacy of the control system. Numerous simulation scenarios were carried out to assess the robot's performance in various hospital ward scenarios.

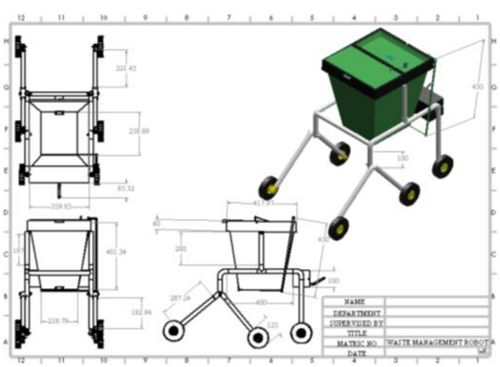

Figure 5: Orthographic view of the waste handling robotic system

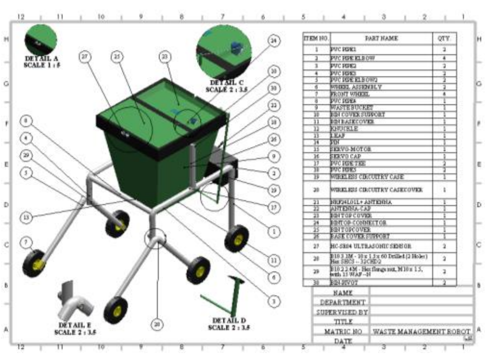

Figure 6: Exploded view of the waste-handling robotic system

Figure 7: The Model of the Waste Handling Robotic System

2.2 Electrical Model of the Waste Handling Robotic System

The electrical model of the waste handling robotic system is designed as;

(a) Supply Voltage (Vs), Vs = 12V supplies the system, whereas 5V powers the controllers.
(b) The Power (P) requirement for the system:

2.2.1 Power requirement

The power required by the system is obtained considering the consumption from the motor, microcontroller, servo, regulator and other electrical components of the system. In terms of current and voltage, power can be expressed a in (14),

$$P = V_s \times I \tag{14}$$

Where P = power in watts (W), V = voltage in volts (V), I = current in amperes (A),

$$P_{motors} = 6 \times (12 \times 1A) = 72\text{W}$$
$$P_{microcontroller} = 5V \times 0.5A = 2.5\ W$$
$$P_{requlator} = 4V \times 0.2A = 0.8W$$
$$P_{servo} = 12\text{V} \times 0.5\text{A} = 6\text{W}$$
$$P_{ultrasonic} = 5V \times 0.015\ A = 0.075\text{W}$$
$$P_{IR\ proximity} = 5v \times 0.020A = 0.1\ W$$

$$P_{total} = P_{motors} + P_{microcontroller} + P_{regulator} + P_{servo} + P_{ultrasonic} + P_{IR\ proximity} \tag{15}$$

$$P_{Total} = 72 + 2.5 + 0.8 + 6 + 0.075 + 0.1 = 81.475W$$

2.2.2 Motor efficiency

The motor efficiency ($\boldsymbol{\eta}$) is computed using (16)

$$Efficiency = \frac{Mechanical\ Output\ power}{Electrical\ input\ power} \times 100\% \tag{16}$$

$$= \frac{51.73}{72} \times 100\% = 71.84\%$$

In Figure 8, ultrasonic sensor 1 senses an obstacle presumed to be a waste within the range of 40 cm; once the microcontroller receives this, it triggers the servo motor to rotate at 45 degrees for 3 seconds. This activity is going to be continuous until the ultrasonic sensor used for level monitoring of the waste container senses a fill of more than 9cm portion of the entire 10 cm of the waste container; the microcontroller then uses this data to stop the servo motor from opening until the waste disposal. The design did not consider classifying the acceptable waste; any waste within the hospital was accepted for disposal.

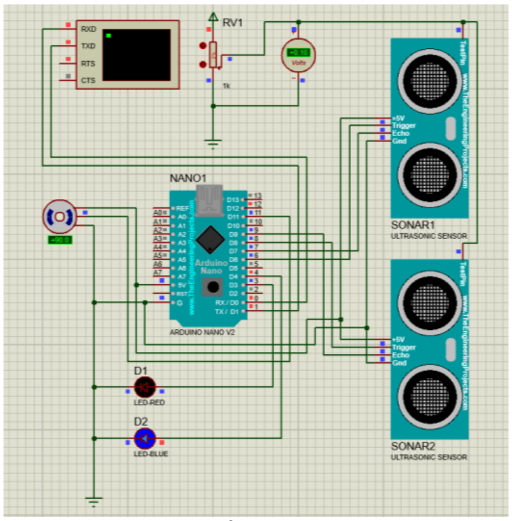

Figure 8: Electrical circuit of the waste handling robotic system

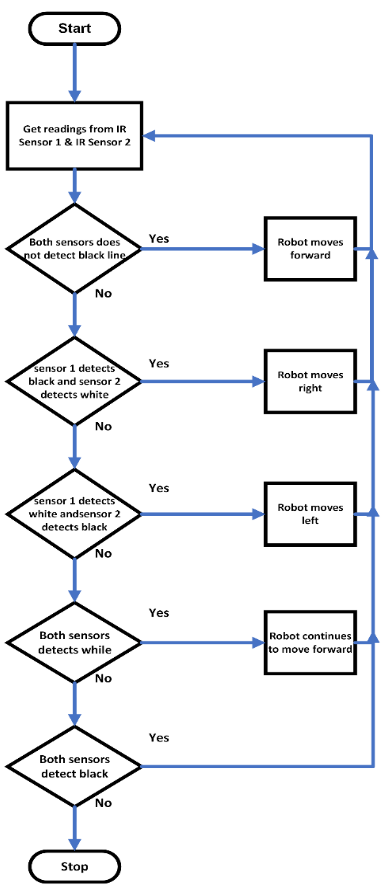

Figure 9: Flowchart for the autonomous movement of the waste handling robotic system

The two LEDs embedded with it provide a real-time notification system to notify the surroundings or users about the status of the waste container. When still in operation, the blue LED will be on at intervals; when the servo motor is locked, the red LED comes on and remains until the waste container is disposed of its contents.

Figure 9 is a flowchart that details the steps undergone by the autonomous navigation system to carry out its locomotion. The operation kick-starts by getting readings from the IR sensors which are transferred to the motor driver and then in turn powers up the DC gear motors of the robot to navigate within the structured system of the hospital.

4. Result, Discussions, and Performance Evaluation

The performance test for the robot was carried out for the mechanical and electrical systems:

The computer-aided designs created from the SolidWorks software, as in Figures 2, 3, 4, 5, 6, and 7, were considered for the prototype fabrication in Figure 10, and all the dimensions used were implemented. The hardware implementation of the waste handling robotic system for hospital wards was carried out, and the results of the fabrication are presented in Figure 8, considering the kinematics model generated. Operations used to fabricate the prototype include marking out, cutting, drilling, and screwing.

The prototype of this design was fabricated using Polyvinyl Chloride (PVC) plastic pipes. They were cut into various dimensions and were assembled with the aid of different types of joints required to achieve the geometry needed for each joint. Polystyrene, a hard, stiff, and light synthetic resin, was used to fabricate the waste container and integrate it with the robot chassis. The developed robust mechanical mechanism could go around all the experimented hospital wards based on the control algorithms embedded in the microcontroller. Whenever the robot meets an obstacle, avoidance, with the help of the proximity sensor, detects and retrogrades its movement in another direction, and it will also climb the available rails. The movement considers the line followers concept, where the robot was designed to follow a dictated path for picking and dumping hospital waste. When the waste bin is filled up, the robot follows the return path to where the waste will be automatically emptied. Under the model, there is an overflow for waste discharge whenever the program commands demand at the dedicated dumping site.

Figure 10: Waste handling robotic system prototype model

The fabricated model operates at the speed of 0.13 seconds and the braking action is determined by the spot on the line follower model. The development of an autonomous waste handling robotic system was actualized by integrating advanced robotic technologies with efficient waste management strategies which ensure cleanliness, hygiene, and operational efficiency in hospital wards. The fabrication process was based on the design principles where compact, mobile robotic platform suitable for navigation in confined hospital ward spaces with the use lightweight and durable materials that ensure ease of movement and prolonged operational life; similarly there was an automation and sensing were integrate sensors such as IR, and ultrasonic sensors were deployed for precise navigation, obstacle detection, and waste level recognition through artificial intelligence (AI) and machine learning algorithms that enable autonomous decision-making, waste collection and path planning. This develop a user-friendly interface for monitoring and controlling the robot were subjected to rigorous testing to validate the robot's navigation and waste-handling capabilities,

This system was able to reduce human exposure to waste, improve waste segregation, and ensure efficient waste disposal in hospital environments.

The electrical design in Figure 11 was implemented and incorporated into the mechanical design in Figure 7; this brought about the prototype model in Figure 10. The results of the electrical implementation comprise some sets of values obtained using standard parameters of the two ultrasonic sensors and values obtained from the actual operation of the servo motor in response to the ultrasonic sensors. The values and the plots are shown in Table 1.

Table 1 presents the standard and experiment for the contactless waste collection of the two ultrasonic sensors and servo motors adopted for the waste handling robotic system for hospital wards.

Table 1: Standard and experiment waste collection operation values for the developed model

S/N	Sensor 1 (centimeters)	Sensor 2 (centimeters)	Action
1	35	10	Open lid (LED-Blue on)
2	32	9	Open lid (LED-Blue on)
3	37	8	Open lid (LED-Blue on)
4	29	7	Open lid (LED-Blue on)
5	25	6	Open lid (LED-Blue on)
6	27	5	Open lid (LED-Red on)

The experiment started from the container at 10 centimetres (cm), which is the original depth of the waste container. Then, wastes were thrown into with the first ultrasonic sensor at the outer part of the waste container sensing any obstacles assumed to be waste within the range of 40 cm and less, and the inner level monitoring ultrasonic sensor sensing to get when the level filled is more than 5 cm of the waste container. When the container filling is less than 5cm the notification LED will indicate blue but immediately it exceeds it, the LED indication will change to red.

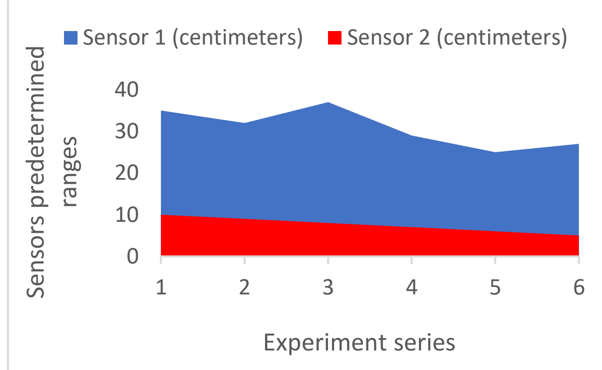

Figure 11: Standard and experiment waste collection of the robotic system

In Table 1 and Figure 11, the standard and experimental data about the operations of the ultrasonic sensors, servo motors, and LEDs employed for the implementation of the autonomous waste handling system were represented. These elements detail how the data and the plot are represented. Sensor 1 and Sensor 2 represent the externally positioned ultrasonic sensor facilitating contactless waste collection and the internally positioned ultrasonic sensor dedicated to waste level monitoring, respectively. Their details unveil the continuous functionality of the ultrasonic sensors integral to the autonomous waste handling mechanism. Six tests were conducted in this instance, as shown in the corresponding plot. The ultrasonic sensor utilized for waste collection operated within the 40cm range and below, while the sensor governing waste level monitoring scrutinized the 10cm threshold of the waste container.

Within the prototype demonstration, as catalogued in Table 1 corresponding with the graphical representation in Figure 11, during waste collection instances where the container's fill level remained below 5cm, the lid exhibited a persistent opening, accompanied by a blue LED illumination. Upon reaching the predetermined 5cm fill capacity for the waste container, the lid promptly closed, synchronously with activating a red LED to indicate the need for prompt waste disposal to continue operation.

Table 2 shows the experiment readings taken by the Infrared Proximity sensors. These readings are translated by the equipped controller for navigation and sent to the system motor driver to power the DC gear motors, providing mobility to the system.

Table 2: Experiment with autonomous navigation operation for the developed model

S/N	IR Sensor 1	IR Sensor 2	Action
1	White	White	Moves forward
2	White	Black	Turns right
3	Black	White	Turns left
4	Black	Black	Stops

The autonomous navigation of the robotised system is achieved with the flow chart developed in Figure 6, which resulted in Table 2 readings. It uses a designated controller out of the two controllers for the robotic system, two Infrared Proximity sensors, two motor drivers, and six hybridised DC gear motors with six wheels. These components operate in harmonious coordination to provide locomotion for the robotized system. The robot can temporarily halt waste collection while on its predetermined track, seamlessly resuming its journey afterwards. Autonomous navigation along the tracked path is achieved through the two infrared proximity sensors, pre-loaded with navigation code on the controller. As detailed in Table 2, the sensor readings are transmitted to the motor drivers, which subsequently power the DC gear motors to propel the system.

5. Conclusion

This study discussed the development of an autonomous robotic system for waste handling in hospital wards. This included the planning and design, in which models guided the process. The mechanical and electrical designs were carried out using the Solid Works and Proteus software. The simulation was also carried out using Solid Works software to test the robot comprehensively within a practical virtual hospital ward environment. The prototype was fabricated following the design. The two controllers were responsible for the autonomous functionality of the waste-handling robot. Controller 1 was responsible for controlling ultrasonic sensors and a servo motor integrated with the waste container to automate the waste collection process; simultaneously, the colour-coded LEDs were embedded in the system to provide real-time updates on the status of waste containers. Controller 2, on the other hand, managed the IR sensors and motor drivers to navigate a structured environment with track lines autonomously. The agility of the robot's mainframe facilitated obstacle traversal during motion. This research exemplified the application of robotics and smart technologies in hospital waste management, provided an innovative solution to the risk of contamination in the hospital, and enhanced the healthcare waste handling system.

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