ISSN 2278-3091
Volume 8, No.3, May - June 2019
International Journal of Advanced Trends in Computer Science and Engineering
Available Online at http://www.warse.org/IJATCSE/static/pdf/file/ijatcse35832019.pdf
https://doi.org/10.30534/ijatcse/2019/35832019

Design of Multi-Purpose Heavy-duty Scanning Robot with Spray Mechanism

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ABSTRACT

A mini multi-purpose heavy-duty scanner robot was designed and built for the purpose of scanning open fields that can be used in different applications such as metal detection, mine detection and similar sensing activities. It can also be used in other agricultural purposes such as seed planting in small farms, fertilizer and pesticides spray and by adding some electronic mechanisms, it can also be used in fruit harvesting and the like. The scanner robot uses a DFRobot Mega 2560 microcontroller that can operate in an autonomous mode and in manual mode using Zigbee as the communications interface between the controller and the robot. This robot also has a GPS tracking system and obstacle avoidance features that makes it very efficient in its intended activity. Experiment results show the capabilities and effectiveness of the robot functionalities. This robot design, when upgraded to full size version, can be used as a model in remote activities in the field of agriculture, military and other commercial purposes.

Keywords: microcontroller, zigbee, agricultural automation, field scanning

1. INTRODUCTION

In this robotics, information and automation era, robots are designed to perform tasks that are very difficult or harmful to humans [1] and [2]. Scanning robots are often used for military, rescue, medical practices [3] and agricultural activities [4], [5],[6] and [7].

These robots serve their purpose by either deploying them autonomously [8] or by controlling them remotely from a certain distance using advanced wireless communications systems [9], [10] and [11]. Most of the advanced robot systems being developed nowadays use advance and intelligent control systems that can intuitively perform critical decision making abilities like the robot shown in [12].

The purpose of this research is to present working design of multi-purpose heavy-duty robot that can be used in a wide range of applications. This robot has a sensing mechanism, a spray mechanism and has the ability to scan small open fields. This robot will be ideal in assisting humans for military operations, mining operations and other agricultural activities. It can run on autonomous mode and in manual mode using an android-based application and Zigbee as its wireless controller.

2. PROBLEM STATEMENT

The objective of this research is to build a heavy-duty robot that can fully scan a small open field with the capabilities of detecting or sensing different objects. A dispenser mechanism will also be added to the robot that will serve as a marker or sprayer upon detection of an object set by the sensors. Lastly, a navigation system that can switch from manual mode and autonomous mode using an android-based application. Table 1 below summarizes the features of the multi-purpose scanning robot.

Table 1: Features of the Multi-purpose Scanning Robot

Feature	Details
Sensing	Can be used for Mining, Military and Agricultural Activities
Spray Mechanism	Can serve as paint marker, or dispenser for water, fertilizers or pesticides when used in agriculture
navigation	Autonomous mode with digital compass
	Manual mode with android-based joystick
communications	Zigbee wireless controller, can be replaced with wifi of LTE

3. ROBOT DESIGN AND FEATURES

The overall design, capabilities and communications systems used by the robot is shown in figure 1 below. The robot was intended to perform open field scanning that can be used in different purposes such as metal detection, mine sensing, seed planting and other similar purposes. Initially, a metal detector was used to demonstrate the capabilities of the robot.

Figure 1 the features of the proposed multi-purpose scanning robot. The robot is intended to scan small open fields autonomously using a GPS tracking system and Arduino clone microcontroller system. Infrared sensors are used by the robot to avoid obstacles during the scanning activity. Initially, a metal detector was used to trigger response on the robot to a certain stimulus. This sensor can be replaced in the future depending on the intended activity of the robot. The robot can also be controlled manually using a Xbee wireless controller via an android application. It also has a spray mechanism that can be used in spot painting, fertilizer or pesticide sprayer or when replaced by a cutter, can be used as fruit harvester. The specific design on each part of the robot is discussed in this paper accordingly.

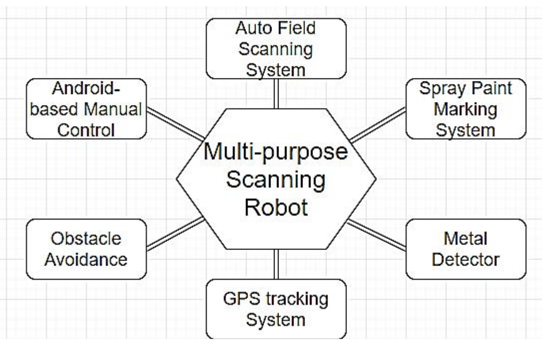
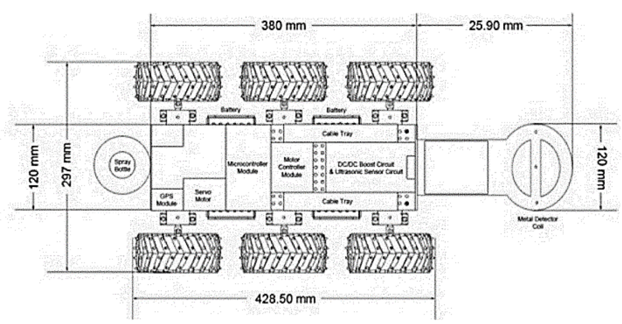


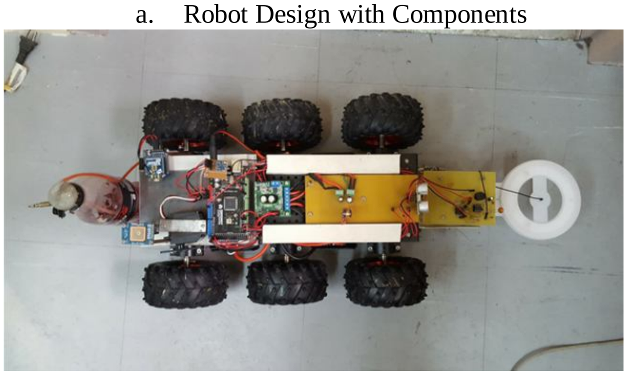
Figure 1: Features of Scanning Robot

3.1 Robot chassis

A six-wheeled heavy-duty robot was designed and built that has the capability of scanning open fields for metals and other similar materials. This robot also has GPS system, a spray paint mechanism and an android-based Zigbee wireless controller. The design layout and actual picture of the mobile robot is shown in figure 2



a. Robot Design with Components



b. Actual Robot Prototype

Figure 2: Robot Design and Prototype

In order for the robot to move, the direction of rotation of wheels are configured in such a way as to enable the robot to move similar to a tank. If the robot needs to move forward direction or reverse direction, all wheels must move in the same direction. If the robot needs to make a turn or rotate, the wheels on the rights side must rotate in the reverse direction with respect to the wheels on the left side. Figure 3 shows how the robot wheels are controlled to make a left turn or a right turn. The motors that control the wheels are connected to the DRobot Mega microcontroller which serves as the main control element of the robot.

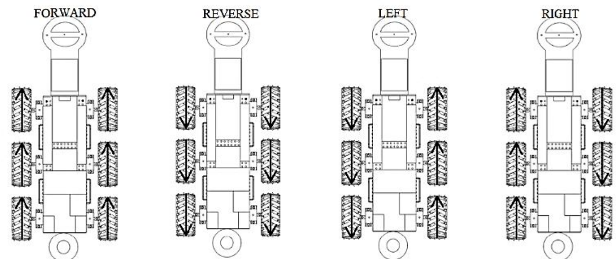


Figure 3: Wheel Movements in 4 Directions

3.2 Spray Mechanism Block

The proposed robot design has a spray mechanism unit installed. This spray unit can be used to mark locations with paints where metals or other objects were found. When used in agriculture, this can be used to spray fertilizers, spray pesticides or dispense seeds during planting. The spray mechanism has 3 main parts, the spray bottle, spray nozzle and the servo motor.

In the spray bottle design, a hole was first punched at the upper part of the bottle and at the center of the cap. A presta valve was attached to the first hole and a modified F Type Female to Female Coaxial Barrel Coupler Adapter connector, commonly used for television antennas, was attached to the hole of the bottle cap. A tube was then inserted through the modified cap and through the bottle just enough to reach the bottom. To prevent liquids from leaking, commercial grade sealant was used. The sealant also secured the cap's position around the tube. The sprayer bottle was mounted at the back of the robot to prevent its contents spilling on the electrical components of the robot.

Figure 4 below shows how the spray mechanism was mounted on the robot chassis.

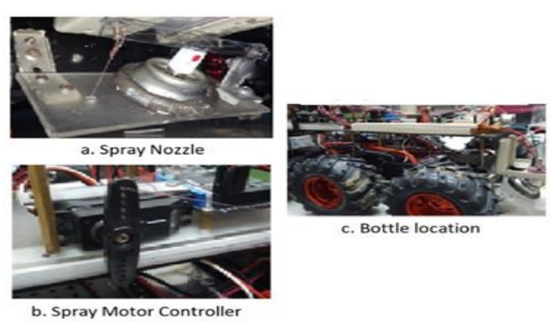


Figure 4: Spray Mechanism

Figure 4a shows the spray nozzle mounted at the back of the robot. The spray nozzle was triggered by a stepper motor (Figure 4b) being controlled by the microcontroller. The stepper motor was tied with the level that will press the spray nozzle when triggered. Figure 4c shows the location of the bottle container at the back of the robot. The position of the container prevents the liquids from spilling into the electronics parts of the robot.

3.3 Global Positioning System

A GPS module was used to implement the autonomous navigation of the robot. The current position of the robot can be monitored through the data from the GPS. This information helps the robot decide on the direction of movement of the multi-purpose robot.

A digital compass was also used for positioning the robot to its designated location during the scanning procedures on the mini open field area. During automatic scanning, while the GPS acts as waypoints for the robot, the digital compass serves as a guide in making sure that the robot is moving along the latitudinal axis by following the North on the digital compass. Aside from the scanning movement the robot also relies on the compass for positioning itself in facing either North, East, South, or West.

3.4 Metal Detector

For demonstration purposes, a metal detector was mounted in front of the robot. This metal detector is used to analyze the capabilities of the robot in scanning metals during the open field scanning procedures. Depending on future applications, the metal detection can be replaced by mine sensors, improvised explosive device detectors, or a camera to locate fruits, vegetables or other similar sensing devices.

3.5 Obstacle Avoidance

The proposed heavy-duty multi-purpose robot has the ability to avoid obstacles during the scanning procedures. An ultrasonic sensor was used to detect objects along its path. Once objects are detected, a new path plan will be used in coordination with the digital compass. The new path for the robot will be decided by the microcontroller.

3.6 Android-based Manual Robot Control

The proposed robot can be controlled manually using an android-based application that communicates directly with the microcontroller via Zigbee wireless communications modules. The communications systems structure for manual control is shown in figure 5 below.

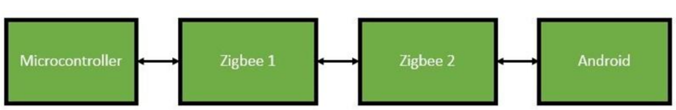


Figure 5: Communications Block Diagram between Microcontroller and Android-based Application

The android based application can detect the current location of the robot and can control the navigation of the robot by controlling its direction. The program can also modify the scanning routine into manual mode and autonomous mode. Figure 6 shows the user interface of the android-based controller.

Figure 6: User Interface of the Android-based Robot Controller

While on the manual mode, the android-based application can be used as a joystick in controlling the speed and direction of the proposed robot. As seen in the interface, the user can direct the robot to move forward or backward (shown on the left side) and left or right (shown at the right side of the user interface).

3.6 Navigation

The top-level code or Level 1 starts up by setting up of the necessary parameters and modules such as GPS, ultrasonic, and Compass. It's also the one responsible for reading and storing the sensor readings. Those sensor readings are then passed on depending on which mode the robot is using. There are two modes: Automatic and Manual. Each mode is activated by a mode flag. Figure 7 below shows the program flow chart for the Level 1 navigation start-up.

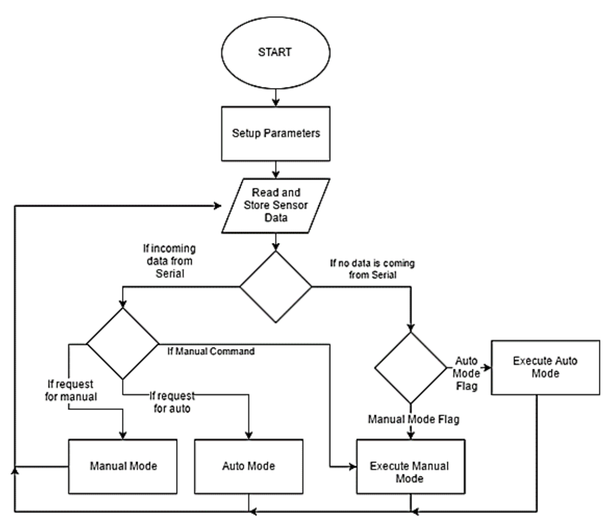


Figure 7: Level 1 Navigation Flowchart

The 2nd Level the Manual Mode Code reads the commands sent through the Zigbee Serial. There two types of command that the Manual Mode processes. The first one is the Speed mode adjust, there are five speed variables: Speed1 and Speed2 is the speed used by the robot during automatic scanning and Speed3 is the speed used on Manual Control. SpeedTurn1 is the turn speed used by the robot on auto mode while SpeedTurn2 is the turn speed used when on Manual. All those Speed variables can be configured to 3 settings: Minimum Speed, Midpoint Speed, and Max Speed. Figure 8 below shows the system flow chart for the manual mode navigation.

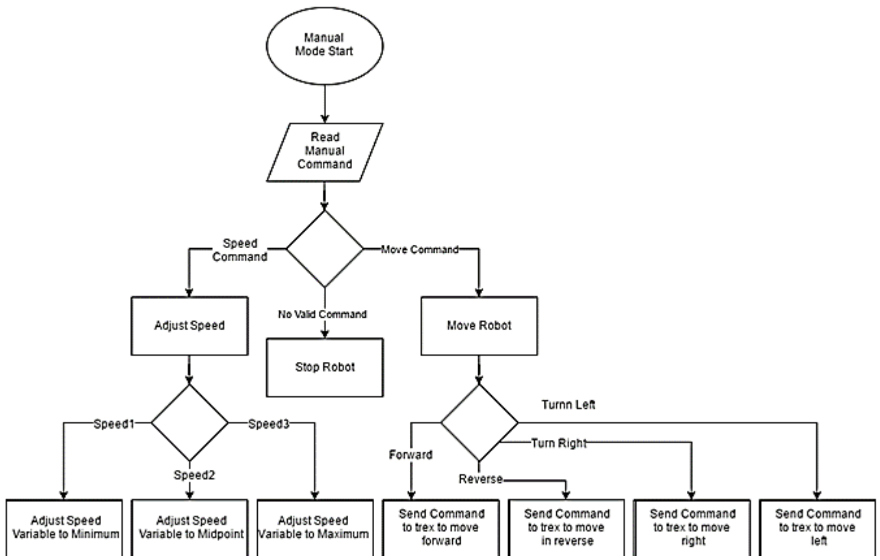


Figure 8: Program Flow Chart for Manual Navigation

For autonomous navigation, scanning algorithm was designed and is responsible for making decisions when the robot is set to autonomous scan. At the start, the algorithm generates waypoints depending on the area or size on the open field. Each waypoint is distanced by 1 meter or 5 decimal increments which means that increasing the scanning area size would mean increasing the number of waypoints. The scanning starts by making sure that the robot is facing the north. The north is configured to be from 80-100 degrees, the 20-degree allowance is to allow the robot to move forward smoothly without having the need to correct itself more often.

During the scanning period, the sensors are activated to detect objects depending on the application of the robot. Once the object has been detected, the robot will stop and put a marker by triggering the spray mechanism. When the edge waypoint has been reached by the robot, depending on its current movement it would turn right, move for a short while before proceeding to scan the opposite direction. This would enable the robot to scan the area back and forth and increase the chances of detecting an object. After the scanning routine, the robot will automatically switch to manual mode. Figure 9 below shows the flow chart for autonomous scanning navigation.

Depending on the position of the robot on the map, four scanning algorithms can be used by the robot. These algorithms vary in the direction of scanning, for example if the robot is at the lower left of the map to be scanned then Scan A should be chosen as it scans northward moving a little bit to the east then moving southward, repeating this cycle until the robot reaches the corner of the area to be scanned. The four scanning algorithms are shown in figure 10 below.

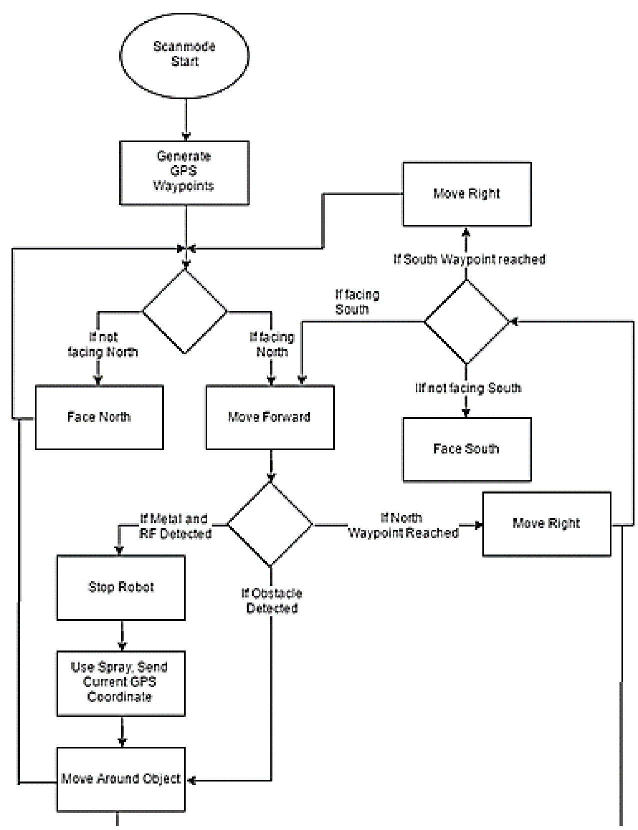


Figure 9: Autonomous scanning Program Flow Chart

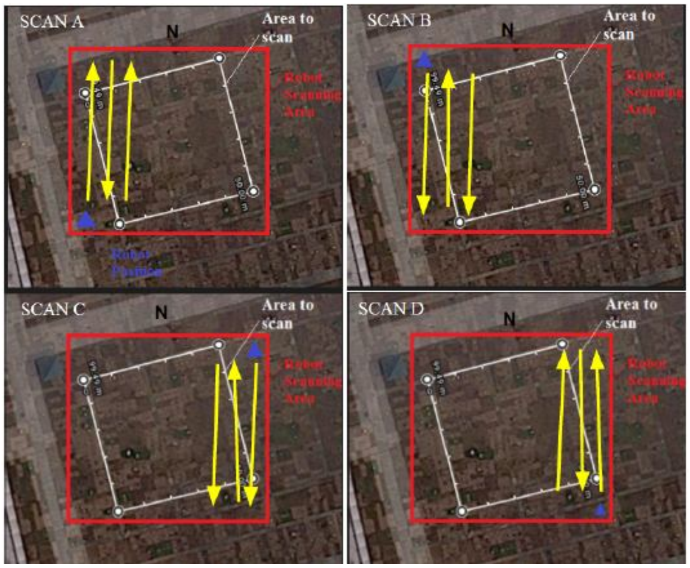


Figure 10: Scanning Algorithm Procedures

4. RESULTS AND DISCUSSIONS

The performance of the proposed multi-purpose robot was analyzed using multiple experimental runs. One important parameter observed is the range or distance between the user and the robot during the manual mode. The communications between the robot and the user is via Zigbee wireless modules. Table 2 below shows the maximum range where full wireless connectivity was observed. The maximum range varied depending on the location of scanning routines inside De La Salle University campus and one off-campus site.

Table 2: Maximum Connectivity Range between the user and the Multi-purpose Robot

Location	Range (meters)
STRC	50
Henry Sy Building	70
Memorial Cemetery	100
Henry Sy (LS to Velasco 5th Floor)	62.5

The speed of the robot also depends on the flooring of the open field area. Comparison of completion times for 40m scan and 50m run were shown in table 3 and table 4.

Table 3: Robot Speed on Concrete Flooring

Trial for 40m scan	Lapsed time at minimum speed	Lapsed time at maximum speed
1	79s	41s
2	76s	42s
3	74s	40s
4	78s	43s
5	75s	46s
average	**76.4s**	**42.4s**

Table 4: Robot Speed on Grass Flooring

Trial for 50m scan	Lapsed time at minimum speed	Lapsed time at maximum speed
1	115s	54s
2	117s	58s
3	116s	60s
4	117s	59s
5	115s	61s
average	**116s**	**58.4s**

The completion times for scanning different sizes of open fields were also recorded during actual experiments. The results are recorded in table 5 below.

Table 5: Autonomous Scanning Completion time

Open Field Dimensions (meters)	Completion time (minutes)
15 x 15	14.313
20 x 20	26.435
25 x 25	38.648

The time spent for a full spray cycle is 1 second. In order to prevent wearing out the nylon string attached to the sprayer mechanism, the sprayer is activated manually. In testing the sprayer, the lever was held down until the sprayer fails to function as intended, the time it lasted is recorded. The sprayer bottle is filled with liquid up to the bottom of the presta valve then air was pumped to build pressure using a handheld air pump. The pressure buildup is just enough for the spray to function well. With this configuration, the pressure lasted for 70.12 seconds, the water level decreased to the top part of the label of the bottle, this was recorded as the first test. The pressure is refilled for the second test which lasted for 184.72 seconds. For this test, the level of the water reached the bottom of the label. The pressure is refilled for the third test. The water level reached approximately half of the bottle, the time recorded was 164.09 seconds. The last test lasted for 234.05 seconds, here the bottle is almost empty already. Based on the results, we can say that the optimal ratio of air and water should be at least 1:1 especially when using handheld air pump in order to get at least 190 pumps before all the pressure is released from the bottle. The pressure that the bottle can hold was tested using a lever type air pump. This type of pump has a gauge that can monitor the pressure of the air inside the bottle. From our observation, the modified bottle can hold up until 30 psi before failing.

5. CONCLUSION

A multi-purpose scanning robot was designed and presented in this research. This robot can be used in different applications such as metal detection, mine sweeping and even in basic agricultural activities for small farms. The metal detector can be replaced by any other sensor that will serve useful depending on the task of the robot.

A spray mechanism is also presented that can act as a marker for metal and mine scanning or as a dispenser for water, fertilizers and pesticides when used in farming.
The heavy-duty robot has a capability to navigate in manual mode and autonomous mode. The autonomous mode scanning algorithm is assisted by a digital compass that will show the correct position of the robot in real time. The manual mode uses a pair of Zigbee wireless controllers that can range as far as 200m between the robot and the user. Finally, an android-based application was designed to fully control the heavy-duty robot whether it is set to autonomous mode or in manual mode. This android-based application can serve as a joystick for manual navigation of the robot.

The design and features of the proposed multi-purpose heavy-duty scanning robot may serve as a basic design that can be used for different important applications in automation industry, military and agriculture.

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