RoboGardner: A Low-Cost System with Automatic Plant Identification Using Markers

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Abstract. In this modern era, automation is inevitable. With the fast paced and busy lifestyles, there is no time even for day to day household activities. There is a need of automation in each and every small activity performed by humans. In this paper we present an autonomous system that caters to the need of automation in gardening by providing a low cost, portable and efficient system for watering indoor potted plants at home and offices. The system comprises of a mobile ROBO equipped with a camera for auto-location and identification of the plants and a sensing circuitry for analyzing the watering needs. The RoboGardner is designed to ease out human workload and performs all the functions without any human intervention. It even provides an automatic feedback mechanism to inform the user about its daily performance. The water level of the RoboGardner's on-board reservoir is also scrutinized automatically by it and the user is alarmed to refill when required. The paper outlines the complete architecture, functional modules and detailed implementation supported with the design circuits. It concludes with the system performance of the RoboGardner along with graphical analysis.

Keywords: Marker Identification, Zigbee technology, Mobile Robot, Obstacle Avoidance, Temperature Humidity Sensor.

1 Introduction

The presence of plants in our life is indispensible. As we know, plants add beauty to the environment, soothe the eyes, provide us oxygen and relieve stress preventing the rapidly growing diseases. Moreover, studies have consistently shown that by simply looking at environments with greenery like flowers and plants as compared to artificially created places lacking nature like rooms and buildings is significantly more effective in promoting recovery from stress [1] [2]. Research also suggests that by viewing places with plants or other nature for a few minutes can promote measurable restoration even in hospital patients who are acutely stressed.

Studies in environmental psychology also depict that the physical benefits of contact with nature and greenery are vanishing in towns and cities due to the disengagement from the natural environment because of the fast paced and modern

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lifestyle [3] [4]. It is claimed that the modern society and way of living especially in urban areas has insulated people from outdoor environment and regular contact with nature [3] [5].

In spite of the innumerable benefits of these plants people are reluctant to either keep these beautiful possessions or are not able to take care of them properly if planted. Unfortunately, the plants die due to insufficient water and care provided to them by their owners. Even this is the result of the busy routine life in today's modern society where time and user ease play an extremely important role in how one adopts their lifestyle.

In this paper we provide automation in the field of plant watering, so that these beautiful possessions can be taken care of automatically without being a burden on their owners [6]. The paper is an improvisation to the earlier system introduced [7], "Plant Watering Autonomous Mobile Robot", the system discussed in the paper had a lot of design constraints and assumptions to reduce complexity of the design. It followed a predefined path indicated by a black line using LDR sensors, the plants were identified using RFID (Radio Frequency Identification) Technology, and each plant was equipped with an RFID Tag. Although the system was scalable, the problem with it was that with each increasing plant the cost of the system increased as it had to be equipped with a tag. Moreover, the range of the RFID module was just 4-inches, beyond that the plant was not recognized, this made the system prone to missing the plants and thus inefficient. Since it was a line follower robot, a 5 cm thick black path had to be laid around the plants which spoiled the beauty of the environment and restricted the movement. The system lacked the ability to act intelligently in real time situations when it encountered an obstacle on its way and stopped without any movement further waiting for the user to clear the path.

The current system overcomes all the disadvantages of the previous design and provides a reliable, efficient, cost-effective and a completely autonomous mobile robot that is capable of taking care of the watering needs of the potted plants without creating any disturbance and inconvenience to the users around the area.

The system is now capable of avoiding real time obstacles autonomously that might come on its way while watering the potted plants. It also checks the water level and sends feedback to the user depicting the watering report. This saves a lot of time and makes the system more reliable and self sustainable. The system now uses a camera module for path planning and mobilization to the plants is achieved using the visual marker tags being identified which act as guidelines for the RoboGardner.

Section 2 discusses the related literature survey with a description of the existing plant watering systems. Section 3 gives an overview of the entire system with the architecture and system behavior. Further section 4 depicts the detailed implementation of the system with different modules for plant identification, watering operation, obstacle avoidance, and water level checker and feedback mechanism of the RoboGardner. The section also highlights the main features with their detailed description that distinguish our approach from already existing ones. Section 5 discusses the results of the proposed system supported with suitable statistics. The paper concludes with the system evaluation which presents the efficiency and reliability of the system and conclusion in Section 7.

2 Related Work

This section reviews the already existing systems designed for watering the plants. The problems faced by each of the portable system is object identification, path planning and obstacle avoidance.

A system designed by Sikorski, as a part of Intel Research performs the exactly same functionality [8]. The system had certain limitations which the RoboGardner tries to overcome. The system used high cost laser range finders to locate pot plants in the lab environment, which failed to work sometimes in the Lab as it contained glass surfaces where the laser finders bounced off. The system used high end hardware which made it very costly. Moreover, apart from that, the system also uses wireless network of Intel Research Lab. Lastly, the potted plants to be watered by the system were considered to be circles when detected by the range finder, with an assumption that only circular base pots were used, but in real life scenario the shape of the pots can vary.

Angelopoulos *et al.* presented a similar system for watering garden plants, the system comprises of TeleosB WSN motes attached to each plant, and each plant is also equipped with water valves that are triggered when the soil moisture of the corresponding plant goes down beyond a certain level [9]. The system performs the same action like the RoboGardner but is not portable, the valves are permanently attached to the plants and create disturbance to the user. Moreover, the valves laid all over spoil the natural beauty of the garden and give it an artificial look.

Zhou *et al.* proposed an approach for watering fields, a field irrigation system using the Zigbee Technology, the system used a star network topology and sensors were placed in different areas of the field along with Xbee devices [10]. The sensors continuously communicated with the base station Xbee attached to the portable controller, actuation is achieved by the valves and water pump attached at the in-field nodes. The system proposed is stagnant and applicable for field irrigation and cannot be used indoors.

The system designed by Kawakami *et al.* is an interactive plant pet where the plants are equipped with the sensors and wheels to achieve locomotion [11]. The plants remind their owners to water them by performing predefined actions. Although the system is scalable but it is not cost effective as each plant has to be placed on a separate mobile robot equipped with expensive hardware, increasing the cost of building the system to a great extent. Moreover, although these plants are equipped with ultrasonic sensors to prevent them from colliding with each other and the objects in the surroundings, if these moving plants are very large in number, moving here there, this might even disturb the user and might come on the way. Lastly, the system doesn't reduce the work load of the users; rather it is just like an alarm to remind them to take of their possessions.

The system proposed by Correll *et al.* is yet another robot gardener system which comprises of a mobile robot equipped with camera and water supply [12]. It is used to take care of potted cherry tomato plants. Each plant has an embedded Linux system to monitor the humidity and fruit ripening status along with watering operation. The whole system is centrally controlled by a central coordinator notebook which allocates tasks to all other components by receiving signal messages from the plants for water and harvesting and accordingly directs the mobile robot.

3 System Model and Architecture

This section states the system model of the system along with architecture and design details. Fig. 1 outlines the System Behavior of RoboGardner. The robot moves independently and locates the plants, waters them and moves to the next plant on its way. On encountering obstacles, it automatically takes up an alternative path to avoid any hindrance in progress.

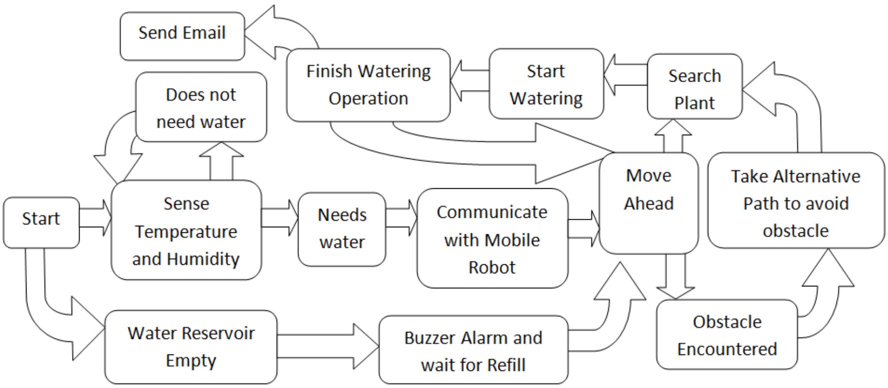

Fig. 1. System Behavior

The design of the RoboGardner is implemented using the Arduino Simulator and MATLAB Simulink [13], besides it requires the interfacing of the hardware components described in this section to get the desired functionality [14] [15]. Fig. 2 presents the system architecture of the Autonomous System.

A. Xbee Series 2

XBee is a wireless communication module that Digi built to the 802.15.4/Zigbee standard. The main feature of the Zigbee is that it uses free bandwidth at 2.4GHz for wireless communication [16] . It is used to transmit the temperature and humidity of the plant to the mobile vehicle wirelessly. Since we are using a Xbee Series 2, the Outdoor RF line-of-sight range is 120 m and the Indoor/Urban range is 40 m which is quite sufficient for the system developed. The Xbee are configured to communicate with each other using XCTU software by setting the PAN ID and address.

B. Arduino Duemilanove

The Arduino Duemilanove controller which has an Atmega AT168 microcontroller that has a pre-installed boot loader is used, so one can download code to the board using an A-B USB cable. The USB cable is also used for serial communication while communicating with the image processing MATLAB module.

C. Temperature and Humidity Sensor Nodes

The system uses the temperature and humidity sensor module, the module comprises of the HSM-20g sensor attached with capacitors and resistors [16]. The input and output voltage is D.C. 5.0V ± 0.2V and D.C. 1.0V-3.0V respectively which is provided easily by the microcontroller.

D. Ultrasonic Distance Sensor

The ultrasonic distance sensor provides precise distance measurements from 2 cm to 3 m. The sensor works by transmitting an ultrasonic burst and provides an output pulse corresponding to the time required for the burst to return to the sensor. By measuring the echo width, the distance to target is calculated. In this scenario, the ultrasonic sensor is used for obstacle avoidance as well as automatic water level checker.

E. Water Pump and Relay

Keeping in mind the portability and to minimize the weight and bulkiness of the robotic system, a DC 12V water pump is used in the design of RoboGardner, and the system is plugged to a 12V DC adaptor. The water pump is triggered using a 6V relay which acts like a switch but instead of physically touching it to switch it on/off we supply voltage to toggle it [17].

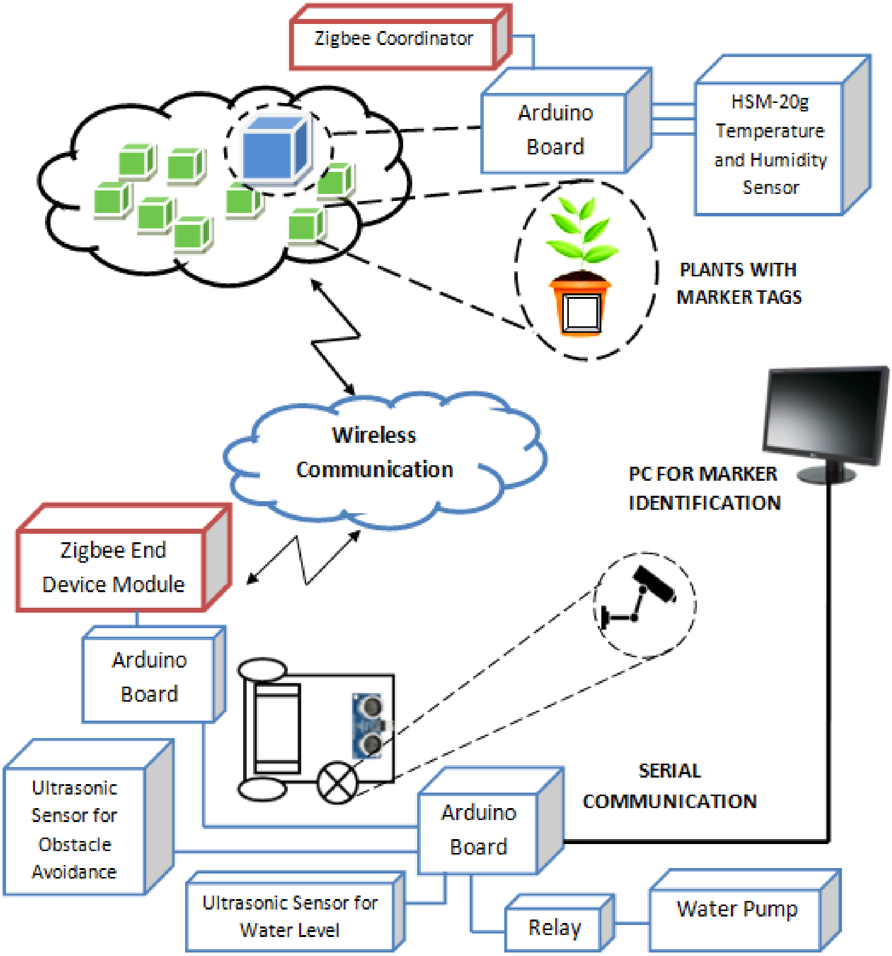

Fig. 2. RoboGardner System Architecture

4 System Implementation

4.1 Working Environment

The region to be watered by the RoboGardner is a square/rectangular field i.e. any compound area at home or any office balcony, entrance or gallery where potted plants are placed along the sides of the area. The camera placed on the RoboGardner can also be mounted on a half rotation servo motor so that it can identify and water plants placed anywhere in the environment rather than just along the sides.

The path to be followed by the robot needs to have some friction and no bumps. There should be direct view of the plant from the mobile robot's camera i.e. there should be nothing between the line of sight of the camera and the plant marker so that it can detect the marker properly.

The system can carry only limited amount of water in one go since the water carrying capacity is 1 liters to start with the demonstration due to the weight the DC motors can drive. This also restricts the number of pots and the size of potted plant to be watered. Fig. 3 depicts the improvised system layout and the working environment of the autonomous system.

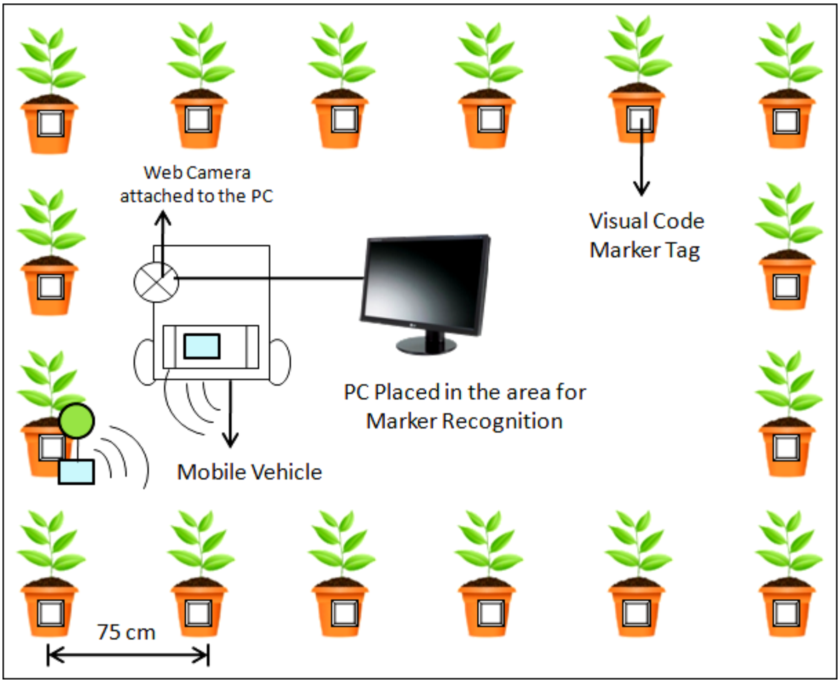

Fig. 3. Improvised System Layout of RoboGardner

The temperature and humidity sensor module is to be placed on the potted plant so that desired values can be obtained for proper functioning of the system. Since the area to be watered is a room, balcony or office gallery, the temperature and humidity of the area is assumed to be the same and thus only one temperature humidity sensor is placed along with Zigbee Coordinator to monitor the watering requirements of the plants. In case of a large area, or indoor/outdoor differences we can use more than one sensor to monitor the area.

The obstacle detected by ultrasonic sensor is taken to be of fixed length and width and accordingly, the timing for turns have been given for alternative path to be followed.

The height of the potted plant is taken as per the height of the mobile robot so that water can be dispensed easily from the on-board water tank to the plant using the water pipe.

4.2 Functional Modules of the System

The RoboGardner performs different functionalities to complete the watering process i.e. locating the plants, finding its way, plant identification, checking the water level, sending alerts to the system. This section gives a brief description of each of the five modules into which the RoboGardner can be broadly classified.

A. Plant Location and Identification
For plant identification visual code marker tags are placed at each potted plant. While moving, the Autonomous robot detects the marker tags placed on the plant pots via the attached web camera unlike in [18] where ultrasonic sensor is used. The idea of these visual code marker tags has been taken from augmented reality applications but a basic image processing algorithm [19] has been used instead of complex AR identification as the need here is just single tag identification. The tag being used in the design is shown in Fig. 4. Fig. 5 shows the snapshots of the image processing phases. The marker identification algorithm involves three main phases:

(I). Pre-processing:
The pre-processing step produces a binary image from the input RGB image captured by the web camera attached at the mobile vehicle that has an accurate representation of the visual code marker in the image. In this way we do not lose any relevant information in the process and it is a simple, computationally efficient algorithm to read the embedded data bits of the captured image [20].

(II). Shape Detection:
Once the image is preprocessed, and a binary image is obtained, we use shape detection algorithm to detect the corner stone circles.

(III). Visual Marker Detection:
After detecting the corner stones from the pre processed image, the centroid of each of the region is calculated and the distance between them is measured so that the orientation can be decided. The orientation, number of pixels and the area of the identified regions in the marker tag are the parameters to identify the tag.

B. Watering Operation
As soon as the robot reaches a plant and the visual marker tag is identified the robot stops and dispenses the water to the plant via the attached water pump and the on-board water reservoir.

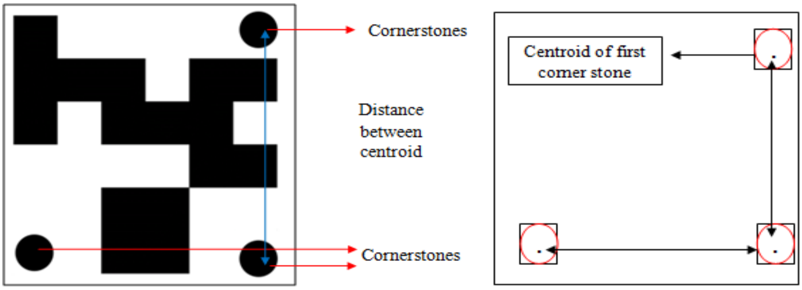

Fig. 4. Visual Code Marker Tag

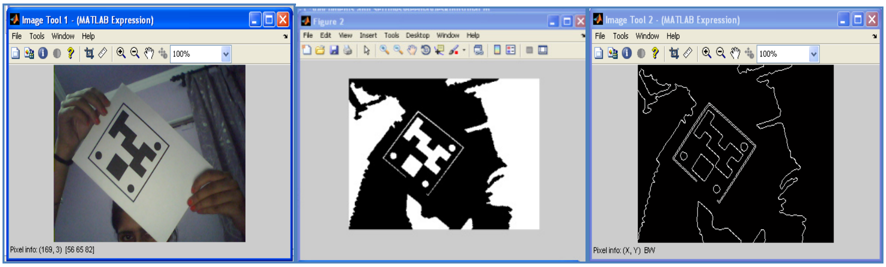

Fig. 5. **(a)** Captured Image **(b)** Binary Image after Thresholding **(c)** Edge Detection

C. Obstacle Avoidance

Since the RoboGardner has to move autonomously, its movement might get hindered due to obstacles in its path. The obstacles might come on the way real time, the mobile vehicle has to be programmed for handling the obstacles that might come accidently. For this, we need obstacle avoidance which enables the robot to take an alternative path to avoid the hindrance, so that its movement is not hampered.

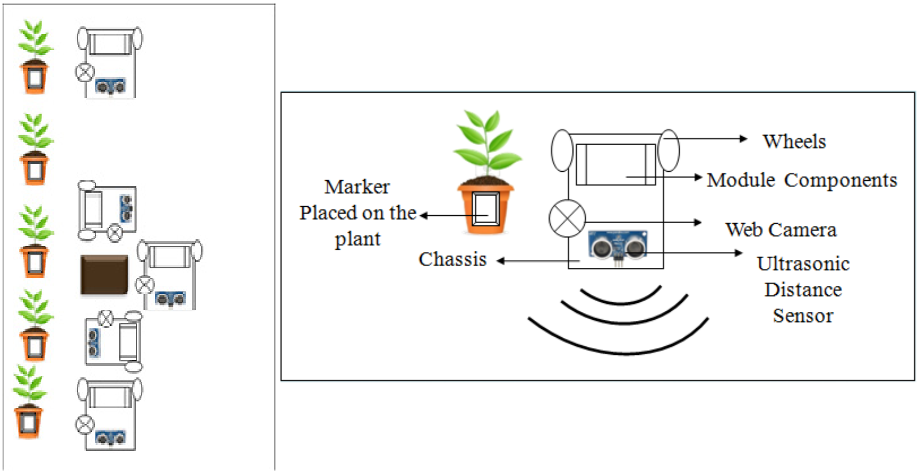

Fig. 6. Obstacle avoidance Mechanism

The ultrasonic distance sensor is used for this purpose of obstacle avoidance as discussed by Borenstein and Koren in [21]. It is placed in the front of the mobile robot, so that as it moves forward, the sensor keeps on detecting the obstacles which helps the robot to take an alternative path to avoid the same.

The Fig. 6 shows the approach taken by the ROBO to avoid obstacles coming in its way. The ROBO senses the obstacle from a distance of 50 m and starts diverting its path by taking a right turn for a predefined distance and then covering the same distance back to reach its original path to continue the watering operation.

D. Automatic Feedback Mechanism

The RoboGardner also has an automatic feedback mechanism. As soon as it completes one cycle of its watering operation, it dynamically generates a feedback report comprising of a text file and an image. The text file comprises of the date and time when the watering operation was completed and the number of plants watered in the cycle. The image depicts the last position of the robot. Fig. 7 and Fig. 8(a) shows the snapshot of the Automatic Email Mechanism.

Fig. 7. Automatic Email Sent by the System

Fig. 8. (a) Email Details **(b)** Plant Watering Report

This report is automatically mailed to the user so that the user gets to know the complete watering scenario by just seeing the report at the end of the day. The text file shown in Fig. 8(b) is dynamically created each time the robot completes watering a set of plants, further, the report is attached and mailed to the user automatically by the RoboGardner. This automatic mailing action is performed using the MATLAB interface which configures the Gmail account of the user where the email address and the password are defined in the code. As the system keeps on sending the mail updates, it simultaneously creates an excel file using MATLAB and Microsoft Excel interfacing, and a graph depicting the performance of the RoboGardner after each cycle, the graph after 10 cycles is simultaneously sent to the system developer for performance evaluation.

E. Automatic Water Level Checker
As the robot autonomously moves around to locate and water plants, it is equipped with a sensor to detect the water level of the on-board reservoir. Since the water carrying capacity of the robot is limited, the water in the reservoir has to be refilled by the user manually. The system generates an alarm using a buzzer attached to it as the water is about to get over.

For detecting the water level, the Ultrasonic distance sensor is used which is placed at the brim of the reservoir container and faces the water reservoir's base. The distance of the water from the sensor is sensed continuously as it moves around to water the plants. A threshold is maintained and programmed in the Arduino Duemilanove board. As the robot keeps on watering the plants, the water in the reservoir keeps on decreasing and the distance values sensed by the ultrasonic sensor keep on increasing as the distance between the water surface and the sensor increases.

As the value reaches the threshold, the buzzer alarm turns on and the robot stops its movement, simultaneously an email is sent to the user stating that the water reservoir needs refilling.

4.3 Complete Working Model

This section focuses on the detailed description of the working system model of the RoboGardner. Apart from the main functional modules discussed in the previous section, the system can be broadly modularized into two modules, one is the mobile vehicle and the second one is the sensing module placed at the plants. Fig. 10 depicts the complete Circuitry of the RoboGardner.

Sensing Module
The sensing module placed at the plant comprises of the Zigbee Coordinator, Arduino Duemilanove board and Temperature and humidity sensor HSM-20g. The temperature and humidity sensor sends a continuous stream of data via the Zigbee Module about the watering needs of the plants. Fig. 9(a) depicts the Sensing Module that is placed at the plant.

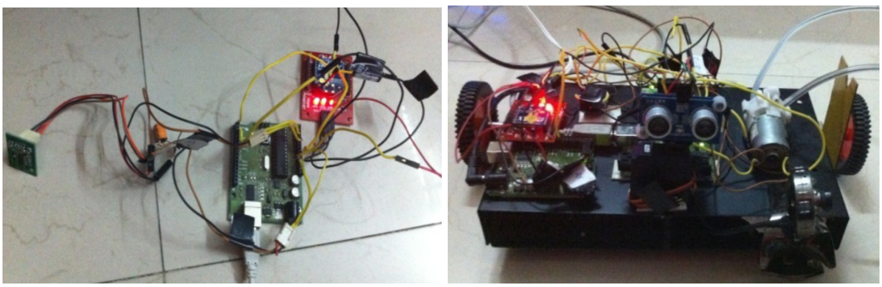

Fig. 9. (a) Sensing Module **(b)** Mobile Vehicle

A preset threshold is maintained, the values sensed by the sensor are compared to the threshold, if the values do not fulfill the threshold condition of the temperature and humidity, the Arduino board attached to the sensor sends a 'Y' to the mobile vehicle via the Zigbee Coordinator device indicating that the plants require water.

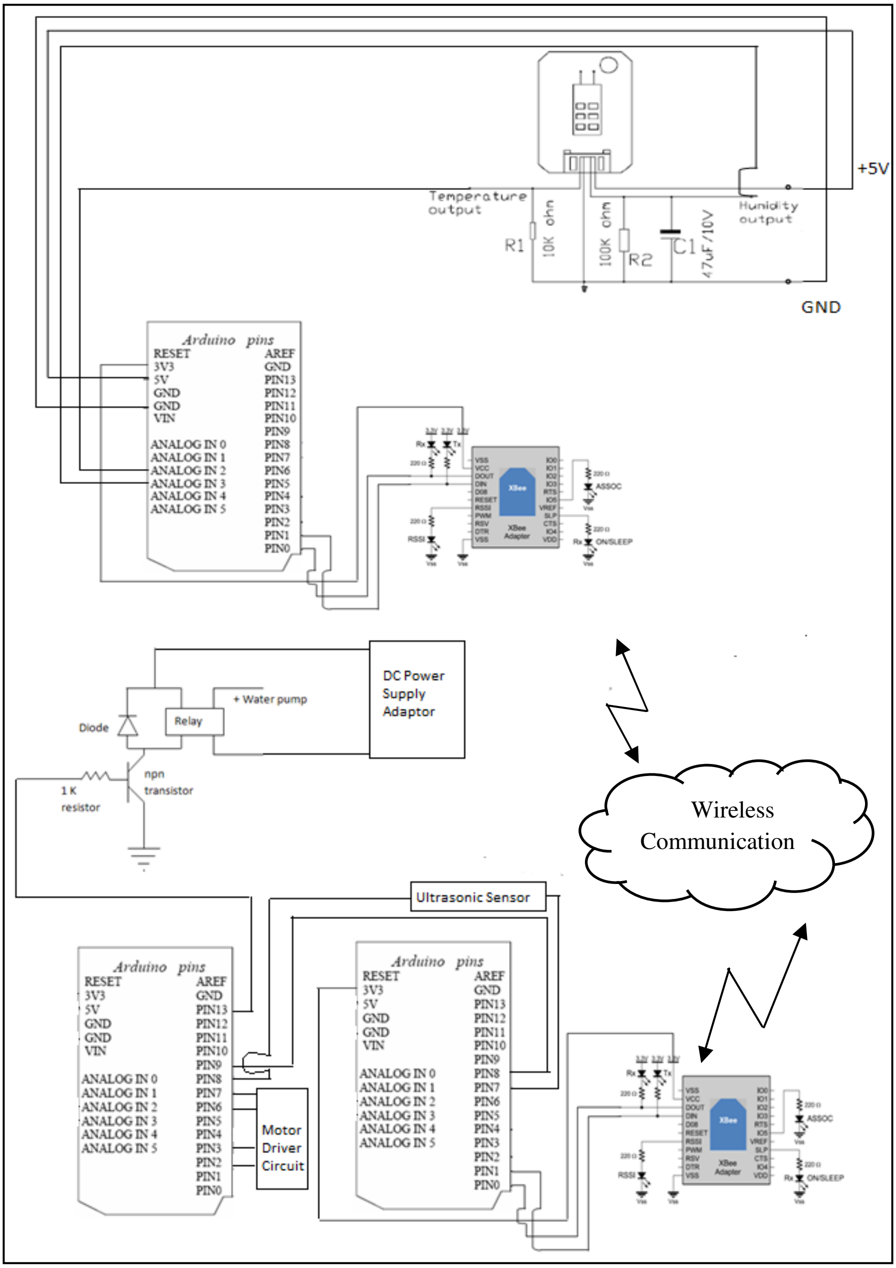

Fig. 10. RoboGardner Complete Circuit

In case, the values fulfill the threshold criterion, an ‘N’ is sent. The Zigbee sends the ‘Y’/’N’ continuously to the mobile vehicle depending upon the need of the plants being taken care of.

Mobile Vehicle

The mobile vehicle is equipped with the Zigbee Receiver, configured as the End Device, Full rotation DC motors, two Arduino Duemilanove boards, Web camera, Relay circuit, two ultrasonic distance sensors, DC Water pump and the on-board water reservoir. The Zigbee End Device keeps on receiving data from the Zigbee Coordinator placed at the plant, as soon as it receives a 'Y' the RoboGardner starts moving towards the plant to water them. Fig. 9(b) shows the mobile vehicle equipped with the sensors and other hardware components.

Each plant is equipped with a visual code marker tag; the camera attached on the mobile vehicle continuously takes snapshot while travelling towards the plant, each image captured by the camera is sent to the PC via serial communication. The image is processed used appropriate program written in MATLAB as discussed in Section 4.2 (A).

Fig. 11. RoboGardner performing the watering operation in real time scenario

Based upon the image captured, if the desired marker tag is present, an 'S' signal is sent to the microcontroller, indicating that a plant is detected. The robot stops its motion, turns on the relay as discussed in Section 4.2 (B) and triggers the attached DC water pump to dispense the water. The watering process requires 10 seconds after which the robot starts its locomotion again in search of the next plant to water. The same process repeats as it keeps on detecting the plants by identifying the attached marker tags. The last plant of each row is equipped with a different set of marker tag, as soon as the RoboGardner waters the last plant of each row an 'R' signal is serially communicated to it, indicating that a right turn is to be taken. In this way the RoboGardner covers the entire square/rectangular region.

5 Results and System Evaluation

This section outlines the results and depicts the performance of the system. The RoboGardner is designed as an improvisation of the previously designed system and to overcome the shortcomings of the already existing systems. The system is far more cost-effective, portable, light weighted, maintainable and efficient when compared to different systems on the stated parameters. The system is reliable and waters the indoor plants autonomously in no significant time.

The Fig. 11 depicts the RoboGardner performing the watering operation in a real time environment of compound area at home. As shown in the Fig the plants are equipped with visual code marker tags and the first plant is equipped with sensing module, the RoboGardner keeps on watering the plants and moves to the other one. The water dispensed is taken to be 100 ml per plant for experiment purpose which can be increased according to the design as and when required.

Time Analysis

It uses a 60RPM 12V D.C. motor. The system is evaluated on the basis of the time required to reach the plant, the watering operation and the number of plants successfully watered. The results are supported with the appropriate statistics and graphical analysis.

$$D=RPM \times dR \tag{1}$$

Where, D= distance travelled in per minute
RPM= Rotations per minute of the DC motor (60 in this case)
dR= distance travelled in one rotation (15 cm)

$D=60 \times 15 = 900$ cm/min
Distance between the centers of two plants is assumed to be 75 cm.
Number of plants to be reached in 1 min without stopping = 900/75= 12
Time required to reach 1 plant T_R = 60/12 seconds = 5 seconds.
Time consumed in each watering operation T_W = 10 seconds.
Total time required to water 1 plant = $T_R + T_W$ = 15 seconds.

Based on the above mentioned statistics, the report generated by the robot depicts its performance in 10 consecutive watering rounds. The Fig. 12(a) shows the number of plants watered in each round in the given number of rounds. The Fig. 12(b) depicts the total time to water the given number of plants corresponding to the stated number in Fig. 12(a) , Time Analysis, the graph shows the linear curves for the time to reach the plant, time to water the plants and the total time spent on the complete watering process in each specified watering round. The X-axis in both curves depicts the watering round number. The y- axis in Fig 12(a) shows the time in seconds.

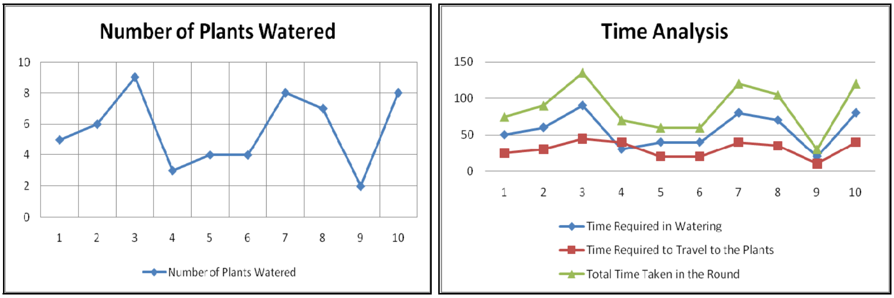

Fig. 12. **(a)** Watering in each Round **(b)** Time Analysis of RoboGardner's Complete Process

Cost Analysis

Table 1 depicts the comparison of the RoboGardner with the Intel's PlantCare System in terms of cost. The total cost of Intel System's major components comes out to be approximately $9000 whereas the RoboGardner in $190. The system presented in this paper is approximately 50 times more cost-effective and is capable of automatically locating, identifying and watering plants according to the watering needs.

Table 1. Cost Analysis and Comparison of RoboGardner and Intel PlantCare System

Intel Research PlantCare System[1] (Major Components)			RoboGardner: A Low-cost System with Automatic Plant Identification using Markers		
Component	Quantity	Cost [2]	Component	Quantity	Cost
SICK Laser Range Finder	1	$5000	Arduino Duemilanove	3	Rs. 1600
Pioneer 2-Dxe Robot	1	$3995	Web Camera	1	Rs. 500
Lead-Acid Batteries	3	$68.44	Dc Motors	2	Rs. 300
Sonar Sensor	8	$236	Relay	1	Rs. 50
			Xbee Series 2	2	Rs. 5000
			Hsm-20g sensor	1	Rs. 800
			Water pump	1	Rs. 250
			Ultrasonic Distance Sensor	2	Rs. 2000
Total Cost (approx.)		$9299.4			Rs.10,500 ($188) [3]

[1] Apart from this it uses the wireless network of Intel Research Lab.
[2] Prices as per ActiveMedia pricelist June 2002.
[3] According to the conversion of Rupees to Dollar (1$=Rs 56).

6 Conclusion

In this paper, we presented a low-cost autonomous plant watering system which comprised of a temperature and humidity sensing module and a mobile vehicle for plant identification and watering. The RoboGardner is designed keeping in mind the need of automation in the watering of plants at homes and offices. It is successfully implemented to water indoor potted plants placed on plain even surface. It senses the temperature humidity of the plants being taken care of, locates and identifies them autonomously and waters them without any human involvement. Apart from the watering operation, the system includes different functional modules like obstacle avoidance, water level checker and automatic feedback mechanism to enhance the usability and reliability of the system.

7 Future Work

In the future, the functionality of the RoboGardner will be further enhanced to ensure a completely reliable and efficient autonomous system development. The web camera which communicates with the PC/ Laptop for marker identification will be replaced with a Serial JPEG Camera Module-TTL connection which is compatible with Arduino Duemilanove board. With this replacement, the image processing would be directly done at the microcontroller without the need of an attached PC. The work in this area is ongoing.

Moreover, in this paper the system is designed keeping in mind that the plants are placed along the sides of the desired watering area in a straight line and the robot is aware of the plant positions and is initially placed in close proximity to them. Work is ongoing in implementing an algorithm for path planning where the RoboGardner will not have a priori knowledge of working space. It would be designed to work viewed as a grid with plants being viewed as points.

The obstacle avoidance would also be improvised using this path planning algorithm for unknown environment and the alternative path to be taken would also be either clockwise or anticlockwise depending upon the real time scenario.

The robot can be equipped with a mechanical arm to increase the usability so that it can water any plant regardless of the height of the pot.

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