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Testing and Validation of Developed Upgradable Mobile Platform for Smart Applications

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Abstract—**This paper presents the continuation of the research done by the same authors on developing an upgradable mobile platform for smart application. The research focuses on home automation including telecaring and remote assistance.The platform developed in this research is 30 cm x 40 cm x 40 cm and weigh approximately 2kg.The platform is capable of navigating itself to a selected location in a flat surface through an optimal path, when the map of that particular surface is given. A smart phone is used as a controlling module of the robot and it can be mounted on the robot through a given mounting dock where all the data communication between the robot and the smart phone happens through Bluetooth. A smart phone application has been developed to perform the controlling task and is capable of communicating with a remote smart phone with the same application through GSM network (SMS) giving remote controlling ability to the platform. The obstacle avoidance system of the platform is capable of identifying obstacles and update its position on the map. The platform is designed so that it can be upgraded by adding external modules on top of it.**

Index terms -Home automation, Telecare, Upgradable, Indoor navigation, Android devices

I. INTRODUCTION

Home automation is an emerging research area in the recent years. The key focus of this is to integrate internet and electronic controlling devices to the domestic environment. The rapid advancement of electronic and information technology happened in the 20th century had made it possible to make this concept reality which was once limited only to science fictions.

The concept of home automation has a very wide spectrum of application areas. Figure 1 illustrates the main branches of home automation.

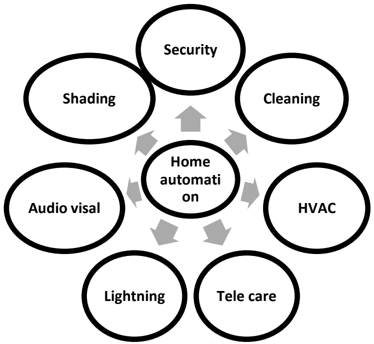


Figure 1. Branches of home automation

Among those branches, telecare describes the remote caring of elderly or physically disabled personals. The requirement of telecaring comes with the aging of the population. Due to the advancement of infrastructure and the medicine, the average life expectancy of the human has recently increased. According to the United Nations, word population aging report 2013, the world population aged 60 years or over has increased from 8 percent in 1950 to 12 percent in 2013 and it is expected to increase this number rapidly such that at the end of 2050 it will become 21 percent [1].

Even though these senior citizens cannot be involved in much productive tasks, it is impossible to ignore their needs in order to sustain the human population. Thus a technical approach for solving this problem is through telecare devices. Due to the increase of aging the demand for more advanced telecaring devices are exponentially rising.

A paradigm shift has happened in the field of telecaring due to the advancement of the field of robotics. With the advancement of computer technology, some researchers in both academia and the industry are focusing on developing robotic servants [2] [3] [4]. Even though some of these robotic servants are implemented in the hospital environment in place of the human nurse, the application of them in domestic environments has not yet become a reality mainly due to high costs attached.

However in recent years, several domestic robotic platforms have stormed the market which seems to have the roots of domestic telecaring robots. Most of these platforms are designed for cleaning purposes. One example is iRobot Roomba developed by the iRobot Corporation. This robotic platform is capable of sweeping the floor of the house. In order to do it, it uses sensors and a navigation system [5]. However these systems are not yet capable of navigating to a specific location, which is a key feature of a telecare robotic system. Nevertheless this concept can be extended to a telecare robotic platform by introducing proper navigation and user interface.

The smart phone technology has recently become so advanced that they are only lag less than five years from desktop computers. These powerful handheld devices have opened a new window for innovation. Thus there is a possibility to integrate this technology in telecare devices. Further it also enables the use of cloud computational platforms to extract the high performance computational capacities to low cost devices [6].

This paper presents the development of a robotic platform for telecaring in the domestic environment by integrating the smart phones. Here the authors have included the feature of upgradability to the platform to be more practical in domestic environments rather than design for a specific application. Thus the platform developed in this research is capable of upgrading using external modules. This paper discusses the hardware construction including the driving mechanism, navigation approach, communication and mobile application development with algorithms and testing and results.

At the initial stage of the research, authors have tested the driving mechanism and the navigation system of the platform which is published in the paper “Development of Upgradable Mobile Platform for Smart Applications” [7].

II. PROPOSED SYSTEM FOR THE MOBILE PLATFORM

A. *Functional Description*

Figure 2 describes the components of the final platform.

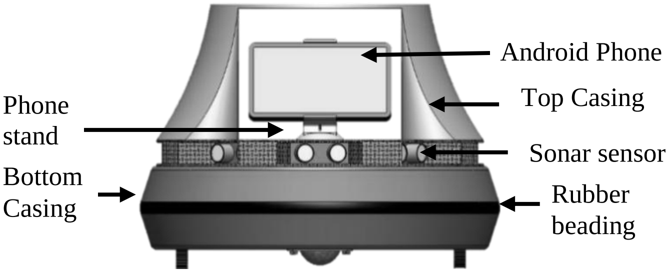


Figure 2. Components of the final platform

The final platform developed throughout this research is an upgradable mobile platform which can be controlled using a Smart phone. The phone can be mounted on the robotic platform as shown in the Figure 2. The phone is connected to the platform using Bluetooth. The platform can be navigated to any location on a flat surface using the smart phone application developed. The application is capable of finding the optimal path to the destination avoiding obstacles.

When an unknown obstacle blocks the path of the robot, it stops at that location and check whether the object moves away in case of a dynamic object. If the object has moved, the platform continue with the previous path and if it stays at that particular location for more than a predefined time period, the robot sends the coordinates of the object to the Smartphone application where the object’s position gets updated on the map. The application recalculates a new optimal path avoiding the obstacle and send it back to the platform to move in that path. The application is further capable of communicating with a remote application through the GSM (SMS) network. Figure 3illustrates an overview of the communication between the platform and the smart phone.

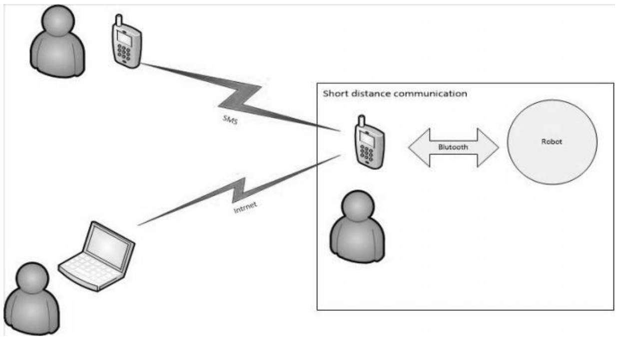


Figure 3. Communication System Overview

B. *Subcomponents of the System*

Figure 4.illustrates the subcomponents of the robotic platform.

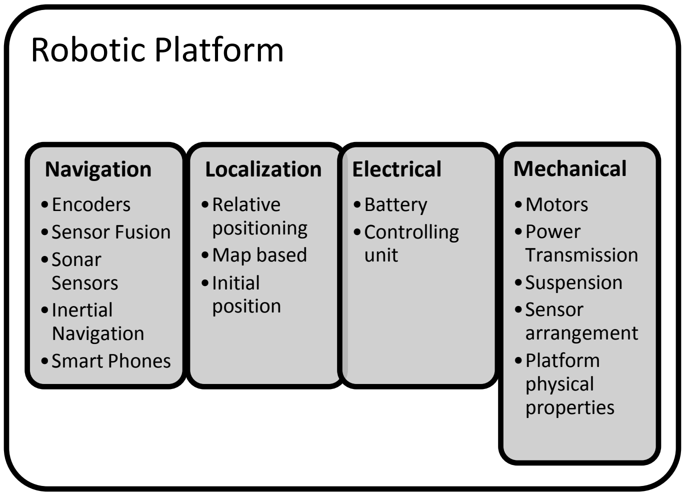


Figure 4. Subcomponents of the System

III. DEVELOPMENT OF THE PLATFORM

A. *Navigation*

Navigation is one of the key aspects in robotic applications, where the robot determines its location and makes required movements. For the upgradable mobile platform in concern, it is required to have at least a basic navigation system. Later on as per the preference of the user; he or she should be able to upgrade the mobile platform using an advanced system such as vision based navigation systems.

I. Obstacle Avoidance

Some of the most popular types of sensors used in obstacle avoidance are Sonar, IR, Laser and Optical cameras. Even though the Laser range sensors give good accuracy, the cost of the device is very high making it not appropriate for low cost commercial products. The optical cameras also require high amount of processing power, making is difficult to be used for a low cost application [8] [9] [10].

The IR and Sonar are the cheapest sensors used for navigation purposes. Both of these sensors have their advantages and disadvantages. In this development Sonar sensors are used due to their relatively high detection range (>4m) compared to the IR (1.5m) in commercially available modules.

SR04 sonar sensor was selected as the sensor could take measurements in the range of approximately 5cm to 350cm.

Arrangement 1

At the initial testing phase, a Sonar sensor was mounted on a stepper motor such that it can be rotated in a half circle.

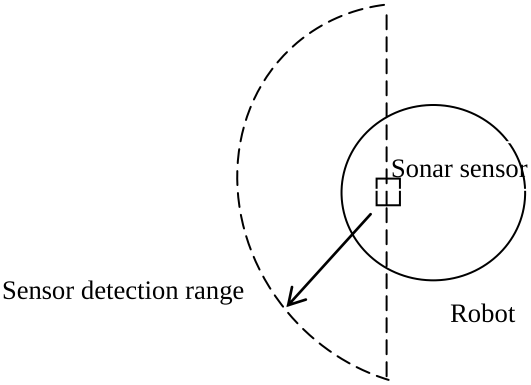


Figure 5. Rotating Sensor Arrangement

The advantage of this method is that it required only a single Sonar sensor to identify obstacles located inside the dotted area (Figure 5).

But the main drawback of this method was in a dynamic situation where the robot moves some distance during a scanning cycle. This makes it difficult to locate the obstaclesefficiently.

Arrangement 2

In the second arrangement, three sonar sensors were mounted 90 degrees to each other on the front side of the platform as seen in Figure 6.

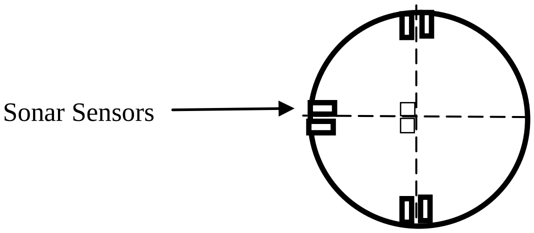


Figure 6. Three Sensor Arrangement

The sensors mounted on the sides of the platform are used to generate the map while the sensor in the front detects the obstacles. The sensor has naturally a detection angle of 15°.

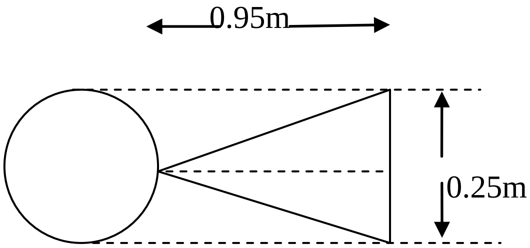


Figure 7. Three Sensor Arrangement

Due to this property, the front mounted sensor can detect obstacles that can be collided with the robotic platform, whose diameter is 0.25m at a distance of approximately 1m as seen in Figure 7. However in contrast to this arrangement, in the previous arrangement, the detection distance is shorter. In other words, in this method the robot needs to detect the obstacle from a distance of approximately 1m.The testing results of this arrangement is presented at the results and discussion section.

For the final platform, five ultrasonic sensors were used to improve the accuracy. Figure 8 shows the final sensor arrangement.

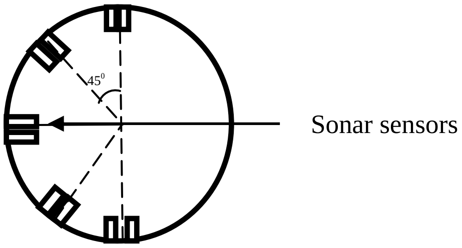


Figure 8. Five Sensor Arrangement

II. Path Finding Algorithm

Path finding is a key requirement of mobile robot navigation. It is vital navigating the robot to the destination with the optimal path. There are several path finding algorithms commonly used.In this project A*(A-star) algorithm is used as it produce the most optimal path. [11]

i. A* Algorithm

For optimal path finding A* (A star) algorithm is used which is an extension to Dijkstra's algorithm and is much faster and simpler in arriving at the shortest path from one vertex to another pre-selected vertex. The algorithm can be expressed in following steps.

Step 1 – Simplify the map using a square grid where the moving problem will be reduced to a two dimensional space. Assign each square by movable or immovable depending on the obstacles present. Immovable squares will not be considered when implementing the algorithm.

Step 2 – The robot will have an initial position (starting node) and a goal position (ending node). When considering the next square to move from the current position, a heuristic function will be used. This function will be applied to all adjacent squares from the starting node and the least value will be used to proceed until the adjacent square becomes the target square.

$$F(n) = G(n) + H(n) \qquad (1)$$

G(n) - the cost (a value used instead of distance) of the movement from the initial node to the node n on the grid following the path generated to get there.
H(n) - the estimated cost of movement from that given node n on the grid to the target node. This is often referred to as the heuristic function, which is a guess as the actual distance is not known. There are many ways to define the heuristic function.
F(n) – estimated best solution
When estimating the cost under Heuristic function Manhattan method is used where the number of squares moved horizontally and vertically to reach the target square is calculated ignoring diagonal movement and obstacles.
It is important for each node to keep track of its parent node so that when the target node is found, the shortest path can be tracked back.
For example take the map shown in Figure 9 where the shortest path from the green node to red node should be found. Here the F G and H values are marked for each node. One vertical or horizontal movement to the adjacent square is taken as 10 and hence a diagonal movement is 14 according to trigonometry (10*Sine45).

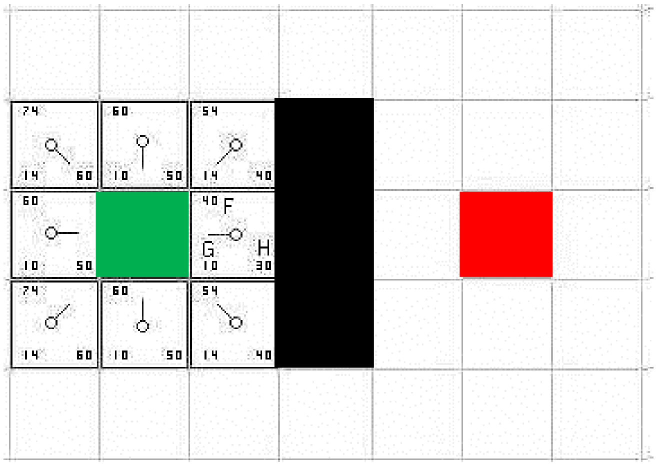


Figure 9. Map of the surroundings

Here two lists are maintained; called open and closed. Open is the nodes considered for robot to move and closed is the nodes selected with the lowest F value. Starting node would be the parent node for the first step nodes. According to the above calculation the next step is to move to the right hand side node horizontally.
Then the said node is deleted from the open list and added to the close list. Now all the adjacent squares are checked, ignoring the ones on the closed list or immovable, add squares to the open list (if they are not there already). The selected square is the new parent. If an adjacent square is on the open list already, check whether this path to the concerned square is a better one. Here we check to see if the G value for that node is lower if we use the current square to get there.
Path shown in Figure 10 could be achieved by continuing this process.

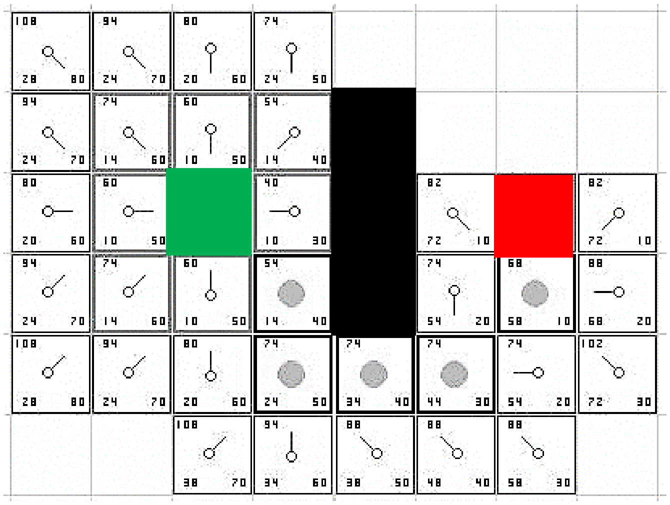
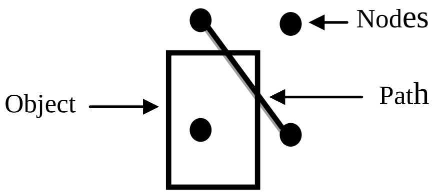


Figure 10. Calculated Path

ii. Application of A* Algorithm
A* algorithm used in the platform runs on the smartphone application developed. When the user select a position on the map, it calculates the shortest path and send the coordinates of the nodes to the internal controller of the robot. However there are some practical limitations in direct application of A* algorithm without any modifications.

Intersection of Objects
If an object falls in between nodes, the calculated path can fall through the object as shown in Figure 11.

Figure 11. Intersection of Objects



In order to avoid the situation, algorithm is modified to skip the immediate nodes found form the object when calculating the path.

Step Path

When connecting two remote nodes, if the angle between them relative to the nodes reference frame is not a multiplication of π/4, it can create step shaped path which is not anoptimized solution as shown in Figure 12 (red line).

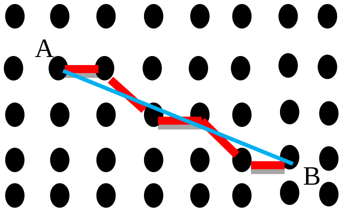


Figure 12. Step Path

In the modified algorithm, both node A and B are directly connected (as shown in blue line) after identifying such situations.

B. Localization

Localization is one of the key aspects in robotic applications, where the robot determines its relative to the given reference frame. For the upgradable mobile platform in concern, it is required to have at least a basic localization system. Later on as per the preference of the user; he or she should be able to upgrade the mobile platform using an advanced localization method.Localization can be basically divided into two main sections as below.

- Outdoor localization
- Indoor localization

Outdoor localization mainly focuses on navigation in areas which are not covered by a roof. In this scenario GPS (Global Positioning System) is the most popular navigation approach. For that, one of the key requirements is clear LOS (Line of sight).But in indoor environments GPS is not a practical approach where LOS is not always possible. Therefore dead reckoning techniques are used in this platform [12] [13].

I. Dead Reckoning

Dead reckoning is one of the earliest localization method used in robotics. The main concept behind this is to calculate the travel distance of the robot from a reference point. One of the key drawbacks of this method is integration of error over the travel distance.

One of the most commonly used equipment for dead reckoning is wheel encoders. Wheel encoders can be used to get the number of rotation of the wheel. In ideal conditions, if the diameter and the number of rotations of the wheel are known, it is possible to simply calculate the travel distances using basic math. But in practice, number of errors can occur due to the uncertainty of wheel diameter and the wheel slipping depending on the terrain [14].

Accelerometers can be also used for indoor navigation purposes; even though wheel slipping and wheel diameter doesn't affect the accelerometers, it suffers from high amount of noise and proportionally increasing error caused by double integration of acceleration to predict the travel distance [15].

In addition to the travel distance measurements, it is also required to measure the robot's current angle. Traditional approach for this is to use a digital compass. But a digital compass is highly sensitive to the changes of the surrounding magnetic field. Thus it is not feasible to totally rely on the compass data.

Another approach is to use a Gyroscope. It can be used to measure the relative rotation angle and it is not affected by the changes to the surrounding magnetic field. But the problem with this approach is it is not possible to detect the absolute angle.

II. Encoders – Mathematical Modelling

A mathematical model is used to estimate the travel distance and the robot's orientation by using the values of the two encoders. Figure 13 shows the wheel arrangement of the differential drive mechanism.

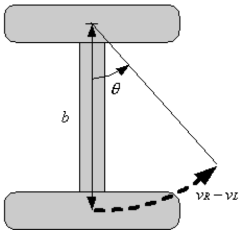


Figure 13. Wheel Arrangement

From Figure 13, the angular velocity of the robot can be calculated by using Eq (2) where Vr is the velocity of right wheel, Vl is the velocity of left wheel and b indicate the distance between two wheels.

$$\frac{d\theta}{dt} = \frac{Vr - Vl}{b} \tag{2}$$

By integrating the above function w.r.t to time;

$$\delta(t) = \int \frac{(Vr - Vl)}{b} dt \tag{3}$$

$$\delta(t) = \frac{(Vr - Vl)t}{b} + \delta_0 \tag{4}$$

Where δ 0 represent the initial orientation of the robot. As the model uses an absolute frame of reference at initial position δ_0 is initially taken as 0. Figure 14 shows the orientation of the platform in an absolute coordinate system. The average velocity of the robot is equal to the average velocity of the two wheels.

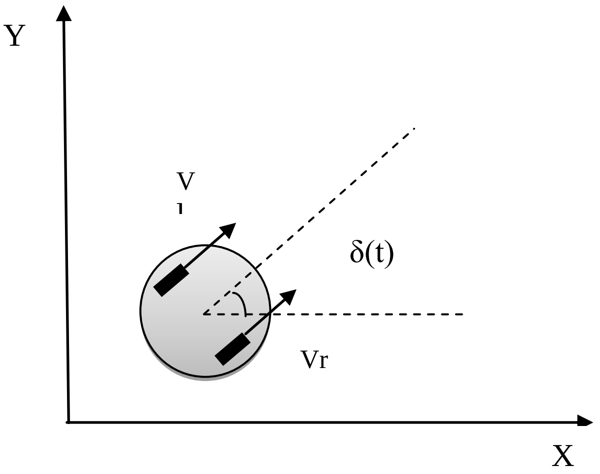


Figure 14. Movement of Platform

$$Vavg = \frac{(Vr+Vl)}{2} \qquad (5)$$

The velocity of the robot at x and y direction can be represented by Equation (6) and (7) respectively.

$$\frac{dx}{dt} = \frac{(Vr+Vl)}{2}\cos(\delta(t)) \qquad (6)$$

$$\frac{dy}{dt} = \frac{(Vr+Vl)}{2}\sin(\delta(t)) \qquad (7)$$

By applying the initial position relative to the absolute frame of reference;

$$x(0) = x_0$$

$$y(0) = y_0$$

The travel distance in the absolute frame of reference is given by equations (8) and (9).

$$x(t) = x_0 + \frac{b(Vr+Vl)}{2(Vr-Vl)}[\sin((Vr-Vl)t/b+\delta_0)-\sin(\delta_0)] (8)$$

$$y(t) = y_0 - \frac{b(Vr+Vl)}{2(Vr-Vl)}[\cos((Vr-Vl)t/b+\delta_0)-\cos(\delta_0)] (9)$$

In order to estimate the angle of the robot three readings are taken from a Gyroscope, a digital compass and the encoders. Encoder data and the gyroscope data are fused to increase the accuracy of the angle reading .The digital compass is only used to get the initial angle.MPU6050 IMU unit is used to take the gyroscope readings. The module is equipped with the I2C communication medium. For the Digital compass, module HMC5883L with I2C communication medium was used.

C. Mechanical Structure Design

I. Base Shape

The base shape is one of the most important factors in the mobile platform structures as the wheel arrangement as well as other equipment installations depend on the shape of the base structure. When we examine animals whichhave shells to cover their bodies, all of those are in circular shape to avoid the environmental barriers while they are moving. If they had sharp edges on the shell there is a possibility of getting tangled with uneven objects in the environment. Similarly avoiding sharp edges from the base shape is important for a mobile robot. Here, by using a circular shape, the stability of the robot is also increased especially in collisions with a foreign object the generated force on the body will directly go through the center of the structure, therefore in such circumstances robot will only slip along the direction of the force along its center. This can further be used to calculate the error occurred due to slip. In contrast an asymmetrical shape makes it difficult to gauge the slip and the direction of slip. This principle will be used in the different levels of the platform as seen in Figure 15.

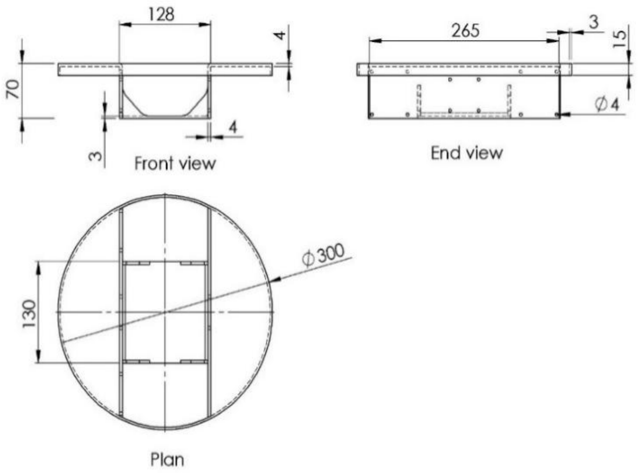


Figure 15. Base shape

II. Suspension System

There are three main practical situations which demands some sort of a suspension system for the domestic robot.

1. Gripping
2. Hardware safety
3. Durability of the components including electronic and mechanical components.

Here gripping is a common phenomenonencountered in a wheeled vehicle. Proper gripping is to ensure that all the driving wheels are contacted with the surface. This is very critical in case of a differential driving mechanism, where the travel distance calculations are based on the wheel rotation. If the driving wheels are not properly contacted with the surface, wheels can slip and cause significant errors in the navigation calculations.

In this platform, the authors use four wheels to make the platform more stable where the two driving wheels are mounted along a diameter of the circular base while two ball wheels are mounted on a perpendicular axis to the axis of the driving wheels. Here all wheels are mounted on independently contractible springs ensuring wheel contact with surface at all times as seen in Figure 16.

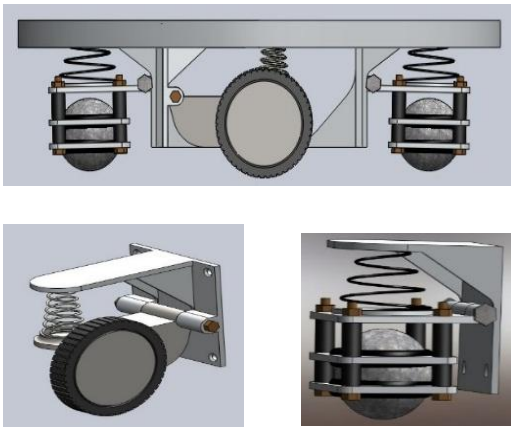


Figure 16. Suspension system

III. Collision Damage Minimization

When looking at design considerations of collision safety of the system, two main areas need to be considered; robot's safety from collisions with other objects as well as the safety of those other objects. This is vital as there can be fragile objects such as glass based objects in a domestic environment. In order to ensure safety in both aspects, a rubber beading is proposed around the bottom level of the platform as seen in Figure 17. This will absorb the forces generated from collisions and will reduce major harms.

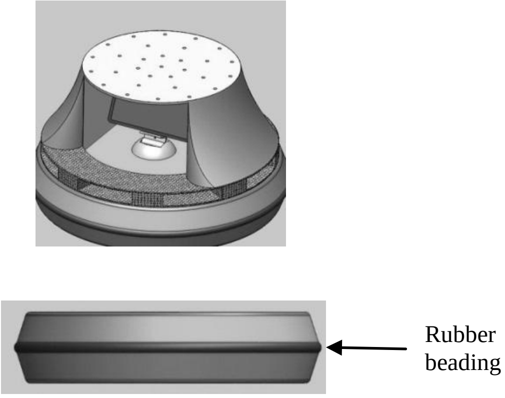


Figure 17. Rubber beading

IV. HMI Device Mounting

The robotic platform is controlled through an android based HMI device (smart phone). Here either the phone could be in the Bluetooth range external to the platform or mounted on the platform. Latter will allow the use of features of the phone such as the camera and accelerometer to be used as functions of the platform. For an example, when the phone is mounted on the platform, its camera can act as a spy camera and can be employed when the owner is away from home and the camera could be accessed remotely through currently available android software applications. The mounting arrangement for the phone need to accommodate different sizes and should be able to rotate around its horizontal axis. For this purpose, a model is proposed as seen in Figure 18.

The primary concerns in designing this arrangement are the stability of the device and the position and orientation of the camera in the device.

Figure 18. Mobile phone dock

D. Electrical System

The robot is controlled via two modules

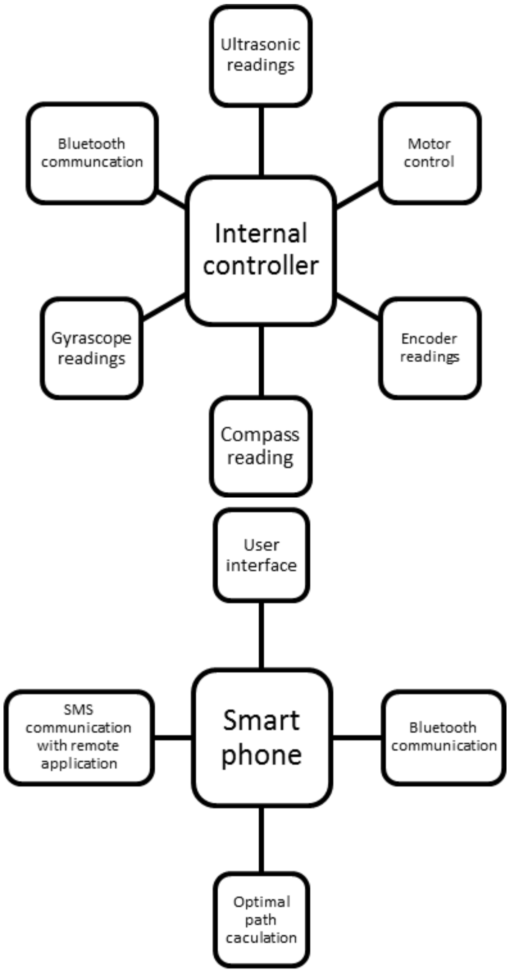
a. Internal controller

b. Smart phone

Internal controller is built in to the robotic platform and it is responsible for processing of internal signals of the robotic platform.

Mobile phone acts as the secondary controlling module and it communicate with the primary controlling module.Primary purpose of the mobile phone is to calculate the optimal path to the destination as in Figure 19.

Figure 19. Function of controllers



I. Arduino Platform

Arduino is an Atmel microcontroller based microcontroller development platform designed targeting on rapid prototype development. All the software and the hardware related to the development platforms are open source and readily available for any kind of modifications. During recent years Arduino has become the most popular microcontroller development platform in the world offering a wide variety of development platforms with different levels of hardware capabilities.

One of the key benefit of using this platform over others is its huge community. Almost all technical and coding support needed can be acquired through the online community. In addition to the technical support, the software used to program the Arduino is designed in such a way that all the hardware level configurations are hided from the end user.This avoids all unnecessary time spent and complexity for general users to carry out the coding.

The capabilities of the base platform can be improved by connecting additional circuit boards called Arduino compatible shields to the base platform. There are thousands of third party developers who develop these shields giving almost every facility to these platforms.

In contrast, one drawback of these platforms are high code execution time and less code density compared to a general microcontroller due to the high level programming language it use.Thus currently it is not very feasible to use it for developing optimized applications.

For the mobile platform, we used the Arduino platform in order to be open source and to give flexibility of designing customized controlling boards in the future. In this project Arduino Mega 2560 development board was used which consist of ATmega2560 microcontroller which runs at 16 MHz [16].The board has PWM channels to control the motors and USART module which in this case is used to connect the Bluetooth module HC-05. Figure 20 illustrates the different components connected to the Arduino controller.

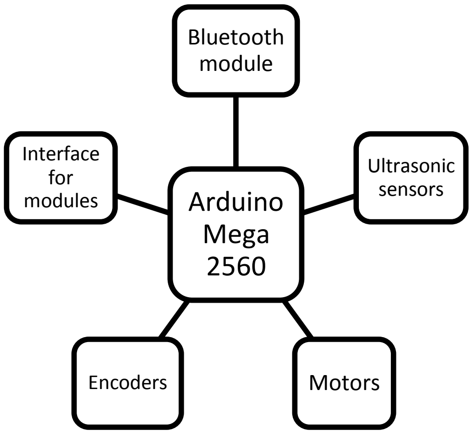


Figure 20. Arduino connections

II. Smart Phone

Smart phones are increasingly becoming a household commodity in the modern society. At the beginning, the name smart phone was used for phones with additional features such as personal digital assistants and medial players. However in recent developments smart phones are equipped with features that are equivalent to that of personal computers with features like web surfing. This is connected to the general smart concept which is related to many other fields such as smart houses.

When considering the use of smart phones for control purposes of a robotic platform several key aspects must be considered. Firstly the functional requirements of such a control need to be compared with what is offered by a smart phone. Then the other available control modules need to be compared with smart phones for compatibility. Finally different platforms in a smart phone need to be compared to arrive at the most suitable one.

Android Technology and Tools

Android is a mobile operating system developed by Google Inc. It is based on the Linux kernel. Currently it is the most popular mobile operating system in the world. Due to its popularity there are a number of third party application developers in the word making various kinds of applications available for user according to their requirements.

This operating system is basically designed to operate in devices with touch enabled displays. Due to its mobile architecture it is designed to run on ARM microprocessor based platforms which helps to significantly reduce the power consumption of the device.

Google Inc. has developed an online application storage for android applications called "Google Play Store" which can be accessed through a personal Google account to both upload and download applications. In addition to Google's official Play Store there are other online application stores like Amazon App Store giving the same facility.

Application Development

For application development, Google has provided the software development platform called Android Software Development kit (ADK). This ADK provides all the required tools to develop software. In addition to the development tools, this development kit has an inbuilt emulator which can be used to simulate the developed software without installing it on a physical device.

For the application development, ADK should be used with an integrated development environment (IDE). There are several widely used IDE's.

- Eclipse
- Google app inventor
- Processing

In this project,"Processing" development platform was used to develop the application.

User interface

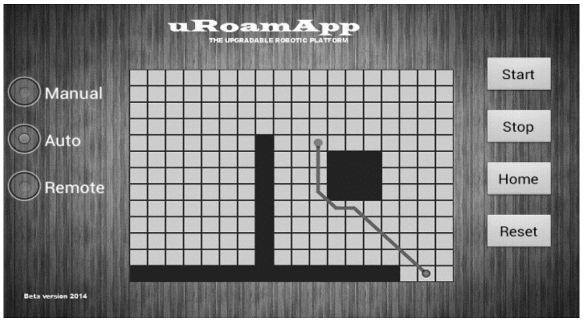


Figure 21. Mobile User Interface

Figure 21 illustrate the interface of the mobile application developed. The interface basically provides three operational modes as manual, auto and remote. In manual mode user can operate the robot by tilting the smart phone. Internal accelerometer of the smart phone is used to get the tilting direction.

In the auto mode the robot operate fully autonomously, and the user will only need to give the destination on the map by touching on that location.

The remote mode gives the robot the ability to operate from long distances where a remote phone can be used to give the destination.

IV.TESTING AND RESULTS

Several tests and experiments were carried out at each stage of the project. This chapter will explain the experiments and results achieved at each stage.

A.Rotating Sensor Arrangement

Here the robot was not given a specific goal, but was allowed to move around a domestic environment. The objective was to observe the behavior of the rotating sonar sensor and how effectively it could avoid obstacles. The observation was mostly satisfactory as the robot was able to avoid many large obstacles. However certain obstacles such as cloth curtains generated problems due to the unstable nature. Also the robot tends to face issues in situations where it encounters obstacle from the opposite direction to that the sensor is sensing. This is due to the time taken for the sensor to perform one scan cycle. Due to this even though direct collisions were not observed, the robot tend to move into confined spaces and get itself in a difficult position.

Therefore it was identified that a faster scanning cycle or a number of fixed sensors need to be used. Further it was identified that an improvement of accuracy and range could be achieved by using an infrared (IR) range sensor.

B. Wall Following

A wall following experiment was performed by fixing the Sonar range sensor at an angle to the travel direction of the platform. Figure 22 shows sensor the arrangement.

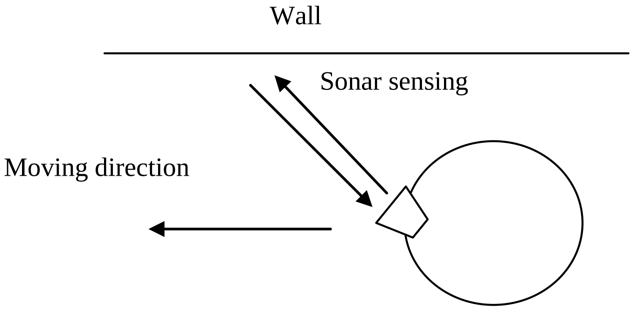


Figure 22. Wall Following Arrangement

It was observed that the platform was able to follow a straight wall reasonably well and the problems occurred when the wall became complicated with sudden changes in direction. It could be identified that the reason was the resolution of the sensing due to the size of the platform and the angle.

C. Map Generation

A map generation experiment was conducted using the platform. Robot was navigated around in a testing area where it encountered walls and the data received through the sonar sensors were used in the software Matlab to generate data which was then used in MS Excel to generate the following map shown in Figure 23. The points marked in red are the obstacles as seen by the robot, which in this case is the boundary of the wall.

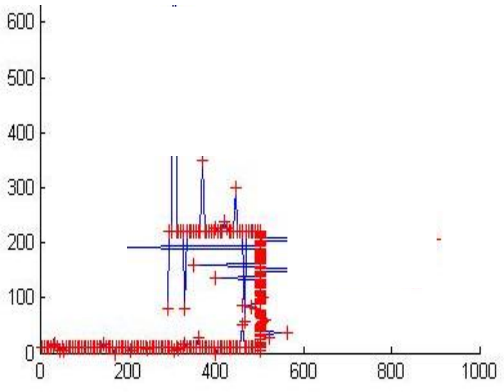


Figure 23. Generated Map

D. Inertial Navigation vs. Wheel Encoding

In addition to the basic obstacle avoidance system, one of the key requirements of this testing platform is to evaluate the two dead reckoning methods. (Inertial and encoders) For that, a simple experimental setup was arranged.

I. Robot Arrangement

Encoders and the IMU were connected to the platform. A Bluetooth communication link was created with the MATLAB r2013. On the robotic platform a simple program was written to capture the accelerometer reading values and send to MATLAB via Bluetooth for further analysis. However as the acceleration only happens in a small amount of time period, high frequent data reading from the accelerometer was required. If data transmission happens within this period, the data reading frequency form the accelerometer has to be reduced to match with the communication speed. Thus data were first stored and then transmitted to the MATLAB as illustrated in Figure 24.

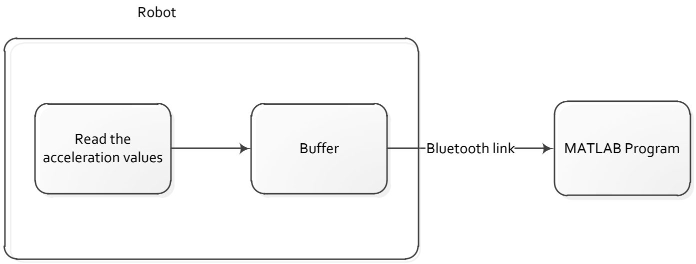


Figure 24. Data Transfer Procedure

II. MATLAB Program

MATLAB program was connected to the robot via Bluetooth connectivity. The Bluetooth connection was created by using the Bluetooth object found in the MATLAB r2013. On MATLAB, the received data was initially stored in a matrix. After that the double integration was performed for the acquired data to get the travel distance. For the process, the data reading frequency from the accelerometer is used. The data is presented in Figure 25 for ease of comparison.

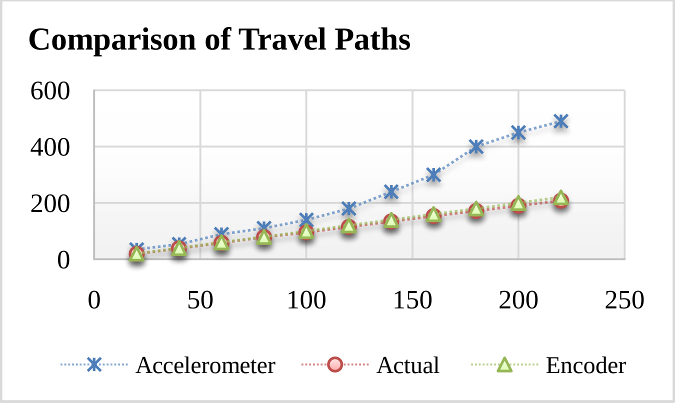


Figure 25. Comparison of Travel Paths

III. Functionality of the Final Prototype

Figure 26 illustrates the test floor arrangement used for validation of the functionality of the final prototype.In the figure, black colored areas indicate the obstacles and the black solid line indicates the generated path by the robot to the intended destination from the starting point. As obstacles a chair which covers an area of 600x600 mm and a wooden wall with length of 2400mm was arranged.

Figure 27 shows the snapshots of the robots travel taken at selected location of the map while it was moving.

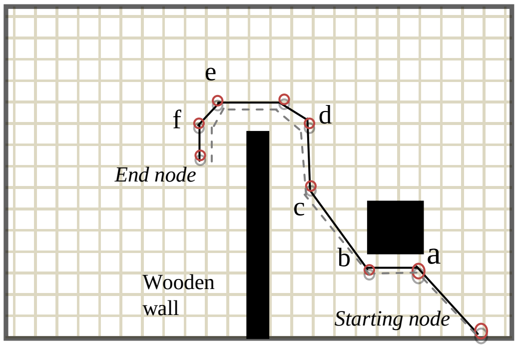


Figure 26. Generated path and the nodes

Figure 27. Robots orientation at different nodes

V. CONCLUSION

Through this project a novel concept of an upgradable mobile platform using smart phones has been developed. However like all other technologies, there are many areas that demands further research and testing before a commercial level product could be manufactured. The project team's intention was to establish the concept and basic design parameters of the said concept. The complete mechanical design or electronic circuitry design was not one of the goals. However the team carried out basic design analysis which could be carried forward in further research under the project.

Another area that should be considered in future developments is the use of more sensors for the purposes of better control and smoothness of travel. This could take the form of bumper sensors to avoid collisions with small objects etc.

Fusion of absolute positioning techniques could also be proposed as a future development. Here use of RFID tags at key locations of the house such as doorways and at the ends of walls could be considered where in case of a kidnapped scenario the robot could re-initialize its true location.

The mobile application can be also improve to get real time video feedback from the camera of the mobile phone which faces to the front side of the platform and broadcast it to the remote phone allowing long distance control.

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