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ROBOTIC LOCALIZATION USING LOW COST INFRARED BEACONS

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Abstract—

Localization is one of the fundamental problems of robotics, and amount of work presented in the literature is tremendous. A mobile robot must recognize its location to move freely in the room. The robot works to compare the previous information with the information from the sensor to recognize the real location. We describe an efficient method for localizing a mobile robot in an environment with beacons. We assume that the robot can identify these beacons and measure their position relative to each other.

Key Words:

Localization, infrared beacons, digital compass, polarization, controller 2051, modification in servo motor, flow chart, applications.

1 INTRODUCTION

It is an exciting time to be in the field of robotics. A key attribute of autonomous intelligent robots is reliable perception in real world environments. Once a robot is able to reliably perceive its environment using its sensors it will be able to perform intelligent actions to accomplish important and useful tasks such as navigation, human-robot interaction, and manipulation of the environment. One of the most important technical issues in a mobile robot is to recognize the position of the robot itself and humans moving around it. As a ship navigates by the stars, a mobile robot makes an autonomous navigation by artificial landmarks attached on the ceiling. Each landmark has an independent ID number and information on the position and angle of an autonomous robot. The Stargazer Robotic Localization System [1] is a unique solution for indoor localization of intelligent mobile robots. It analyzes infrared ray images reflected from the passive landmark with characteristic ID. The output of position and heading angle of a robot is given with very precise resolution and high speed. It is remarkably robust in environments that contain infrared and fluorescent lights or sunshine. These are tasks that are fundamental to many applications of mobile robots ranging from robotic vacuum cleaning, hospital delivery robots, elder care robots etc

2 OBJECTIVE

Our goal was to design an efficient, low cost and a highly precise robotic structure for robot to locate its position. Many advance systems for robot localization have been introduced worldwide but they are very expensive and use other technologies. In a country like Pakistan such systems are rarely used because of high costs. The main objectives of our project include,

1 Design/implement IR Beacons [2].
2 Design/implement hardware for the movement of system.
3 Software implementation of the robot localization system.
4 Wireless communication

3 FIRST DESIGN

The robot localization problem is a key problem in making truly autonomous robots. If a robot does not know where it is, it can be difficult to determine what to do next. In order to localize itself, a robot has access to relative and absolute measurements giving the robot feedback about its driving actions and the situation of the environment around the robot.

We started our work by assuming a structure which was using digital compass [3] and a compact circuitry. We describe an efficient algorithm for localizing a mobile robot in an environment with landmarks. We assume that the robot has a camera and maybe other sensors that enable it to both identify landmarks and measure the angles subtended by these landmarks. The assembly is shown in Fig 1.

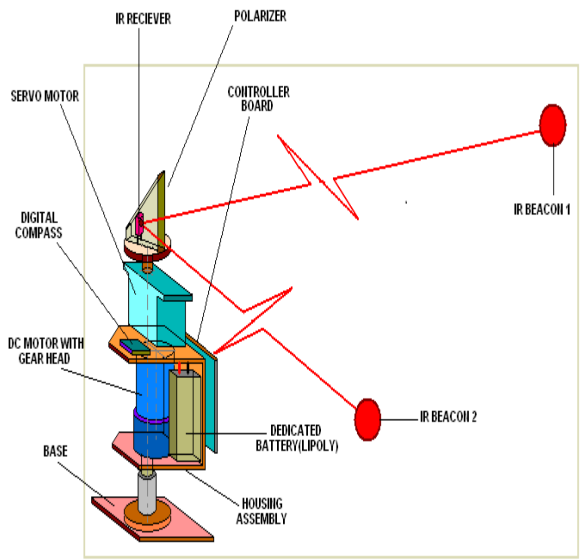

Fig.1: Robot with Digital Compass

Given this information, the robot has to determine its location as accurately as possible. What makes this difficult is the existence of uncertainty in, both, the driving and the sensing of the robot. The uncertain information needs to be combined in an optimal way.

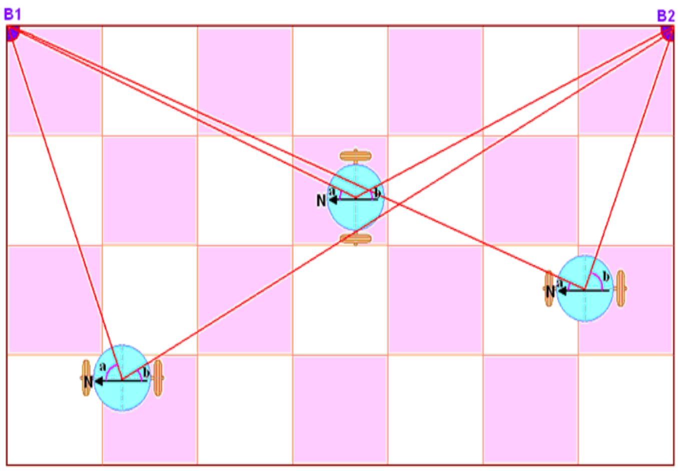

Fig 2: Graphical Representation using Two Beacons

The design was complicated and heterogeneous in terms of sensor usage. On the transmitting side we were using IR and on the receiving side digital compass was used for manipulating the signal. Angle manipulated by the digital compass was not giving the desired results so we had to jump to an alternative solution to the problem of robotic localization. The second proposed design is elaborated in the following heading.

4 SECOND DESIGN

The first proposed solution was heterogeneous in terms of sensors. So in next design, we used three IR polarizers by replacing digital compass which provided homogeneous solution to the problem of robot localization. We started our work on a new design which was not using digital compass instead we were using a pair of IR polarizer to set our reference position and one more polarizer, mounted on the top of the system to scan the beacons.

We used IR transmitter (beacon) and receiver. Transmitter emitted the light while the receiver received infrared light. Infrared sensors require filter system to filter out the uncertain voltage level of IR receiver. The principles are very simple. Beacon is transmitting the frequency of 38 KHz [4] using 555 timers. And special circuitry is also made for IR receiver. IR receiver is placed is the polarizer as is shown in the Fig 3.

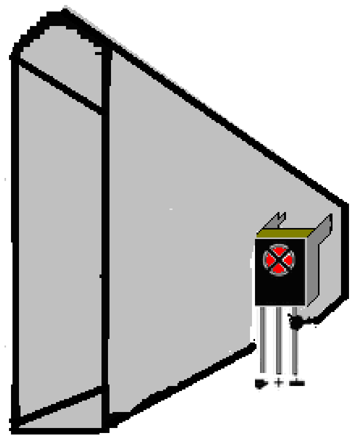

Fig 3: IR Receiver with Aluminum Tubes

At start, we made a robotic structure which could locate its position anywhere in the range of beacons placed around. We used two beacons for completion of our task.

When beacons are off, robot will revolve at angel of 400 degree so that no place is left to check whether beacon is present there or not. When both beacons are switched on, receiver will identify both of them and polarizer will move in between them like a pendulum, the angel then formed between these two beacons will be calculated via programming and will be compared to the already present data structure and will find out the robot's present location. It can be shown in binary form as well as on LCD.

We ended up with a sort of structure which was having polarizer on the top and other circuitry was mounted around the servo as shown in the Fig 4:

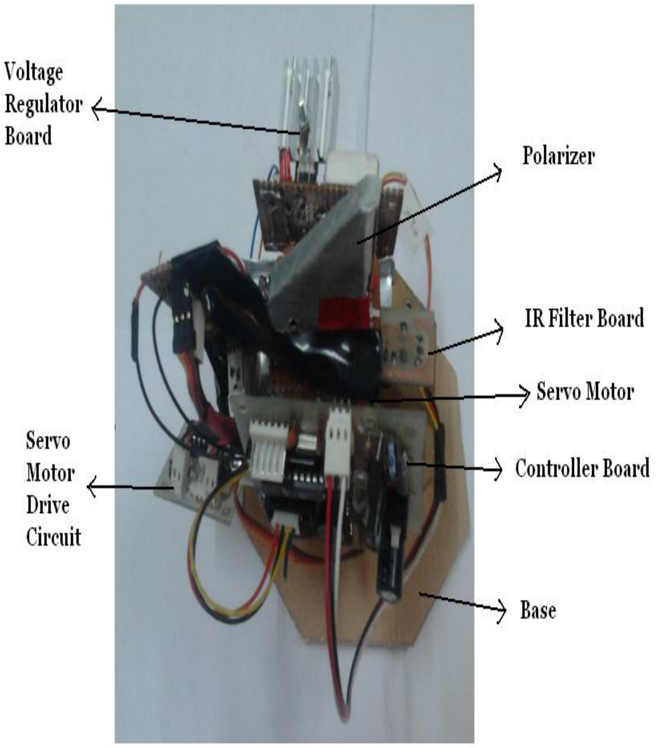

Fig. 4: Design Hardware without Digital compass

The system did not give us desired result because:

- Servo speed was so fast
- Produced instability in a system
- IR receiver was not detecting properly
- Some polarization effects
- Extensive programming

5 FINAL DESIGN

In our final design, we used one polarizer and three beacons. A mirror was inclined below the IR sensor. Beacons emitted IR beam which strike on the mirror passing through the polarizer to the IR sensor. Servo moves freely like DC motor on which the mirror is placed. IR sensor detects the beam of all three beacons. Three angles will be subtended out of which one angle will be greater than the other two. Inter beacon angle, in this case, is dictated by time between the beacons.

5.1 BLOCK DIAGRAM

Here is as block diagram of that proposed design in Fig 5:

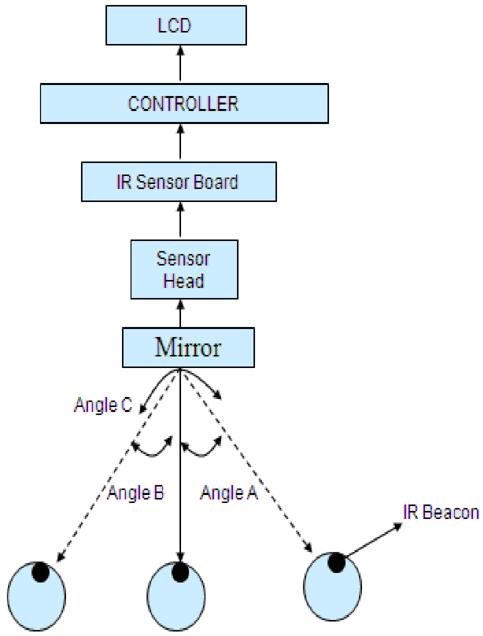

Fig 5: Block Diagram with Three Beacons

We assumed that the robot can identify these beacons and measure their position relative to each other. Such sensor information is generally uncertain and contains noise. Given the position of possibly misidentified landmarks on a 2D map of the environment and noisy measurements of their bearings relative to each other, the algorithm estimates robot's position with respect to the map of the environment.

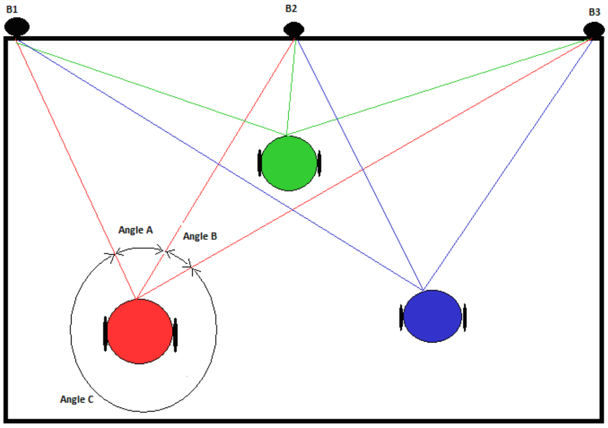

Fig 6: Graphical Representation using Three Beacons

Another approach, which we used in our final design, can also be made in which we used one polarizer and two beacons. A mirror is inclined below the IR sensor. Beacons emit IR beam which will strike on that mirror passing through the polarizer to the IR sensor. Servo is moving freely like DC motor on which that mirror is placed. IR sensor will detect the beam of two beacons and will send the signal to microcontroller, which will calculate the time consumed between two beacons and will show the parameters on LCD.

Block diagram of the design is shown in Fig 7:

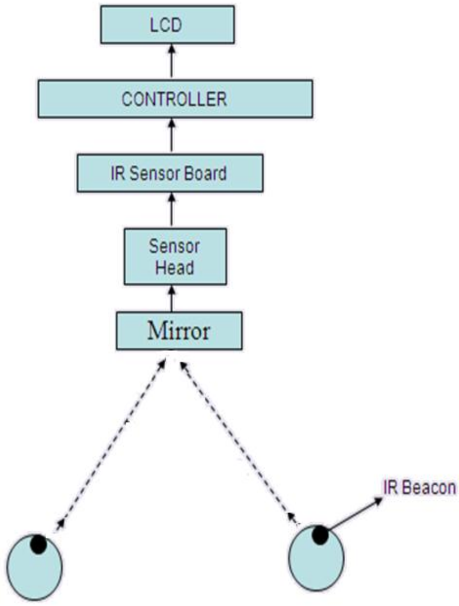

Fig 7: Block Diagram with Two Beacons

5.2 FLOW CHART

Flow chart for the design is shown in Fig 8, which is illustrating the working of the project:

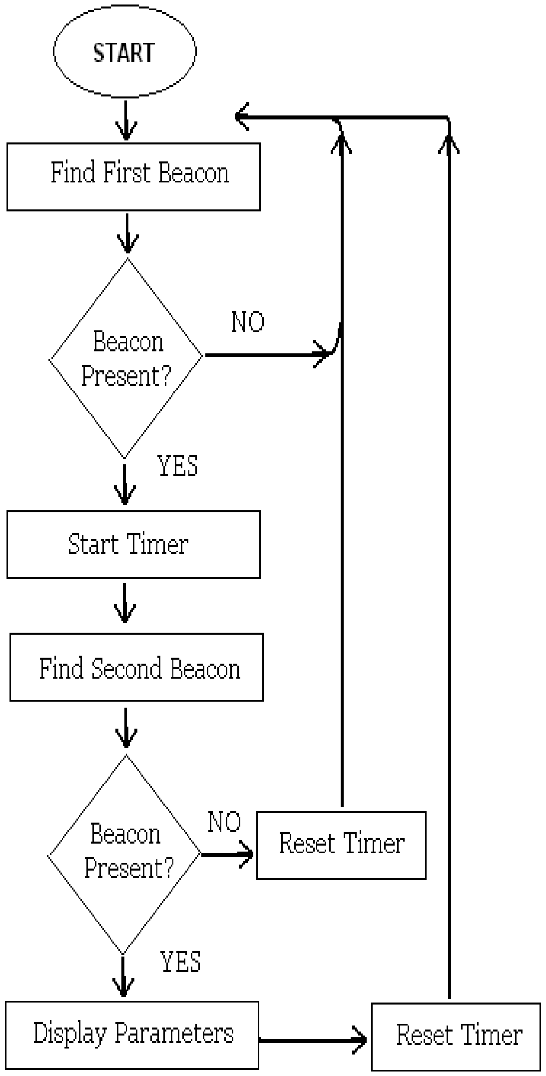

Fig 8: Flow Chart for Robot Using Two beacons

For polarization of sensors [5] first we used aluminum tubes. These tubes cover the photodiode of the IR sensor. The benefit of doing that the photodiode of receiver detect the IR only through the tube and as the tube path is narrow so the field of view of IR receiver got low. But the problem was that as IR can be detected in the line of sight so the field of view became less on both horizontal and vertical axis.

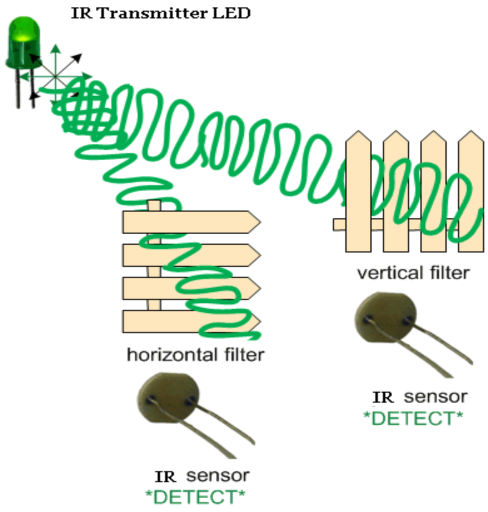

Fig. 9: Polarization Phenomenon for IR

We devised another way in which we used mirror arrangement in such a way that the IR beam from beacon first strikes the inclined mirror and then the IR receiver, which was placed in a round tube covered from all sides with the help of aluminum foil sheet except the aperture of the tube so that IR beam could pass through that opening.

5.3 VOLTAGE FLOW

Here is a complete voltage flow diagram in Fig 10, which is illustrating that how much voltage is used and how it is distributed in the whole design. We are using 12V as the main input source which is distributed to main controller board and to the servo board which is converting this 12V into 5V. The 5V source is supplied to low pass filter receiving board and to the servo motor.

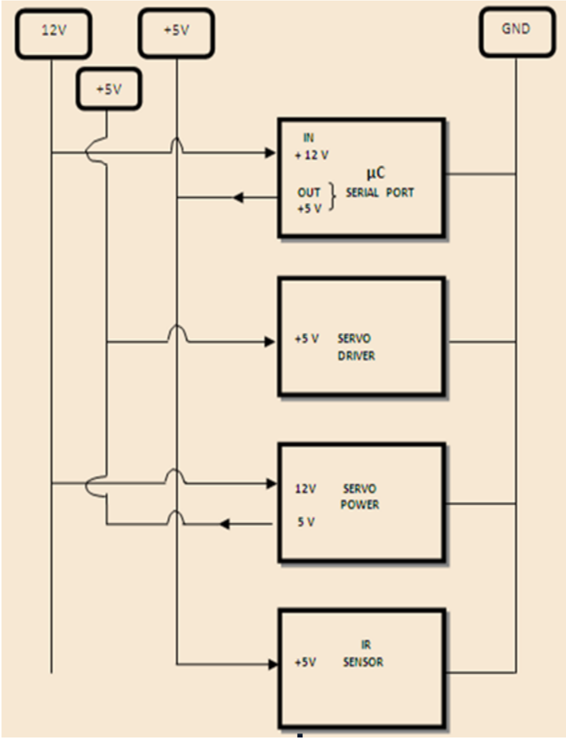

Fig 10: Voltage Flow Diagram for the Hardware

5.4 POLARIZATION

Polarization is the essential part of our project. In fact we spent a lot of our time on these issues. Polarization is an important optical property inherent in all IR waves. However, it can cause troublesome, and sometimes, unpredictable results when ignored.

There are two types of IR polarization which are stated below:

1). Wide beam polarization

2). Narrow beam polarization

Wide beam is the one which carries IR waves from all the directions and the aperture of the polarizer is relatively open and greater than the narrow beam polarizer.

Narrow beam polarization is the one which carries a thin beam of IR to pass through the aperture of polarizer. It is very sensitive; whenever a beacon transmits IR exactly in front of receiver, only then it receives the IR beam and then sends signal to the microcontroller to perform accordingly.

We have polarized our IR sensor because we need a narrow beam of IR wave; we have to be very precise in receiving it because we have two to three beacons and our receiver has to identify all of them while our servo motor is rotating.

A POLARIZATION USING ALUMINUM CAPS

As the results of polarization, using tubes was not satisfactory so we used Aluminum caps. The caps are designed such that they cover the IR sensor IC from all the sides and have an opening at photodiode side from where sensors detect the IR. The shape was chosen such that it is slanting from front to back so that IR sensor can detect the IR in vertical direction from large area. Different field of views in horizontal axis was achieved by changing the width of the opening.

The aluminum caps which were used are somewhat like the one shown in Fig 11.

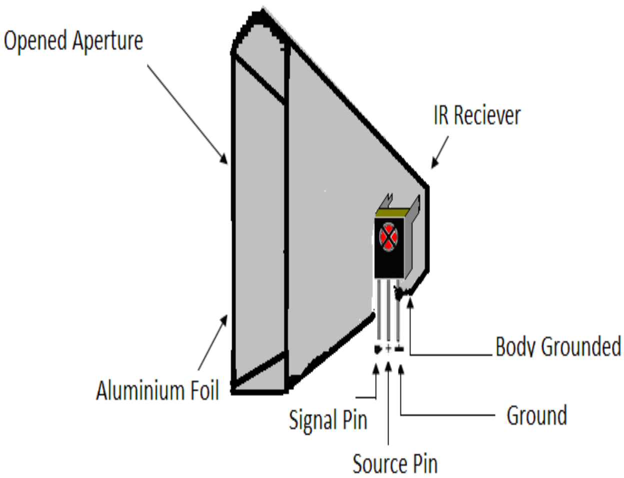

Fig. 11: Polarizer with Hood

B POLARIZATION USING MIRROR STRUCTURE

We used mirror arrangement in such a way that IR beam from beacon first strikes the inclined mirror and then to the IR receiver which was placed in a round tube which was covered from all sides with the help of aluminum foil sheet except he aperture of the tube so that IR beam could pass through that opening. Here is a picture of that polarizer.

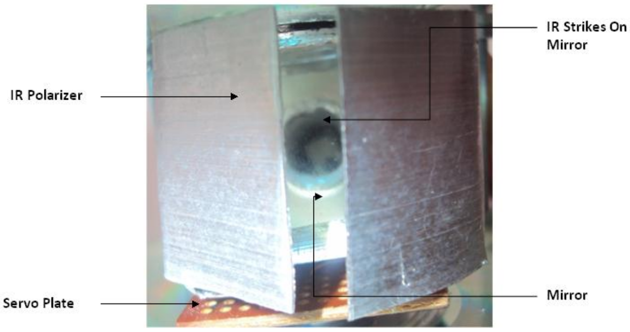

Fig. 12: Polarizer with Mirror Structure

5.5 IR TRANSMITTER

For the high intensity signal and smaller size we have designed our own IR transmitter which transmits IR ray of 38 KHz. In Fig 13, actual picture of IR transmitter is shown:

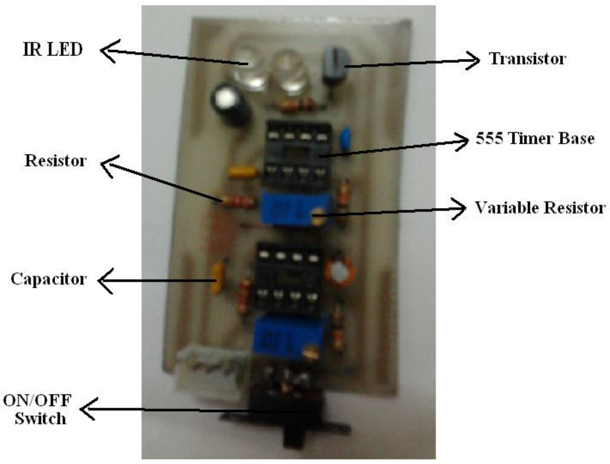

Fig. 13: Picture of IR Transmitter

A transmitter produces rapid pulses of IR in specific patterns, which a receiver can interpret. We use IR for human to machine communication on a daily basis; that's how television remotes work. The circuit diagram for IR transmitter is given below in Fig 14, which shows how transmitter works:

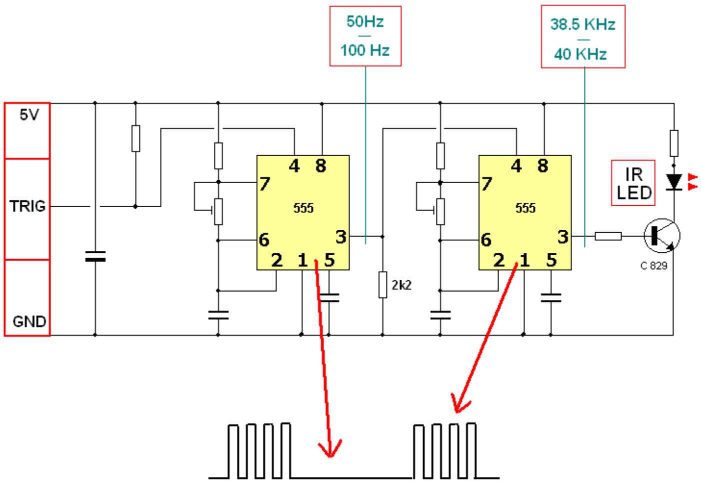

Fig. 14: Circuit Diagram of IR transmitter

Two 555 timers are used. The first 555 generates pulses of about 1.5 m sec duration, with 30 m sec interval (signal frequency is about 32 Hz). The second timer 555 timer IC generates the carrier signal, which is 38 KHz. This carrier signal is generated by using resistor and capacitor combination. The transistor switches the carrier signal (38 KHz) on and off, according to the previous (32Hz) signal. These two signals are then modulated with the transistor. This means, one timer creates 38 kHz carrier frequency and the other creates 4 Hz, these signals overlap each other with the help of transistor and the output comes out to be an IR burst. An oscilloscope representation is shown in Fig 15.

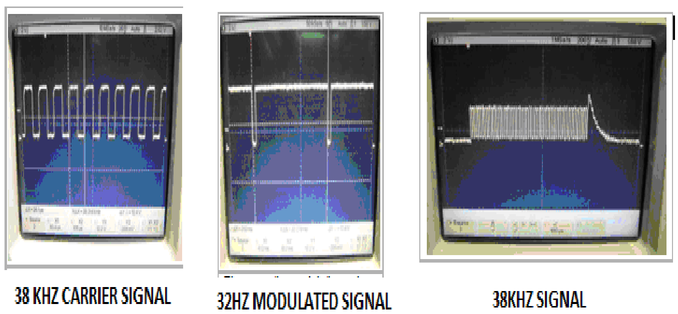

Fig. 15: Oscilloscope representation of Signals

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Following is shown a comparison of already present transmitters' speed with the one which we made. It can be seen that the speed of RC5 is very slow while the speed of transmitter that we made has relatively high speed.

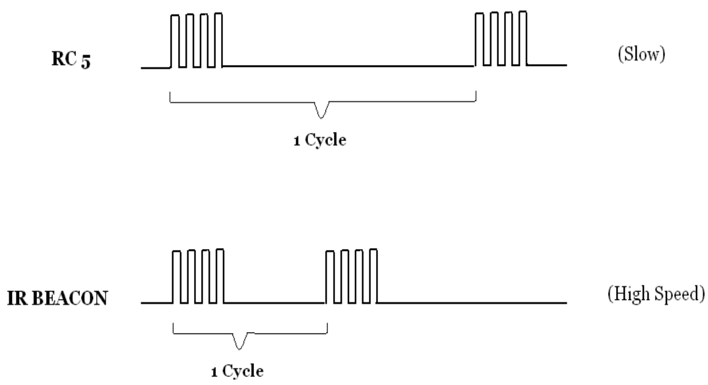


Fig. 16: Comparison of speed of RC5 and IR beacon

5.6 IR RECEIVER

The IR receiver will receive the desired signal which the transmitter will transmit. In our proposed system, the transmitter will keep on transmitting the signals until the receiver detects the pulse and when the IR receiver detects the pulse it makes, it will give a signal to the controller board which will then govern the servo and will perform calculations etc.

IR receiver has 3 legs, left most indicates the signal, middle is the source and the right most indicates the ground as shown in Fig 17:

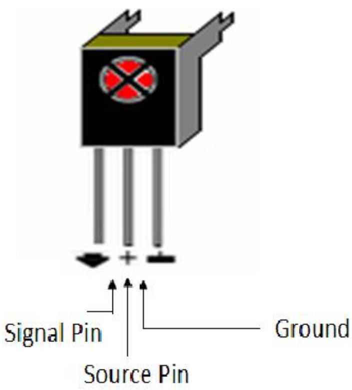
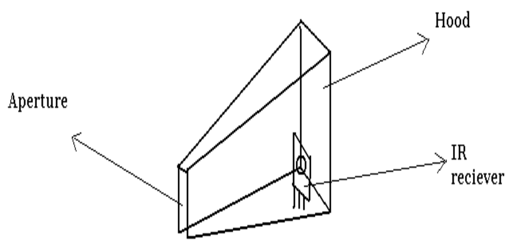


Fig 17: IR Receiver

The figure below shows IR encapsulated in an aluminum sheet. The purpose of encapsulating the IR is just to have a line of sight clear of obstacles. So that when the input (low pulse) is given, the IR receiver present in the foil detects the signal easily.



5.7 MECHANICAL MODIFICATION OF SERVO INTO FREE ROTATION

We have to modify a servo to move freely, as to complete our task in robotic localization we have to cover the full surrounding for polarizer to find IR beacon so we will modify the servo to move freely and then program it accordingly to move at any angel we require.

There are actually only two modifications to make to the servo:

1. Replace the position sensing potentiometer with an equivalent resistor network

2. Remove the mechanical stop from the output shaft

On opening the casing of the servo motor, following parts will be seen in it; these include DC motor, potentiometer and gear as shown in the Figure:

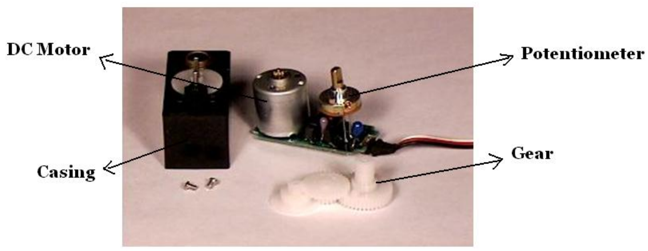
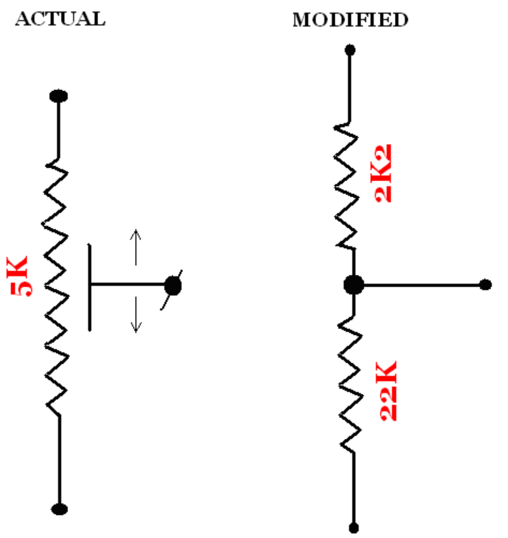


Fig. 18: Internal View of Servo

Now for the actual modifications, we need to desolder the potentiometer from the board. Once the pot has been removed, we need to wire in the resistor network in its place.



As seen in the picture below, the pot has been replaced by the resistor network.

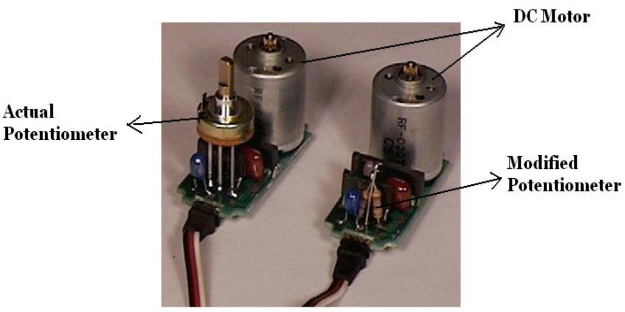
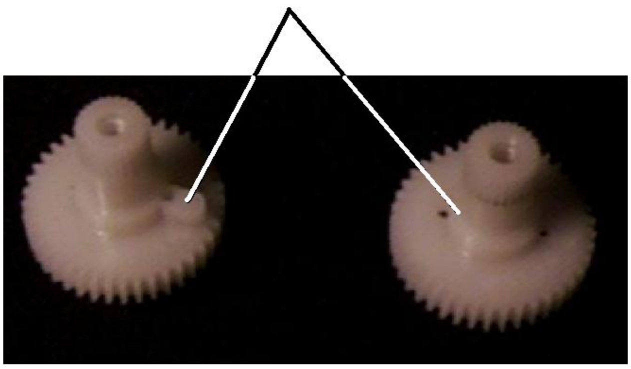


Fig 19: Actual Picture of Servo Board with Pot Replaced

Before reinstalling the gears, you will need to modify the gear with the output shaft so the mechanical stop is removed. The mechanical stop is a small tab of plastic on the lower gear surface. In the picture below, you can see the tab on the left gear. This should be cut down flush with the surface so as to get the entire tab removed as is shown with the gear on the right side.



The gears were then replaced as they were when taking the motor apart, along with the top of the case, the bottom plate, and the two screws.

The motor should now be able to turn all the way around.

5.8 FINAL HARDWARE

Final hardware design is shown below in Fig 13:

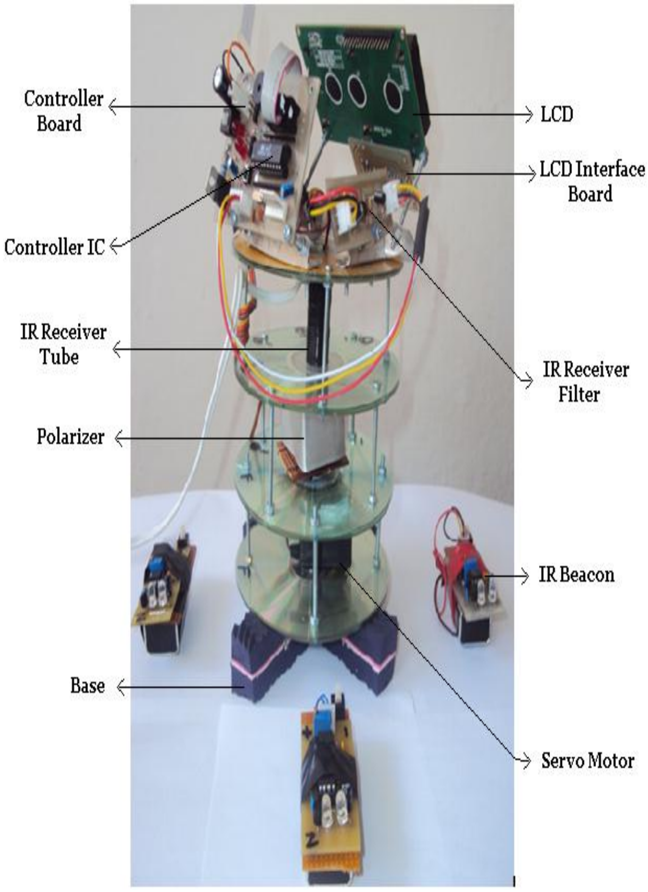


Fig. 13: Final Hardware Design

6 APPLICATIONS

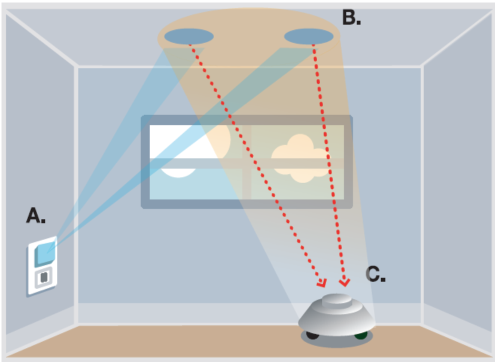
Localization is a critical issue for many field robotics applications. In outdoor environments, differential GPS systems can provide precise positioning information. There are many applications, however, in which GPS cannot be used, such as indoor, underwater, extraterrestrial, or urban environments.

Application of robots employing navigation through sensors instead of a central GPS technology can aptly be categorized under smart applications. The use of fuzzy logic in robot navigation can enable robots to make navigation or piloting decisions like humans, self correcting the errors without any need of human input [6]. One smart application of such smart technology might be for use in a collision avoidance system in power wheelchairs [14]. Although more complex sensing would be needed in case of avoiding dynamic obstacles, but the research design can easily simplify the obstacle avoidance system to cater for fixed obstacles in the environment semi automating the wheel chair to aid the disabled.

Robots that can work in several environments bring in the need of a new sensor and a navigation system for each environment. This might also bring in the need for a different hardware architecture for successful navigation in each type of environment [15]. The design of this robot, however, avoids this. Whatever the environment is, as far as it is compatible with infrared transmission, the infrared beacon as a technology can be standardized over a variety of environments for different applications and easy navigation. As such, the researched design forms a whole catalogue of applications rather than just the ones listed. Whether to be used for simple domestic tasks, or for military applications, the pre-placed beacons help the robot navigate the area with low investment on equipment such as processing, memory and sensing hardware. This also makes this robot more suitable for operations which risk destruction of robot; such as mine sweeping operations, aiding in fire rescue navigating controlled area for surveillance where the only use of camera would be to transmit record images not as a robot's functional component.

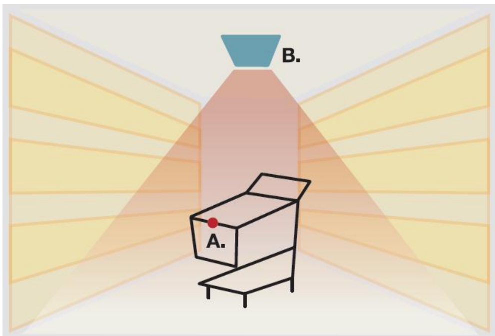
6.1 MOBILE DEVICE NAVIGATION

- ❖ Reliable and direct return to re-charging station
- ❖ Multi-room systematic navigation
- ❖ Instantaneous recovery from theft
- ❖ Efficient and thorough floor coverage



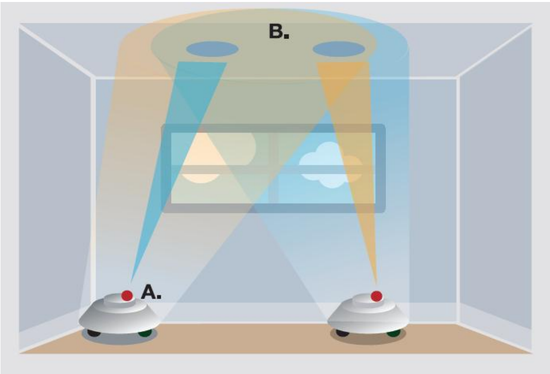
6.2 ASSET TRACKING

- ❖ Asset tracking in warehouses, malls, stores, etc.
- ❖ Motion tracking of people
- ❖ Mobile consumer devices



6.3 MULTIPLE DEVICE NAVIGATION

- Parallel coverage, patrol, and surveillance
- Clandestine inter-robot communications
- Navigational coordination



7 COMPARATIVE ANALYSIS

Robotic navigation is a much covered topic in research, proving to be a hot research topic. On one hand the robots are being programmed to work accurately and logically while on the other, they are needed to 'think' fuzzy like humans to perform better in their specific applications. Whether this is for smoother movements or for taking smarter decisions where an unsure decision is needed, making robots perform like humans is of significant use [6]. Such designs use fuzzy logic like the one employed in the current design where the robot uses beacons to evaluate its position. Such navigation is not a sure decision; as the robot moves forward the values representing, for example, forward speed will change with respect to the thrust needed to move sideways to avoid a collision. The fuzzy logic here takes into consideration these changing values and readjusting variables like thrust to make human like decisions [6]. This design can gain the same advantage at a much reduced cost with much less expensive sensors to create the same kind of logical inputs for the robot to evaluate. Where complicated sensors were to be used with complex image processing involved for image sensing and evaluation and intensive programming to compute in the situations [7] or where laser sensors were used to accurately navigate building areas [8], simple IR sensors that allow the robot by making decisions in accordance with the beacon placement can be much less costly in comparison.

The case of laser sensors can also be compared by another approach with the design in this research. A robot using laser sensors will have to recreate a logical map of the environment which will take approximately 30 minutes to 2 hours [8]. Comparing this with the design under research, the robot does not need to create complex maps to carry out the navigation, instead the robot will scan the beacons in run time and take more humanistic decisions as it works its way through. With this logic in consideration, it can be safely said that the technology bypasses the need to recreate complex mapping in the memory and hence is an improvement of design per se.

Using minimal sensors has gotten much research attention to decrease complexity in robotics [9] even though sensors are one of the basic components of a robot [10]. The use of infrared sensors for navigation has found its way into robotics as a common sensing application [11]. Robots, now, are not only used for interaction with humans but also with each other so as to work in pairs [11]. As mentioned previously in this research paper, this design enables the robots for inter-robot communications that do not need to involve humans as a result being quicker and bypassing hassle. Invention complex biometric sensors might get a new set of advantages enabling the robot to detect more accurately using a wider range of sensors and integrating them together to further analyze information of all different forms of media [12], but some times it might just be easier to use a single type of homogenous sensors which make the processing much faster and reduce the decision making time. The homogenous signal reception by the sensors allow the robot to process a single kind of information employing much efficient and faster processing technology to safely navigate. Research literature focuses on attuning sensors to track things in the environment [12], the design however has the advantage of homogenous IR sensors which do not need to employ this. Electronic consciousness on one hand might be the name of complex sensing ability or processing technology, but the robot design in this research employs homogenous sensing to achieve the same electronic consciousness much explored in fiction [13].

In comparison to advanced research literature robotics, the designed robot involves modifications of servo motor and usage of locally available infrared sensors to achieve tasks much more cost effectively. Thus, it can safely be assumed that the research on this design as successfully provided a cost efficient robot with minimal processing requirements and human like functionality.

8 CONCLUSION

We have achieved our goal and have made a robotic structure which can locate its position anywhere in the range of beacons placed around. We are using two beacons for completion of our task. When beacons are off, robot will scan for the beacons – when both beacons are switched on, receiver will identify both of them. A mirror is inclined below the IR sensor. Beacons emit IR beam which will strike on that mirror passing through the polarizer to the IR sensor. Servo is moving freely like DC motor on which that mirror is placed. IR sensor will detect the beam of two beacons and will send the signal to microcontroller, which will calculate the time consumed between two beacons and will show the parameters on LCD.

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