A Beacon-based Docking System for an Autonomous Mobile Robot

K. Varun Raj*, Kiran Patil, D.V. Kaushik Kariappa,and Amit Madhav Jakati
E&C Department, M.S.Ramaiah Institute of Technology, Bangalore-560012

* Corresponding author (email: varunrajk@gmail.com)

Abstract

We propose an autonomous docking system for a mobile robot which helps the robot to dock at a specific location with a particular orientation. This system uses active IR beacons which transmit infrared signals all through out the workspace. The beacons are placed in such a way that the docking target forms the midpoint of the line joining the beacons. The robot is equipped with an Ultrasonic Range Meter (SRF05) and a set of infrared receivers. The robot, using all its sensors, detects the beacons and successfully reaches the docking-target with the required orientation. Several experiments are conducted and the results prove the efficacy of the docking system.

Keywords: Beacon-based docking system, IR beacons, SRF05 range sensing, triangulation, automatic charging.

1 Introduction

Docking is essential for a mobile robot that is required to perform precise interactions. Industrial forklifts, mobile manufacturing assembly robots, and rescue robots all need to move to an object of interest and dock with it to carry out their tasks. Docking can be defined as moving from the current position to a desired position and orientation, while following a safe trajectory [1]. The final position and orientation of the robot must be adequate for the tolerances required by the particular task. A definition more suiting would be, a robot should move as near as possible to a target surface, without colliding with the target, and align its viewing direction with the normal to the surface [2].

One immediate application of the docking system is automatic recharging. As the robots are being purchased by private homes to perform household tasks such as cleaning, they have to be cheap, compact, and multi-functional. Many researchers around the world are addressing this problem [3]-[7]. Authors in [3] and [4] discuss methods for automatically recharging the batteries on the mobile robot. Large number of expensive sensors such as laser, sonar sensors or camera were used which increase the overall cost of the robot. In [5] and [6], recharging capabilities to achieve long-term autonomous mobile robot control are presented. Authors in [7] used a single beacon and cheap infrared sensors to achieve the docking operation. But its application is limited to automatic recharging.

In this paper, a new beacon-based docking system is presented. Here the beacons form the landmarks through which the pose of the robot is determined. The robot, using IR beacons, with the help of a range sensor (e.g. Sonar) can detect where these beacons are located. Based on the position of the beacons, using the concept of triangulation, the robot orients itself normal to the line joining the beacons. Thus it reaches the required docking location with proper orientation. This approach opens up a lot many applications than just automatic recharging.

The paper is organized as follows. In Section 2, The design of the robot platform used for implementing the algorithm is presented. Docking system algorithm is discussed in Section 3. Implementation of the algorithm is explained in Section 4. Section 5 discusses some of the important applications of the docking system algorithm. Results of the experiments conducted on the robot are discussed in Section 6. The paper concludes with some remarks and directions for future work.

2 Design of the Robot Platform

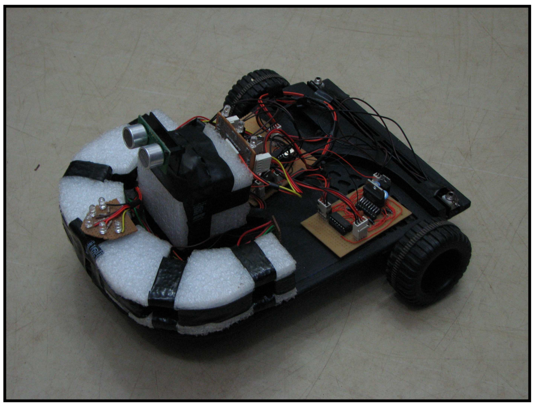

Figure 1: Robot built for experimentation.

The robot's mechanical structure is constructed using hard plastic to make it light weight. Two plastic wheels with rubber rims and one caster wheel are used for the robot's locomotion. It is designed to move on the flat and smooth surfaces. Some of the factors that influenced the architectural design of our robot base include mechanical/control simplicity, reduced overall mass, efficient sensing mechanism (which must combine only a few sensors), re-configurability, and importantly an economic solution (in order to build a large number of such robots while still keeping the total cost within a manageable budget). The vehicle can carry sensors and a payload which allows users to configure it with various hardware modules depending on the application requirements. We have used the differential steering principle for steering control. Geared DC motors with 60 RPM are used in this robot. The drive electronics of each robot has provision to run two DC brushed motors. The IR receivers are placed in such a way that they are oriented in one half plane of the robot with each IR sensor's field of view of about 36 degrees. Figure 1 shows the robot with ultrasonic sensor and IR sensors housed into it. The mechanical specifications of the platform are shown in Table 1 .

Table 1: Platform mechanical specifications.

Dimension	*Length*	290mm
	Width	190mm
	Height	50mm

2.1 Onboard Computing

The robot is fitted with Microchip PIC micro-controllers which hosts the control software. PIC 16f84a is used for controlling the motor outputs and also receives input from all the IR sensors. The main algorithm is executed in this micro-controller. Another micro-controller PIC 16f877a is used in ultrasonic driver module. This module generates a high signal if an obstacle is present within its field of view and low signal otherwise. This chip generates the required trigger signal for the ultrasonic sensor and also a PWM signal for the motors.

2.2 Power Source

In order to achieve isolation between logic and drive powers, two separate multi-volt DC adapters are used. A constant regulated power supply of 5V to the micro-controller and other digital circuitry is provided by the adapter through a 7805 voltage regulator.

3 Beacon-Based Docking System Algorithm

We present a new algorithm which makes the robot to perform a successful docking operation. The robot first detects where the beacons are located on the field and then advances towards them. No complicated IR intensity measurements are used for the detection of the beacons. Instead, beacons are detected using the combined information from both ultrasonic range sensor and the infrared sensors. The docking algorithm consists of two modes of operations:

1. Seek source mode.
2. Beacon recognition mode.

3.1 Seek Source Mode

When the robot is powered on, it performs the seek source mode operation. In this mode, based on the signal received by the IR receivers housed in the robot, it will align itself in the direction of any one of the beacons and moves towards that beacon. The selection of the beacons is arbitrary and depends on its initial position and orientation. The following steps are performed by the robot in this mode:

1. Check for central IR receiver, if it receives signal then go straight.
2. Else, check the left IR receivers, if it receives the signal then turn left and go to step one.
3. Else, check for right IR receivers, if it receives the signal then turn right and go to step one.
4. If none of the IR receivers are receiving signals then turn right by default and then repeat step one.

3.2 Beacon Recognition Mode

The robot enters into this mode of operation when it recognizes the beacon based on the combined information from ultrasonic sensor and infrared sensors. This mode is used by the robot to register the beacons detected. The algorithm is sequential with respect to this mode. Once a beacon is recognized the robot shifts to a different state. The following steps are performed by the robot in this mode:

1. Check for central IR receiver and check for ultrasonic sensor, if both sensors give high signal then beacon is detected.
2. Else, beacon is absent.

If the robot is within 1m radius of beacon then the sonic ranger detects an obstacle, and also the central IR receiver will indicate a presence of source in front of the robot. This information by both the sensors indicates the presence of the beacon. Any other logic combinations of these two sensors would only indicate that there is either an obstacle in front or not.

4 Implementation

This section discusses about the detailed working of the algorithm. When the robot is powered on, it shifts to the seek source mode. As discussed in the previous section, the robot starts to search for a beacon by rotating about itself till it points towards one of the two beacons. The beacon it selects to seek is completely dependent on the information it gets from the IR receivers placed in the front bunker of the robot. If the left IR receivers receive the signal then the robot turns left and if the right IR receivers receive the signal then the robot turns right till its heading direction points at a beacon. The robot starts to move towards the first beacon it selects. At times, there might be a situation when the robot might end up in an oscillation seeking both the beacons. The solution to this problem is implicit. A small noise in the system will have the robot shift from that situation back to the normal Seek-Source mode. The mode is illustrated in the Figure 2.

As shown in the Figure 2, the robot selects the left beacon and moves towards it. The robot will meet the 1m circle boundary at one of the points shown by the green colored arrow. As it reaches the 1m circle boundary of the beacon the Seek-source mode ends and state shifts to Beacon-Recognition mode. The robot registers the detection of first beacon. This is illustrated in the Figure 3

Now, the robots searches for the second beacon. To do this, the robot turns for a small amount of time to avoid recognizing the same beacon as the second beacon. Then, it goes back to Seek-source mode. Although it has gone back to the previous mode of operation, it is not shifted back to the previous state but shifted to a new state. In this state the robot performs the operation of Seek-source mode and searches for the second beacon. When found, it moves towards the beacon. This is illustrated in Figure 4.

The robot while moving towards the second beacon, it will meet the second 1m circle boundary at one of the points shown by the double sided arrow in the Figure 5. Once the robot reaches the second circle boundary, the robot detects an obstacle in front of it. The robot then shifts back to the Beacon-Recognition mode and recognizes the second beacon. We can observe geometrically that the robot is almost close to the voronoi partition between the two beacons.

The robot is now oriented in some direction which is not normal to the line joining the beacons. So, the robot starts to rotate about itself till it is directed along the angular bisector of the triangle, formed by the beacons and the robot, which is very close to the perpendicular bisector of the line joining the two beacons (observed by geometry). This information about the angular position of the robot is calculated based on the signal received by the IR receivers housed in the robot. This is illustrated in the Figures 6 and 7. Once the robot reaches this orientation, it moves in straight line until the extreme IR receivers receive the signal. When this happens, the robot has reached its docking target, which is the midpoint of the line joining the two beacons, with the required orientation. This is illustrated in Figures 8 and 9.

4.1 Three-Beacon Convergence

This is basically an extension of two-beacon concept. In the two-beacon problem, there are two symmetrical spaces about the beacons. So, the robots lying on either sides of the beacons will converge differently at the docking target. Although, this concept has few important applications, there are tasks where the convergence has to be unique. This can achieved by just using another beacon along with the previous two beacons and all the three being placed on the vertices of an equilateral triangle. The robot first uses the 2 bea-

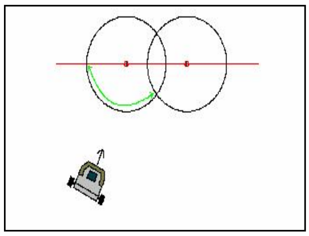

Figure 2: Seek-Source mode.

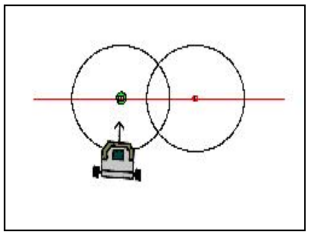

Figure 3: Beacon-Recognition mode.

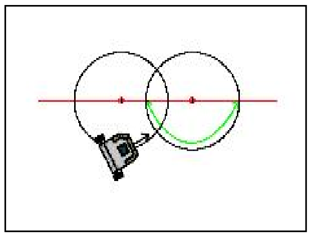

Figure 4: Seek-Source mode.

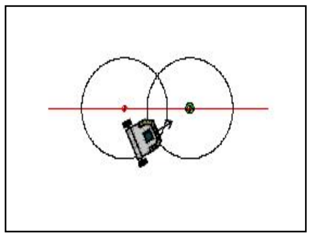

Figure 5: Beacon-Recognition mode.

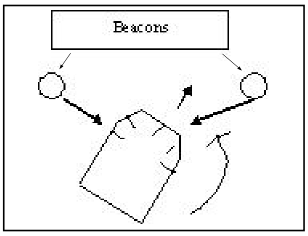

Figure 6: The robot calculates its orientation based on the direction of IR signals coming from the beacons.

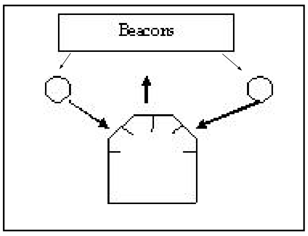

Figure 7: Robot attains the required orientation using triangulation.

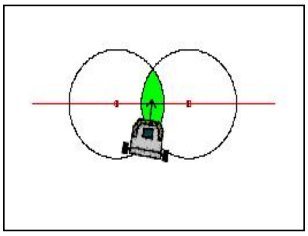

Figure 8: Robot starts to move towards the target.

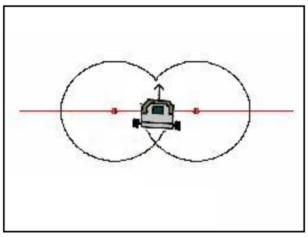

Figure 9: Robot reaches the target.

con docking concept to attain the midpoint of the line joining the beacons with direction normal to the line. Then robot moves on till it finds the third beacon. The advantage of this three-beacon convergence is that the robot placed anywhere in the plane will reach that point. Figure 10 illustrates the three-beacon convergence concept.

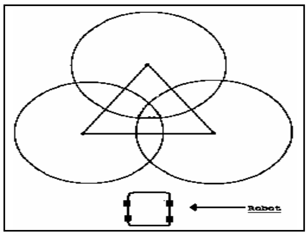

Figure 10: Beacon-Recognition mode.

5 Applications

There are variety of applications which can make use of the algorithm presented in the paper. The usage of two beacons opens up many applications of which few are discussed below:

1. Autonomous Battery charging capabilities for a mobile robot.
2. Agent-Deployment and transport system for a mobile robot.

5.1 Autonomous Battery Charging Capabilities for a Mobile Robot

With robots being more autonomous these days, it becomes necessary for them to check their power needs by themselves while performing other operations. If the battery gets depleted, the robot needs to locate the charging station and dock to it. It can make use of the algorithm presented in this paper to reach the docking station and dock to the charging unit till the batteries are completely charged. Then it can carry on to perform its previous operation. If there are more robots and fewer docking stations, there could arise a problem of collisions and confusion between these robots. In order to solve this, the robot communicates with the docking station and finds out whether it is vacant. If it is vacant then the robot registers to use the charging unit. If there is already another robot seeking, the requesting robot must wait until the first robot has reached the station before beginning to navigate to its allocated bay.

5.2 Agent Deployment and Transport System for a Mobile Robot

In some scenarios where in the robots have to explore the hostile area, the carrier robot which is equipped with all the sensors and communication unit cannot be risked and therefore smaller inexpensive bots have to be used to do the exploration. In order to transport the bots to the hostile area, the carrier robot can make use of the algorithm presented in this paper. The docking target is now the point where the agents are to deployed. This is illustrated in Figure 11. On reaching the docking target the carrier robot deploys the bots, and the bots perform the task they are assigned. After the completion of the tasks, these bots reach the carrier robot by making use of the same concept where the carrier robot happens to be the docking target. The carrier robot then carries these bots back to the base. This is illustrated in the Figure 12.

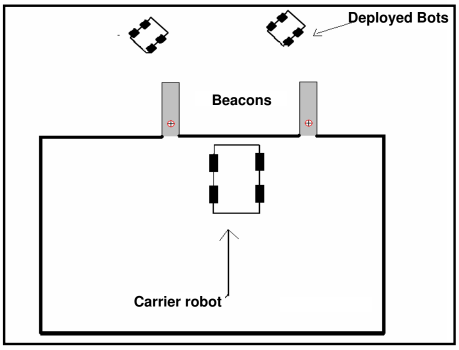

Figure 11: Carrier robot deploying smaller bots.

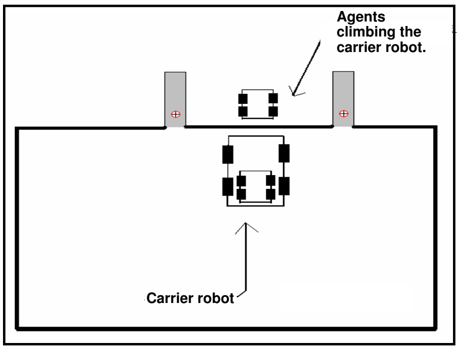

Figure 12: Smaller bots climbing back the carrier robot.

6 Experimental Results

We conducted variety of experiments to prove the efficacy of the algorithm. Experiments are conducted for various beacons placements, and different robot positions. The observations of the experiments are tabulated as shown in Tables 2-3. Table 2 shows the convergence of the result with the beacons being placed 1.5mts apart. The workspace is divided into three regions - left region, central region and right region as shown in the Figure 13. The robot is placed at

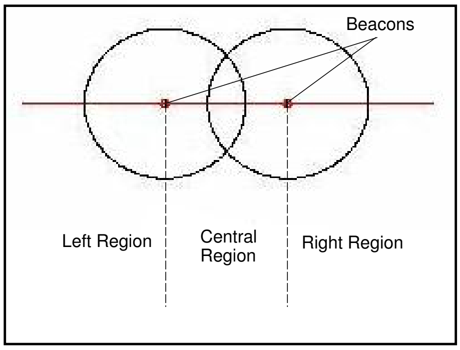

Figure 13: Workspace is divided into three regions.

random locations with random initial orientations. Statistics shows that the mean and standard deviation of robot's final position (from the left beacon) is 74.42cms and 2.64cms respectively. Table 3 shows the convergence of the result with the beacons being placed 2mts apart. The mean and standard deviation of robot's final position (from the left beacon) is 99.83cms and 2.79cms respectively. Snapshots taken from one of the experiments are shown in Figures 14-19.

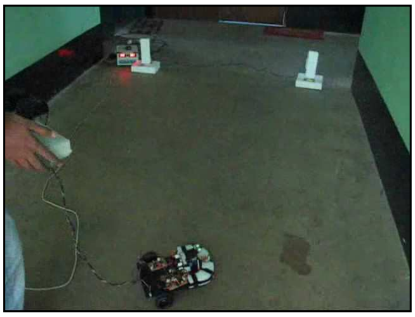

Figure 14: The robot is placed randomly in the workspace.

Figure 15: It starts moving towards the right beacon

Figure 16: Right beacon is recognized

Figure 17: The robot searches for the second beacon

Figure 18: It recognizes the second beacon

Figure 19: Achieves the required orientation

7 Conclusion

What we propose as a docking system for a mobile robot is an inexpensive and very simple one. It just uses a set of IR trans/receivers and one ultrasonic range sensor which are easily available and inexpensive in the market. The problem of three-beacon convergence is a very useful and interesting one. It will be interesting to see the behavior of multi-robot algorithms using this docking System. The paper first covers about building and design of the robot and then in the later section the design of the docking system is presented. A set of IR transmitters are used in the beacons to emit signal in all directions in the workspace. A bunker housing in a set of 5 IR receivers are used to receive the IR signal. The ultrasonic ranger SRF05 gives us information about the obstacles present in its field of view. This combination of sonar and IR sensor makes it possible for a robot to dock to the target. Lastly, the paper presents experimental results along with snapshots taken from an experiment.

Table 2: Observations for distance between the beacons being 1.5mt apart. Final position is measured from left beacon

Initial Position	*First beacon sought*	*Final position*
Right region	*Right beacon*	77cms
Right region	*Right beacon*	77cms
Right region	*Right beacon*	79cms
Right region	*Left beacon*	74cms
Center region	*Right beacon*	75cms
Center region	*Left beacon*	74cms
Center region	*Left beacon*	73cms
Center region	*Right beacon*	75cms
Left region	*Left beacon*	71cms
Left region	*Right beacon*	76cms
Left region	*Left beacon*	72cms
Left region	*Left beacon*	70cms

Table 3: Observations for distance between the beacons being 2mt apart. Final position is measured from left beacon

Initial Posittion	*First beacon sought*	*Final position*
Right region	*Right beacon*	98cms
Right region	*Right beacon*	99cms
Right region	*Right beacon*	98cms
Right region	*Right beacon*	98cms
Center region	*Right beacon*	97cms
Center region	*Left beacon*	104cms
Center region	*Left beacon*	103cms
Center region	*Left beacon*	105cms
Left region	*Left beacon*	101cms
Left region	*Right beacon*	97cms
Left region	*Right beacon*	98cms
Left region	*Left beacon*	100cms

References

[1] R.C.Arkin and R.R. Murphy, ”Autonomous navigation in a manufacturing environ-ment.,” IEEE Trans. on Robotics and Automation, 6(4): 445–454, August 1990.

[2] P Questa and G Sandini, ”Time to contact computation with a space-variant ret-ina-line c-mos sensor.”, in Proceedings of the International Conference on Intelligent Robots and Systems, Osaka, Japan, 1996.

[3] Oh, S., Zelinsky, A., and Taylor, K., ”Autonomous battery recharging for indoormobile robots”

[4] Silverman, M.C., Nies, D., Jung, B., and Sukhatme, G.S., ”Staying alive: a docking station for autonomous robot recharging,” IEEE International conference on robotics and automation, pp. 1050-1055 (2002)

[5] Hada, Y., Yuta, S., ”Robust navigation and battery recharging system for long term activity of autonomous mobile robot,” International conference on advance robotics, pp.297-302 (1999)

[6] Hada, Y., Yuta, S., ”A first experiment of long term activity of autonomous mobile robot result of repetitive base-docking over a week,” International symposium on experimental robotics, pp. 235-244 (2000)

[7] K. H. Kima, H. D. Choia, S. Yoona, K. W. Leea, H. S. Ryub, C. K. Woob, and Y. K. Kwaka, ”Development of Docking System for Mobile Robots Using Cheap Infrared Sensors” 1st International Conference on Sensing Technology November 21-23, 2005 Palmerston North, New Zealand