Dual Mode: Establishing a Line-of-Sight Communication and Object Detection using Infrared Sensor Module

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Abstract

Miniature wheeled mobile robot is a very reliable and feasibly cheap material for robotic research. The cheap mobile robot can be repurposed for other task. This paper especially highlights the implementation of mobile robot for navigation. One of the purpose of navigation is to avoid collision. One of the most prevailing usage for object avoidance is infrared module. However, infrared signal can also be used for direct communication. In this paper, a dual mode function of infrared sensor module is presented. Using the same infrared module, communication and object detection are established. The proposed infrared module and switching algorithm are applied to a group of Arduino powered wheeled mobile robots. Preliminary lab-scaled tests show that the solution proposed in this paper perform well. Using an artificial experimental setup, the result shows that 19 out of 20 experiments (at 95% probability) were successful of detecting an object. The result also shows that 18 out of 20 simulations (at 90% probability) were able to successfully conduct a communication.

Keywords: Infrared sensor; Line-of-sight communication; Object avoidance; Switching algorithm; Wheeled mobile robot

1. Introduction

The use of robots in industrial complex is rising together with the ripe of robotic technology. Swarm or multi robots were one of the concepts born from that technology. The main reason of using multi robots is the aspect of economic efficiency [1]. With additional communication feature, the performance of those small mobile robots may outrun the one from a single sophisticated robot unit yet expensive to produce [2]. However, communication becomes a quite significant hurdle for multi-robot system, due to its limited technical specification [3] [4]. Some potential use of multi robots, has been suggested by a couple of researchers, including:

1) With the accumulation of sensing from multi robots, area recognition can be achieved faster and over wider coverage [5] [6];
2) With a large number of robots, the failure of one robot will not affect the completion of a task [4];
3) The weight to perform one task will be smaller, since it is distributed among robots [7] [8].

Doan, et.al [9] utilized wireless Bluetooth module HM-10 to accompany infrared module for communication. Bug algorithm was used as planner for managing robot's sensors. Infrared sensor module was used by Vitanza, et.al. [10] to sense distance and to communicate among robots. The communication utilized a Pulse-Position Modulation protocol. The whole system was applied onto Thymio robot, an open hardware based robotic platform.

Another open-source robotic platform called Mona was used by Hu, et.al. [7] [11] for researching inter-robot and robot-base communication. The communication was supplemented with radio frequency communication for enhanced robustness. Radio frequency was also used by Agajo, et.al. [12] on their Arduino nano-based 4-wheeled robots. A different approach was conducted by Reina, et.al. [13] which involved developing a virtual pheromone from infrared module. They used Kilobots as experimental robotic platform.

Those researches presented the challenges of multi-robot communication, since different approach or setup was used for both navigation and communication. In this paper, the authors propose a dual-mode implementation of infrared module for both object detection (and subsequently object avoidance) as well as direct line-of-sight communication. For that purpose, an algorithm for switching between object detection and communication is also developed.

This paper is organized as follows: the first part of this paper is an introduction, where the motivation of the research is presented. It is followed by the proposed infrared module and the methodology used to design the switching algorithm between modes. In part II, the mobile robot platform, infrared module and the switching algorithm is presented. The result of the research is detailed and discussed afterward in part III. Finally, this paper is ended with conclusion.

2. Method

2.1. Mobile Robot Platform

This research uses the previously built mobile robot platform [14], e.g. Figure 1, which incorporates an Arduino-based microcontroller board as the processing source. Arduino-based mobile robot is gaining momentum in mobile robotic research albeit the less powerful processing capabilities [15] [16]. Figure 2 shows the robotic system's block diagram. Each mobile robot is powered by four type 18650 batteries and given a unique ID that will be transmitted among robots during communication.

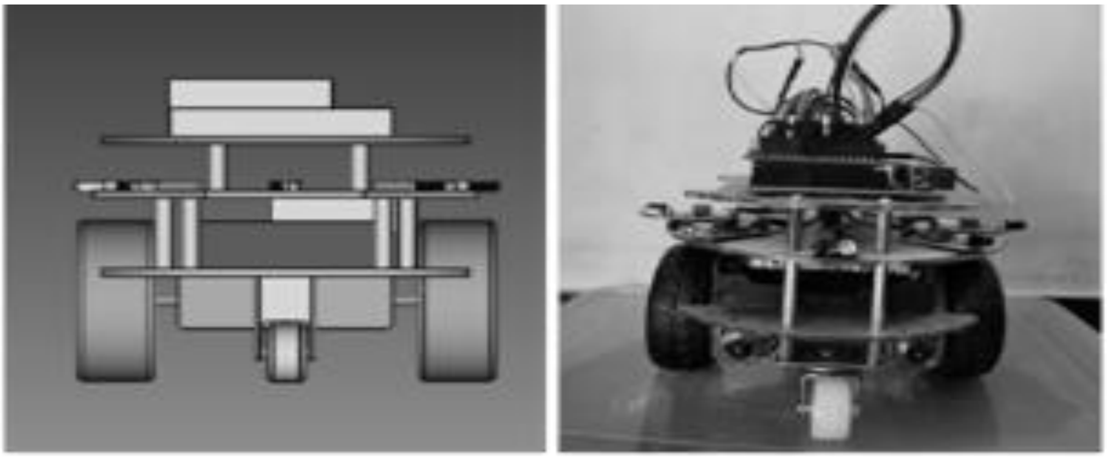

Figure 1. Mobile Robot Platform used in this Paper [14]

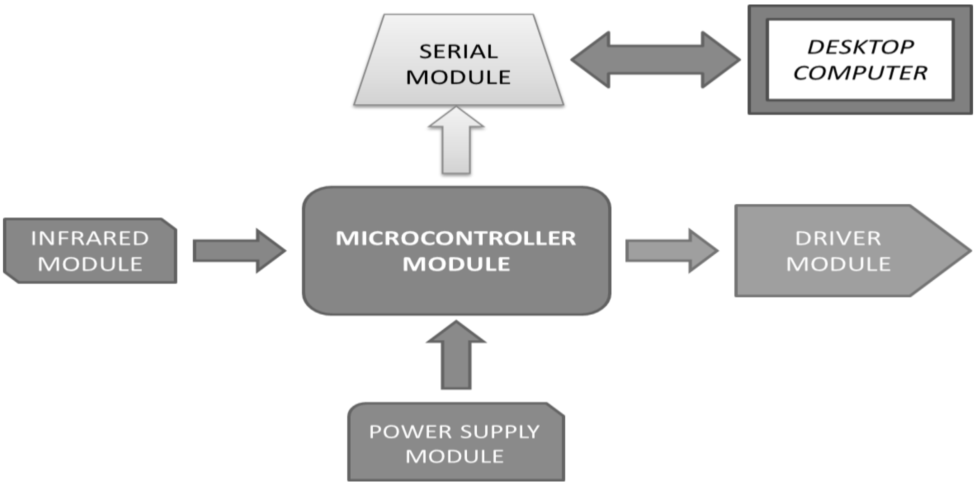

Figure 2. Block Diagram of Mobile Robot Platform

2.2. Infrared Module

Figure 3 shows the layout of the placement of the infrared modules on the mobile robot platform. Each module is given an identification for convenience purpose during navigation and communication, i.e. the number 0 to 7. Each module is placed 45° radially equidistance. This configuration ensures that the robot's sensing has a 360° coverage.

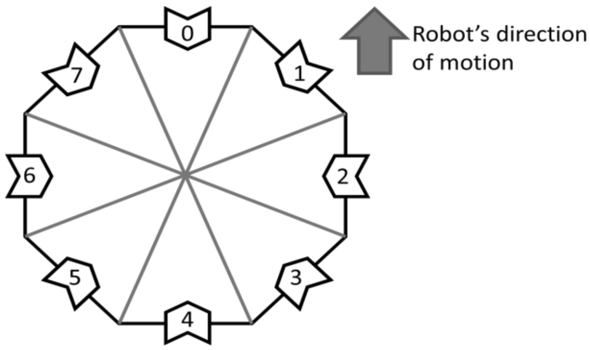

Figure 3. Layout of the Placement of the Infrared Modules [14]

The infrared module is built using an infrared LED as transmitter and a photodiode as receiver. Other electronic components are also used to complete the circuit, as shown by Figure 4.

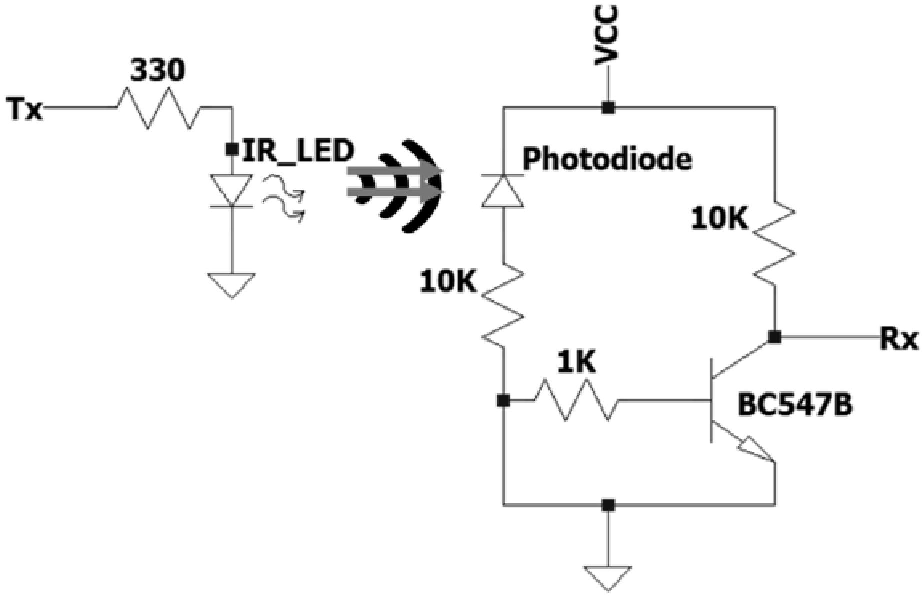

Figure 4. Circuit Diagram of Infrared Module

Within the circuit, an IR LED diode (5 mm in diameter and wavelength of 940 nm) is connected through a resistance to a DC supply. A photodiode (based on 1838 IR receiver), is connected in reverse biased condition through a potential divider of a 10 KΩ variable resistor and 1KΩ resistor in series to the base of the NPN-type transistor BC547. While infrared signal falls on the photodiode, it will cause a voltage at the base of the transistor. The transistor then works like a switch, that goes low to high logic at a certain amount of time. This transition can be used as input for the microcontroller for any action as per the program. The label Rx, Tx, and Vcc correspond to the connection of the wire to the microcontroller's pins. The transmitter and receiver diodes are separated 3 mm away by a small vertical structure. Figure 5 shows the built module.

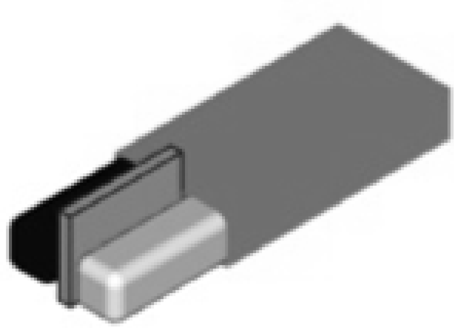

Figure 5. The Developed Infrared Module

2.3. Switching Algorithm

The switching algorithm involves checking the received return signal from an object. The robot transmits infrared signal containing its unique ID in hexadecimal format. These ID's were obtained from one of Arduino IDE's features, i.e. the Serial Monitor, which is extracted from the infrared LED diode. If the received signal contains the same ID, then the detected object is a static object or an obstacle. Otherwise, if the received signal contains a different robot ID, i.e. from another robot, then communication procedure will ensue, as illustrated by Figure 6.

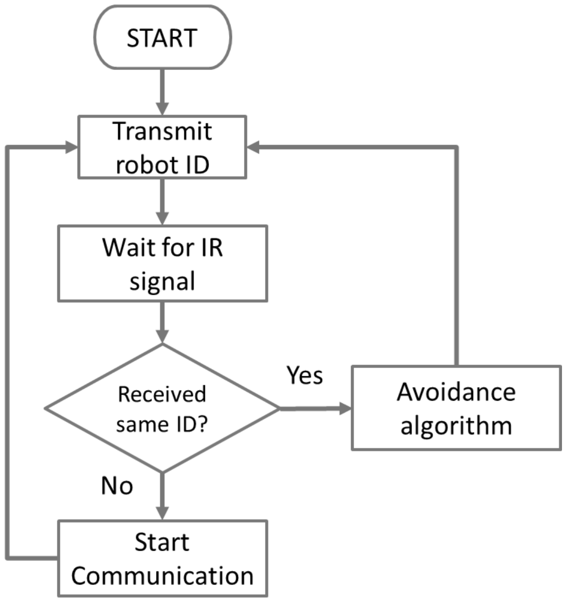

Figure 6. Flow Diagram of Switching Algorithm

The avoidance algorithm includes checking the position of the detected object (*q*, whether a robot or an obstacle). The position *q* is determined by calculating the robot's current position coordinate (*x*), distance sensed by infrared sensor (*d*), and the ID of the sensor (*n*), such that:

$$q(x, d, n) \tag{1}$$

The communication procedure includes requesting connection toward the other robot. After the connection is established, all infrared modules other than the one detecting the incoming signal will be turned off. The data transmission will proceed. Information transferred may vary depending on the task of the robot. After communication is completed, the avoidance algorithm will be engaged, to ensure that both robots will move away from each other. Figure 7 illustrates this process.

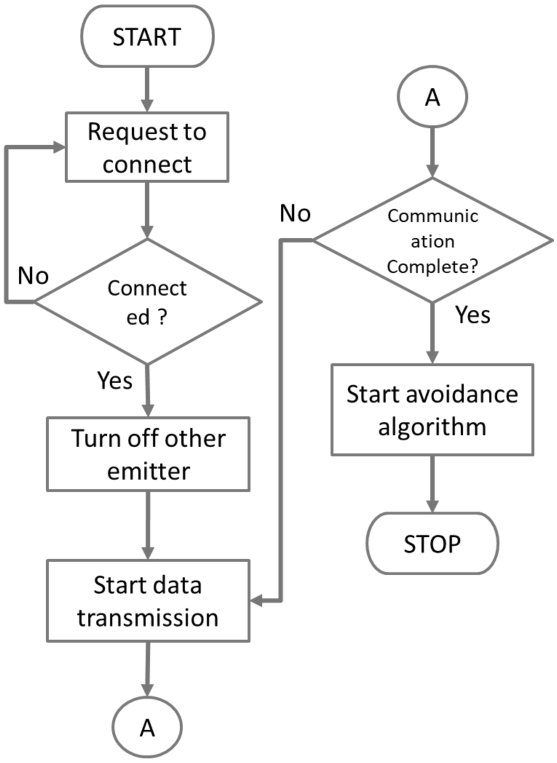

Figure 7. Diagram Flow of Communication Procedure

In this research, the infrared communication protocol used is the NEC protocol [17]. This protocol is chosen since it has extensive documentation available, which in return is due to its usage in multitude of field, such as in IoT [18] [19], communication in nuclear power plant [20], underwater communication [21], and even in medicine [22]. Also, this communication protocol is widely supported by Arduino-based microcontroller board manufacturers [23].

3. Results and Discussion

Two scenarios are choreographed for the purpose of testing the switching algorithm, i.e. between wall detection and conversation. Two units of mobile robots are used in this experiment. Unique identities in hexadecimal form for each robot is established as follows:

- The first unit is given identity of 0x68, and
- The second unit receives identity of 0x30.

In the first scenario, each robot is placed in a concocted artificial lab-scaled area. This setup is to evaluate the ability of robot to read its own ID and hence recognize whether the thing it is facing is a wall or a static object.

Meanwhile, the second scenario ensures that in the concocted lab-scaled setup, the two robots will have to meet or face each other and hence are forced to communicate. The artificial experimental setup for the second scenario is documented in Figure 8.

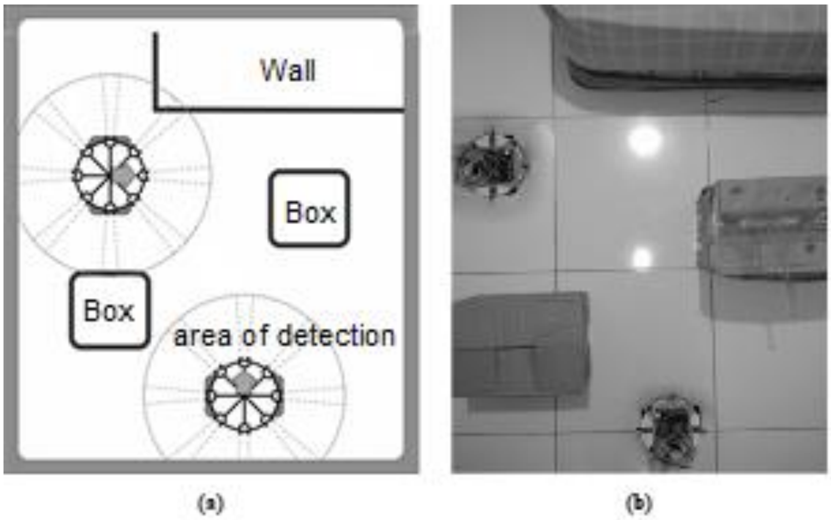

Figure 8. Artificial Setup for Experiment (a) Virtual and (b) Actual Setup

In this figure, the simulated setup in Virtual Engineering Environment (VEE by Agilent) software is shown in (a) and the actual setup is shown in (b). The area of detection is set to 30 cm by software, even though the emitting distance of the infrared light is more than 1 m away.

For the first scenario of detecting a static object, i.e. a wall, sensor #0 (the front of the robot) receives a message of 0x68, which is itself. This moment is captured in Figure 9 below.

Figure 9. Robot 1 Facing a Corner

The reading can be seen in the captured Serial Monitor window in the following Figure 10.

Figure 10. Reading when Robot 1 Facing a Corner

For the second scenario, as shown by the situation in Figure 11, the first robot's sensor #2 "captures" an ID 0x30 owned by second robot's sensor #0. Figure 12 shows the moment when the second robot's ID is captured in Serial Monitor, as the two robot's sensors meet in a line-of-sight.

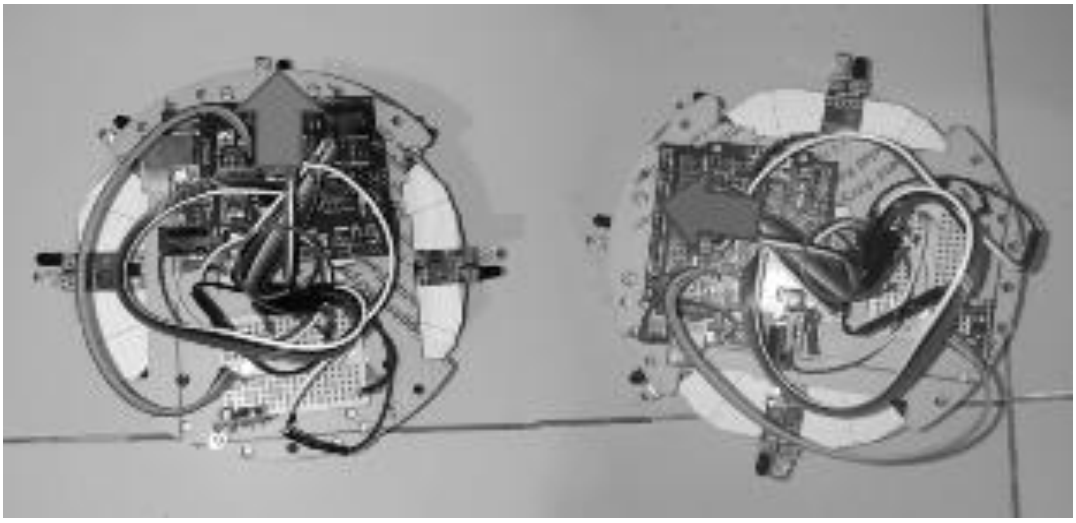

Figure 11. Robot 1 (Left) Meets Robot 2 Situation

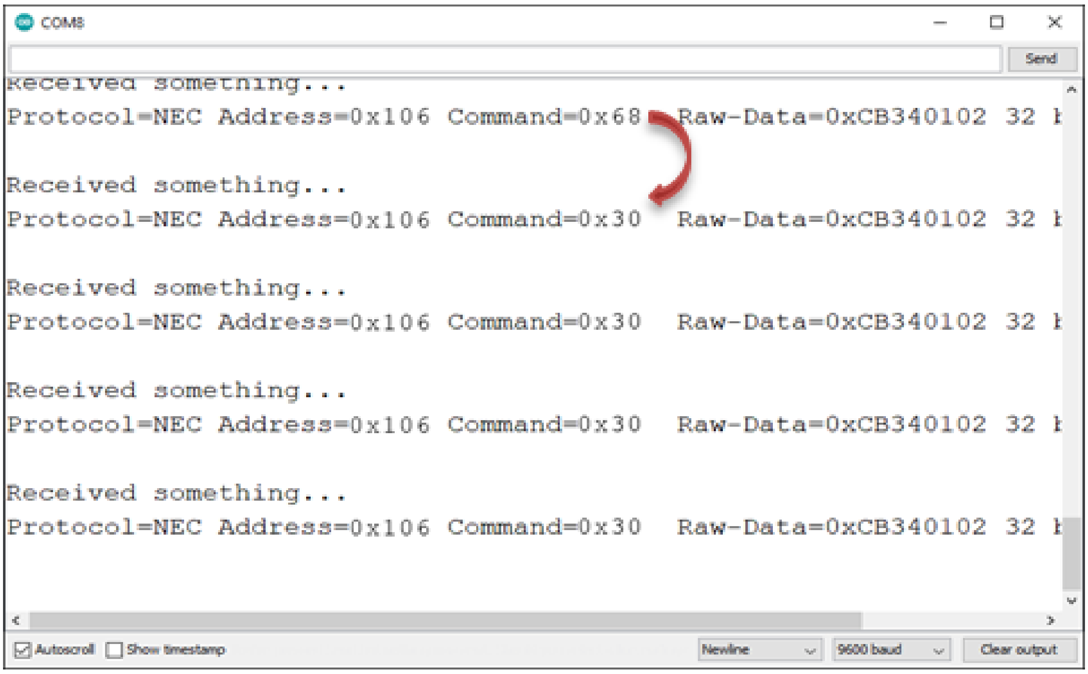

Figure 12. Reading when Robot 1 (Left) Meets Robot 2 Situation

Each scenario was simulated 20 times. The success rate p is calculated as ratio of number of miss r and total number of experiment R, such that:

$$p = \frac{r}{R} \times 100\% \quad (2)$$

The experiment's results are summarized in Table 1, where '1' means the algorithm works, while '0' means otherwise.

Table 1. Results of Each Scenario

No.	Scenario	
	First	Second
1	1	1
2	1	1
3	1	1
4	1	1
5	1	1
6	1	0
7	1	2
8	1	2
9	1	1
10	1	1
11	1	1
12	0	1
13	1	1
14	1	1
15	1	1
16	1	1
17	1	0
18	1	2
19	1	1
20	1	1

The result of first scenario in Table 1 shows that the object detection algorithm works very well at 19 out of 20 experiments were successful, i.e. at 95% success rate. The only miss, at experiment #12 is due to battery issue. Meanwhile the success rate of the second scenario is also high at 90%, where 18 out of 20 experiments, the robots were able to communicate.

However, there were a couple of glitches, which are indicated by number ‘2’ in the table. These situations happened when the robots were able to communicate, but failed to navigate away from each other. Post-experiment evaluations indicate that this glitch is either due to the sequence within the program code fails to process the sensor reading in time or due to the limited processing capability of Arduino. Nevertheless, if these situations are considered a failure, the success rate is still as high as 75%, where 15 out of 20 experiments, the robots were able to communicate.

4. Conclusions

This paper has elucidated the design and development of dual-mode usage of infrared sensor module. The infrared sensor modules are employed as both obstacle avoidance and communication. Also, a switching algorithm was also developed to accommodate the transition between modes. The sensing module is consisting of eight infrared sensors, which are placed on a mobile robot, arranged 45° radially equidistance to ensure a 360° sensing coverage. Using a lab-scaled artificial experimental setup, the result shows that 19 out of 20 experiments (at 95% probability) were successful of detecting an object. The result also shows that 18 out of 20 simulations (at 90% probability) were able to successfully conduct a communication. If glitches are considered as failures, then the success rate is 75%. These results conclude that the robots which use the proposed switching algorithm are able to avoid any collision with moving or stationary objects, while also performing a line-of-sight communication. Suggestion for future work includes (1) correcting and adjusting the code for better and more efficient run-time latency, (2) switching current Arduino-based microcontroller to a more powerful microcontroller, and (3) adding vertical “skin” on the mobile robots for better infrared reflection.

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