International Journal of Electrical and Computer Engineering (IJECE)
Vol. 12, No. 3, June 2022, pp. 2477~2487
ISSN: 2088-8708, DOI: 10.11591/ijece.v12i3.pp2477-2487

Design and implementation of a centralized approach for multi-node localization

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Article Info

Article history:

Received Jul 27, 2021
Revised Nov 5, 2021
Accepted Nov 30, 2021

Keywords:

Centralized approach
Distance sensor
IR Sender and receiver
Localization

ABSTRACT

In this paper, a centralized approach for multi nodes localization is introduced. This approach is based on using a beacon fixed at the lower middle edge of the environment. This beacon is provided with a distance sensor and can scan the environment to measure the distance between the detecting node and the beacon. Also, remote control is fixed on the beacon to distinguish the identity of the detecting node. Two nodes are used in this approach, each node contains eight cells, and each cell has a 5 mm infrared (IR) transmitter and TSOP4P38 IR receiver. If any one of the IR receivers has received the beacon ID, the transmitter which belongs to the same cell will respond by sending the node ID to the beacon. The beacon measurements and the information received from the detected nodes are then used to estimate the location and orientation of the visible nodes and the results will be saved in the main computer. Several experimental results have been tested with different distances from the nodes to the beacon. Also, different rotation angles at the beacon have been experienced to analyze the performance of the introduced approach.

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1. INTRODUCTION

A sensor is defined as a small tool used to detect or measure certain physical quantities and convert them into human-readable signals through a specific relationship to be displayed or processed further. Sensors are used for a variety of measurements, including: temperature, light, humidity, motion, pressure, and sound [1]. In a multi-node system, localization forms a great issue. The information collected from sensor nodes should include their location to provide a clearer view of the observed sensor environment because without location, the data will be geographically meaningless [2], [3]. Object tracking, monitoring, and all applications that need quick and effective data routing, such as bringing firefighters to an emergency location, or military issues, are just a few of the many fields where the positioning property offers new opportunities [4], [5]. Localization may be divided into two categories: centralized and distributed architectures depending on the architecture utilized to locate the nodes [6], [7]. Each node in a distributed architecture can compute its own position by communicating with its neighbors; however, this architecture has the disadvantage of requiring additional hardware for position determination at each node [8], [9]. The centralized architecture has a central unit that collects all received data and it performs most of the computations to estimate each node's position. The main disadvantage of this method is that any failure in the central unit causes the system to break down [10]. Furthermore, the centralized architectures also struggle from the scalability issue. The central unit may get congested as a result of the large-scale networks [11], [12]. As previously mentioned, localization is a significant issue in wireless sensor networks, and as long as localization is being used, choosing sensors for communication and distance measurement will be a dilemma [13]. To compute distance, a node can be equipped with a camera, laser scanner, linear variable differential transducer (LVDT), ultrasonic, or infrared sensors [14], [15]. Many applications require low-cost sensors that can measure distance accurately. The LVDT, laser scanner, and camera will be excluded despite being accurate because they are unfortunately expensive [16], [17]. The accuracy and inexpensiveness of infrared (IR) and the ultrasonic (US) sensors make them a very suitable choice for measuring distance [18], [19]. On the other hand, distance calculation isn't the only requirement for localization; some techniques require knowledge of the sender and receiver's identities, while others rely on node connections to determine the nodes' positions. Again, we are looking for low-cost sensors to achieve communication among the indoor system nodes which are the infrared sensors [20]. From the results of experiments, the TSOP4P38-IR receiver with a remote control circuit is the best one to achieve communication among nodes in indoor environments while the best sensor for detecting distance is the HC-SR04 ultrasonic sensor [21].

A hybrid indoor approach that combines distributed and centralized architectures was proposed in another paper. This approach aims to build a tree of nodes by the beacon with the help of connectivity among nodes. Each node takes advantage of the information flowing through the tree to locate itself [22]. A centralized architecture is used by other work in which two tables are constructed by collecting the information obtained from scanning the environment by both beacon and visible nodes. These tables have been used later to localize the invisible nodes [23]. Another paper is implemented using the locations matching algorithm. This algorithm aims to develop multi-color objects recognition and localization system. The system comprises two beacons with long-distance IR sensors to get the absolute locations estimations of objects. In this system, each object has different surface color and different reflectivity factor [24]. In another paper, the environment is provided with a distance infrared sensor to scan the robots and estimate the absolute locations and orientations of a number of team robots without knowing their IDs. The orientation obtained from the distance infrared sensor is matched with the relative orientation recorded using onboard sensors to create the IDs of these robots [25]. In this paper, the HC-SR04 ultrasonic sensor and the TSOP4P38 IR receiver with a remote control circuit will be used to realize the centralized approach practically. This work covers the electronic circuits and the structures for each of the beacon and nodes. It also includes how the beacon and nodes are communicating. The system description will be explained in details in section 2 and the results and discussions are examined in section 3. Finally, the conclusion will be in section 4.

2. RESEARCH METHOD

In our proposed multi-node system, there are four components: nodes, beacon, computer, and data logging software. The beacon is placed in the middle of the bottom edge of the frame and can detect the nodes by scanning the environment and communicating with each node to obtain its ID. Then, using a USB cable, all collected data will be sent to the computer. This is necessary for the data logging software to be able to create the nodes based on their computed positions and IDs, as illustrated in Figure 1.

2.1. The system hardware

The hardware of the system consists of one beacon and two nodes. All are placed on a white board has a length of 80 cm and a width of 80 cm. The structure of the beacon and nodes, as well as all of the circuits required to make them work, are described below.

2.1.1. The nodes structure

We previously stated that the system has two nodes. As can be seen in Figure 2, each node has 3 parts. The first part is the node base which has 2 wheels besides 2 balancing screws. Each wheel is attached to a servo motor in case we want the node to move. The second part is an 11 cm height white cylindrical body to make the beacon sonar able to scan the node. The node upper part (third part) consists of two layers. The first layer, as in Figure 3(a), was divided into 8 cells to accommodate eight of 5 mm IR transmitters and eight TSOP4P38-IR receivers. The node roof, as shown in Figure 3(b), represents the second layer. This layer comprises a 9 V battery, a control board, and a relay connected to a remote-control circuit to select the node identification code. The relay with remote control circuit along with the first layer will form the communication part.

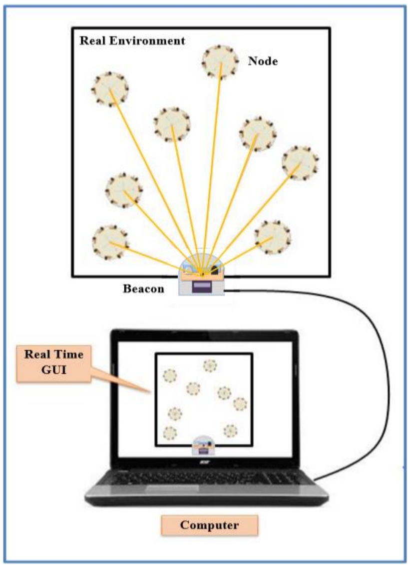


Figure 1. Experimental setup infrastructure

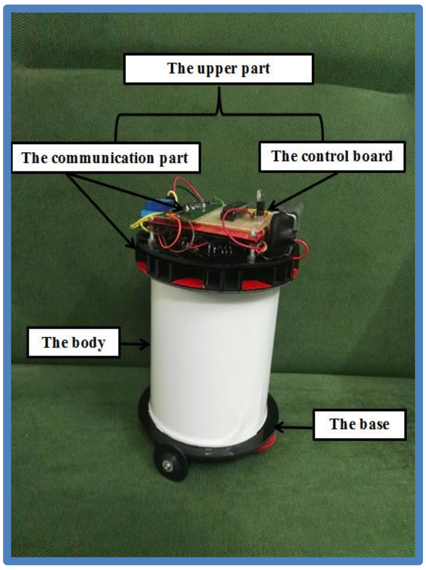
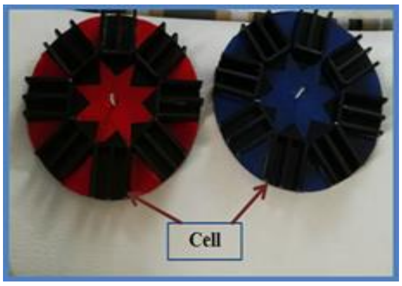
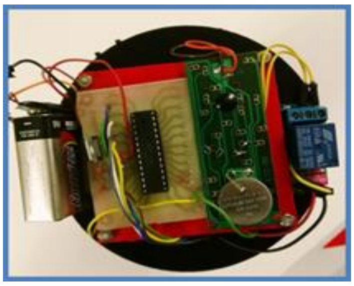


Figure 2. Illustration of node parts



(a)



(b)

Figure 3. The upper part of node (a) first layer and (b) second layer

In the node structure, the control board has an ATMEGA328P microcontroller. The ATMEGA328P is a low-power CMOS 8-bit microcontroller that uses the advanced reduced instruction set computer architecture to execute an instruction in a single clock cycle, resulting in high throughput of up to 1 MIPS per 1 MHz. There are 32 GBS on the microcontroller, each with eight bits. There's also 32 KB of flash program memory, 2 KB of SRAM, and 1 KB of EEPROM on board. The microcontroller also has twenty-three input/output lines, which require an operating voltage of 1.8 to 5.5 V.

A 16 MHz crystal, as well as two 22 pF capacitors, are included on the control board to create an external crystal oscillator. The crystal oscillator's role is to generate a clock signal that synchronizes all of the microcontroller's components. Although the ATMEGA328P microcontroller includes a 1 MHz internal oscillator, using an external oscillator will speed up the microcontroller's activities. On one side, the 16 MHz crystal is connected to microcontroller’s pins 9 and 10, and the other side is connected to with 22 pF capacitors. Last but not least, the control board contains a voltage regulator that converts the battery’s 9 volts to 5 volts, which is the proper operating voltage for all of the microcontroller, TSOP4P38 IR receiver, and relay. The node upper part schematic diagram is shown in Figure 4.

2.1.2. The beacon structure

The beacon, as shown in Figure 5, is also consists of three parts. These parts are used to compute the distance from the beacon to each of the nodes and obtain their IDs. Below is a description of each part. The first part, which is the sonar, is responsible for nodes detection and distance measurement. This part is made up of an HC-SR04 ultrasonic distance sensor which is fixed on a servo motor to control the movements of the sensor and can rotate from 0 to 180 degrees. The servo is fixed with two screws on a square plastic board. The job of this part is to sense the nodes, compute the detection angles, and calculate the distance between the beacon and each of the nodes.

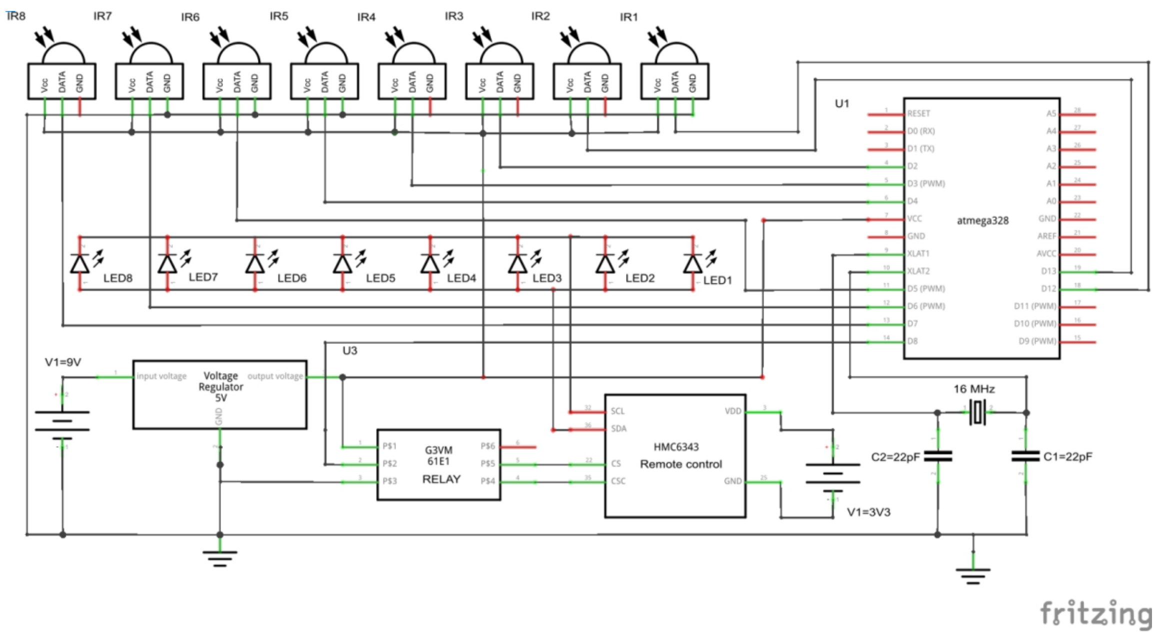


Figure 4. the node upper part schematic diagram

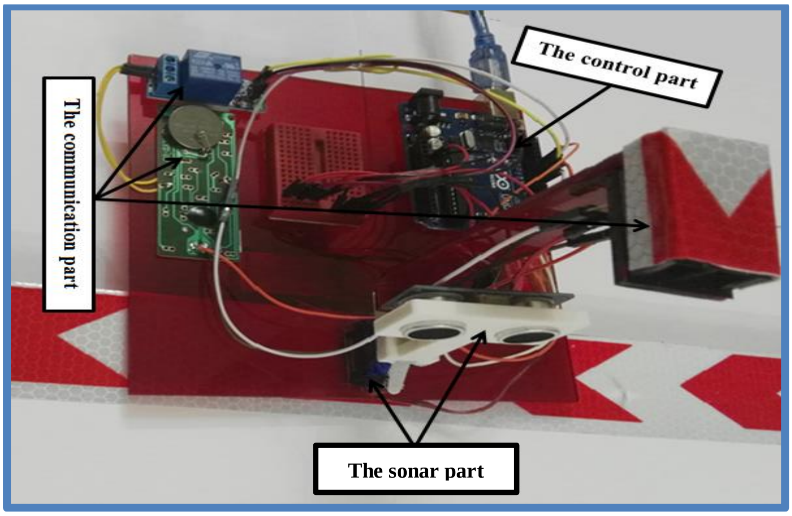


Figure 5. The parts of the beacon

The second part is the communication part, which involves a relay connected to a remote-control circuit; both are positioned on the same square plastic board as in the previous part. The relay acts as a switch that closes the remote-control circuit when it receives a signal from the beacon control. Closing the remote-control circuit will cause the beacon ID to be sent through a 5 mm infrared transmitter. Both the 5 mm IR transmitter and the TSOP4P38 IR receiver are located inside a cell that is fixed to the servo motor to rotate along with the ultrasonic sensor. The TSOP4P38 IR receiver is used to receive the nodes' IDs. The information exchanging operation between the nodes and the beacon is handled by the communication part.

The third and final part is the control part. This part is represented by an Arduino Uno located on the square plastic board. It is important to point out that the Arduino Uno board has 14 digital input/output pins and 6 analog inputs. The operating voltage of this kit is 5 V and the clock speed is 16 MHz. Finally, this Kit has a 1 KB EEPROM, a 32 KB flash memory, and a 2 KB SRAM. The communication and the sonar parts aren't able to work unless they receive commands from the control part. The schematic in Figure 6 displays how all the beacon parts are connected, as well as all the Arduino pins that were used.

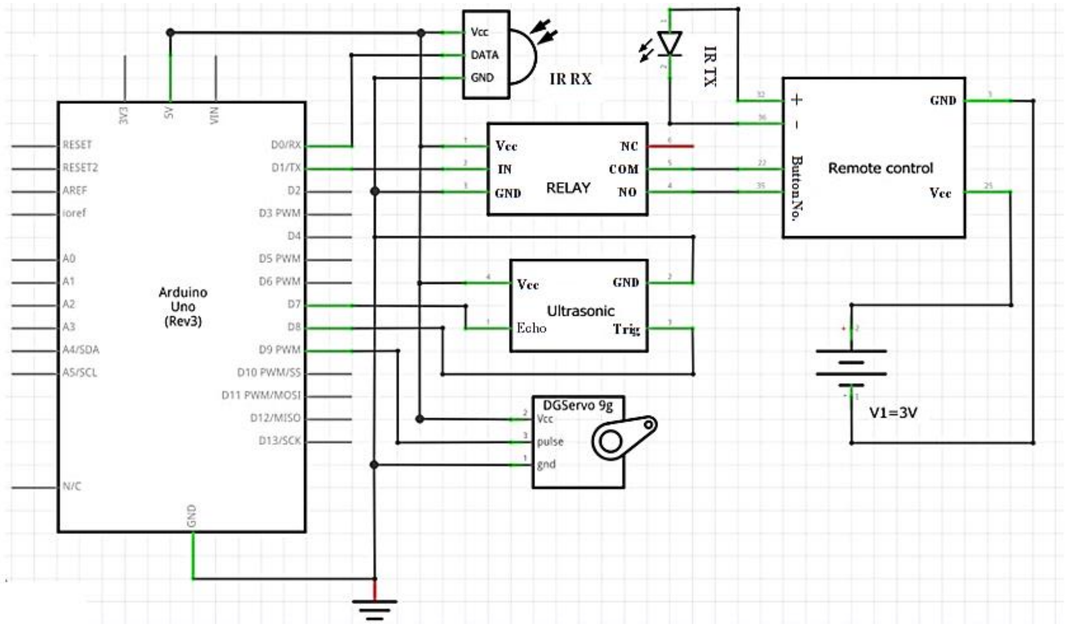


Figure 6. The schematic diagram of the beacon

2.2. Software for data logging

The control part represents the mastermind that controls the other parts of the system, while the software is like a soul that gives life to the hardware. Figure 7 depicts the graphical user interface (GUI) for the system software, which was created using Visual Basic 2010. The start button causes the beacon to start working by rotating the sonar part from 0º till 180º. The sonar will back to 0º when the reset button is pressed. To demonstrate the behavior of both the beacon and nodes, this software can be divided into two procedures.

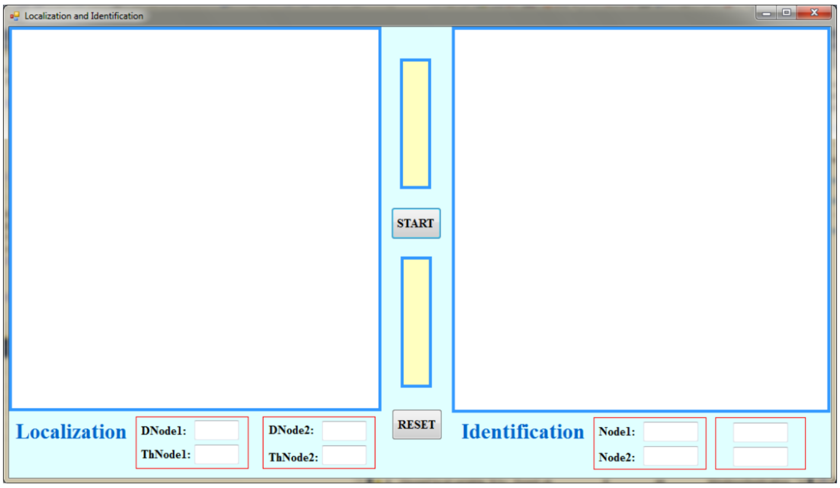


Figure 7. The graphical user interface of the system software

2.2.1. The procedure based on beacon

Using this procedure, the detecting angle and the distance (the polar coordinates) of nodes with respect to the beacon coordinates can be calculated. Figure 8(a) demonstrates the flow chart for the procedure based on beacon. The steps for this procedure are:

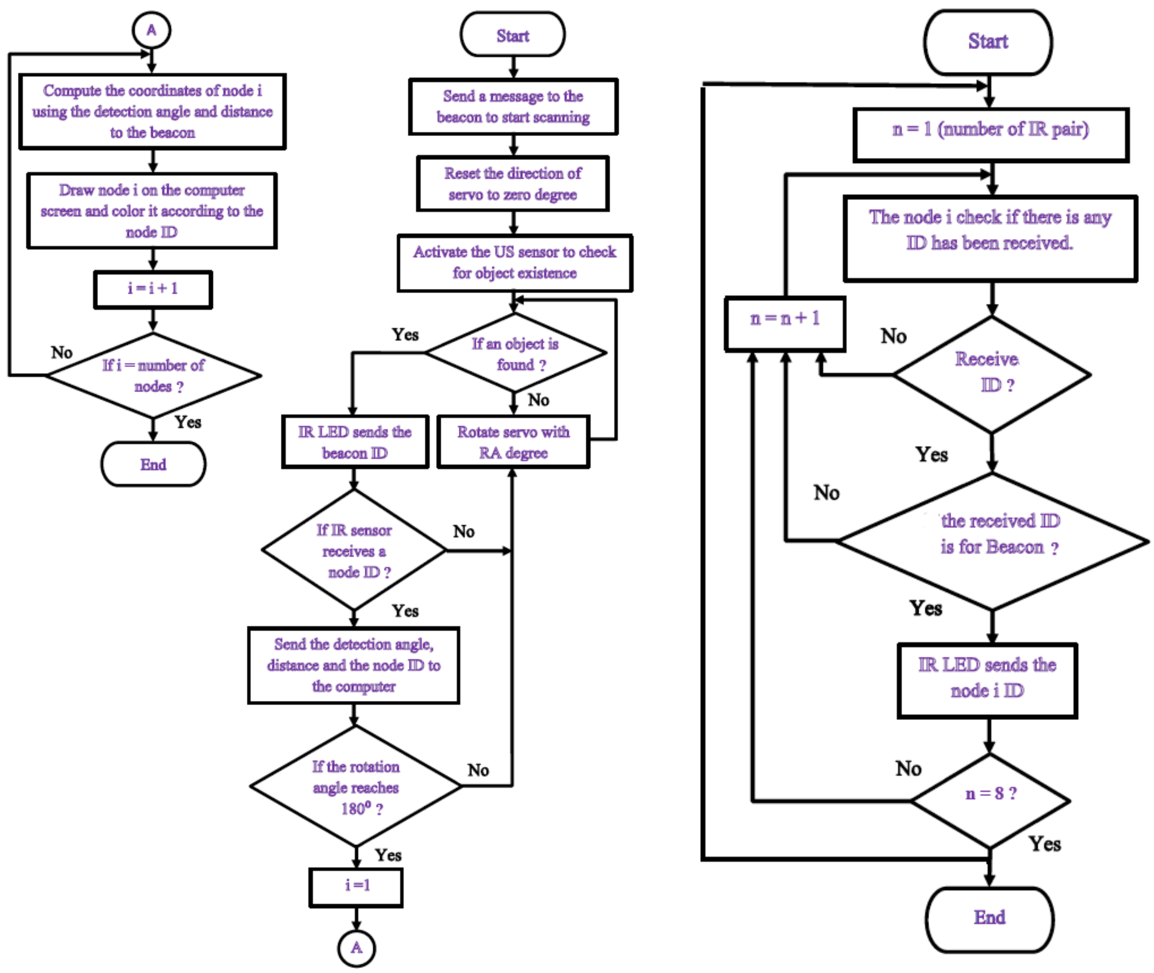
a. Pressing the start button causes a command to be written to the serial monitor.
b. The microcontroller in Arduino reads the serial and commands the servo motor to rotate at180º while simultaneously activating the ultrasonic sensor.

c. The ultrasonic sends eight ultrasound pulses at each degree and waits for an echo. The IR sender will be enabled, and the beacon ID will be sent in the case of the pulses hitting some object and reflected. If this is not done, the servo will advance to the next degree.
d. If the node ID is received by the beacon receiver, then the distance, detecting angle, and node ID will be all written to the serial monitor, where the visual basic program can read them.
e. Repeat steps 2-4 until the servo motor reaches 180º, then set the node counter to 1.
f. The Visual Basic software will use the obtained data to calculate the precise coordinates of node i, assign it a color based on its ID, and finally draw it on the computer screen.
g. When the nodes counter does not match the total number of nodes, then the counter will be raised by one and step 6 will be repeated.

2.2.2. The procedure based on node

The purpose of this procedure lies in communicating with the beacon when the node obtains the beacon ID. Each node has eight TSOP4P38 IR receivers evenly distributed on its circumference. The receivers are always kept in a listening mode. A flow chart for this procedure is shown in Figure 8 (b). Below are the steps for the procedure based on node:

a. The node microcontroller on a regular basis checks each IR receiver starting with IR1 to verify whether any IR receiver has received the beacon ID.
b. If the beacon ID has been received by any receiver, the IR sender will transmit the node ID. If not, the IR receivers' counter will be incremented by 1 and handed to the next IR receiver.
c. Repeat steps 1 and 2 if the IR receivers' counter reaches eight.



(a) (b)

Figure 8. The flow chart of (a) the beacon-based procedure and (b) the node-based procedure

3. RESULTS AND DISCUSSION

To test the system, one of the nodes was placed at a 32-cm distance and at a 48-degree angle, it was labelled in red and assigned the code 0xFF18E7. The other node was set at 56 cm away from the beacon, and at an angle of 89 degrees. The second node was marked in blue and assigned the code 0xFF9867 as illustrated in Figure 9. The software program was then run, yielding the results shown in Figure 10; from this figure, the distance, ID and angle for the red node are 32 cm, 0xFF18E7, and 48 degrees respectively while the distance, ID and angle for the blue node are 56 cm, 0xFF9867, and 89 degrees which are exactly the same values as in the real environment. Figure 11 displays both the GUI output and the real-world environment after the scan is completed. The system accurately estimates distances and angles. The nodes were properly drawn based on their determined positions and colors. The system also provides successful communication among the nodes and the beacon.

Figure 9. The real-world environment before the scan started

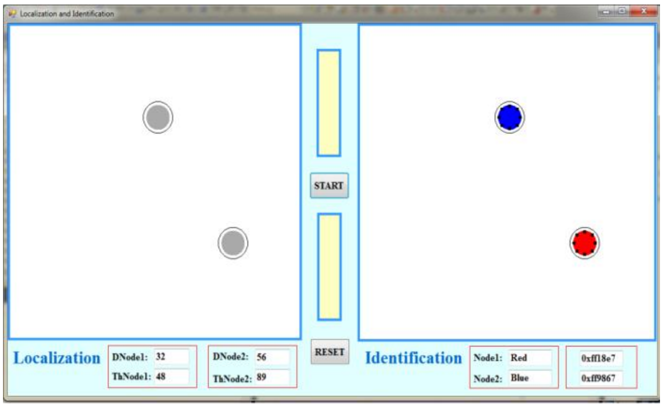


Figure 10. The results of the GUI program's debugging

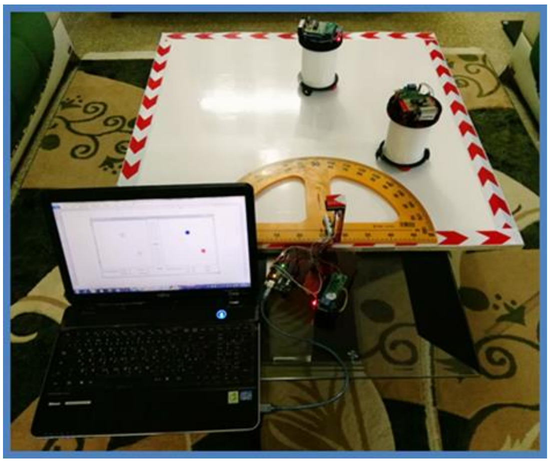
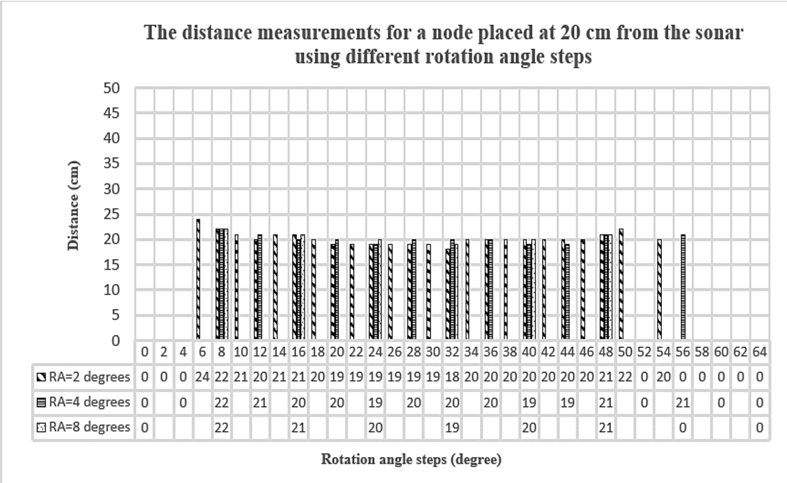


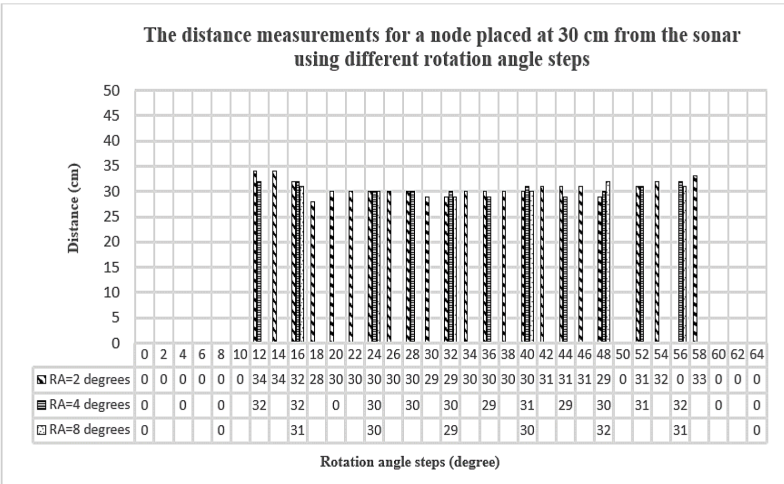
Figure 11. The environment once the scanning is finished along with the results of the debugging

The measured distances for a node located once at 20-cm and the other time at 50-cm apart from the sonar are shown in Figures 12(a) and 12(b). For both curves, different rotation angles of 2, 4, and 8 degrees were used to repeat the distance measurements. As an example, RA=2 degrees mean that the beacon scans the environment by rotating 2 degrees at each step. In Figure 12(a), the ultrasonic detects the existence of the node at a distance of 20 cm, for 24 readings when RA equals 2 degrees (blue bars), 12 readings when RA equals 4 degrees (red bars) and finally 6 readings when RA equals 8 degrees (green bars). On the other hand, Figure 12(b) is analogous of Figure 12(a) expect that the node is placed at distance of 30 cm. This procedure was repeated for other different distances 40 and 50 cm. All the figures showed that the accurate measurements for distances are occurred when the ultrasonic sensor is exactly in front of the detected node.

We'll use the preceding curves to calculate the percentage of accurate measurements, as illustrated in Figure 13(a), which investigates the effect of the rotation angle step on ultrasonic reading accuracy. Different distances were measured, and the percentage of precise readings out of total readings, excluding zeros, was calculated. For example, if the distance between the node and the sonar is 40 cm and the RA is 2 degrees, the total number of readings is 19 and the number of accurate readings is 7, resulting in a 37 percent accuracy rate. The percentages for the 4 and 8 degrees, on the other hand, will be 36 and 33 percent, respectively. This means that the accuracy percentage of readings increases as the step of rotation angle decreases.



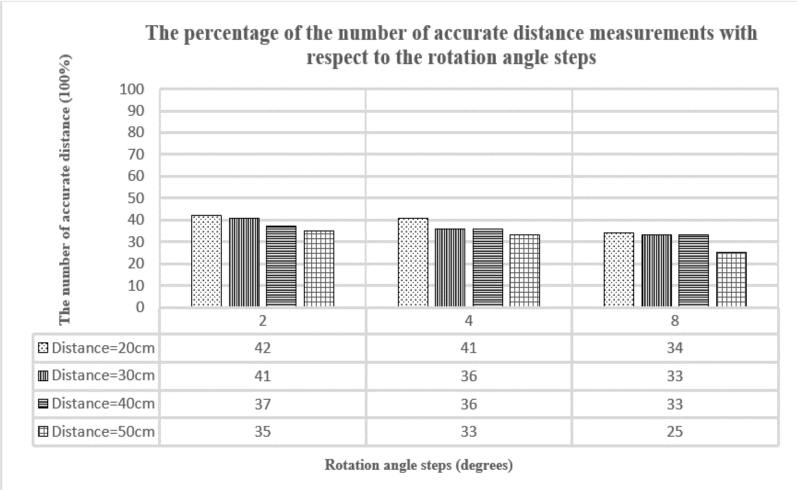
(a)



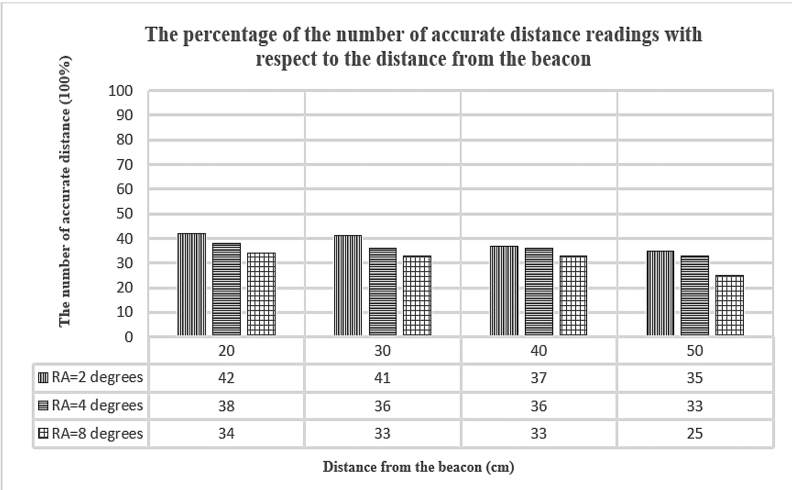
(b)

Figure 12. The measurements of distance for a node positioned at (a) 20 cm and (b) 30 cm from the sonar using 2, 4, and 8 degrees of rotation angle steps

In Figure 13(b), the relationship between the distance at which the node is placed and the influence of that distance on the accuracy percentage of ultrasonic readings has been studied. It is obvious that the closest node has the highest accuracy percentage. For instance, when the RA is 2 degrees and the distance is 20 cm, there will be 10 accurate readings out of 24 total measurements, resulting in a 42 percent accuracy rate. When the same rotation step is used but the distance is 50 cm, there are 7 precise readings out of 17 total measurements, resulting in a 35 percent accuracy rate. This means as the distance between the node and the ultrasonic sensor decreases, the accuracy percentage of readings will increase. From Figures 13(a) and 13(b), we find that the readings that indicate the exact position of the node have the highest percentage of accuracy. These readings were used in the Visual Basic code to calculate the exact locations of the nodes.



(a)



(b)

Figure 13. The Percentage of accurate distance measurements in relation to (a) the rotation angle steps and (b) the distance from the beacon

4. CONCLUSION

This paper discussed the use of the centralized approach for the practical implementation of a multi-node localization and identification system. In this research, very precise node location estimations were obtained. Also, excellent connectivity between nodes and the beacon was accomplished. The percentage of accurate distance readings for several rotation angle steps (two, four, and eight degrees) was tested. We concluded that decreasing the rotation angle steps improves location estimate accuracy, but this will increase the time required to complete the environment scanning. As a result, reducing of rotation angle step leads to increase the number of correct readings and thus increasing the accuracy percentage. The percentage of the accurate distance readings with respect to the distance from the beacon was also studied. We concluded that the closest distance to the beacon has the maximum accuracy. This result occurs since the nearest node to the beacon has the largest number of readings for all rotation angle steps. Finally, we found that the readings that relate to the exact position had the maximum accuracy percentage at each rotation angle step and at each distance.

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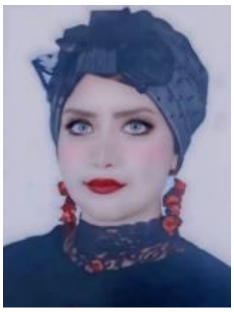
BIOGRAPHIES OF AUTHORS



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