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An Algorithm for Indoor Robot Path Planning Using Low-Cost IR Sensor Array System

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***Abstract*— In this paper, a new algorithm for indoor robot path planning is presented. The robot localization problem is solved by using an IR transmitter fixed on the robot and a low-cost IR sensor array distributed regularly in the environment. The robot location depends on a group of IR receiver sensors that sense the IR transmitter signal. The location of each IR receiver sensor depends on it is the location in the IR array and the robot location is estimated from the locations of the sensed IR receiver sensors. The localization process is applied using the modified binary search algorithm to scan the IR array and the robot location is computed by applying the centroid algorithm on the locations of the sensed IR receivers. A virtual path from the robot location to the target point is drawn using the tangent visible graph algorithm. A chain of the IR receivers within the sensing range of the virtual path is activated to be scan through the robot moves to the target. This process helps in reducing the computation time of the robot localization. At each step of the robot movement, it is direction is corrected dependent on the locations of the two next IR sensors in the chain of the active IR receivers. The simulation results for different types of IR array environments are shown good performance for this algorithm.**

Keywords*— *Binary search algorithm, Localization, Path planning, Visible tangent graph.

I. INTRODUCTION

In the smart robotic field, one of the most important requirements is the autonomous navigation. A strategic technique toward the target location is the robot navigation. this process has four basic components [1]: the first stage is the perception, it is extracting the meaningful information by robot uses its sensors; the second stage is the localization, it is the process of determining the robot location in the employed space; the third is cognition and path planning, the robot achieves its goal by deciding how to steer; the last stage is the motion control, the robot realizes the desired trajectory by regulates its motion. Presently, with the fast increase in the information technologies and multimedia facilities, the localization and path planning techniques have significantly improved [2], specifically in an indoor environment, such as airport lobbies, exhibition rooms, garages, supermarkets, etc. However, according to the restrictions of position detection, localization timing and localization timing for complex indoor environments, the perfect localization technique was not applied successfully.

Now, the robots performing different tasks. the most basic requirements are the localization techniques. It is used to estimate the location and orientation of the robot depending on the environment and the previous knowledge of the system such as the original position chart. The localization technique is important because it is difficult to achieve any task autonomously without precise information about its location in the indoor environment. The path planning technique is defined as an orderly sequence of transformation and alternation after the present position of the robot to the destination in the existing environment. anywhere, there are two techniques: global and local path planning [3,4]. A global path developer typically makes a complex path constructed with low-resolution on an identified environmental map while the local path planning algorithm makes a low-level path and not require a priori knowledge of the existing environment based on the information acquired from sensors. It works excellently in dynamic environments range. But when the target location is so far, this method is not good. Generally, by mixing both approaches, we can remove some of their weaknesses and improve the advantages of the mixture [5–7]. In a robotic system, sensors may be used for obstacle detection, distance measurements, communication, etc. [8, 9]. Localization and path planning was the most important problem in selecting an appropriate sensor for distance measurement in the automaton system [10]. sensors such as infrared sensors, laser scanner, and ultrasonic can be prepared on a mobile robot for remoteness measurement [11-13]. The low-cost sensors in many applications are used for determining the distance as a replacement for the expensive sensors such as camera and laser scanner [14-16]. Conversely, not only the distance scheming design is required for localization; the character of the source and receiver of the Localization algorithms also required to estimate the nodes' locations and depended on the connectivity between the nodes. Again, we are looking for cheap sensors for an indoor system to realize the communication among nodes which are the infrared sensors [17]. Some types of sensors have been used for the localization and path planning systems, such as LRFs, WiFi positioning, the RFID, ultrasonic positioning, Bluetooth technology, vision sensors, an infrared IR transmitter and receiver, and VLC visible light communication technology. Although the hardware required Bluetooth [18, 19] and WiFi [20] it is simply combined into mobile policies, both Bluetooth localization Systems and WiFi are simply

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disturbed because interfering with extra signals disturbs their precision. LRF [21] positioning and Ultrasonic [22] systems have the benefit of high precision and simple system construction. Now, still, the sensors of the two classifications are impotent to detect the indoor mobile robot correctly if the robot is enclosed by certain affecting things. LRFs is limited with transparent walls in an environment, it is used in an indoor environment. An accurate localization can be obtained using an RFID radio frequency identification system with dense and IC tags [23] in a reasonable configuration. In this paper, to fit the requirement of the research area, we propose an indoor mobile robot localization and path planning algorithms system using an IR receiver sensors to solve the problem of detecting the place, orientation, and accomplishment of the target location.in the first categories with the localization scheme, it is a modified on the binary search algorithm and is called a matrix search, it replaces each element in decimal digit by one of two logical principles (one for active IR receiver sensor or zero for not active IR receiver sensor). i.e. the binary digit instead of the decimal digit, as a result, the sorting stage is canceled. Then the processing time is reduced and, the information from the IR receivers is focused on the central main control unit to detect the robot's position. then after detecting the robot position another new algorithm called the arc of circle tangent construction algorithm is the practice to transfer the robot from its prior place that is obtained in the first stage over its trajectory to the essential target, it replaces the obstacle with the robot and drawing a virtual circle according to some robot kinematic concluded the tangent to the target with the shortest time. The paper is ordered as follows: Section (II) explains the literature review and related work for an indoor robot localization and path planning system, (III) presents the specifics about the environment of an indoor mobile robot. The robot control with a low level is discussed in section (IV). the robot dynamic path construction is offered in section(V). Simulation results are presented in section (VI). To finish, in (VII) conclusions are conferred.

II. INDOOR PATH PLANNING SYSTEM

This paper introduces a new algorithm for an indoor path planning structure built on activating the IR receiver sensors which distributed regularly in the working environment. These IR sensors are used to localize the robot through the robot moving toward the target. The primary location of the robot depends on using the modified binary search algorithm to scan the environment. A virtual trajectory represents the path that the robot tracks to scope the target that is drawing using the visibility binary tangent algorithm. Wholly the IR receiver sensors inside the sensing range of the virtual trajectory are activated. The robot follows the trajectory represents by these activated IR sensors and it is the location at each step of movement is compute by scanning only these activated IR receiver sensors.

The original position of the mobile robot

The planned system consists of a 2-D environment with several holes distributed regularly (Fig. 1) fitted with an array of IR receiver sensors. The IR sensors in this system are classified into two groups: the first one represents one IR transmitter sensor fitted on the base of the mobile robot, while the second one is represented by an array of various dimensions of IR receiver sensors distributed regularly in the environment. The central unit scans The array of the IR receiver sensors column by column to identify the signal that came from the IR transmitter equipped on the robot. Only the IR receiver sensors that are located inside the sensing range of the IR transmitter are identified. Then the identified sensors are illustrious as a group and the centroid algorithm is used to detect the robot location from the scenes of the identified receiver sensors. The initial localization process is reliant on using the modified binary search algorithm to scan all the columns of the IR receiver array.

A. Binary search algorithm

The Binary Search Algorithm calculation is suitable to look for the decimal number among an arranged exhibit of information. It works in logarithmic time also it is a straightforward calculation and can be improved. The searching development is proficient by over and over separating the cluster into equal parts. Through the searching, if the value of the search amount is less than the entry in the mid of the array, it restricted the exhibit to the lesser partial. Somewhat else, restricted it to the higher part. Continually checkered until the required number is originating or the array is unfilled. Each stage of the algorithm procedure, we must recall the start and the finish of the lasting portion of the array. This calculation has the advantage of its multifaceted nature relies upon the logarithm of the exhibit size [24]. Fig. 2. show the phases for the binary search algorithm.

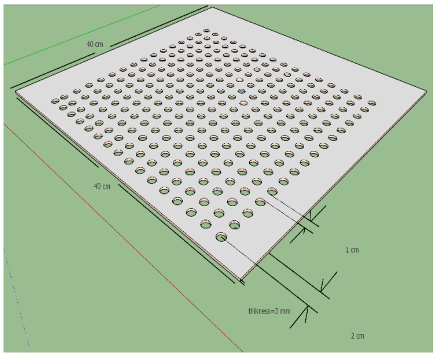

Fig. 1. map of (16*16) an empty-hole environment.

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Binary Search Algorithm
Def. A: Store array
Def. N: Array size
Def. X: The value to be searched
Lowerbound=1
Upperbound=N
While x not found
  If Upperbound < Lowerbound then Exit   : x not found
  Let midpoint=Lowerbound+ (Upperbound – Lowerbound)/2
    If A(midpoint) < x then Lowerbound=midpoint + 1
    If A(midpoint) > x then Upperbound=midpoint – 1
    If A(midpoint) = x then Exit   : x found
End While
End Algorithm
```

Fig. 2. The Binary Search Algorithm.

B. The modified binary search algorithm

In this paper, the localization process is dependent on using the modified binary search algorithm. The differences between the proposed algorithm and the binary search algorithm are summarized in the resulting steps:

- the binary search algorithm is constructed using the decimal digits, as a result, the sorting sequence is the first period in this algorithm. But in this system, two logical principle states are used (one for active IR receiver sensor or zero for not active IR receiver sensor). as a result, no sorting sequence is required for this stage.
- The IR receiver sensor is arranged in the 2D array; consequently, the matrix search algorithm is applied to each row and the column of this array.
- In this environment, several IR receiver sensors are used consequently, the searching procedure is a practice to more than one value at each time. Since the position of each IR receiver sensor is supposed to be known, the information composed from the robot IR transmitter sensor can be used to estimate the robot position.
- The progression of the localization process starts with the modified binary search algorithm crossways the rows of the IR receiver sensors array. The IR receiver sensors symbols each column inside their sensing range by one and the further by zero. This technique repeats until labeling each IR sensor within the sensing range with a value of 1, consequently, the information from the active IR receiver sensors is directed to the microcontroller to detect the robot's location.

C. The Robot orientation estimation

The current orientation of the robot is very important to draw the line follower path. For this purpose, at first, the robot moves one step forward which is shown in Fig. 3. Use the modified binary search algorithm to compute the new location of the robot. By knowing the last and the current location we can estimate the robot orientation according to the following equation.

$$\theta = \tan{-1}\ ((y1 - yo) / (x1 - xo)) \qquad (1)$$

D. Drawing the robot virtual trajectory

This section defines the phases for the construction of a virtual trajectory from the initial position to the destination for the mobile robot using the algorithm of a tangent visibility graph. The process is summarized by searching for the shortest path for the mobile robot by assuming the shortest path between the robot trajectory path to the destination. The investigation of this method is characterized:

Step1: Firstly, the initial position, Radius, velocity and direction of the mobile robot must be identified and the position and radius of the circle that the robot uses as a path to move to the tangent line and the target location also, must be identified.

Step 2: compute the arc trajectory required to place the mobile robot to the destination. The diameter of this arc depends on the speed of the mobile robot.

Step 3: Find the tangent points on the circle that represents the arc path for the mobile robot movement from the destination point that is shown in Fig. 4. The tangent points are computed from equations 2 and 3.

$$xt=(r^2\, xd + r\, yd\, (xd^2 + yd^2 - r^2)^{0.5}) / (xd^2 + yd^2) \qquad (2)$$
$$yt=(r^2\, yd - r\, xd\, (xd^2 + yd^2 - r^2)^{0.5}) / (xd^2 + yd^2) \qquad (3)$$

where (xt, yt) the organizing axis of the tangent argument and (xd, yd) the coordinate axis of the target argument.

Step 4: Drawing a straight line represents the tangent line between the arc trajectory of the robot and the destination point, which is shown in Fig. 5.

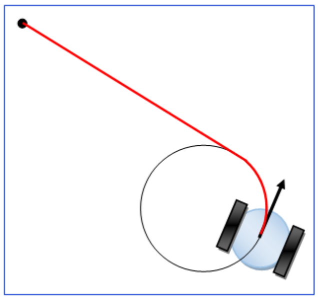


Fig. 3. robot orientation to draw line follower path.

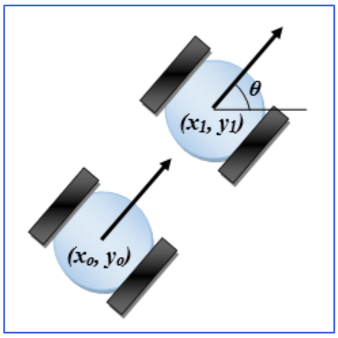


Fig. 4. Finding the tangent points.

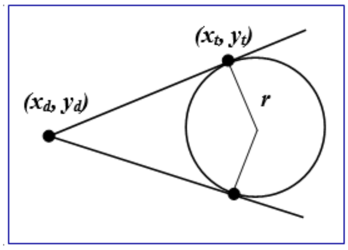


Fig.5. Drawing the robot virtual trajectory from its location to the target.

Step 5: check the obstacles which are intersected the path from the robot point to the destination. when the distance from the center of the obstacle and the direct line from source to destination is less than the radius of an obstacle then the intersection is occurring that is shown in Fig. 6. The equations (4), (5), (6) and (7) are used to check this intersection.

$$a = (yt - yi) / (xt - xi) \qquad (4)$$

$$b = -1 \qquad (5)$$

$$c = yi - a * xi \qquad (6)$$

$$h = Abs\ (a * x0 + b * y0 + c) / Sqrt\ (a\ 2 + b\ 2)) \qquad (7)$$

The intersecting obstacle is avoided by drawing a tangent path between the present location of the robot and the tangent argument to the obstacle.

Step 6: Steps 2, Steps 3, Step 4 and step 5 are repeated until completing the robot virtual path.

E. *Choosing the active IR receivers for robot trajectory*

The active IR receivers represent the IR sensors inside the sensing range of the robot trajectory. The selecting of these sensors is applied according to the succeeding steps.
Step 1: firstly, the robot trajectory is transferred from a continuous path into the discrete path as shown in Fig.7. This discrete path simplifies the process of distinguishing the neighbor IR receiver sensors.
Step 2: activate the IR receiver inside the sensing range of the discrete arguments of the robot trajectory which is explained in Fig. 8. This process helps in reducing the localization time by reducing the number of scanned IR receiver sensors.
Step 3: separate the active IR receiver sensors into two types. The IR sensors locate at robot trajectory (black color) are labeled as type A and the IR sensors locate near the robot trajectory (red color) are labeled as type B Fig.9. This arrangement helps to control the orientation of the robot through the moving process.

F. *Control the movement of the robot to the target point*

This section deals with the controlling of the robot orientation through it is a movement to the destination point. At each step of the robot movement, one of the active IR receiver sensors is closeness to it's positioned. The changing of the robot orientation is dependent on the type of this active IR receiver according to the following steps.

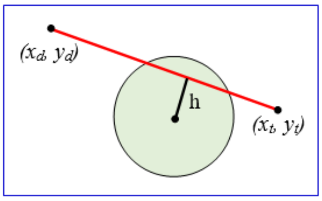


Fig.6. Checking the intersection of an obstacle with the robot.

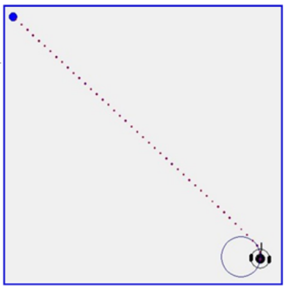


Fig.7. Discretion the robot trajectory.

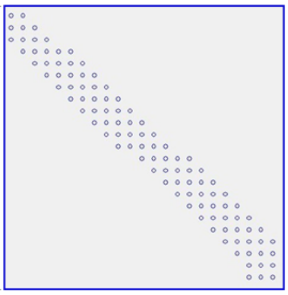


Fig.8. Discretion the robot trajectory.

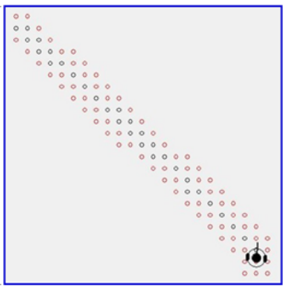


Fig.9. Separate The active IR sensors into two types.

Step 1: At first, the robot location is at the first A-type IR receiver sensors. Use equation 1 to compute the orientation of the line between the first and the second A-type of IR sensors. If the orientation of this line is greater than the robot orientation then the robot orientation must be enlarged to its first step movement, else it must be decreased.
Step 2: At the current position, if the closeness active IR sensor is from A-type then the robot must repeat step one. If the closeness active IR sensor is from B type and located at the right side of the A-type active IR sensor (Fig. 10) the robot must turn left at it is next movement step else it must rotate right.
Step 3: Step one and step two must be repeated until the robot scopes the target point.

III. THE SIMULATION RESULTS

The planned indoor path planning algorithm is simulated using the Visual Basic programming language. the environment consist of various (16*16, 32*32 and 64*64) IR receiver sensors with dimensions that is assumed to be (1000*1000) pixels which distributed regularly in the environment, the first step in this procedure is to find the robot position by using the scan process using a new algorithm called the modified binary search algorithm. A new path planning algorithm called the virtual tangent visibility graph algorithm is used to determine the path planning from the robot source to the target location. Active IR receiver sensors are distinguished to reduce the processing time of localization new techniques.

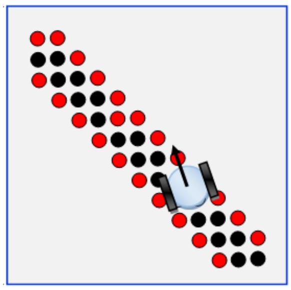


Fig.10. Control the robot's orientation.

The simulations are repetitive for changed topologies illustrative a different robot position, by changing the sensing range of the IR receivers and changed dimensionally for the IR receiver sensors. The parameters used in this scheme are:

- The various number of IR receiver sensors in the environment.
- The execution time (second) for the robot to reach the target for different sensing rang and different environments.
- The different sensing range for the IR sensors.

Fig.11. shows the snapshot for robot path planning in a 32*32 Pixels environment. The goal of this simulation is to show the different path planning execution time in different types of environments and sensing range for the IR sensors.

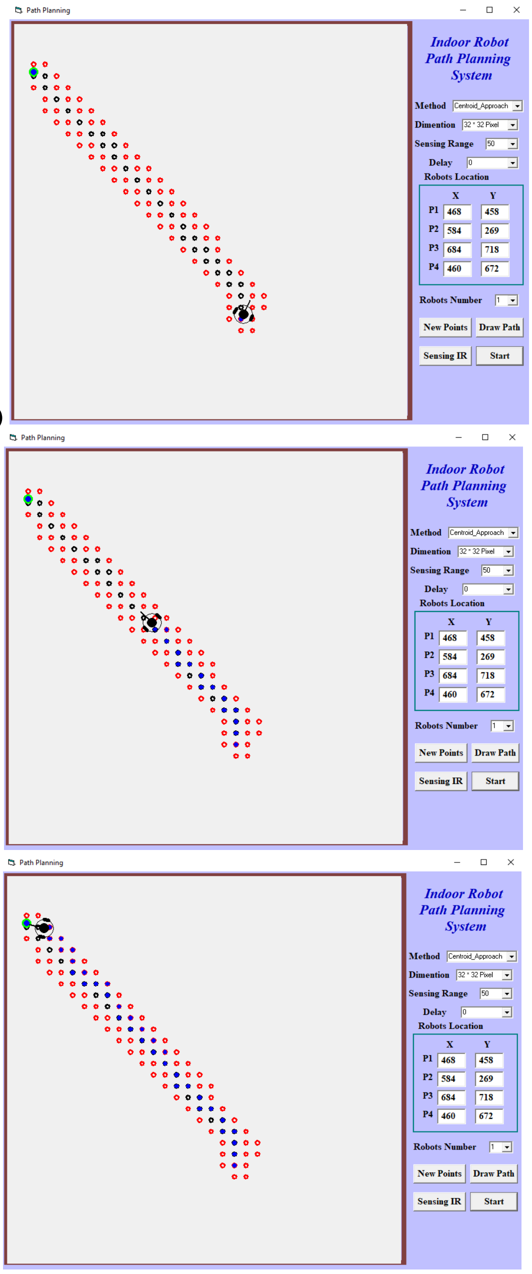
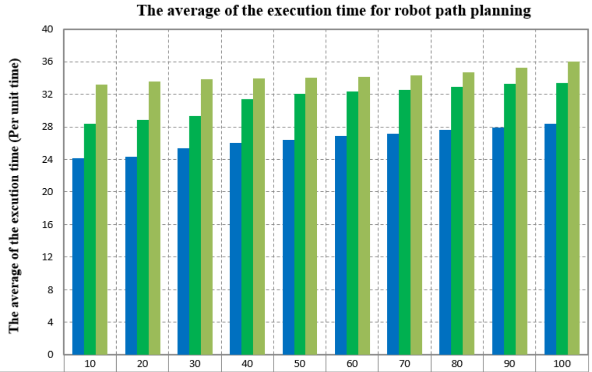


Fig.11. Snapshot for robot path planning in a 32*32 Pixels environment.

Fig. 12 shows the robot path planning comparison among different types of the environment and different sensing range for IR receiver sensors. The execution time is increased as the IR sensing range is increased and also, the environment with 16*16 IR receiver sensors has less execution time than the other type of the environments.

The second simulation (Fig. 13) shows the complete robot path planning for different dimensional environments. 64*64 IR sensors environment produces a more accurate path planning than the other types of the environment as shown in Fig. 14. Also, the accuracy is increased in path planning as the IR receiver sensing range is increased and for all types of the environments.



	10	20	30	40	50	60	70	80	90	100
16*16 IR sensors	24.1	24.3	25.4	26	26.4	26.89	27.13	27.6	27.92	28.35
32*32 IR sensors	28.34	28.81	29.33	31.35	32.04	32.31	32.49	32.91	33.32	33.41
64*64 IR sensors	33.15	33.6	33.81	33.92	34	34.13	34.33	34.68	35.25	35.97

Fig.12. The execution time comparison for different environments.

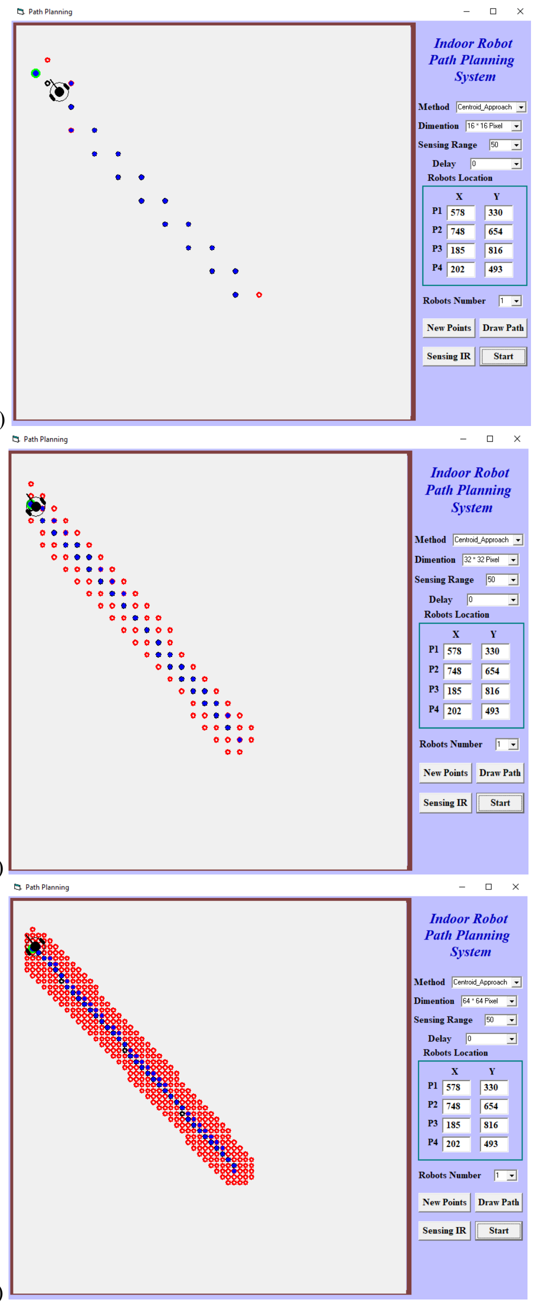
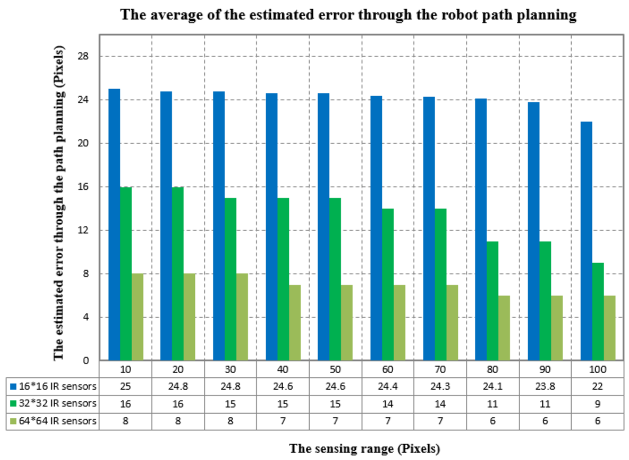


Fig.13.The complete robot path planning in different environments.



	10	20	30	40	50	60	70	80	90	100
16*16 IR sensors	25	24.8	24.8	24.6	24.6	24.4	24.3	24.1	23.8	22
32*32 IR sensors	16	16	15	15	15	14	14	11	11	9
64*64 IR sensors	8	8	8	7	7	7	7	6	6	6

Fig.14.the average of the error comparison through the robot path planning with the various dimensional environment.

CONCLUSION

This paper proposed a new technique using low-cost IR transmitter-receiver sensors to solve the path planning of an indoor mobile robot system. The IR transmitter is fixed on the robot and the IR receivers are distributed uniformly in the environment with various dimensions. Two simulation results are discussed in this paper: The execution time for the path planning and the error estimation through the path planning process. The results show that as the sensing range of the IR receiver sensor increased, the execution time is decreased and as the dimension of the environment increases the execution time also increases. This happens because the larger number of IR sensors means higher computation time. The second simulation results show that as the IR receiver sensing range rises the average of estimated error is reduced. Also, increasing the dimensional of the environment leads to increase the accuracy in path planning.

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