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# A SIMPLE INDOOR NAVIGATION SYSTEM BASED ON LED ARRAYS FOR MOBILE ROBOTS

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## ABSTRACT

Simultaneous Localization And Mapping (SLAM) algorithms have been generally used for mobile robots to move to their destinations. In order for robots to move to the destinations using SLAM, each mobile robot needs to detect its surrounding environment, which usually requires high-cost sensors such as LIDAR and high computational power for running mapping and filtering algorithms. Especially, when a user needs to control a large number of robots, it becomes more difficult to find the paths of robots without collision and the communication between the user and the robots becomes more complicated.

This paper presents a simple indoor navigation system based on LED arrays installed on the ceiling which guide multiple robots on the corridor to their destinations. The paths indicated by the LED arrays can be viewed as “virtual railroads” in the sense that the robots can move only along the virtual paths beneath the LEDs. In this system, high-cost sensors and extensive computations are not necessary for the robots to perceive their surrounding environment and reach to the destinations. A single camera per robot to look at the LEDs on the ceiling and a simple vision processing to follow them is sufficient.

When a robot starts to move, it receives its identity (ID) color from the LED at the starting point and the robot moves toward the location where its ID color is indicated. Thus, the operator can simply guide the mobile robots by turning on and off the LEDs. By installing ultrasonic sensors along with the LEDs, the operator can detect the robot beneath a certain LED. When a robot is detected, the corresponding LED is turned off and the next LED is turned on to guide the robot. Following this procedure, the robot can finally arrive at its destination. This system does not require any wireless communication link between the operator and the robots. The performance of the proposed indoor navigation algorithm is presented by simulations.

## INTRODUCTION

Indoor navigation is one of the fundamental topics in mobile robotics. For some decades, it has been considered significantly because of its applications in service robots; such as delivery, cleaning, or entertainment. To perform these tasks, it is necessary to move a mobile robot to its target location. The most popular navigation methods are dead-reckoning based [1,2] and mapping based methods. Vision based [3] and communication technique based systems like RFID [4] or Wi-Fi [5] systems have also been applied to mobile robot systems.

A dead-reckoning navigation method is a simple algorithm and easy to use for various mobile platforms, but precision errors and sensor drifts lead to increasing cumulative errors in the position of robots [6]. Simultaneous Localization And Mapping (SLAM) [7] algorithm is popular in mapping and navigation techniques, however, it usually requires high-cost sensors such as LIDAR and high computational power for running mapping and filtering algorithms. Especially, when a user needs to control a large number of robots, it becomes more difficult to find the paths of robots without collision and the communication between the user and the robots becomes more complicated.

Since working with a team of robots is more efficient than with a single robot for some applications, various methods for multi-robot navigation systems have been proposed [8]. Especially, when a user needs to control a large number of robots, it becomes more difficult to find the path of each robot. It has to be considered, when a team of mobile robots is operating in the same environment, that their motions should be planned to avoid a collision between themselves all the time. To resolve this problem, motion planning algorithms for multi-agents [9] are usually applied, which compute each robot's trajectory and guide them to their destinations.

In this paper, we address a simple indoor navigation system for multiple mobile robots. The goal is to guide individual robots to their destinations while collisions between the robots are avoided. As described in Fig.1, the paths indicated by the LED arrays on the ceiling can be viewed as "virtual railroads" in the sense that the robots can move only along the virtual paths beneath the LEDs. In this system, high-cost sensors and extensive computations are not necessary for the robots to perceive their surrounding environment and reach to the destinations. A single camera per robot to look at the LEDs on the ceiling and a simple vision processing to follow them is sufficient. A modified A* for path planning, which works in real time and can be applied to multi-robot systems, is proposed.

This paper is organized as follows. In the following section, we introduce the proposed indoor navigation system architecture. The third section describes our algorithm for searching and path decision. The fourth section, we present simulation results of the proposed method, and the last section is the conclusion.

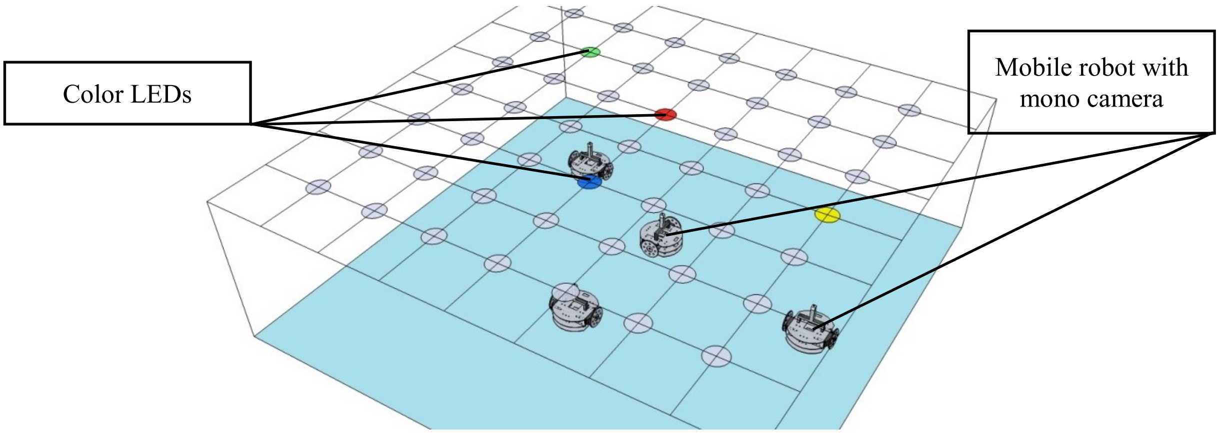



Fig. 1. Concept of the proposed navigation system

## SYSTEM ARCHITECTURE

The proposed indoor navigation system consists of two parts. One is a mono-camera-equipped mobile robot and the other is a module with an LED and an ultrasonic sensor. A simple algorithm is responsible to look at the LEDs by a mono camera mounted on the robot. A system configuration of the proposed navigation technique is depicted in Fig.2, where two LED lights, L1 and L2, are attached on the ceiling. The robot's desired trajectory is the straight-line segment connecting the orthogonal projection points, A and B. The robot employs a vision algorithm which is required to guide the robot from one point to another in its workspace. When LED L1 tuned on, the robot prepares to move and searches to find next target. When L1 turns off and L2 turns on, robot moves to beneath L2 and it reaches its desired goal, point B. Through this simple algorithm, we can guide a mobile robot from one point to the other point.

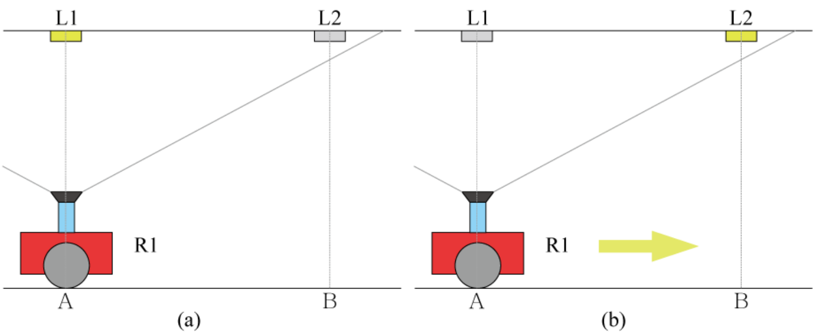



Fig. 2. Proposed indoor navigation system

The following is a detailed description of the steps of this procedure. When a robot starts to move, it receives identity (ID) color from the LED at the starting point and the robot moves toward the location where its ID color is indicated. In this scenario, the operator can simply guide mobile robots by turning on and off the LEDs. When a robot is beneath a certain LED, the ultrasonic sensor detects the robot and the corresponding LED is turned off, while the next LED is turned on. Following this procedure, the robot can finally arrive at its target destination. When it arrives, it stops there and the operator returns the robot's ID color for reuse. In this process, the system does not require any wireless communication link between the operator and the robots.

Preliminary studies are conducted to show the fact that using a mono camera with the LED indoor navigation system can determine the movement of an individual robot. In Fig. 3, $\phi_1$ is the phase angle of the robot's direction and $\phi_2$ is the phase angle of the current indicator's direction. The phase difference, $\Delta\phi$, is defined by

$$\Delta\phi = \phi_1 - \phi_2 \qquad (-\pi < \Delta\phi \le \pi). \tag{1}$$

The phase difference decides the rotating direction of robot. If $\Delta\phi$ is higher than $5^{\circ}$ it turns left and $\Delta\phi$ is lower than -$5^{\circ}$ it turns right.

Let $d_1$ be the distance from the image center to the next indicator. And $d_2$ be the radius of range for detection where the robot locates near its target destination.

The distance to the destination, Δd, is defined by

$$\Delta d = d_1 - d_2 \tag{2}$$

The distance to the destination decides the robot's movements. If Δd is positive, the robot moves forward and if Δd is negative, the robot stops.

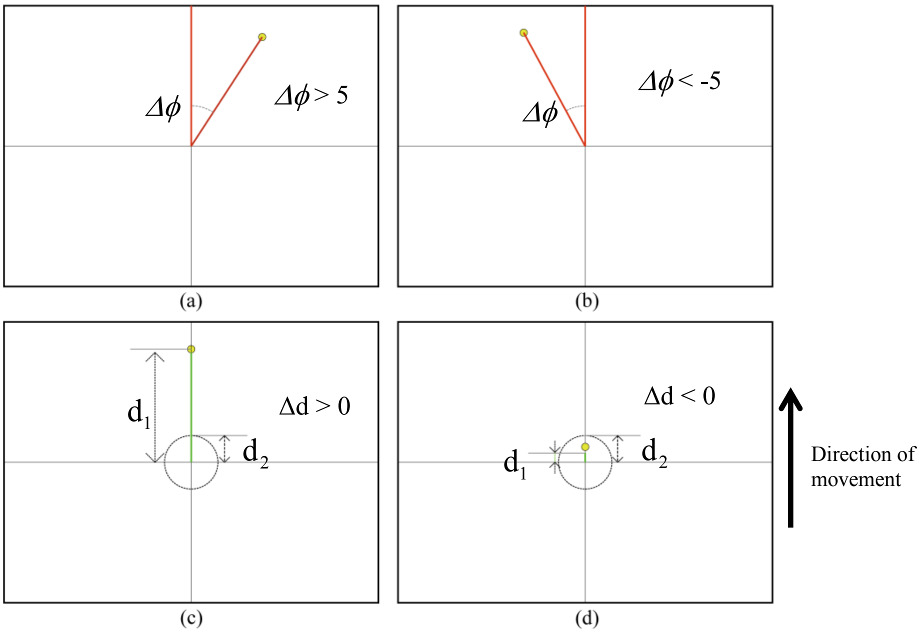



Fig. 3. The view of a camera looking up the ceiling. Each case corresponds to the robot movement of : (a) turning left (b) turning right (c) moving forward (d) stop.

## NAVIGATION ALGORITHM FOR A MULTI-ROBOT SYSTEM

This section explains how multiple robots simultaneously move to their destinations without collision. For an individual robot, we apply a A* based real time path planning method which is used to find the shortest path of a robot.

### A. A* based real time path planning

The A* algorithm addresses the problem of finding a shortest path from an initial point to a goal point [10]. We apply A* procedure to our system to compute the cost-optimal paths for individual robots. A genetic A* is not usually used in robot navigation system because it requires a discrete search graph [11], whereas the configuration space of a robot in

real world is continuous. We apply A* procedure to a discrete map which shows the locations of indicators attached at the ceiling with regular intervals.
Because a robot's obstacle map changes continuously when other robots are moving, it is not proper to apply genetic A* in our system. To resolve this problem, a robot recomputes its optimal path continuously while other robots are moving. Through this method, we can guide individual robots from an initial position to a goal in the shortest way.

**B. Multi-robot path planning**

In the case of a multi-robot system, a robot's optimal path can be overlapped by other robot when both robots move to the same target at a same time. We applied some methods to avoid this situation. The proposed procedure to avoid collision is given as follows.

**Step 1:** When a robot finds the next target indicator, it memorizes the target indicator which is the shortest way to the goal.

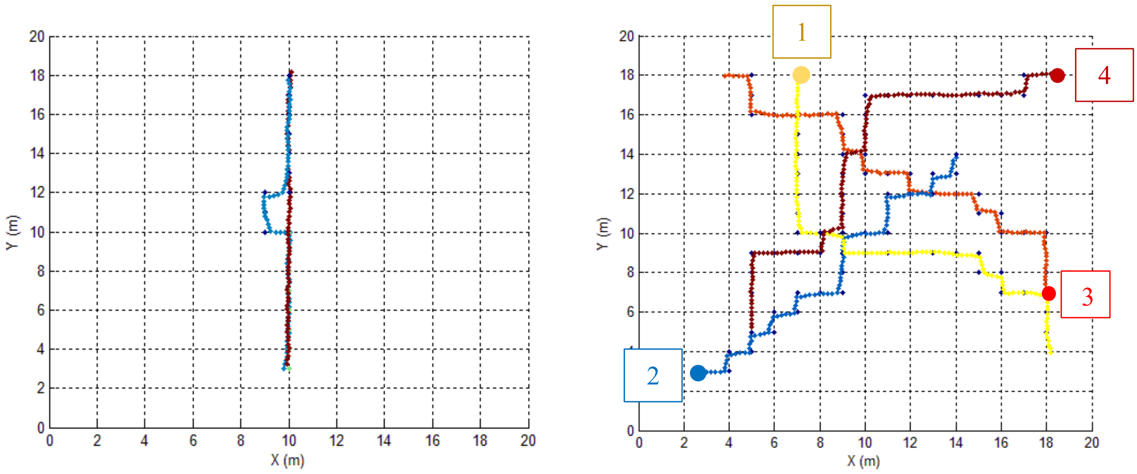
**Step 2:** The robot memorizes the other target indicators and assigns ranks to them. The shortest way to the goal receives the highest rank and the furthest receives the lowest rank.

**Step 3:** If the highest rank target indicator is overlapped between two robots at the same time, the robot which occupied the target earlier gets the higher priority. If they select the same target at the same time, their traveling time is compared and the one which has higher traveling time selects the target at first. In the other hand, the other robot excludes that target and restarts from step2.

A simulation of this algorithm's performance is provided in the following section.

## SIMULATION RESULTS

In the simulation, we test the basic functionality of the proposed algorithm, guiding robots to their final goals without a collision. The virtual space of this simulation is an empty 20m x 20m space where LED array modules are installed every meter. In Fig. 4(a) when two robots' paths are overlapped at the same time, one arrives earlier selects the fastest path, otherwise, the other which arrives late renounces its fastest path one and select second ranked path. Four robots are used in the second simulation, those initial position and orientation were set to (3, 3), (18, 3), (5, 18), (18, 18) each. In fig.4 (b), each of robots finds their optimal trajectory without collision between themselves. Through this simulation, we verified performance of our navigation system works well not only for a single robot system but also for a multi robot system.




(a) (b)

Fig. 4. The simulation result of the proposed algorithm. (a) The case that the optimal paths of two robots are overlapped at the same time. (b) The trajectories of four robots without a collision.

## CONCLUSION

We have presented a simple indoor navigation system that is a centralized multi-agent navigation based on simple methods and equipment. The system applies the A* based real time path planning which computes the optimal path of multi-robots. In a multi robot navigation system, we proposed some method to find the collision free path for every robot. Simulation is performed to implement navigation system with 2 and 4 mobile robots. Though the simulation, we showed that our method works on multiple mobile robot system. A further advantage of our method lies in its general applicability. Since it can guide many robots simultaneously, the proposed system can be applied to many service robot applications. In addition, it could be applied in parking system for unmanned vehicle.

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