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# A Self-Localization and Path Planning Technique for Mobile Robot Navigation

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***Abstract*— In this paper, we propose a system to cope with the problem of autonomous mobile robot navigation. It is able to perform path planning and localize the robot in the real world environment. The path planning is first carried out using the known map, and the laser range scanner is then used to localize the robot based on the ICP registration technique. During the robot motion, the potential field is taken into account for obstacle avoidance. For the path planning, the visibility graph is established based on the current position of the robot. The Dijkstra algorithm is then used to find the shortest path to the goal position. Experimental results for both the simulation and real world environment are presented.**

***Index Terms*— mobile robot localization; navigation; path planning; ICP registration; potential field**

## I. Introduction

Self-localization and path planning are two important issues for autonomous mobile robot navigation. For the autonomous motion, the robot should have the ability to localize its current position, perform the path planning for the future movement, and move to the next position as expected.

Currently there exist many techniques for mobile robot localization. The approaches can be categorized into two groups based on the property of the adopted sensor for data acquisition. One technique which uses the internal sensors such as odometry, gyro and accelerometer is called dead-reckoning. The other adopts the external sensors such ultrasound, laser scanner or camera systems, etc. This approach relies on the information obtained from the environment, and can avoid the internal error made by the robot motion. To increase the applicability of the sensor information, many researchers have combined various types of sensors to achieve better localization results [1], [2]. In this work, only a laser range scenner is used for our mobile robot localization and navigation.

The vision-based approaches are commonly used for robot navigation. Weiss et al. proposed an invariant descriptor called Weighted Grid Intergral Invariant feature (WGII) for the outdoor localization [3]. To avoid the accumulation error during the robot motion, Siegwart and Nourbakhsh suggested to use landmarks for global localization [4]. Hsieh et al. proposed a method which uses an omnidirectional camera to capture the specific color of the landmarks for localization [5]. For other sensor-based approaches such as active beacon system, the ultrasound transmission beacon and the receivers are mounted on the robot and the known positions in the indoor environment, respectively. The mobile robot is then localized by triangulation [6]. Yoshitaka et al. combined the infrared intensity and 2D point data from the laser-based SOKUIKI sensor to perform the localization via ICP (iterative closest point) registration [7].

The objective of path planning is to let the robot move from the starting position to the goal, and simultaneously avoid the obstacles during the motion. The current techniques can be categorized into two groups based on the availability of the environment maps [8]–[10]. Based on the given map of the environment, Bhattacharya and Gavrilova used the Voronoi diagram for path planning and smooth the path for better obstacle avoidance by iterative refinement [11]. Rawlinson and Jarvis considered the map as topological instructions and the database of the nodes with the corresponding motion [12]. When the robot gets to a node, the required motion is issued accordingly.

For the path planning with unknown maps, Naroditsky et al. proposed a unitary vector set to represent the local collision-free directions in the image coordinate system [13]. This so-called vision vector space is then used to determine the directions of walkability. Ge and Cui applied the potential field to guide the robot towards the goal and avoid the moving obstacles in a dynamic environment [14]. Acar and Choset proposed a technique for the robot equipped with 16 ultrasonic sensors to explore the entire unknown environment and build the map [15].

In this paper, we propose an autonomous navigation system to guide the robot to the goal quickly and safely. Given the map of the environment as well as the starting and goal positions, we first find the shortest path by Dijkstra algorithm and then register the laser scanning data with the map for localization. Finally, the potential field is taken into account to the collision with obstacles.

The rest of the paper is organized as follows. The path

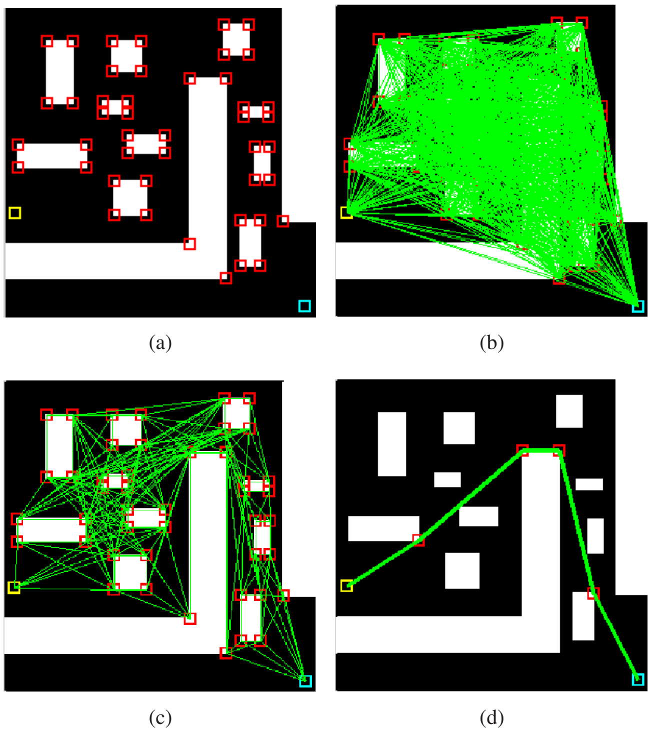



Fig. 1. The diagram of path planning algorithm. (a) The results of Harris corner detection. (b) The connection of all vertices. (c) The visibility graph. (d) The shortest path.

planning algorithm is introduced in Section II, and the implementation of the navigation system is described in Section III. In Section IV, we demonstrate the feasibility of the proposed system with simulation and experiments on the real world environment. Finally, we conclude the paper in Section V.

## II. The Path Planning Algorithm

In this section we introduce the path planning algorithm for finding the shortest path, and describe how it is used in the proposed navigation system. Fig. 1 shows an example of the path planning algorithm. We first find the vertices of the polygons in the map by Harris corner detector (see Fig. 1(a)). The red squares indicate the verteices, the yellow square represents the starting position and the cyan square represents the goal position. Fig. 1(b) illustrates all of the connecting lines among the vertices. The visibility graph as shown in Fig. 1(c) consists of the connection between any vertex pair without obstacles. Finally we find the shortest path from the starting position to the goal by Dijkstra algorithm, as shown in Fig. 1(d).

### A. The Visibility Graph

In the path planning problem, searching for a suitable motion path using the Voronoi diagram is safe, but in general not the shortest or fastest one [11]. Therefore, we build the visibility graph based on the vertices of the obstacles to identify the shortest path.

As shown in Fig. 1(c), in the visibility graph every two connected vertices are able to see each other (i.e. the connecting line does not pass through the obstacles). For the visibility graph denoted by $g_{vis}(S) = (V, E)$, where $S$ is the set of all obstacles, $V$ is the set of vertices of $S$ and $E = \emptyset$, the algorithm is shown in Algoritm 1.

**Algorithm 1** Visibility Graph

```
for all vertex v_n ∈ V, n = 1, 2, ...m do
    if v_i has the ability to see a vertex v_j, v_i ≠ v_j then
        add the (v_i, v_j) to E
    end if
end for
return g
```

### B. The Dijkstra Algorithm

In this work, the Dijkstra algorithm is used to find the shotest path from a single source to all other nodes in a positive weighted and directed graph. We consider all vertices of the obstacles as nodes and compute the distance between every pair of connected nodes from the visibility graph as the weight. The Dijkstra algorithm is thus carried out in the following steps:

1) Set the distance of the initial node zero and the other nodes infinity.
2) Mark the initial node as the current node.
3) For the current node, compute the distances from all unvisited neighbors to the initial node. If the distance is less than previously recorded distance, overwrite the distance.
4) If all nodes are visited, then the program stop, or select the smallest distance of neighbors as current node and go back to step 2).

## III. The Implementation of Autonomous Navigation System

In the autonomous navigation system, the robot should know where it is and then it can decide how to get the goal. For this reson, the self-localization plays a significant role in the robot navigation. The localization methods highly depend on the sensing techniques used for data acquisition. Since only the laser range scenner is used to collect the environment information, the ICP algorithm is used to register the laser scanning data with the known map for robot localization.

### A. System Configuration

The configuration of the proposed navigation system shown in Fig. 2. The pose of the mobile robot is denoted by the position and orientation $(x, y, \theta)$ in the map. In the beginning we compute the visibility model, which is the data

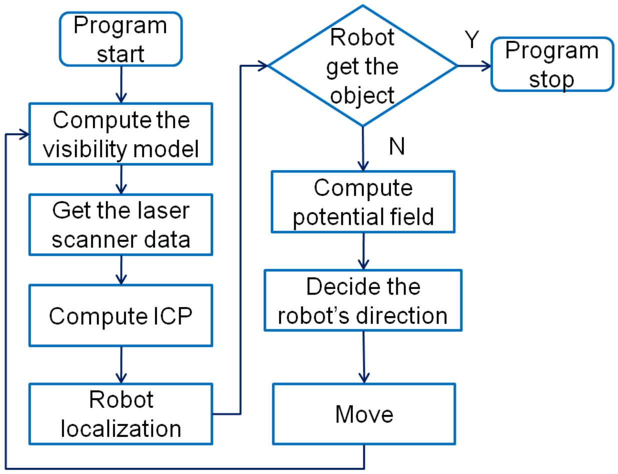
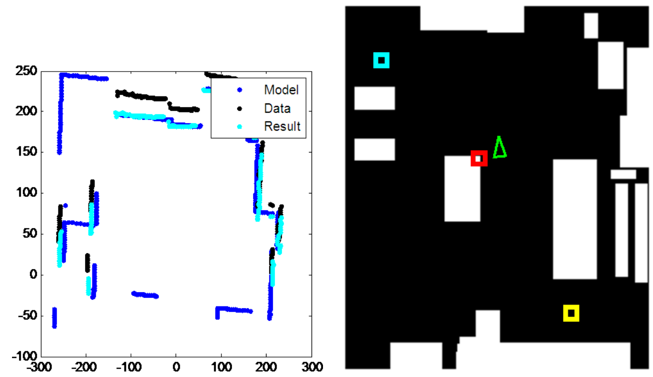



Fig. 2. The configuration of navigation system




(a) (b)

Fig. 3. Self-localization of the robot. (a) The results of ICP registration. (b) The pose of the robot.

points obtained from the edge of obstacles around the robot in 5 meters, and use the laser scanning data points to localize the robot position via ICP algorithm. If the robot does not reach the goal, it determines how to move to the next position and repeat the above process. Otherwise, the robot has achieved the goal and the the navigation is completed.

### *B. Robot Localization*

As described in the previous section, we register the laser scanning data and the visibility model to localize the robot using the ICP algorithm. Suppose the initial pose of the robot is given by $(R_{\theta s}, R_{xs}, R_{ys})$ and the transformation derived from the ICP registration is $(\theta, x, y)$. Then the current pose of the robot is computed by the following equations:

$$R_\theta = R_{\theta s} + (-\theta)$$
$$R_x = R_{xs} + x$$
$$R_y = R_{ys} + y$$

The minus sign for the angle indicates that the data points from the laser range scanner are opposite to the oreintation of the robot.

Fig. 3 shows the localization result using range data registration. As illustrated in Fig. 3(a), the blue points represent the visibility model, the black points indicate the laser scanning data points, and the cyan points are the registration results using the ICP algorithm. An example of the localization result is shown in Fig. 3(b). The white and black regions indicate the obstacles and the free space, respectively, the green triangle is the position of the robot with the moving direction represented by the sharp angle.

#### *Iterative Closest Points*

The data registration is commonly applied to reconstruct the 3D object surfce, register the medical images, and combine the photos with overlapping scenes to build an image panorama. In the registration problem, we have to select an appropriate method to align the data points. In this work, the information we are dealing with contains two sets of data points, one is obtained from the laser range scanner and the other is available from the map. By registering these two sets of points, the robot can localize itself in the environment. To solve this registration problem, we adopt the ICP algorithm, which has been widely used to register two given data point sets.

In our implementation, the laser scanning data set and the visibility model are consider as *Data* and *Model*, respectively. With the initial settings on the transformation parameters, the number of iteration and the tolerance of error, the ICP algorithm is implemented as follows:

1) Find the correspondences between the two point clouds.
2) Measure the transformation parameters by mean squared cost funtion.
3) Transform the data points using the estimated parameters.
4) If the error is larger than the tolerance or the number of of iteration is less than the defined maximum, then go back to Step 1). Otherwise, complete the procedure.

#### *Potential field*

Potential field has been widely used in robot path planning [16]. The major problem of the potential filed techniques is the possibility of getting stocked in a local minimum when the polygon is concave. In the proposed system, the potential field only considers the current robot position and the environment. That is, the potential field is taken into account locally. The advantage of this approach is that the robot can adapt to the environment in case some obstacles not in the map show up during the robot motion.

Fig. 4 illustrates how to use potential field for robot motion. The figure shows that the robot is pulled by the

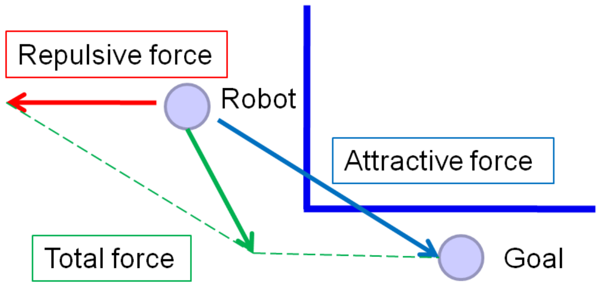



Fig. 4. The illustration of potential field used in this work.

goal and pushed by the obstacle simultaneously. The former is called the attractive force and the latter is called the repulsive force. The summation of the two force vectors gives the direction for the robot to move at the position. Mathematically, we have

$$F_{att} = -k_{att}(x - x_{goal})$$
$$F_{rep} = \begin{cases} k_{rep}(\frac{1}{\rho} - \frac{1}{\rho_0})\frac{1}{\rho^2}, & \text{if } \rho \leq \rho_0 \\ 0, & \text{if } \rho > \rho_0 \end{cases}$$

In the above equations, the attractive force is denoted by $F_{att}$ and the repulsive force is denoted by $F_{rep}$. $\rho$ is the distance between the robot and the obstacles and $\rho_0$ is the safety distance.

We set $F_{rep}$ as zero if $\rho$ is larger than $\rho_0$. Finally, the summation of the two forces is denoted by $F_{total}$ where

$$F_{total} = F_{att} + F_{rep}$$

## IV. Experiments

The proposed robot navigation system has been tested in the real world environment. Fig. 5 shows the experimental setup of the mobile robot. A laser range scanner LMS 100 (scanning angle from -45 to 225 degree, frequency 50 Hz, range up to 20 m) and a laptop computer are mounted on the mobile robot. The computer is used to derive the motion plan and behavior of the robot. It receives the data from the laser range scanner and sends out out the commands of robot motion to the motion control circuit. The mobile robot with differential drive wheels can then move based on the control signals from the circuit.

### A. Simulation

Fig. 6 shows a synthetic map with $300 \times 300$ pixels for simulation. It contains many obstacles and one of them is with concave shape. The conventional potential field techniques wil cause the robot stocked in the indentation area due to the local minimum. The proposed system can avoid this problem since we plan the motion path in advance (see Fig. 1(a)). The robot has to pass the four vertices (the red squares) called subgoals in order to get the final destination (the green square). During the motion, the robot first arrives the $t_{th}$ subgoal then goes forwards the $(t+1)_{th}$ subgoal. In this process, the robot does not get stocked in any local minimum and the path planning can avoid the obstacles adaptively. The result is shown in Fig. 6, the yellow square is the starting position and the cyan square is the goal. The path planning for the robot motion is represented by the green lines.

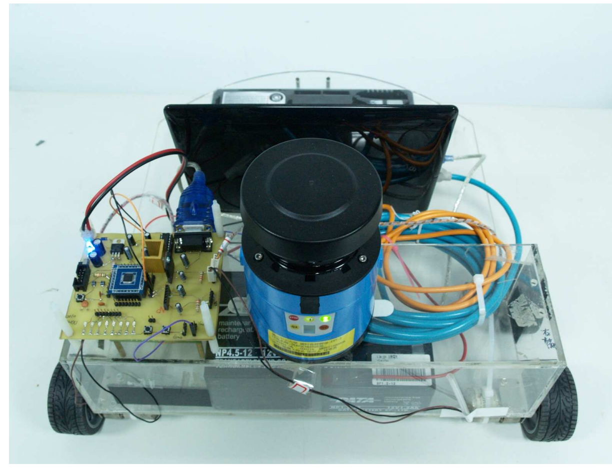


Fig. 5. The autonomous mobile robot used in this work. It consists of the control circuits, differential-drive wheels, laptop computer and laser range scanner.

### B. Real environment

We have also tested our system using a mobile robot in the indoor environment of $640 \times 540$ cm$^2$ with some furniture in it. Fig. 7(a) shows the map of the environment, where the yellow square is the starting position and cyan square is the goal. We first compute the visibility graph (see Fig. 7(b)), and then find the shortest path via the Dijkstra algorithm (see Fig. 7(c)). Fig. 7(d) shows the final result as the potential field is employed for motion planning.

Given the vertices of the shortest path as shown in Fig. 7(c) we can then use our mobile robot to navigate through the vertices in the environment. In the navigation process, we extract five results of the registration and localization in the robot sequential motion (see Fig. 8). The registration results are shown in the left figures. The blue points represent the visibility model, the black points represent the data points, and the cyan points are the the registration result. The right figures are the localization results. The green triangle represents the position of the robot and the motion direction is indicated by the sharp angle.

Fig. 9 is a series of the robot motion from the starting position to the goal. It clearly shows that when the robot gets close to the obstacles, it moves away from the obstacles in the next step and achieves the goal finally. The robot is able to automatically move to the goal from start, avoid the collision with the obstacles, and localizes its own positons. These

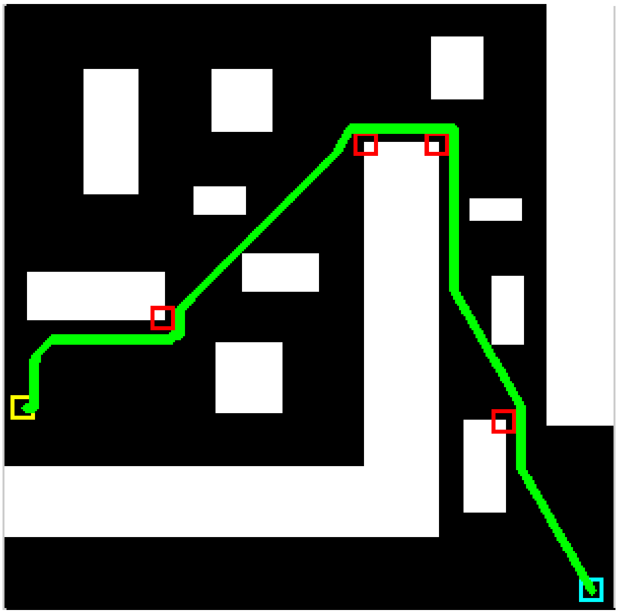
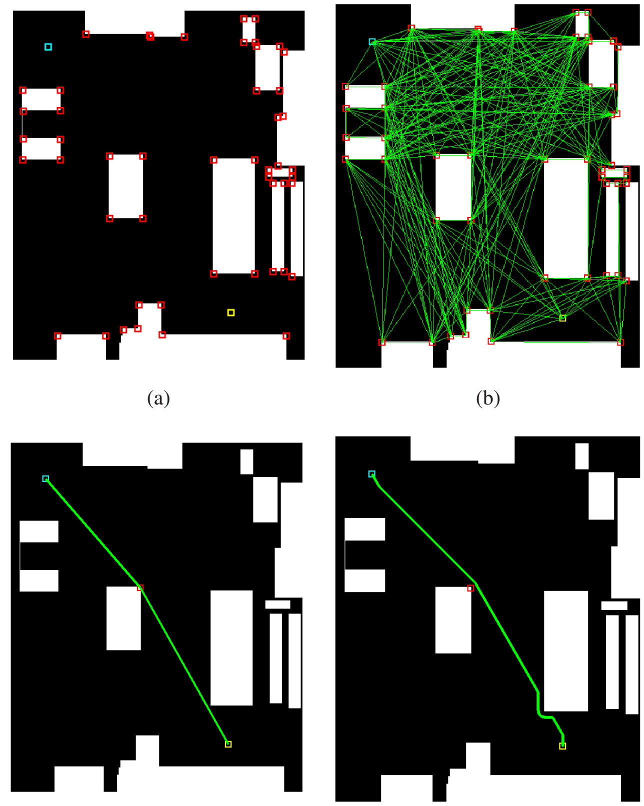


Fig. 6. The simulation result with a given map:
Path planning with potential field.



(a) (b) (c) (d)

Fig. 7. Simulation in the real environment. (a) The map of real environment with the starting position and the goal. (b) The visibility map. (c) The result of path planning algorithm. (d) The result of path planning algorithm with potential field.

two experiments demonstrate that our navigation system is feasible in both the simulation and real world environment.

## V. Conclusion

In this paper, we propose a navigation system to deal with the problem of robot motion in the known environment using the laser range scanner. First we build the visibility graph and find the shortest path by Dijkstra algorithm, then localize the robot by registering the laser scanning data and the visibility mode based on the ICP algorithm. Finally, the potential field is incorporated to decide the robot motion for the next step. Experimental results in the real world environment have shown the feasibility if this work. In the future we will register the known map globally in the localization process to avoid accumulation error and modify the robot motion to make it move smoothly.

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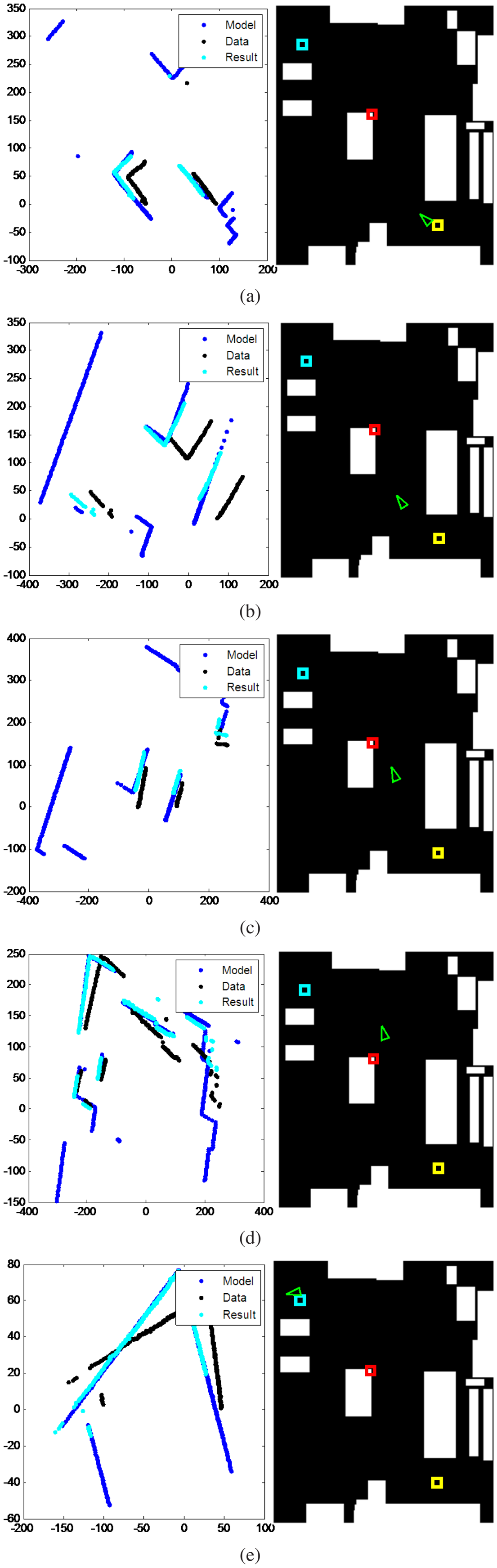


Fig. 8. The 5 positions of robot sequential motion from start to goal.

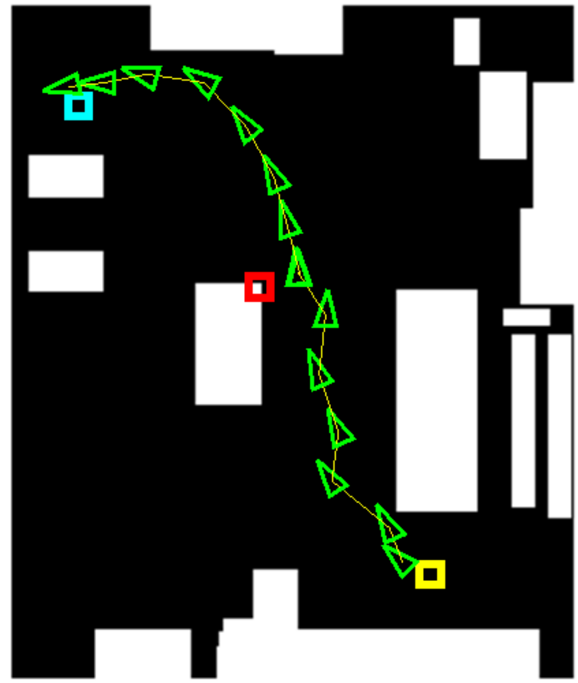

Fig. 9. The result of localization and path planning implemetation.

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