Potential Based Navigation Method Considering Global Path Planning Method and Local Reactive Motion

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Introduction

Many industrialized countries have a problem of aging society and low fertility. As the trend proceeds, the demand of autonomous mobile robots has been increased to supplement the shortage of manpower to work or support elderly people. The essential skill for such kind of robots is to determine how to move from a start to a goal without collision in a changeable environment. In order to obtain the skill, mapping, localization or navigation techniques have been studied well in recent years. However, these conventional methods generally take high computational cost because they have to handle huge amount of calculation. The high computational cost could interrupt the other functions like their house work or nursing care. And also, high calculation cost requires expensive high performance calculator, which could disturb the spreading of such robots due to the economical cost.

Therefore, we propose the navigation method with low calculation cost and which can be used with inexpensive sensor and calculator. Navigation method usually can be classified into two types: global planning method and local reactive method. We propose the two types of method respectively, and finally mix them to build one navigation method which can consider global path planning and local reactive motion with low computational and calculation cost.

Methodology

Local Reactive Method

Our local method is based on the APFM (Artificial Potential Field Method). This method is known as simple but strong in destination reaching problem. In APFM, moving away from obstacles is defined as the effect of the repulsive potential while movement toward a goal is defined as the effect of attractive potential.

We use this idea with the integration-type sonar ring shown in Figure 1. The integration-type sonar ring is set of 16 pairs of ultrasonic wave sensor, which can measure integration value obtained by summing up amplitude of reflecting pulses of ultrasonic wave. The integration value represents density of objects in the range of an ultrasonic wave sensor. By plotting integration values with respect to angle, setting a threshold and compared them, we can recognize which directions are open and which directions are filled with obstacles. We use the integration values directly as repulsive potential field in the frame of APFM as shown in Figure 2-(a) by red line.

As for the attractive potential field, we use a linear function which becomes minimum at the direction of a goal as also shown in Figure 2–(b) by blue line. We used RGB camera to detect a land mark placed on the goal.

By summing up them, we get a composed potential field as shown in Figure 3. In this case, there are spaces in the direction from 50 to 75 deg and 120 to 130 deg, and goal is places in the direction of 120 deg. Because it can be said that second space is closer to goal, the robot choose this direction. Repeating to move toward such direction, the robot will finally reach its destination.

This algorithm is not based on complex calculation but on sensing, therefore the robot can decide its direction to move. And also, the integration-type sonar ring takes much lower cost than a laser range finder, which is one of the most used sensor for mobile robots. Thus, we could build a local reactive navigation method with low computational and economical cost.
Global Path Planning Method

On the other hand, our global path planning method is based on PRM (Probabilistic Roadmaps). In this method, nodes are distributed to whole map and they are connected by line segments, thus roadmap is generated. After that, the shortest path on the roadmap is determined. The original method have a problem of disconnected problem, which cannot decide a path because the start and the goal is not connected by the roadmap. Moreover, the computational cost increases rapidly as the number of nodes are increased because of the algorithm to find the shortest path. To overcome these problems, we uses the artificial potential field method and map-segmentation technique.

The sequence of the algorithm is as follows. (i) A potential map is created from a given map. (ii) The map is decomposed into \( n_x \) and \( n_y \) pieces in x and y direction respectively. (iii) Each area is classified into high potential area and low potential area depending on the total potential value of the area. (iv) The number of nodes are decided depending on the type of the area. More nodes are assigned to high potential areas and fewer nodes are assigned to low potential areas. (v) Nodes are distributed to relatively low potential grids inside an area. (vi) Nodes are finally connected by straight line segment.

Key points are “map segmentation” and “node distribution to low potential grids”. By using map segmentation, nodes can be distributed also to narrow spaces because there must be more than one node in each area. Furthermore, nodes can be distributed considering the surrounding environment because the number of nodes is changed depending on the potential values. And also, using the potential field and forbidding to distribute nodes to high potential area can restrict the range of distributing nodes. In other word, nodes get close each other. Owing to this, we can prevent a path to be disconnected.

Eventually, we constructed an improved method in respect of success rate of path planning and the calculation cost.

Mixed Navigation Method

However, the local method cannot consider the global environment because it does not have a map of environment, while the global method cannot adapt to changeable environment because it is based on the static map. Therefore, we mix these method to complement the weak points each other, hence the proposal method can be used in global environment and can react to undescribed obstacles in the given map with low calculation cost and inexpensive sensor.

The schematic of the proposal method is shown below.
Results and Discussion

Evaluation of Global Planning Method

As for the global path planning method, we simulated the original PRM and our improved method (PBPRM: Potential based Probabilistic Roadmaps) changing the number of nodes $V$. Each case is repeated 30 times, and we obtain (i) success rate $sr$ [%], (ii) mean calculation time $t_{\text{mean}}$ [s] for path planning, (iii) mean distance of the path $d_{\text{mean}}$.

In environment shown in Figure 5, the result is shown in Table 1. We can find that the success rate and the length of the path of the PBPRM superior to those of the PRM, and the calculation time is better by the PRM than by the PBPRM in both case of $V = 100$ and 130. And also, the success rate is increased but calculation time is also increased largely as the number of nodes are increased. According to this result, we can say that PBPRM can achieve higher success rate with shorter calculation time.

The reason of increasing the success rate is explained using Figure 5 as follows. The first reason is that nodes could be distributed to whole area uniformly owing to the techniques of partitioning the whole map and distributing nodes to all the segmented areas. The distribution of nodes are lacking in uniformity in PRM, while it is uniform in PBPRM. The second reason is that the number of nodes could be changed for each area depending on the total potential value of each area. Owing to this technique, more nodes could be distributed to relatively complicated areas or areas with many obstacles. It becomes easier to connect nodes by lines as the number of nodes is increased. The third reason is that the place where nodes are distributed could be restricted to the part in which the potential value is relatively low. Restricting the places for nodes enables nodes to be existed closely each other, which makes easier to connect nodes by line segments.

Evaluation of Proposal Navigation Method

The proposal navigation method is investigated by simulation. In this simulation, we assume that the robot initially has the map and knows the position of the start point and the end point ($start = (5, 5), goal = (95, 95)$), then plans a global path using them. Firstly, the robot makes a path shown in Figure 6-(a). However, the path runs through an object because it does not know the existence of some new obstacles. If we use only global path planning method, the robot cannot reach its destination. On the other hand, the trajectory by the proposal method is shown in Figure 6-(b). In this Figure, the number of the local goal is described. Until the second local goal, the robot just follows the planned path. After that, the robot intends to go to the third local goal, however it notice the existence of an obstacle placed on the planned path. Hence, it changes its behavior of the local motion planning, and deforms the original planned path. Thus, the robot can avoid the new obstacle. After being able to see the next local goal, the robot moves straight to it, and restart to follow the original path.
Next, we see how the robot decides its behavior based on the sensor data during the local motion planning mode. At checkpoint 1, the robot starts to move to a different way from the original path. The potential values measured at this point is shown in Fig. 6. At this point, the position is (24, 58) and the direction toward the local goal of 3 is 13.6 deg. There is only one space where the robot can move from 90 deg to 230 deg because there are obstacles in the other direction. Therefore, the robot moves to the direction of the center of the space, which is about 170 deg.

Conclusion

This work proposed a navigation method which can be used in a dynamic environment and can react to unknown obstacles with low calculation cost. The proposed method is composed of a global path planning method and a local motion planning method. We designed each method so as to decrease the calculation cost, and combined them in the end to build a navigation method with low computational cost.

The presented work builds upon the previous work of local navigation using the integration-type sonar ring based on the artificial potential field method. The method decreases the calculation cost by using integration values from the sensor directly to the repulsive potential field. Since this method is based completely on the sensor data without any given maps, it is efficient for reactive motion against unknown obstacles. The validity is confirmed by experiments, in which the robot could successfully avoid obstacles and move toward a goal in small areas, but it also showed that it cannot be used in vast areas.

As for the global path planning method, we proposed PBPRM (Potential Based Probabilistic Roadmaps Method). This method improves PRM by using the artificial potential field method and map-segmentation. It is effective to distribute nodes uniformly over the whole environment, which decreases the path planning failure which occurs due to the unconnected problem. It can make a path from relatively few nodes, which is also computationally efficient. This method was evaluated by simulation experiments. From the evaluation, we found that the path planning works properly in static environment, with limitation that it cannot adapt to the change of the obstacles in the environment.

Because the local method has a merit of reactive motion but cannot perform global planning, while the global method has a merit of global planning but it cannot react to unknown obstacles, we combined them to complement each other’s weak points, and finally we built a navigation method which can be used in global and dynamic environment. In simulation, the proposed method planned a path in a global environment, and could also avoid a collision with dynamic obstacles, sensing its surrounding environment in real time.

However, this method has not been evaluated in real environment using a robot. Experiments in real environment should be done to investigate its validity. Moreover, this method was designed so as to decrease the calculation cost of navigation in order to concentrate on other tasks. Hence, it is desirable to use the algorithm with other sensors like cameras and manipulators like robot arms. Additional sensors and manipulators can enable the robot to perform specialized tasks, like tracking people, recognizing objects, and grabbing them. Generally, such tasks are computationally expensive. Hence, a computationally efficient navigation system like the one proposed in this work is very essential in keeping the overall computation low.

The proposed low cost and efficient navigation component can easily be integrated in robots specializing in complex tasks, and is expected to play a vital role in realizing the dream of robots living and working with humans, in the near future.