High speed navigation of a mobile robot based on robot's experiences

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Abstract – In this paper, it is shown how a mobile robot can navigate with high speed in dynamic real environment. Our control scheme is developed based on the dynamic window approach [2]. Although the mobile robot is able to navigate using the DWA, there is a fundamental limitation that the robot can avoid only "visible" obstacles. There are many dangerous regions where dynamic obstacles appear abruptly, in human co-existing real environments. The robot should move "slowly" to prevent unexpected collision in practical application. In order to achieve high speed and safe navigation, a robot should collect environmental information. After collecting sufficient data, a robot navigates in high speed in safe regions. This paper proposes a computational scheme how a robot can distinguish regions of high risk. The proposed scheme is experimentally tested in a real office building. The experimental results clearly show that the proposed scheme is useful for improving a performance of autonomous navigation.

***Key words**:* autonomous navigation, obstacle avoidance, dynamic window approach, high speed navigation.

1. INTRODUCTION

From the viewpoint of autonomous navigation, safe navigation in human-coexisting environment is an essential problem to be solved. On the other hand, high speed navigation is preferable in order to achieve service efficiencies. There are fundamental difficulties when we want to increase the speed of a mobile robot. Such problems can be classified into three categories as follows: 1) Dynamic and mechanical limitations. 2) Control and computational limitations. 3) Unexpected dynamic changes of environment.

The first problem implies that there might take place wheel slippage or rollover of the robot when excessive speed is applied when the robot makes a sharp cornering or an emergency stop. In practical applications, the first problem is rarely considered, because other problems provide more strict limitation on the maximum speed of the mobile robot.

The second problem can be interpreted as a real-time obstacle avoidance problem. There have been a lot of research activities for the dynamic obstacle avoidance problem. A mobile robot can navigate real environment without collision by adopting some useful developed technologies.

Our major scope in this paper is to solve the third problem addressed above. In order to deal with unexpected dynamic changes of the environment, a robot should utilize its own experiences. Humans fully exploit their experiences in real environment in many cases. Suppose that a person is walking in corridor. He might walk fast when there is no obstacle. He might reduce the walking speed when he expects that another person possibly burst into the corridor through the door from a room. Alternatively, a person might reduce the speed when he already knows that a part of the floor is slippery. This fact implies that a person possibly changes walking speed even though there are no visible obstacles. In the presented case, a person should have a location dependant, preliminary knowledge of the environment for control of a walking speed.

Limitations of speed control are proposed by Mandow *et al.* in [3]. In this study, well-defined speed constraints are addressed with respect to vehicle features and operational conditions. However accumulation and exploitation of experiences were not explicitly dealt with. Sadou *et al.* focused on occlusion of obstacles in [4]. This study points out one significant consideration of dealing with unexpected obstacles. However, the scope of unexpected obstacles is limited to the occluded obstacles and an explicit model of the obstacles geometry is required. Bennewitz et al. proposed the adaptive navigation strategies using motion patterns of people, which is one example of exploits experiences in real environment in [5]. However, this approach does not deal with unexpected obstacle avoidance problem.

The dynamic window approach (DWA) [2] suggested that the optimal velocity of robot is computed using the admissible velocity space. The admissible velocity space is the collection of velocity candidates which satisfy the kinematics and dynamic constraints of robot. The DWA is one of the most efficient obstacle avoidance algorithms.

Although there have been many researches on the obstacle avoidance problems, it is still difficult to deal with unexpected dynamic obstacles. This paper proposes one approach to deal with unexpected obstacles. The presented experimental results clearly show that the proposed strategy greatly contributes to improving the robot's speed.

2. EXPERIMENTAL SETUP

Fig. 1 The service robot platform, corridor environment and a grid map.

Our robotic platform for experiments is shown in Fig. 1. The robot is driven by two wheel differential wheels. Two laser range finders are equipped both in front and back of the robot. This robot moves at translational velocities up to 0.8m/s. Our target environment is corridor environment and the size of a grid map is 30m × 10m.

As preliminary experiments to investigate robot's dynamic performance, we experimentally measured the stopping distances and stopping time for the case of emergency stops due to abrupt appearance of obstacles. From the experimental results, the required stopping distance was 0.42m for the speed of 0.8 m/sec, and 0.15m for the speed of 0.5m/sec.

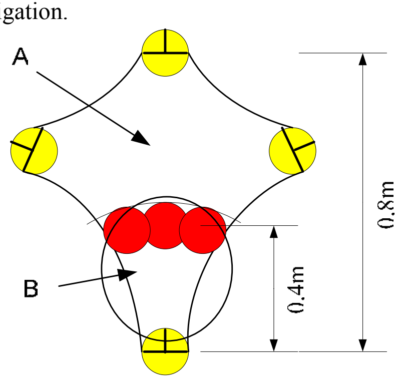
3. COLLISION-FREE HIGH SPEED NAVIGATION

3.1 Detecting unexpected obstacles

Our collision-free navigation scheme is designed based on DWA in [2]. Other navigation technologies such as localization are adopted from the research in [1]. In DWA, the performance measure function is composed of three objects. One is the clearance object which evaluates obstacle distances. The role of a clearance object is to prevent collision with obstacles. The second objective is a velocity object, which encourages fast movement of the robot. The third object is a target heading object that steers robot orientation to the goal position. The resultant velocity of the robot is determined so that the velocity solution can maximize the performance measure function.

Exploiting the conventional DWA, the robot can achieve collision-free navigation in dynamic real environment. However, it can only cope with "visible" objects around the robot. Our scope is to find out the region of high risk due to unexpected dynamic obstacles. To this end, we employ a clearance object in DWA to detect unexpected obstacles. Once unexpected obstacles are detected, detected locations are registered to the environmental map.

One way to detect unexpected obstacle is to consider collision region around the robot. Fig.2 shows the reachable regions of a robot during navigation.



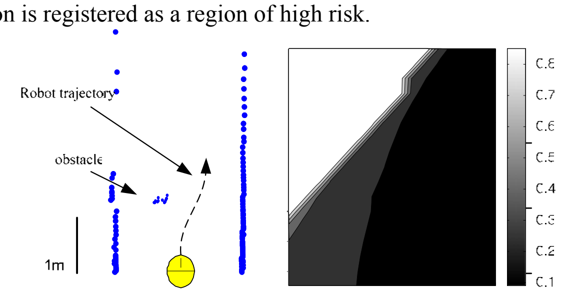
Current pose

Fig. 2 Reachable regions of a mobile robot.

The area A indicates the reachable region of the robot when the robot moves at 0.8 m/sec without obstacles. If a robot maintains current speed in an admissible velocity space, then the resultant reachable region becomes area A. Area B indicates the reachable region when the robot detects sudden unexpected obstacles. When the robot tries to make an emergency stop, the resultant robot location will be somewhere in area B due to the limited acceleration of a robot. This fact implies that if any obstacle suddenly appears in region B, collision takes place always.

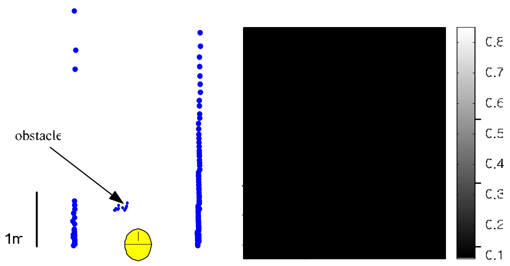
In order to investigate the effect of obstacles, clearance objects are experimentally obtained in Fig. 3 and Fig. 4. Fig. 3 shows a computational result of a clearance object for the avoidable obstacle. An obstacle appears in left front of the robot and the distance to the obstacle was 1.2m as shown in Fig. 3(a). A computed clearance object is shown in Fig. 3(b). The vertical bar of Fig. 3(b) indicates the pixel brightness according to the clearance values, and computed clearance values in the admissible velocity space are represented in gray-scale. If the clearance value is high, then the robot has enough time before collision. From Fig. 3(b), it is clear that if the robot velocity is chosen in the white region (around the left top of the admissible velocity space) the robot can avoid an obstacle.

On the other hand, if an unexpected obstacle appears in front of the robot as shown in Fig. 4(a), the resultant clearance object values are all zeros as shown in Fig. 4(b). This fact implies that the robot cannot find out a collision-free velocity solution in the dynamic window. When an obstacle appears in the region B in Fig. 2, clearance values become zero. If the robot encounters this result, the region is registered as a region of high risk.



(a) (b)

Fig. 3 Clearance values for the avoidable obstacle.



(a) (b)

Fig. 4 Clearance values for the suddenly appeared obstacle in front of the robot.

Although it is possible to detect unexpected obstacles using the presented scheme, it rarely takes place in practice. From our experience, the maximum clearance value in the dynamic window decrease a lot for the case of unexpected obstacles, but the clearance does not reach zero in most cases.

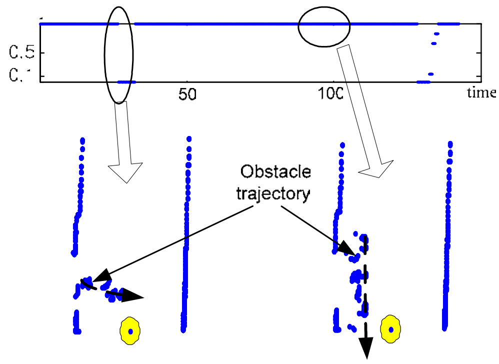


Fig. 5 Clearance values for two cases. The left is an unexpected obstacle and the right is an expected obstacle that can be avoided.

Fig. 5 shows the result of clearance change for two cases. The left represents an unexpected obstacle and the right shows an avoidable, expected obstacle. The top of Fig. 5 shows the clearance values during navigation. It is clear that the clearance changes abruptly when an unexpected obstacle suddenly appears in front of the robot. From the right figure of Fig. 5, a maximum clearance does not change even though there is an avoidable dynamic obstacle. From experiments, the threshold of clearance change for classifying unexpected obstacle is set to be 0.8.

3.2. Navigation experiments

When the robot navigates an unknown environment, the initial navigation speed is set to be slow enough to cope with unexpected obstacles. In experiments, the initial speed of navigation was 0.2 m/sec. If the robot recognizes that the environment is safe for the low speed navigation, the robot gradually increases speed to achieve high speed navigation. When the robot detects unexpected obstacles, it registers the obstacle location to the map

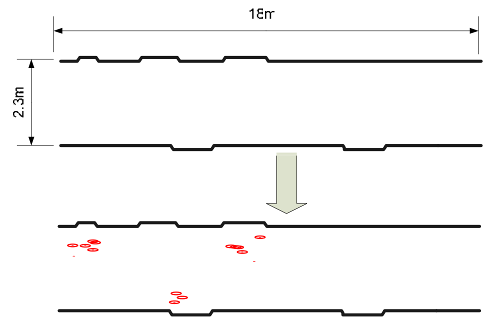


Fig. 6 An experimental result of an updated map. The map contains locations of high risk, where unexpected obstacles appeared.

Fig. 6 shows the result of an updated map of the environment. The robot repeatedly navigated a corridor, and the robot registered locations of obstacle appearances as dotted regions. The dotted regions are considered as regions of high risk, which correspond to door locations. Unexpected obstacles are humans who burst into the corridor. After accumulating the high risk regions, the robot controls navigation speed.

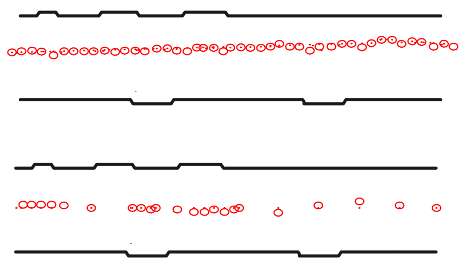


Fig. 7 A resultant robot motion in a corridor.

Fig. 7 shows the resultant robot motion in a corridor. In the safe regions where no unexpected obstacles detected, the robot navigates with 0.8 m/sec. If the robot moves through the high risk regions, the speed is reduced to 0.2 m/sec. The top of Fig. 7 represents slow speed navigation at the initial stage, where the robot does not have information about the corridor. The bottom of Fig.7 shows a robot motion after accumulating environmental knowledge about unexpected obstacles. The average speeds of navigation were 0.2 m/sec for the low speed case, and 0.45 m/sec for the high speed case. If the safe regions increase in the environment, the difference between two cases becomes large.

4. CONCLUSION

In this paper, we proposed a collision-free high speed navigation strategy. The algorithm to detect unexpected dynamic obstacles is developed, and applied to register the region of high risk. Then, the robot utilized the accumulated experience on the environment. Experimental result clearly showed that the proposed approach is useful for improvement of navigation speed. Although the scope of this paper is limited to the velocity control in order to deal with unexpected obstacles, this paper points out a new direction towards the intelligent behavior control of autonomous robots based on the robot's experience.

REFERENCES

[1] Woojin Chung, Gunhee Kim, Munsang Kim, and Chongwon Lee, "Integrated navigation system for indoor service robots in large-scale environments," *Proc. of the IEEE International Conf. on Robotics and Automation, New Orleans, USA*, pp.5099–5104, 2004

[2] Dieter Fox, Wolfram Burgard, and Sebastian Thrun, "The dynamic window approach to collision avoidance," *IEEE Robotics and Automation Magazine*, Vol. 4, No. 1, pp. 23-33, 1997.

[3] A. Mandow, V. F. Mufloz, R. Fernandez, and A. Garcia-Cerezo. Dynamic Speed Planning for Safe Navigation. In Proc. of the Int. Conference on Intelligent Robots and systems (IROS), 1997

[4] Sadou, M. Polotski, V. Cohen, P., Occlusions in obstacle detection for safe navigation, Intelligent Vehicles Symposium, 2004 IEEE Intelligent Vehicles Symposium

[5] M. Bennewitz, W. Burgard, and S. Thrun. Learning motion patterns of persons for mobile service robots. In Proc. of the IEEE Int. Conference on Robotics & Automation (ICRA), 2002