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Evaluating the Performances of the Agoraphilic Navigation Algorithm under Dead-Lock Situations

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***Abstract*—This paper presents a summary of the research which was conducted in developing a new free-space based (Agoraphilic) navigation algorithm. This new methodology is capable of maneuvering robots in static as well as dynamically cluttered unknown environments.**

The new algorithm uses only one force to drive the robot. This force is always an attractive force created by the free-space. This force is focused towards the goal by a force shaping module. Consequently, the robot is motivated to follow free-space directing towards the goal. As this method only based on the attractive forces, the robot always moves towards the goal as long as there is free-space available. This method has eradicated many drawbacks of the traditional APF method.

Several experimental tests were conducted using Turtlebot3 research platform. These tests were focused on testing the behavior of the new algorithm under dead-lock (local minima) situations for APF method. The test results proved that the proposed algorithm has successfully eliminated the local minima problem of APF method.

***Index Terms*—Agoraphilic algorithm, free-space, local minima, navigation, artificial potential Field**

I. Introduction

Mobile robot navigation plays a vital role in the field of robotics. The Agoraphilic navigation algorithm has been developed to overcome many challenges in mobile robot navigation. The work presented in this paper is a continuation of authors previous work involved with Agoraphilic algorithm [1]–[3].

There are a number of path planning methods developed for robot navigation [4]–[7]. Among them, Artificial Potential Field (APF) [8], cell decomposition [9], mathematical programming [10] and roadmap [11] are identified as fundamental path planning algorithms. APF method is popular among researchers due to many advantages, such as simplicity, adaptability, etc. However, there are well documented inherited problems in APF method such as [8], [12]:

1) Trap situations or Dead-locks (local minima)
2) No passage between closely spaced obstacles
3) Oscillations in narrow corridors
4) Goal Non-Reachable with Obstacles Nearby problem (GNRON)
5) In dynamic environments, traditional approaches fail to implement the navigation task.

These inherited drawbacks have motivated researchers to improve the APF method and overcome these problems. Consequently, an improved artificial potential field-based regression method was developed by G. Li, A. Yamashita [13]. This method made it possible to navigate robots in unknown environments without local minima. Also, R. Iraji et. al [14] proposed a methodology using virtual obstacles in dead-lock situations to create an extra repulsive force at the trapping point to push the robot away from the local-minima. Another virtual obstacle-based methodology has been discussed in [15] which also addressed the local minima problem of the APF method. Harmonic function-based methods were used to control the local minima problem involved in the APF method. Navigation algorithms, used harmonic function-based methods are also discussed in [16]–[19]. The Bacterial Potential Field (BPF) method, developed by O. Montiel et. al [20] has been combined the APF concept with the Bacterial Evolutionary Algorithm (BEA) reduce the drawbacks of the APF method including the locale minima problem. Path planing algorithms capable of maneuvering robots in a dynamic environment while minimizing the disadvantages of traditional APF methods were also discussed in [8], [21]. However, all these methods have attempted to adders the limitations of the APF method while keeping its basic concept. As a result of those attempts, those algorithms have lost some of the main advantages of the APF method such as simplicity and adaptability.

The novel Agoraphilic algorithm is developed to reduce the drawbacks of APF method while keeping its advantages. It imitates the human navigation behavior to reach the goals. In contrast to APF method, the Agoraphilic algorithm does not look for obstacles to avoid but for space "solution" to follow, hence the term "Agoraphilic". Also, for this reason, it is termed as an "optimistic" navigation algorithm.

The paper is organized in the following order: Section II describes Agoraphilic algorithm for dynamic environments. Section III presents the experimental results for various dead-lock cases. Section IV presents a discussion of the obtained results and section V discusses the conclusions.

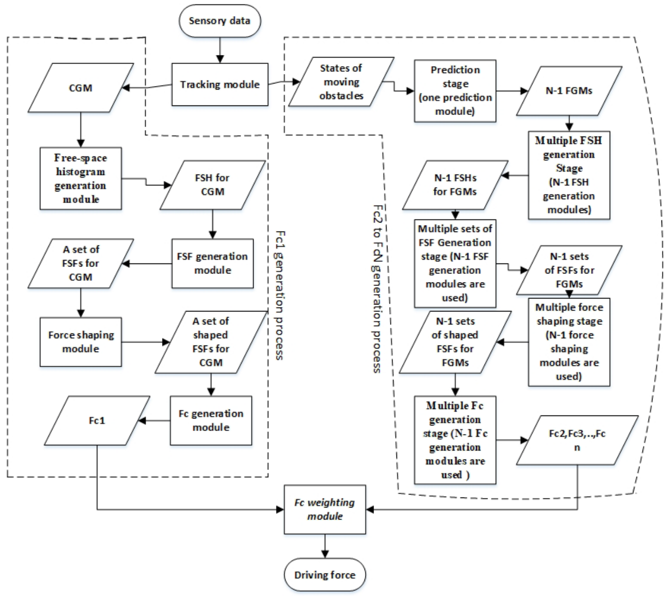

Fig. 1. Main modules of proposed algorithm

II. Agoraphilic Navigation Algorithm

The Agoraphilic algorithm uses an attractive force to drive the robot through the free-space to the goal. On the other hand, the APF method uses an attractive force as well as repulsive forces to navigate the robot to the goal.

The proposed new algorithm uses seven main modules.

1) Object tracking module
2) Prediction module
3) Free-space histogram generation module
4) Free-space forces generation module
5) Force shaping module
6) Instantaneous driving force component (Fc) generation module
7) Instantaneous driving force component weighting module

These modules are repeatedly used in the proposed algorithm as shown in Fig. 1.

A. Object tracking module

The output of robot's sensory data is used as the input of this module to produce two outputs. One of the outputs is a map. This map contains information about locations of moving and static obstacles. This map is known as the Current Global Map (CGM). CGM is used by a Free-Space Histogram (FSH) module as its input to develop the Current FSH.

The second output gives current estimated states (location and velocity) of the moving obstacles. This output is used by the prediction module to predict the future positions of the moving obstacles.

B. Prediction module

The prediction module predicts the future locations of the robot and its environment to create the Future Global Map (FGM). Prediction is done based on the current and the previous estimates of the states of the robot and the moving obstacles. This module helps the algorithm to identify future growing free-space. The necessity of prediction module was identified when multiple moving objects interrupt the robot's path at the same time [1].

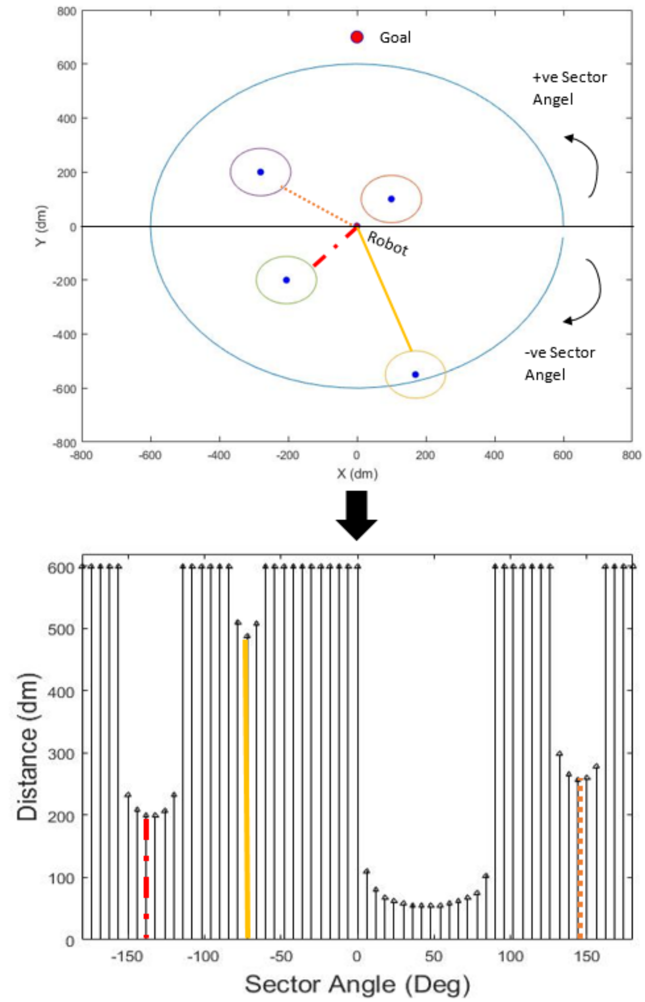

Fig. 2. FSH for a simple environment

C. Free-space histogram generation module

A global map (CGM or FGM) is taken as input by the free-space histogram generation module. Then creates a robot-centered polar map as shown in Fig. 2. This polar map is converted to a Free-Space Histogram (FSH). The FSH carries information about the space profile of the robots surrounding environment [3].

In this module, the occupied cells by obstacles of the global map are identified. Predetermined safety boundaries are applied to the occupied cells using an enlargement technique. The CGM and all the FGMs are sent through a free space histogram generation module to create current free-space histograms and future free-space histograms [22].

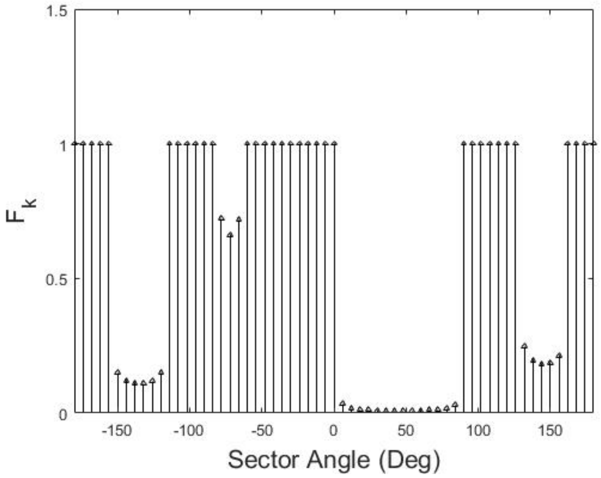

Fig. 3. A set of FSFs created by FSF generation module

D. *Free-space force generation module*

A FSH is used as the input for this module and outputs a set of Free-Space Forces (FSF), Fig. 3. The FSF generation module divides the surrounding of the robot to 'k' sectors. An initial sector force (F_k) is then derived for each of the sector. Usually, the initial sector for is directly proportional to the square of the normalized sector distance (d_k), Eq. 1. However, if d_k is greater than the pre-determined d_{max} value, an initial sector force for the corresponding sector is taken as u_k [1].

$$\vec{F_k} \quad = \quad (d_k/d_{max})^2.\vec{u_k} \tag{1}$$

Where:

$$\vec{u_k} \quad \stackrel{\text{def}}{=} \quad [\cos(\theta_k)\sin(\theta_k)]$$

E. *Force shaping module*

The force shaping module takes a set of FSFs as its input. The task of the force shaping module is to focus the FSFs directly to the goal. The force shaping module uses a weighing system to modify the FSFs. In this process forces pointing towards the goal get higher weight while FSFs pointing away from the goal gets lesser weights [1].

F. *Instantaneous driving force component (F_c) generation module*

The instantaneous driving force component (F_c) generation module takes a set of the shaped FSFs as its input and generates an instantaneous driving force component (F_c).

G. *Instantaneous driving force component weighting module*

This module takes all the instantaneous driving force components as its input. Then these component forces (F_c) are weighted according to the accuracy of the prediction. The weighted average of instantaneous driving forces is taken as the final driving force of the current iteration.

III. RESULTS

To demonstrate the performances and validate the new algorithm, experiments were conducted. TurtleBot3 waffle pi (TB3 waffle pi) research robot platform was used for the experimental validation. This is a Robot Operating System (ROS) standard platform. Tb3 waffle pi consists of 360° LiDAR sensor, signal board computer (robot's PC) runs with Ubuntu, OpenCR 32-bit ARM controller, Bluetooth module and Rasberry Pi camera. The LiDAR sensor was used to capture the robot's environment. The sensor data is passed to a remote PC via the robot PC using a Wi-Fi network. The main algorithm is programmed in the remote PC. The algorithm processes the sensory data and send appropriate motion commands to the robot's PC.

Experiments presented in this paper focus on the local minima problem. In those experiments, obstacle location and size of the object were changed accordingly. Two deferent scenarios were created to investigate the algorithms behavior in different types of dead-lock situations.

A. *Scenario 1*

Under this scenario a 61x19x25 cm obstacle was located on the straight line connecting the starting point of the goal, Fig. 4. This obstacle positioning creates a local minima for traditional APF method.

Obstacle location was varied on the same line and robot's paths were observed.

1) Experiment 1: In this experiment, the robot's starting position was (0, 0), goal location was (250,-250) cm and the obstacle was placed at (200,-200), table 1.

TABLE I
SUMMARIZED INFORMATION OF EXPERIMENT 1

Robot's start point	**Goal location (cm)**	**Obstacle location (cm)**	**Path length (cm)**
(0,0)	(250,-250)	200,-200)	500

In this experiment, robot could reach the goal without any collusions using Agoraphilic navigation algorithm, Fig. 5. The robot's path length was recorded as 500cm.

2) Experiment 2: The robot's starting position was (0, 0), goal location was (250,-250) cm and the obstacle was placed at (150,-150) cm in experiment 2, table 2.

TABLE II
SUMMARIZED INFORMATION OF EXPERIMENT 2

Robot's start point	**Goal location (cm)**	**Obstacle location (cm)**	**Path length (cm)**
(0,0)	(250,-250)	150,-150)	490

The robot's path relevant to this experiment is shown in Fig. 6. In this experiment the robot's path length was recorded as 490cm.

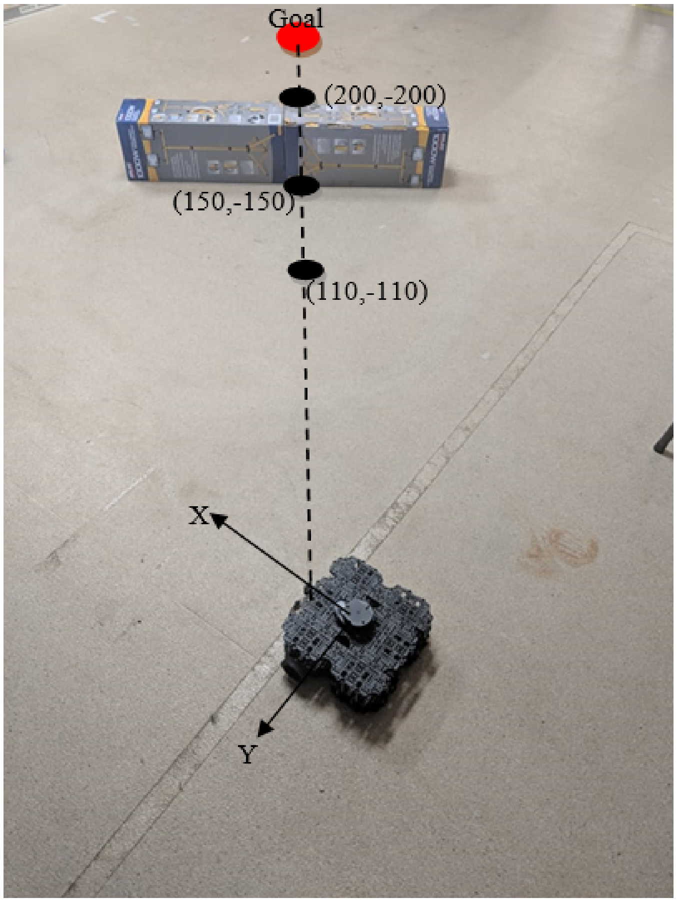

Fig. 4. Experimantal setup

Fig. 5. Robot's path recorded by the remote PC's MATLAB software for experiment 1

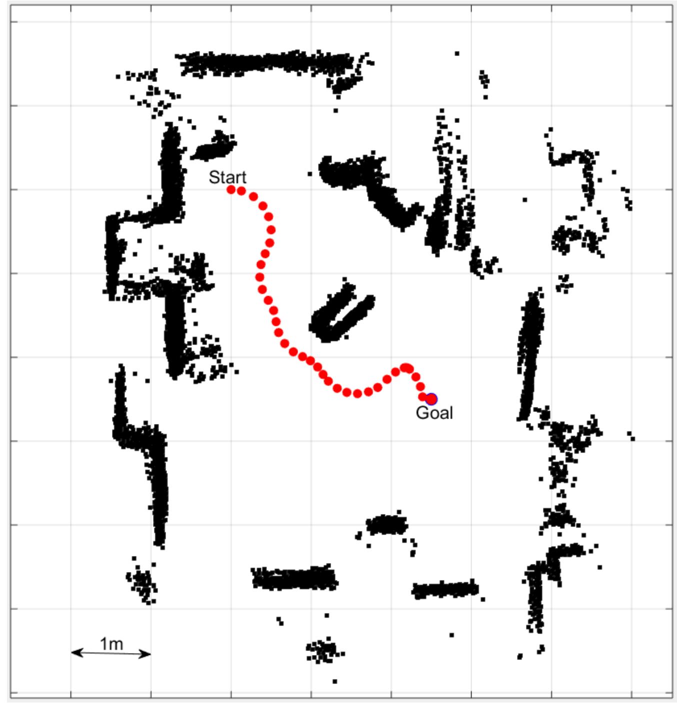

Fig. 6. Robot's path recorded by the remote PC's MATLAB software for experiment 2

TABLE III
SUMMARIZED INFORMATION OF EXPERIMENT 3

Robot's start point	**Goal location (cm)**	**Obstacle location (cm)**	**Path length (cm)**
(0,0)	(250,-250)	110,-110)	480

3) Experiment 3: In this experiment the robot's starting position was (0, 0), goal location was (250,-250)cm and obstacle was placed at (110,-110) cm, table 3.

In this experiment also robot could reach the goal without any collusions using the proposed navigation algorithm. Robot's path length was recorded as 480cm, Fig. 7.

B. Scenario 2

Under this scenario obstacle size was doubled (122x19x25 cm). The obstacle was located on the same straight line connecting the starting point and the goal, Fig. 4. This obstacle positioning creates a local minima for traditional APF method.

Obstacle location was varied on the same line and the robot's paths were recorded.

1) Experiment 4: In this experiment the robot's starting position was (0, 0), goal location was (250,-250) cm and obstacle was placed at (200,-200) cm, table 4.

TABLE IV
SUMMARIZED INFORMATION OF EXPERIMENT 4

Robot's start point	**Goal location (cm)**	**Obstacle location (cm)**	**Path length (cm)**
(0,0)	(250,-250)	200,-200)	550

Fig. 7. Robot's path recorded by the remote PC's MATLAB software for experiment 3

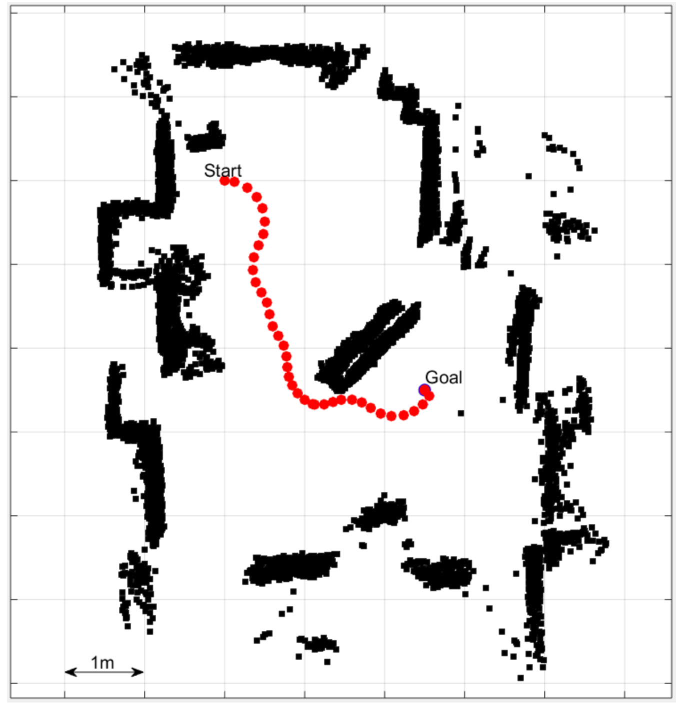

Fig. 8. Robot's path recorded by the remote PC's MATLAB software for experiment 4

In this experiment, robot could reach the goal without any collusions using Agoraphilic navigation algorithm. The robot's path length in this experiment was recorded as 550cm, Fig. 8.

2) *Experiment 5:* In this experiment, the robot's starting position was (0, 0), goal location was (250,-250) cm and obstacle was placed at (150,-150) cm, table 5.

TABLE V
SUMMARIZED INFORMATION OF EXPERIMENT 5

Robot's start point	**Goal location (cm)**	**Obstacle location (cm)**	**Path length (cm)**
(0,0)	(250,-250)	150,-150)	580

In this experiment robot has traveled around 580cm to reach the goal safely, Fig. 9.

3) *Experiment 6:* In this experiment, the robots starting position was (0, 0), goal location was (250,-250) cm and obstacle was placed at (110,-110) cm, table 6.

TABLE VI
SUMMARIZED INFORMATION OF EXPERIMENT 6

Robot's start point	**Goal location (cm)**	**Obstacle location (cm)**	**Path length (cm)**
(0,0)	(250,-250)	110,-110)	580

As shown in Fig. 10, the robot could reach the goal without any collusions using Agoraphilic navigation algorithm in experiment 6. In this experiment robot's path length was recorded as 580cm.

Fig. 9. Robot's path recorded by the remote PC's MATLAB software for experiment 5

Fig. 10. Robot's path recorded by the remote PC's MATLAB software for experiment 6

In all these experiments robot was positioned at (0,0) coordinates facing towards the x-direction. In all cases robot has initially gone towards the x-direction and started turning away from the obstacle at around (50,-50) coordinate. Then it has followed the free space leading to the goal. In all the cases the robot directly moved to the goal after passing the obstacle. Furthermore, it could be observed that the path length has significantly increased (15%) with the size of the obstacle. Changing the passion of the obstacle on the start point and the goal line has not influenced on robots path length significantly.

IV. Discussion

In traditional APF method, the robot is considered as a particle in the space. Obstacles create repulsive forces on the robot. In the other hand, goal creates an attractive force on the robot. The robot is navigated to the goal by the vector summation of these attractive and repulsive forces. Under the static environment, the robot can easily get into a position where attractive force is equal to repulsive forces acting on the robot. This makes the resultant force of robot zero. Consequently, the robot get stuck in these local minima and fail to reach its goal. The robot's force analysis for traditional APF method is shown in Fig. 11. F_a is the attractive force from the goal and F_r is the repulsive force from the obstacle.

In contrast, the presented Agoraphilic navigation algorithm creates only one attractive force on the robot. This force is developed from the free-space concept. Consequently, the robot moves towards the goal as long as there is free-space around it. The robot's force analysis for Agoraphilic algorithm is shown in Fig. 12. F_{a1} to F_{a6} are the free-space forces and

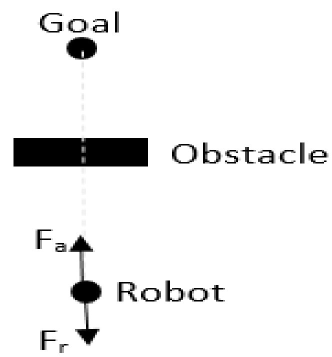

Fig. 11. Robot's force analyses from APF algorithm at a local minima situation

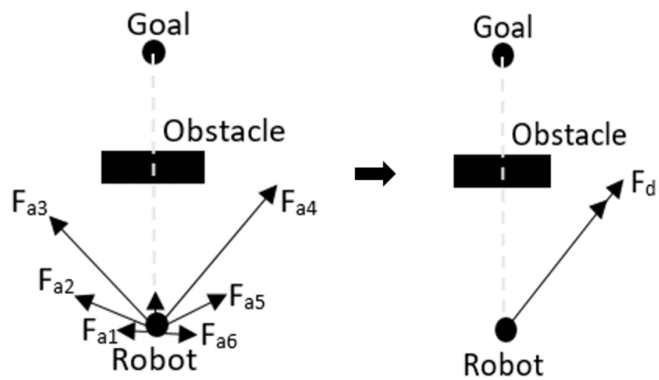

Fig. 12. Robot's force analyses from Agoraphilic algorithm at a local minima situation for APF method.

F_d is the final driving force of the robot. The test results also proved that Agoraphilic algorithm has successfully eliminated the local minima problem of APF method.

V. Conclusion

The Agoraphilic algorithm is a novel navigation algorithm capable of driving robots in unknown static as well as dynamic environments. This algorithm uses a single attractive force to pull the robot through the free-space towards the goal. A set of free-space forces is derived from the surrounding free-space and shaped towards the goal by a force shaping function. The final driving force is derived by these shaped forces.

Furthermore, the conducted real-world experiments successfully validate the new free-space concept. Moreover, these experiments proved that the Agoraphilic algorithm has eliminated the local minima problem of APF method.The test results also proved the theoretical fact that it is impossible to have such local minima under new free-space concept.

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