

Local minimum solution for the potential field method in multiple robot motion planning task

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Abstract—This work presents a new approach to solve the problem of local minimum which happens usually in the case of multiple robots navigation. The multi-robot path planning based on artificial potential field is among of the most popular method for trajectory planning. However, in some spatial-temporal coordinates, the algebraic sum of all the potentials generated by all the torques/forces is null. In such case, all the robots in the working area stopped and their speeds become null too. Purposely, this work solved the problem of local minimum in a multi-robot system which is validated by Matlab/Simulink simulation.

Keywords—multi-robots, path planning, potential field, local minimum

I. INTRODUCTION

The technique development of planning mobile robot is one of the major trends of existing research. This idea is motivated by requirement of the industrial application. Firstly, existing industrial robots lack flexibility and autonomy: usually, these robots use the preprogrammed operations in environments with high constraint, and their are not capable of operating with new environments or adapted with new situations. Secondly, there is an emerging market for really autonomous robots. However, despite of the impressive progress autonomous robotics, a certain problems still require more research. The trajectory planning of mobile robot in static and dynamic environments is one of the most studied areas for allowing a mobile robot to move from initial point to goal. There are many research projects dealing with this problem and propose practical solutions to solve this task.

A first path planning method is to decompose environment of robot into cells Latombe [17] and Glavaski [3]. In these cases, the discrete environment is represented in a graph and finds a trajectory returns to search a path in a graph.

Another planning method is the dynamic window approach [12]. This method is directly related to the dynamics of the robot. It takes account on we the limits of the speed and acceleration of the robot.

The polynomial approaches for the generation of trajectories is another planning technique [4]. In this approach two types of trajectories are used: the use of Bezier curves and use of spline curves.

The Deterministic Kinodynamic Planning Approach (DKP) is a very recent planning method. It is introduced by Gaillard [2]. This method is quite complex, but it would be adhered

the constraints kinematics and dynamics of the robot. DKP provides a solution that collect a local path planner based on spline function and global planner with A* algorithm. The advantage of this algorithm is that it generates a wide variety of polynomial pieces, allowing to find a solution even in very complex environments.

Finally, noted the use of technical potential fields for path planning. The artificial potential field initialized by Khatib [18] is a celebrated approach for the implementation of real-time trajectory in the current years.

In this work, we study the path planning for multi-robot system. For that reason, the technical of potential fields is used. In the following we present in first section the principle of artificial potential field concepts. In the second part we present the problems of uses of potential field technique in path planning. Next in the following section we present the methods used in literature for solving the problem of local minimum. Then we present the study local minimum problem for multi-robot system. In the final part we proposed The non-minimum algorithm.

II. BASIC ARTIFICIAL POTENTIAL FIELD CONCEPTS

With the artificial potential field(APF) the mobile robot moves in configuration space by a field of forces.It mainly consists of force vectors, caused by the obstacles and target positions. The attractive force is exerting by the target to guide the robot to its destination, while the obstacles generate repelling forces towards a robot modeling the presence of obstacles in the space of the robot.

The main building block of APF is the action force, which corresponds to linear speed and angular velocity of robot. Every condition emits a output force [10]. The figure 1 shows the two types of forces: attractive/ repulsive respectively produced by the target and obstacles.

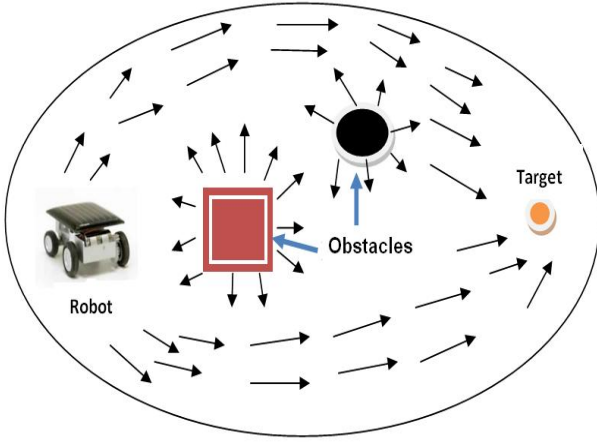


Fig. 1. Combination of attractive and repulsive potential fields due to goal and obstacles

For each position of the robot, a force resulting from the combined action of obstacles and target is calculated [8]. It indicates to the robot how to perform its movement. The robot then moves in the orientation indicated by the APF. So the correct combination of forces (repulsive/ attractive) allows the robot to move from the initial point to goal. If new obstacles appear during the movement of the robot potential field it must be updated to include this new information. The application of APF allows increasing the capacity of security for robot environment. So, instead of forcing the system to follow a given path, the presence of fixed or mobile obstacles is considered and the robot reacts with environment.

The technical potential field is the subject of several research projects. For example the following works: Ge et Cui (2002)[11], Melchior and al (2009)[5] and Guys and al(2014)[1].

General structure of potential field: In planning paths the robot is considered in the space of configuration W as a particle subjected to an artificial potential field $U(X)$. with $X = (x, y)^T$ the position and direction vector of robot.

For each iteration, the artificial forces $F(X)$ induced by potential field, then indicate the direction of robot.

$$F(X) = -\nabla U(X) \quad (1)$$

APF is defined as the sum of a potential field attractive $U_{attra}(X)$, pushing the robot to the final configuration, and a repulsive field $U_{repu}(X)$ modeling the presence of obstacles in the space of the robot.

$$U(X) = U_{attra}(X) + U_{repu}(X) \quad (2)$$

The resultant force is:

$$F(X) = F_{attra}(X) + F_{repu}(X) \quad (3)$$

Attractive Potential Field: The function is given by:

$$U_{attra}(x) = \frac{1}{2} k \rho^2(X, X_g) \quad (4)$$

with :

- K : positive scaling factor.
- X : position of the robot.
- X_g : goal of the robot.
- $\rho(X, X_g) = \|X_g - X\|$: distance from robot to goal.

The function $U_{attra}(X)$ is positive or null and attains the minimum in goal point. Attractive force $F_{attra}(X)$ is negative grads of the attractive potential field function:

$$F_{attra} = -\nabla [U_{attra}(X)] = -k\rho(X, X_g) \quad (5)$$

Repulsive Potential Field: must be used to create a potential barrier around the obstacles. This barrier cannot be traversed by the robot.

The repulsive potential field is described by:

$$U_{repu}(X) = \begin{cases} \frac{1}{2} \eta \left(\frac{1}{\rho(X, X_O)} - \frac{1}{\rho_0} \right) si \rho(X, X_O) \leq \rho_0 \\ 0 si \rho(X, X_O) > \rho_0 \end{cases} \quad (6)$$

- $\eta > 0$ positive scaling factor.
- $\rho(X, X_O)$ the minimum distance (robot and obstacles).
- ρ_0 distance influence imposed by obstacles; its value depends on the condition of the obstacle and the goal point of the robot, and is usually less than half distances between the obstacles or shortest length from the destination to the obstacles.

If robot is not at the destination:

$$F_{repu} = \nabla [U_{repu}(X)] = \begin{cases} \eta \left(\frac{1}{\rho(X, X_O)} - \frac{1}{\rho} \right) \frac{1}{\rho^2(X, X_O)} si \rho(X, X_O) \leq \rho_0 \\ 0 si \rho(X, X_O) > \rho_0 \end{cases} \quad (7)$$

The APF is extensively used for trajectory planning of the robot since is responsive and can be very easy to implement in real time. However, this technique has some limitations. In the following we present the defects of potential fields.

III. DEFECTS OF POTENTIAL FIELDS

The technique of artificial potential field has its own disadvantages. Koren and Borenstein [16] identified some problems that are inherent in the application of potential fields, which are:

- 1) **Trap Condition to Local Minima:** mobile system can be in a position where the potential field is zero, which means that the mobile system is blocked in local minimum (figure 2). This problem can be treated in different ways. For example it is possible to trigger a specific behavior when we encounter such a minimum: random movement, followed from walls.

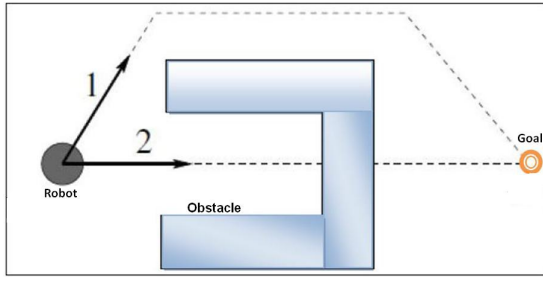


Fig. 2. Example of local minimum

- 2) **Problem of Closely Spaced :** This situation is similar to the previous, if two obstacles are placed nearby, such as a door, the repulsive forces of each obstacle are combined into one repulsive force that points out of the opening between obstacles (figure 3).

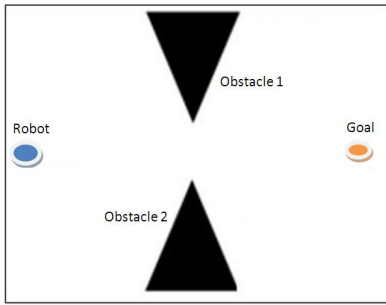


Fig. 3. Example problem of Closely Spaced

- 3) **Oscillations Problem :** sum of force is calculated by summing components of the environmental Impact. However this situation causes the oscillations in the path of the robot (Figure 4). This can be handled by assigning some distance criteria for the obstacles which may indicate attraction distance. However more intelligent solution is checking the visibility of those obstacles while agent traversing in its own path.

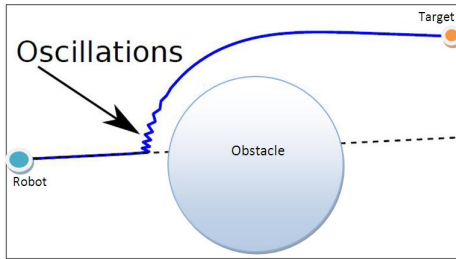


Fig. 4. Oscillations of a path obtained with the potential field

IV. METHODS OF SOLVING THE DEFECTS OF LOCAL MINIMUM

Defects of local minima in the potential functions makes this method incomplete. Indeed, the potential field method cannot guarantee the presence a path linking the starting point to the goal point can be found in finite time, since the paths it produces may become blocked in a local minimum. Solving

the problem of local minima is essential to make the method potential fields suitable for path planning of robot.

The first idea proposed to overcome the problem of local minima is to create a graph linking the local minima to the starting points and the goal point [14]. A search shortest path can then be performed on this graph. The path is then constructed by following this path and the potential field. This method still requires research of all local minima of space, then building and the search of the shortest path on this graph, which increases the computing time of this approach.

Another idea is to couple the potential field method in a stochastic method. The mobile follows the path provided by the potential field, until a local minimum. The stochastic method is then used to exit the mobile of this local minimum. So the robot can again follow the potential field to reach a new local minimum or destination. The stochastic methods used may be a method of Monte Carlo [15] simulated annealing [13] or an ant colony algorithm [9].

Safadi [7] in his paper discussed local path planning algorithm based on Virtual Potential. The author introduced APF, demonstrating the problem of Local Minimum. They described the modification to avoid the local minimum and also presented the implementation of the algorithm. The concept of solving the problem is in Figure 5.

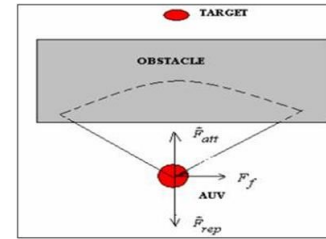


Fig. 5. Presentation of the virtual force

More recently, a method for transforming local minima (which are stable equilibrium points) in unstable equilibrium was proposed by Mabrouk (2008)[6]. An internal state of the agent is assigned to the mobile.

The internal state is modeled in dynamical system of coupled first order differential equations that use the APF where in the agent is presented. He depends on the interaction of the mobile with its environment and locally deforms the potential field. When the mobile is not moving in the environment, the internal state of the agent deforms the potential field, which enables avoid from local minima in the APF. This technique solves defected of trajectory planning robot.

V. LOCAL MINIMUM PROBLEM FOR THE MULTI-ROBOT

The planning problem of a single robot to a specific target area is widely studied in robotics. In order to adapt the known approaches to multi-robot problems we must add the collision avoidance between robots. Thus, whenever more systems are used in the same spaces, there is necessary to coordinate their trajectory. The path planning of individual robots is calculated so that collisions between robots and obstacles, and between the robots are avoided. Especially for multi-robot systems

can produce several undesirable situations, as congestion or trapped in a local minimum.

To solve this type of problem, there are three major families of approaches are used: Navigation by potential field, approaches by graphs, and cell decomposition. Since we are interested in this study of potential field techniques. We study the use of this technique in the multi-robot planning.

The method of potential field has been programmed on a Matlab/Simulink simulation to generate the trajectories of robots in a dynamic environment. The configuration space of two robots is presented in Figure 6.

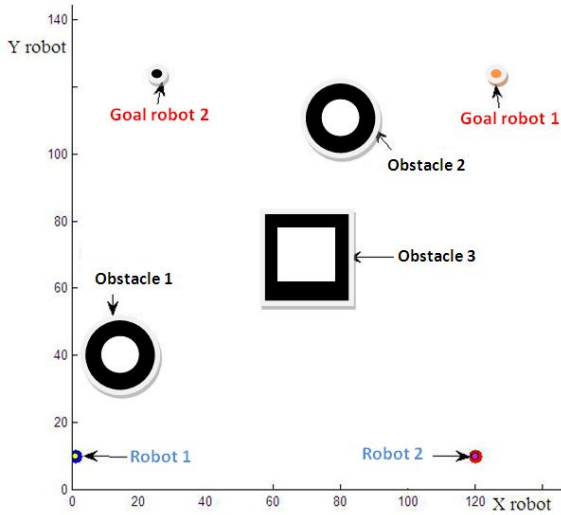


Fig. 6. configuration space of robots

In the following we present two cases of simulation:

Case 1: In this case the positions of robots are: initially robot 1 in position(1, 10) and robots 2 in position(140, 20). The simulated trajectory of two robots in this case 1 is illustrated in Figure 7.

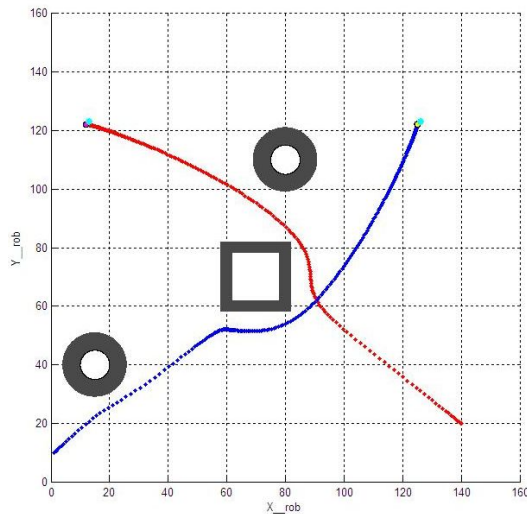


Fig. 7. trajectory of two robots in this case 1

Figure 7 presents the trajectories of two robots: the blue trajectory for the robot1 and red trajectory for the robot2.

In this case the two robots move with security. Thus, the attractive forces leading the two robots to the goal point although the repulsive potential field generated by obstacles create a potential barrier around to obstacles. So the trajectory is distorted at the border of obstacle to keep the Security of robot planning.

Case 2: In this case the position of robots 2 is changed. The new position of two robots are: robot 1 in position(1, 10) and robots 2 in position(120, 20). The simulated trajectory of two robots in this case 2 is presented in Figure 8.

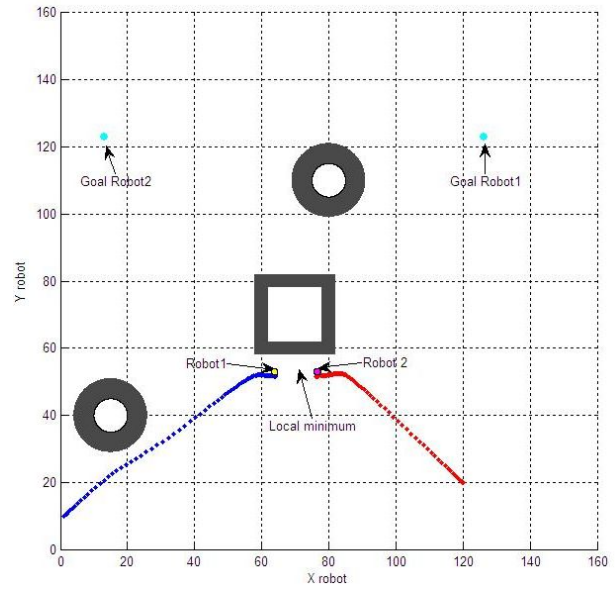


Fig. 8. configuration space of robots

The results of this case presented the trajectory of two robots. The trajectories are blocked in a local minimum. So the planning is interrupted and the speeds of two robots practically zero for a large period of time. the figure 9 represents the appearance of speed during the simulation time for robot 1.

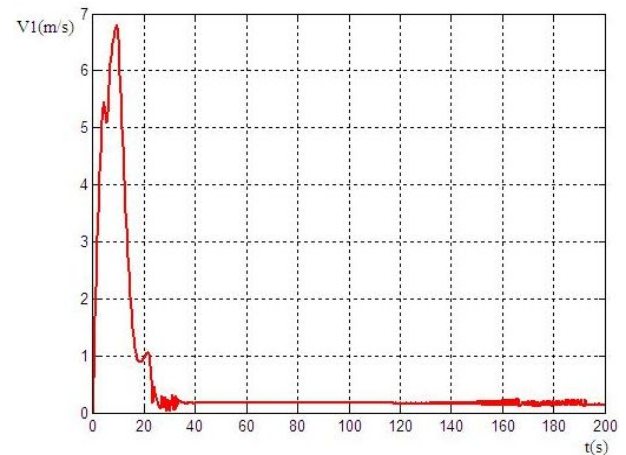


Fig. 9. speed of robot 1

Also, the appearance of speed for the robot 2 is same as the robot 1. The speed of robot 2 is represented in figure 10.

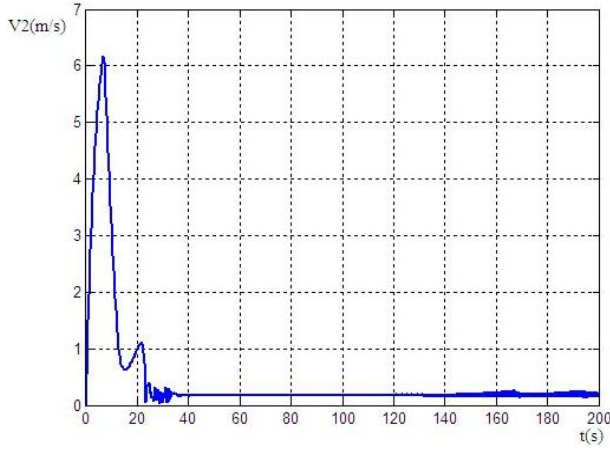


Fig. 10. speed of robot 2

VI. NON-MINIMUM SPEED ALGORITHM

The non-minimum speed algorithm proposed by us consists of controlling the speed of only one robot permanently to solve the problem of local minimum when happens. This robot should be master and the most reliable one. The idea consists in controlling the master robot speed above a positive and nonzero threshold v_{min} if it is far from the goal.

Let us consider a system of n robots where:

- v_{min} : the minimum speed of master robot,
- v_m : speed of master robot,
- v_i : actual speed of the robot i ($i = 1, \dots, n-1$),
- d : actual distance between master robot and its destination,
- d_{min} : minimum distance between the master robot and its target.

Steps of Algorithm:

- **Step 1:**
calculate the actual distance d
($d = \| \text{master robot coordinates} - \text{target coordinates} \|$) and the actual speed v_m of the master robot,
- **Step 2:**
If ($d \geq d_{min}$) & ($v_m < v_{min}$)
Then $v_m = v_m + v_{min}$
Else $v_m = v_m$
- **Step 3:**
If the distance $d < d_{min}$
Then End.

The simulation result of this algorithm is as following (figure 11):

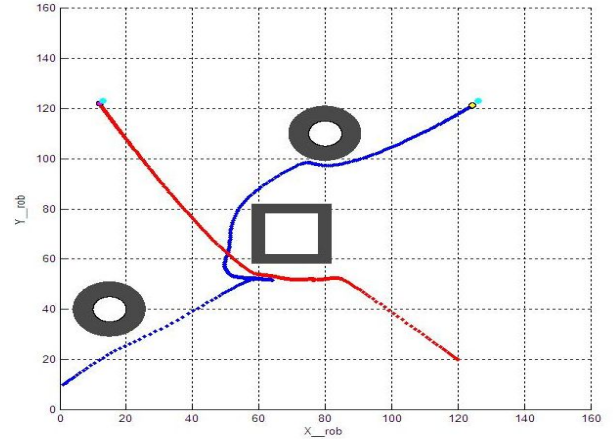


Fig. 11. solving local minimum problem

In this case, local minimum problem is solved and the two robots arrive at their destination. The two robots have escaped from local minimum produced in case 2. So the trajectories of two robots move away from obstacles zone. In order to anticipate the obstacles zone, the Trajectories of two robots is Deformed.

As clearly illustrated in figure 12 after implementation of algorithm the speed of master robot augments if speed near of zero.

This solution solves the problem of local minima products in multi-robot system. So the force of potential field can guide the movement of two robots in a secure way. The direction of motion of two robots is calculated in real time.

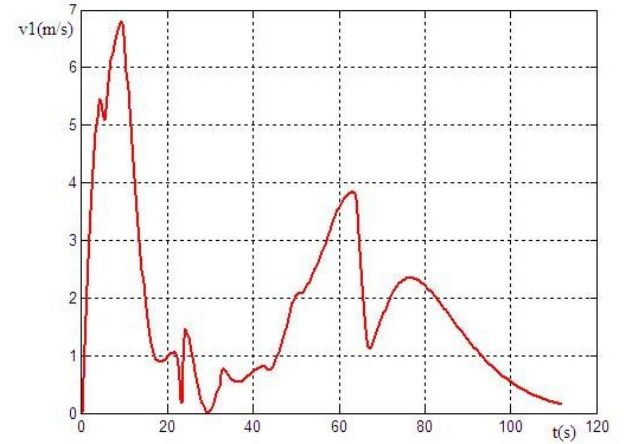


Fig. 12. Speed of robot 1 after implementation of the algorithm

likewise the speed of robot 2 augmented and the robot escape of the local minimum (figure 13).

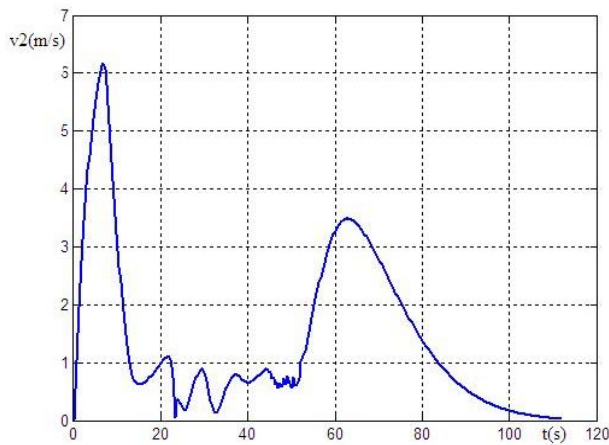


Fig. 13. Speed of robot 2 after implementation of the algorithm

VII. CONCLUSION

Throughout our work, we have examined the problematic of motion Planning of multiple robots systems. So, the technique of artificial potential field is utilised for this planning. This technology allowed us to guide the two robots to the planned destination. However, the problem of local minimum is product and the planning is interrupted. This study solve the problem of local minimum produced in multi-robot system.

So as to study the cooperation between two robots we use Matlab/Simulink simulation to generate the trajectories of robots. This simulation testify the functionality in real space. However a test on a real robot is necessary to validate the functionality of algorithm.

REFERENCES

- [1] L. Guys, S. Puechmorel, L. Lapasset, "A Centralized Approach for Aircraft Trajectory Planning : the Harmonic Navigation Function", *IEEE Transactions on Intelligent Transportation Systems*, 2014.
- [2] F. Gaillard, "Approche cognitive pour la planification de trajectoire sous contraintes", *PhD thesis, Universite des Sciences et Technologie de Lille-Lille*, 2012.
- [3] D. Glavaski, . and M. Volf, and M. Bonkovic, M, "Robot motion planning using exact cell decomposition and potential field methods", *Proceedings of the 9th WSEAS international conference on Simulation*, pages 126-131, 2009.
- [4] M. Defoort, "Motion planning for cooperative unicycle-type mobile robots with limited sensing ranges: A distributed receding horizon approach", *Robotics and Autonomous Systems*, 2009.
- [5] Melchior, P., Metoui, B., Najar, S., Abdelkrim, M. et Oustaloup. A, "Robust path planning for mobile robot based on fractional attractive force", *American Control Conference*, 2009.
- [6] M. Mabrouk and C. McInnes, "Solving the potential field local minimum problem using internal agent states", *Robotics and Autonomous Systems*, pages 1050-1060, 2008.
- [7] H. Safadi, "Local path planning using virtual potential field", *McGill University School of Computer Science*, 2007.
- [8] S.M LaValle, "Planning Algorithms", *Cambridge University Press*, 2006.
- [9] D. Zhao and J. Yi, "Robot planning with artificial potential field guided ant colony optimization algorithm", *Springer Advances in Natural Computation*, page 222-231, 2006.
- [10] M-A. Goodrich, "Potential fields tutorial", *Autonomous Robots*, 2002.
- [11] Ge, S. et Cui, Y, "Dynamic motion planning for mobile robots using potential field method", *Class Notes*, 2002.
- [12] D. Fox, W. Burgard, and S. Thrun "The dynamic window approach to collision avoidance", *IEEE Robotics and Automation Magazine*, pages 23-33 ,1997.
- [13] J. Barraquand and J.-C. Latombe, "Integration of the artificial potential field approach with simulated annealing for robot path planning", *IEEE International Intelligent Control Symposium*, page 536-541, 1993.
- [14] Barraquand, J., Langlois, B., and Latombe, J. C, "Numerical potential field techniques for robot path planning", *IEEE Transactions Systems*, page 224-241, 1992.
- [15] J. Barraquand and J.-C. Latombe, "Robot motion planning : A distributed representation approach", *The International Journal of Robotics Research*, page 628-649, 1991.
- [16] Y. Koren and J. Borenstein, "Potential field methods and their inherent limitations for mobile robot navigation", *IEEE International Conference on Robotics and Automation*, 1991.
- [17] JC. Latombe, "Robot Motion Planning", *Springer Science and Business Media*, 1991.
- [18] O. Khatib, "Real-time obstacle avoidance for manipulators and mobile robots", *International Journal of Robotics Research*, page 90-98, 1986.