Modified Approach Using Variable Charges to Solve Inherent Limitations of Potential Fields Method.

Milena F. Pinto, Thiago R. F. Mendonça, Leornardo R. Olivi, Exuperry B. Costa, André L. M. Marcato
Electrical Engineering Department
Federal University of Juiz de Fora, UFJF
Juiz de Fora, Brazil.
milena.faria@engenharia.ufjf.br, andre.marcato@ufjf.edu.br

Abstract—**There are several methods to control robot's trajectories. The potential fields technique is one of the simplest algorithms that require less computational resources. This work presents a modified version of the potential fields method using variable charge and adapted attractive fields that allows the robot to achieve the goal in dynamical and complex environment which the original approach is not able to solve. The algorithm has been validated using the MobileSim simulator together with Matlab. The results prove the algorithm efficiency in schemes with multiple local minima, goal close to obstacles and less oscillation in narrow passages. This control method can be used in industrial applications such as automatic forklift operation, robotic manipulators and wheeled robots.**

I. INTRODUCTION

Over the years several methods were developed with the aim to monitor and control mobile robots or robotic manipulators. Their usage increased by the reason of robots capacity to work in difficult accessing environments or even hazard to humans, for example space or underwater explorations, monitoring environments with complex topography, materials transportation, among others. According to [1], robots have other benefits such as their size, flexibility and fault tolerance.

Usually, industries have flexible environment enabling the creation of non-convex obstacles. In face of this problem, there is a configuration set necessity of new approaches that allow the robots to move safely to the goal point avoiding obstacles. Moreover, they need to react quickly and planned.

In certain industrial applications, mobile robots are battery supplied, requiring rational usage of energy. Thus to increase their useful time, efficient computer applied techniques and low power processors are recommended [18].

The path planning is a crucial step in robotics application. There are lots of consolidated methods, for instance, potential fields, evolutionary, discrete (e.g. A*) and *Bug* algorithms. The A* algorithm has great efficiency, since it finds the optimal path, when it exists. However it has a high computational cost [2]. The evolutionary algorithms are stochastic techniques used to determine trajectories. Its main drawback, as the earlier mentioned, is the need of computational resources and the possibility of not finding a solution [3]. Unlikely, the *Bug* and potential fields techniques do not have the necessity of highly computational capacity since it doesn't have the step of environment decomposition to create trajectories independently of the numerous obstacles [4]. The path is planned on the run.

The potential fields method is often used due to their computational simplicity and it does not require a map when equipped with a range finder sensor. This technique was initially developed for robotic manipulators and extended by Khatib as seen in [5], with the purpose to use physical concepts for mobile robots as attractive potential points for goal coordinate and repulsive potential for obstacle coordinates. Consequently, several modifications were made aiming at strategies to avoid attraction to local minima points, such as shown in [6 to 8].

As stated by [9] since the resultant force acting on the robot is calculated by adding all the components inserted in the environment, the calculation method causes oscillatory motion when passing through obstacles, and sometimes it becomes difficult to reach the destination, once it will suffer a large repulsion when the obstacle is closest to the target point.

This work proposes a new approach of potential fields method considering variable charge in order to solve local minima obstacles, guaranteeing the reachability of the goal point. It can be also combined with the avoid past behavior technique discussed in [13] which add charges throughout the visited path enhancing the performance. For this reason, it can be applied for trajectories control of mobile robots in dynamic industrial area. The algorithm has been validated using a virtual robot along with Matlab, for parameter transfer and commands. This paper is organized as follows. Section II presents a brief review and related works regarding potential fields technique. A detailed description of the proposed algorithm is shown in Section III. The performance of this approach and conclusions are given in Sections 4 and 5.

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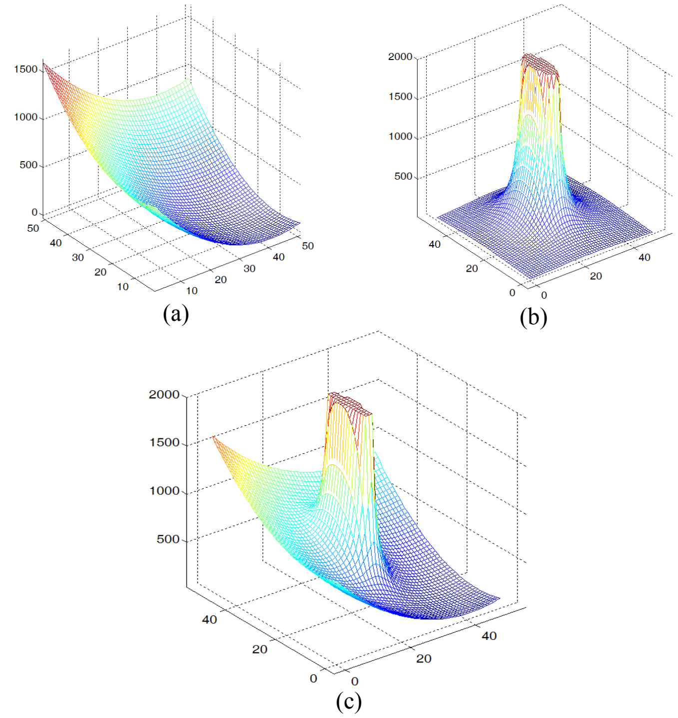
II. RELATED WORKS

The potential fields method is either a path planner and an autonomous controller. The trajectory is defined by the gradient of the potential field generated by the interaction of three main elements: the robot, obstacles and goal point. The robot searches for a route that takes him at destination avoiding collision. [5]

The most common and simplest forms of potential field are the attractive and repulsive gradient, whose functions are usually the parabolic and inverse of distance, respectively. Figure 1 represents those functions.

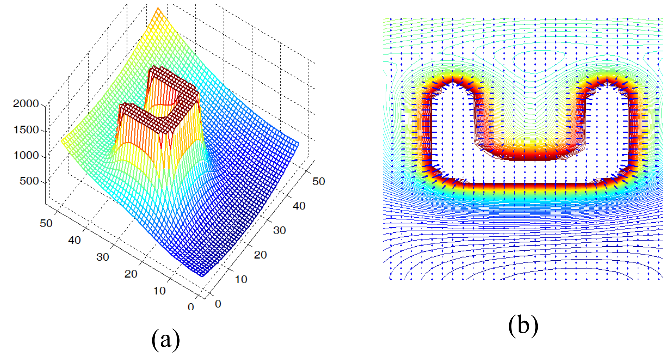


(a) (b)

(c)

Figure 1. Most common used potential fields. (a) Attractive. (b) Repulsive. (c) Combined field.

Although computationally efficient, path planning with potential fields has its drawbacks, as described in [14]. One common problem associated with this method is the trap situations due to local minima, as can be seen in Figure 2.



(a) (b)

Figure 2. Trap situation with local minima. (a) Surface. (b) Gradient.

Another inherent issue in the utilization of this kind of attractive potential field is that function magnitude tends to low values when the target is near a repulsive force generator, causing unreachable coordinates [16].

In order to improve results, it is possible to combine other types of potential fields besides the conventional attractive and repulsive already discussed. In [12] is shown how to utilize uniforms, tangential, random and others type of potential fields. For instance, for an investigator robot, which needs to approach a destination surrounding the target as it come forward, is useful to combine an attractive potential, which will cause the robot to approximate and a tangential potential that will force the robot to move in circles.

Several papers were published over the years with the intention to improve some of the issues regarding this technique. To overcome the local minima issue, in [13] is discussed a dynamically updated potential field adding repulsive forces along the path taken by the robot. Another solution is proposed in [17], which uses harmonic functions for path planning. For solving unreachable destinations near obstacles, in [16] is considered a new repulsive function in which the relative distance between the robot and the destination is taken into account. The problems of narrow passages in the presence of obstacles were solved in [19], which used a modified Newton's method applied in potential fields technique. Despite the existence of algorithms capable to solve each of the potential fields problems individually, to the best of our knowledge, there is no known method able to work with all conditions mentioned earlier.

In the following section is discussed the new approach proposed able of solving local minima, reachability to target near an obstacle and narrow passage situations.

III. VARIABLE CHARGE POTENTIAL FIELDS METHOD

Instead of using the conventional attraction and repulsion function, as shown in Figure 1, in this approach is considered the electrical force model given by the Coulomb's law. By considering both robot and obstacles as positive charges, repulsive force will be generated, preventing collisions. However, once the objective coordinate is represented as a negative charge, there will be attractive interactions with the robot and target point. Figure 3 illustrates the surface plot of the force varying with distance from a positive and a negative charge.

It can be noticed that both functions increase magnitude when the robot comes closer, then the problem of unreachable destinations near obstacles is solved. Nevertheless, when the target point is moving far away from the target, the attraction force drops, indicating an unstable condition which will make the robot keep on moving in that direction. So it is necessary to balance the interactions between positive and negative charges in such a way to provide the expected movement.

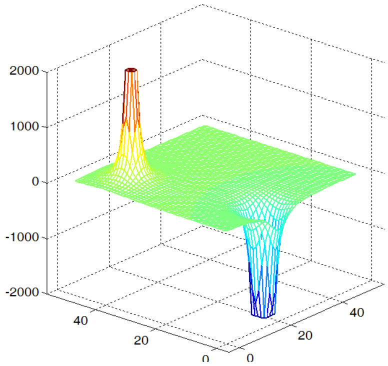


Figure 3 - Surface plot representing the force from a positive and a negative charge.

The balance is accomplished by increasing the positive charge of the obstacles whenever the robot reaches a threshold distance and by increasing the negative charge whenever the robot moves on the contrary direction. In this way, the local minima will be filled smoothly until its inexistence, and the attraction will always surpass the repulsion. Figure 4 shows the filling of local minima by the increase of the obstacle charge.

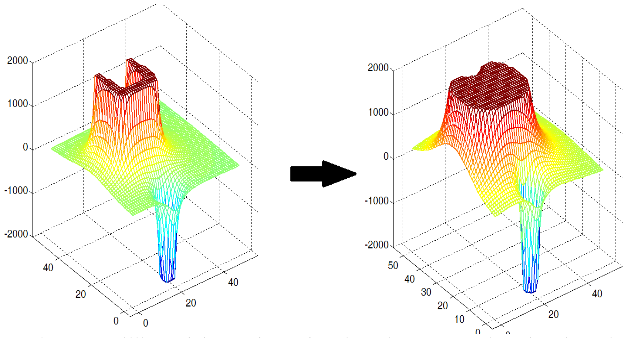
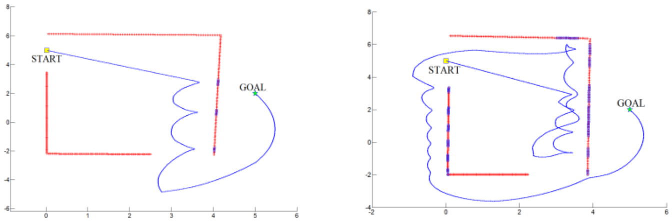


Figure 4. Filling of the surface after the robot approaches the obstacles.

Furthermore, this method can be combined with the avoid past behavior technique discussed in [13], which add charges in the path taken by the robot in order to optimize the trajectory results. The parameters for the simulation were determined empirically in the calibrations process. Figure 5(a) and Figure 5(b) present the results concerning good and bad selection of those parameters. It can be seen that good selection makes the robot go more directly to the objective position and the opposite occur with bad ones.



(a) (b)

Figure 5. Trajectory defined by the algorithm. (a) Good parameters. (b) Bad parameters.

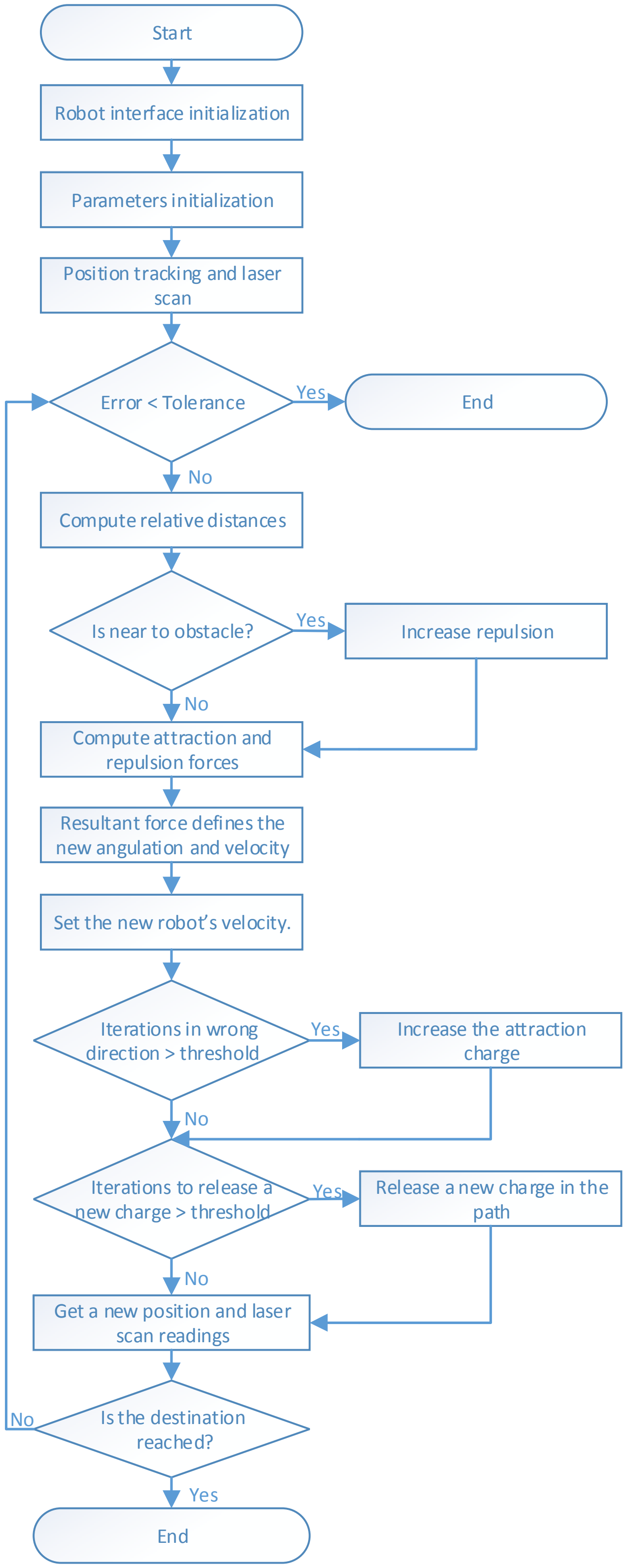


Figure 6. Proposed method algorithm.

It can be visualized in Figure 6 the program diagram of the proposed method. The initial parameters mentioned are the values of the charges of the goal point and obstacles at the beginning of the process; the increment rate when distance from obstacles cross the threshold; number of iterations allowed for the robot to move in opposite direction; the increment rate when distance from target rises during predetermined number of iterations and the number of iterations set to release a new charge in the path.

The data stemming from the laser scan is used to determine the position of the obstacles allowing to compute the distance to the robot. If it is lower than an established limit, repulsion will be increased causing it to move away. The next step evaluates the resultant force after this change in charges. So is possible to determine the linear velocity once its proportional to the magnitude of the force. The angular velocity derived from the angular difference between the force vector angle and the robot's current position.

It is important to verify the direction of movement. If it is in the opposite direction to the objective, the negative charge will increase in order to make it move towards the goal.

Receiving the robots new position by the sensors, the laser scan will update the obstacles new coordinates. The proceeding goes on until the objective is reached.

IV. RESULTS

The results were obtained with the HttpThru platform developed by [10] and MobileSim simulator [15]. This platform relies on XML packages that are transmitted over HTTP protocol, becoming an ideal alternative for devices interaction among the network such as mobile robots [11]. It was used the MobileSim software in order to use the device commands, making it easy to run the same program for both simulator and real robot. The control algorithm was developed in the computational tool Matlab and the commands are sent to the simulator interface through HttpThru and then interpreted.

It was used the proposed configuration presented in Section III. During the tests, both target and obstacles were considered statics in order to simplify the algorithm evaluation.

The performance of the algorithm can be analyzed by the results showed in the Figures 7 to 18. The layouts used in these simulations are a combination of difficult tasks mentioned in this paper such as narrow isle, closest objectives and multiple local minima.

The results are showed in the following sequence. First the MobileSim visualization which represent the robot dimension, the laser's range and the path in a full layout. Second the Matlab representation of the detected obstacles in red and the increased charges in blue. Furthermore, the starting point is represented by a circle and the target by x.

As mentioned in Section III, it's possible to notice how the increased repulsion of the obstacles elements approached by the robot changes the trajectory. In other words, each time the robot comes near an obstacle, the path will be altered. In this way, collision will be avoided efficiently. Due to the fact that the negative charge increases whenever the robot moves away, it is observed that the path also is modified.

Figure 7 and 8 show a set of obstacles to verify the algorithm performance in narrow isle condition. Notice that to reach the destination the robot has to move between obstacles and get repelled whenever comes to close.

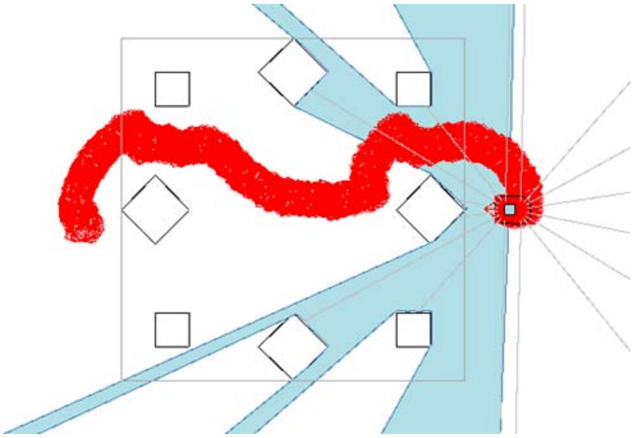


Figure 7. Narrow passage condition in MobileSim.

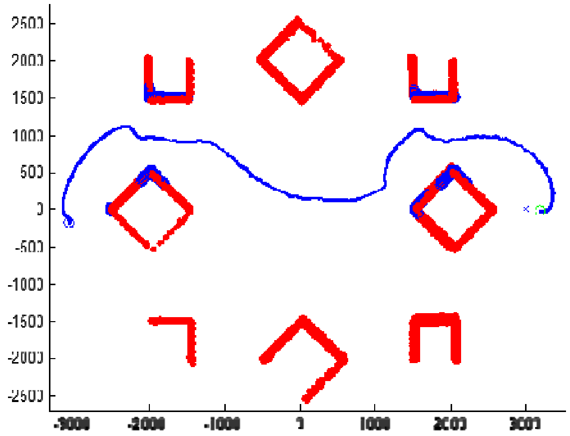


Figure 8. Approached charges by the robot in narrow passage condition.

The layout presented in Figure 9 and 10 have a task where the robot needs to reach a target inserted between obstacles and close to one of them. It's observed the ability to execute the duty with efficiency and simplicity.

Figure 11 and 12 present an environment designed to verify the method's behavior at local minima situations. Also, the goal position is near an obstacle, providing a difficult set where other methods cited were not able to solve. As can be seen by simulations, results are satisfactory. The green circles in Figure 12 illustrates the added charges throughout the path as used in the avoid the past behavior technique discussed in the earlier Section. It's noteworthy that when there's a deeper non convex barrier, probably the robot will oscillate more times until converge to a solution.

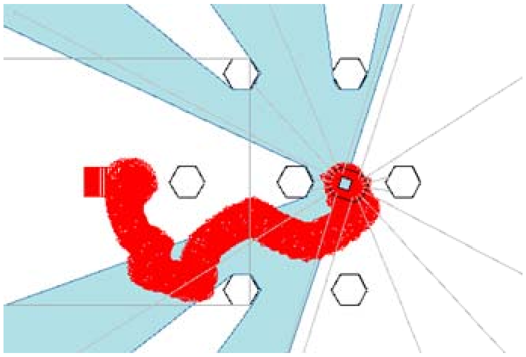


Figure 9. Target inserted between and near obstacles in MobileSim.

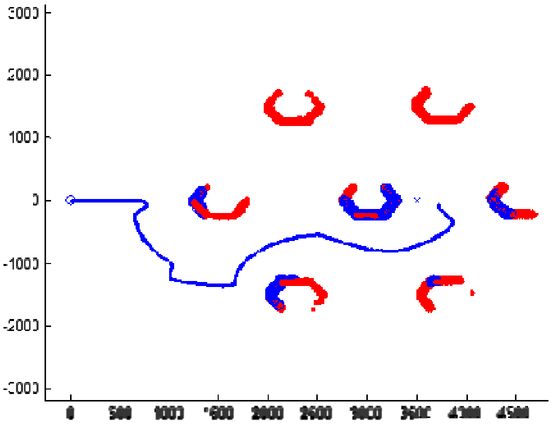


Figure 10. Approached charges by the robot when target is inserted between and near obstacles.

A double trap situation with a local minima problem was utilized in the situations represented in Figure 13 and Figure 14 in order to further validate the proposed algorithm's performance. The results show the method's ability to surpass local minima issues, where is possible to conclude that the robot will reach the goal with more non convex obstacles in the environment.

The method discussed in this work has many parameters that need to be adjusted in a way to allow safe and efficient operation. For instance, the size and maximum velocity of the robot will determine the minimum distance that the charge increase the value, with the purpose to avoid a possible collision. Others factors are the barriers and objective charge's increment steps that need to be well chosen for each layout in order to achieve better results, such as smooth curves and fast convergences.

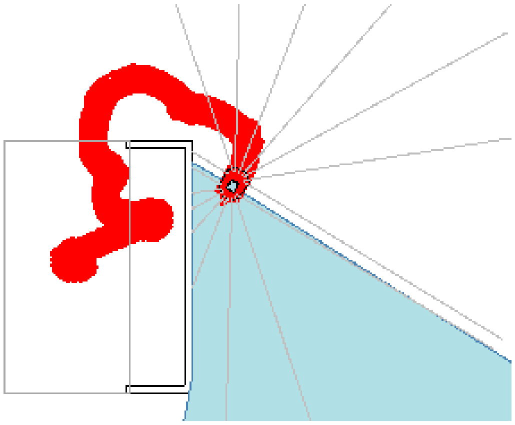


Figure 11. Local Minima condition in MobileSim.

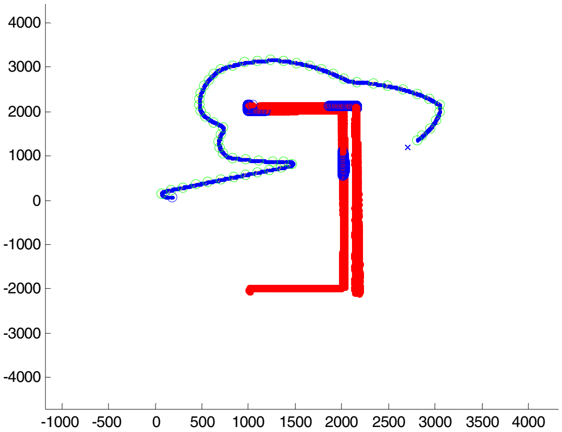


Figure 12. Approached charges by the robot with local minima situation.

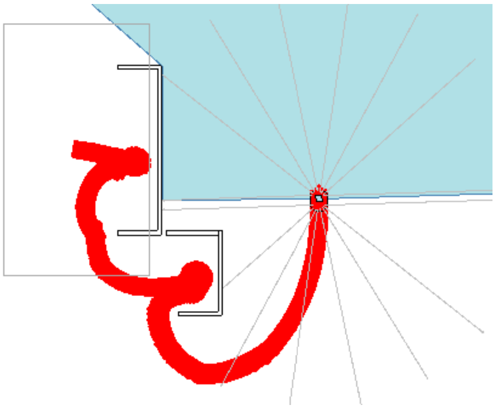


Figure 13. Double trap situation in Mobile Sim.

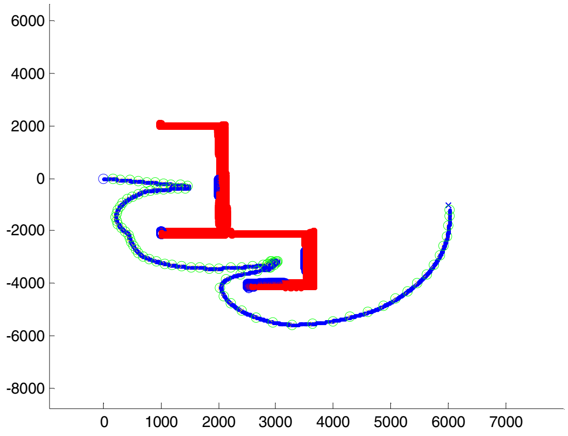


Figure 14. Approached charges by the robot with double local minima situation.

V. CONCLUSION

As stated in several works, the performance of potential fields for trajectory control in cases where the target is close to an obstacle with narrow passages and multiple local minima are unsatisfactory. As presented in results, some cases considering those conditions were simulated and the robot reached the destination efficiently proving its applicability for dynamic environment.

The technique discussed in this work has shown good performance considering all drastic conditions. The balancing of repulsion and attractive forces constrains the robots movement through narrow isle, absorbing excessive oscillations.

The parameters for the simulation were determined empirically. For future works, it is intended to use smart techniques such as reinforced learning or neural networks to configure them automatically, enhancing the results.

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