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Obstacles Avoidance for Mobile Robot Using Enhanced Artificial Potential Field

Mohamed Jasim Mohamed* **Mustaffa Waad Abbas****
,Department of Control and Systems Engineering/ University of Technology*
*Email: moh62moh@yahoo.com
*Email: Mustaffa.waad@yahoo.com

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Abstract

In this paper, an enhanced artificial potential field (EAPF) planner is introduced. This planner is proposed to rapidly find online solutions for the mobile robot path planning problems, when the underlying environment contains obstacles with unknown locations and sizes. The classical artificial potential field represents both the repulsive force due to the detected obstacle and the attractive force due to the target. These forces can be considered as the primary directional indicator for the mobile robot. However, the classical artificial potential field has many drawbacks. So, we suggest two secondary forces which are called the midpoint repulsive force and the off-sensors attractive force. These secondary forces and modified primary forces are merged to overcomethe drawbacks like dead ends and U shape traps. The proposed algorithm acquirs information of unknown environment by collecting the readings of five infrared sensors with detecting range of 0.8 m. The proposed algorithm is applied on two different environments also it is compared with another algorithm. The simulation and experimental results confirm that the proposed algorithm always converges to the desired target. In addition, the performance of algorithm is well and meets the requirements in terms of saved time and computational resources.

Keywords: *Mobile Robot, Local Path Planning, Obstacles Avoidance, Potential Field.*

1. Introduction

The existence of robots in various types became very significant in the industrial sector and especially in the service sector. Due to the growing interest of the service robots, they can achieve their mission in an environment which contains several obstacles [1]. The mobile robots have the advantage of the simplicity of manufacturing and mobility in complex environments. The capacity to move without collision in such environment is one of the fundamental questions to be solved in autonomous robot-like problems. The robot should avoid the undesirable and potentially dangerous objects. These possibilities have much interest of the subject of robot-like research [2].

The methods to plan a path for mobile robot can be classified into two types: global path planning techniques and local path planning techniques or obstacles avoidance techniques. The global path planning techniques are related to those techniques that are done before the robot moves. On other hand online obstacles avoidance techniques are associated with those techniques that are done while the robot motion [3].

Artificial potential field is popular approach for obstacles avoidance. Artificial potential field method (APF) is one of the mostly studied and used methods in mobile robot path planning [4]. The Artificial potential field method was proposed by Khatib, which is a virtual force field method. Although this method is fast and efficient, it has the following drawbacks and limitations; trap situations due to local minima, no passage between closely spaced obstacles, oscillations in the presence of obstacles and oscillations in narrow passages [5].

To overcome these limitations, several authors have tried to solve the local minima problem by presenting new potential functions so that the destination becomes the global minimum. Others tried to solve these problems by combining the simple potential method with artificial intelligence models like neural network [6], genetic algorithm [7] and fuzzy logic [8]. But unfortunately these methods contribute to increase in the complexity of the algorithms.

In this paper, we proposed an algorithm using a simple potential functions with specific rules and conditions, that overcome the conventional artificial potential field.

The simulations of experiments verify that this algorithm is not bound to the limits as is the case with traditional artificial potential field methods.

The reminder of this paper is organized as follows: section II gives brief introduction to the traditional artificial potential field, section III describes the problem, section IV gives the determination to the robot system that is used, section V illustrates the proposed algorithm, section VI shows the simulation of number of local path planning cases and a comparison study are given. Finally, section VII introduces the conclusions.

2. A Traditional Artificial Potential Field Method

The basic idea of Artificial Potential Field (APF) method is that the movement of objects in the environment is considered as a movement in the abstract artificial force field, which is composed of the attractive force field of the target and repulsive force field of the obstacle. In fact, the robot descends on the potential field according to gradient descent method to reach its destination while avoiding obstacles [9].

Therefore, the artificial potential field is defined in equation (1). The robot follows this gradient of the field as shown in equation (2).

$$\boldsymbol{U} = \boldsymbol{U_{att}} + \boldsymbol{U_{Rep}} \qquad \ldots(1)$$

$$\boldsymbol{\nabla U} = -(\boldsymbol{\nabla U_{att}} + \boldsymbol{\nabla U_{rep}}) \qquad \ldots(2)$$

Where:U_{att} is the attractive force of the target, U_{Rep} is the repulsive force of the obstacle.

The attractive and repulsive forces are shown in equations (3) and (4) respectively [10].

$$\boldsymbol{U_{att}} = \frac{1}{2}\boldsymbol{\xi d^2(q, q_{goal})} \qquad \ldots(3)$$

$$\boldsymbol{U_{rep}} = \begin{cases} \frac{1}{2}\boldsymbol{\eta}(\frac{1}{d(q,o)} - \frac{1}{\rho})^2, & \boldsymbol{d(q,o)} < \rho \\ \boldsymbol{0}, & \boldsymbol{d(q,o) \geq \rho} \end{cases} \qquad \ldots(4)$$

Where: ξ and η are the gain's coefficients of attraction and repulsion functions respectively, ρ is the largest impact distance of single obstacle, $d(q, q_{goal})$ is the Euclidean distance between the locations of robot and the target, $d(q,o)$ is the minimum distance between the affected areas of obstacle and the location of the robot.

3. Problem Description

The problem is how to drive a mobile robot to a certain target point in an unknown environment without any collision. This means how to make the mobile robot avoids obstacles online based on the available infrared sensors readings only.

4. The Robot And Sensors

In our algorithm, the robot is modeled as a circle with the ability of turning around its center, just like rover robots or two wheel robots as shown in Figure (1). The robot is supplied with five infrared distance meters each with the range of 80 cm. The first sensor puts on the front of the robot, this sensor will be referred to as the "zero degree sensor". The reset four sensors are put on the both sides of the zero degree sensor with angle of -40°,-20°, 20° and 40° .The robot model is shown in Figure (2).

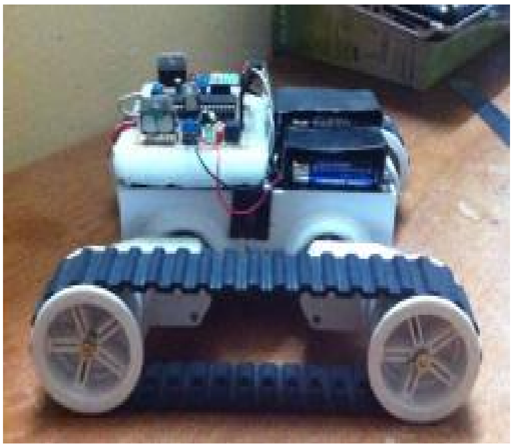


Fig. 1. Rover Mobile Robot .

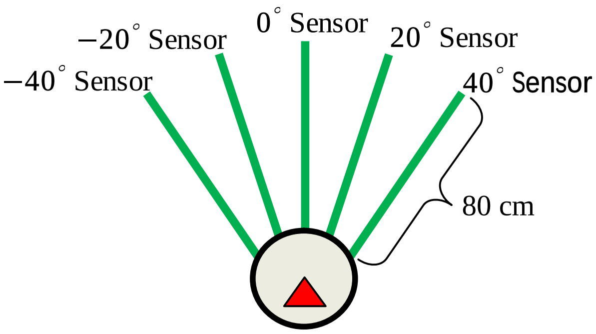


Fig. 2. Robot Model.

5. Proposed Algorithm

The proposed algorithm is based on the principles of artificial potential field path planning and our proposed ideas. These ideas are suggested to overcome the lack of the artificial potential field and to ensure a reliable on-line path planning. The proposed algorithm is presented as a sequence of steps as follow.

5.1. Attractive Force Calculations

Before the robot starts to move the gradient descent of attractive force is calculated; then according to this gradient, the robot is directed toward the point of target.

The proposed and used attractive force shown in equation (5) has small deference from the conventional equation shown in (3). As shown in equation (3), the different term is the square of the distance between the robot and the position of the target, while for the used attractive force in equation (5) this term is only the distance from the robot to the position of the target. This function is chosen to give the robot more allowance to move around the target and even go in the reverse direction when that is necessary.

$$Uatt(P_R) = \xi_{att} d(P_R, P_T) \qquad \ldots(5)$$

In equation (5) P_R and P_T are the position of the robot and the position of target respectively. The gradient of the attractive force is illustrated in equation (6).

$$\nabla Uatt(P_R) = \xi_{att} \frac{P_T - P_R}{d(P_R, P_T)} \qquad \ldots(6)$$

The scaling factor ξ_{att} is used to increase the effect of attractive force and to prevent the sharp redirection that may cause by large repulsive forces in some cases. The factor ξ_{att} is chosen to be 2. This choice is based on the system observation and the maximum resultant repulsive force that could apply on the robot.

5.2. Collision Detection

After the attractive force of target point is calculated and the robot is directed according to gradient of this force, the statuses of sensors are checked to get the information about any possible collision.

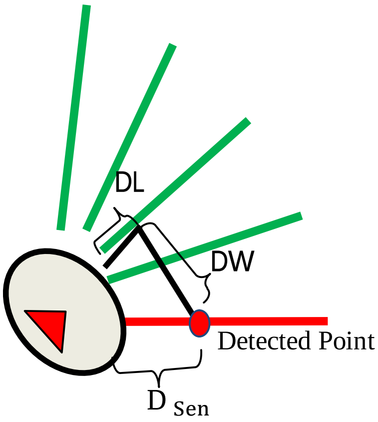
Although the sensors may detect many obstacles, not all of these detected obstacles are considered to make collisions. In fact, the detected obstacles are elected as possible collision points. The detected point/points is/are defined as collision point/points, if and only if the conditions (7) and (8) are satisfied.

$$D_{Sen} \times \sin(\theta_{Sen}) \le robot\ radius \qquad \ldots(7)$$

$$D_{Sen} \times cos(\theta_{Sen}) \le robot\ step\ size \ldots(8)$$

In equation (7) and (8) D_{Sen} is the distance detected by the sensor and θ_{Sen} is the angle of the sensor that detects this distance. The robot step size is the straight distance that the robot moves through it after the direction of the robot is specified base on the forces applied on it. Step size is initialized at first to a distance equal to sensor range (80 cm).

The above two conditions are better illustrated in Figure (3).



Detected Point=Collision Point if:

$$DW \le robot\ radius,$$

$$DL \le robot\ step\ size$$

Fig. 3. Collision Points
$DW = D_{Sen} \times sin(40^\circ), DL = D_{Sen} \times cos(40^\circ).$

5.3. Repulsive Force Calculations

When the collision point/points is/are specified the repulsive force from this/these point/points is/are calculated according to equation (9).

$$\boldsymbol{Urep(P_R)} = \sum_{i=1}^{nc} \frac{1}{d(P_R,P_{Ci})} \quad \dots (9)$$

Where: P_R is the position of robot, P_{Ci} are the positions of collision points and nc is the number of detected collision points. Equation (10) shows the gradient of the repulsive force.

$$\nabla Urep(P_R) = \sum_{i=1}^{nc} -\frac{(P_{Ci}-P_R)}{d^3(P_R,P_{Ci})} \quad \dots(10)$$

The deference between the proposed and the traditional equations of repulsive force is that the largest impact distance of single obstacle ρ is removed in the proposed equation of repulsive force. The reason for this is that the robot works in an unknown environment and the repulsive force is calculated only for the collision points that are detected by the sensors.

The primary proposed attractive force and repulsive force provide a safe path for the mobile robot to reach the target point. In fact, these forces are enough when underlying environment is simple and does not contain local minimum or dead ends. Therefore, extra types of secondary repulsive and attractive forces are suggested here to contribute with the primary forces. These forces are called "*Midpoint repulsive force*" and "*Off-sensor attractive force*".

5.4. Midpoint Repulsive Force

The midpoint repulsive force is proposed to get the robot out of U shape traps or dead ends. It gives the robot sense of direction, like where the robot comes from and where the robot should go.

The midpoint repulsive force depends on the previously detected collision points (P_{PCi}). We classify the previously detected collision points (P_{PCi}) into three types of points which are; X-points, Y-points and XY-points. The mechanism of classification is based on the direction and the position of the robot related to the target point at the instant of detection the collision point/points. This classification depends on two steps. The first step depends on the direction of the robot. The following three conditions determine the direction of the robot as shown in (11), (12) and (13).

$$\cos(\theta_r) > \sin(\theta_r) \quad \dots (11)$$

$$\cos(\theta_r) < \sin(\theta_r) \quad \dots(12)$$

$$\cos(\theta_r) = \sin(\theta_r) \quad \dots(13)$$

In (11) to (12) θ_r is the direction of the robot with respect to the x-axis. The three last conditions are better illustrated in Figure (4).

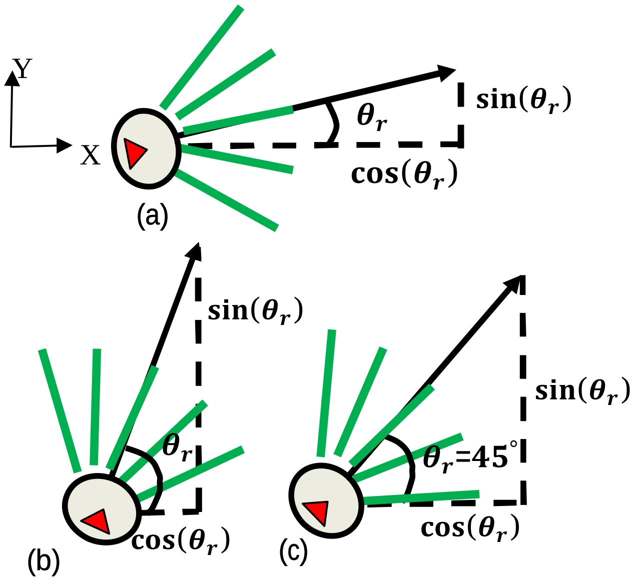


Fig. 4. First step condition.
(a) $\cos(\theta_r) > \sin(\theta_r) = True.$
(b) $\cos(\theta_r) < \sin(\theta_r) = True.$
(c) $\cos(\theta_r) = \sin(\theta_r) = True.$

In other word, the satisfaction of first condition (11) informs that the change in the position of the robot along the x-axis during its motion larger than the change along the y-axis. The satisfaction of the second condition (12) indicates that the change in the position of the robot along y-axis larger than x-axis. Finally condition (13) satisfied if the change in the position of the robot along the x-axis and y-axis is the same.

The second step depends on which of the above three conditions are satisfied. If condition (11) is true then the detected collision point/points at that instance is classified as X-point, if this point/points lies between the x-axis of the robot and the x-axis of the target. If condition (12) is satisfied the collision point/points is classified as Y-point, if this point/points lies between the y-axis of the robot and the y-axis of the target. In same manner, if condition (13) is satisfied the point/points is classified as XY-point. Figure (5) shows this classification.

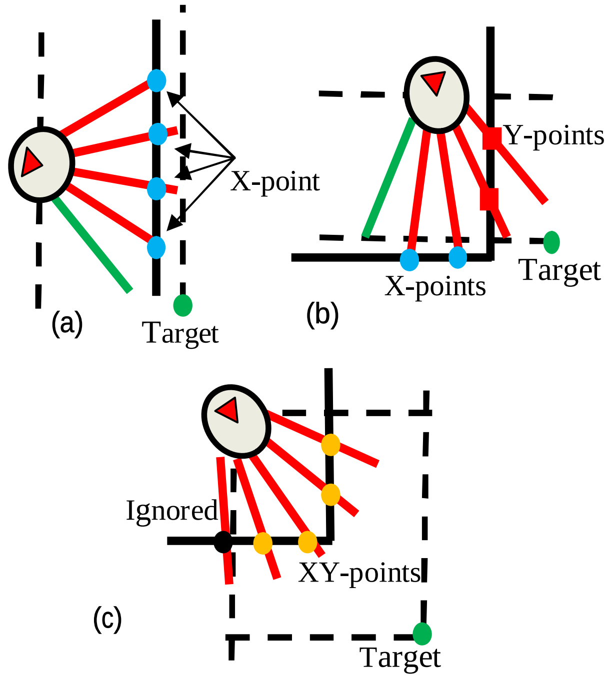


Fig. 5. Collision Points Classification.
(a) $\cos(\theta_r) > \sin(\theta_r) = True.$
(b) $\cos(\theta_r) < \sin(\theta_r) = True.$
(c) $\cos(\theta_r) = \sin(\theta_r) = True.$

In Figure (5-b) some points are classified as X-points because they are out of the range of y-axis of the target and the robot. The ignored point in Figure (5-c) is ignored by the midpoint repulsive force because it is out of the XY-axis range of the robot and the target but this point is not ignored by the prim repulsive force.

The basic purpose of this classification is to ensure that the midpoint repulsive force does not take into account the points that the robot passes them and they have no importance any more. Thus, the midpoint force ignores the X-points if these points become out of the range of x-axis of robot and x-axis of target and the same for Y-points and XY-points, if they out of the y-axis range and the xy-axis range respectively.

The midpoint P_M is calculated for the P_{PCi} as in equation (11).

$$P_M = \left(\sum_{i=0}^{n} P_{PCi}\right)/n \qquad \ldots(11)$$

Where: n is the number of previously saved collision points.

The purpose of the midpoint repulsive force is to be an antagonist for the attractive force of target. It has the ability to reverse the direction of the robot or drive the robot away from the target point, when it is necessary. Therefore, the repulsive force of the midpoint is calculated in different way. It is calculated as the negative of the distance between the robot and the midpoint as in equation (12) and the gradient of it in equation (13).

$$Urep_{MP}(P_R) = -\xi_{MP}\, d(P_R, P_M) \qquad \ldots(12)$$

$$\nabla Urep_{MP}(P_R) = -\xi_{MP}\,\frac{P_M - P_R}{d(P_R, P_M)} \qquad \ldots(13)$$

The factor ξ_{MP} in (12) and (13) is chosen to be 1 or half of the factor of the attractive force ξ_{att} in order to make the effect of attractive force superior to determine the direction of the robot. This almost leads the robot to the target. Figure (6) shows the effect of this force.

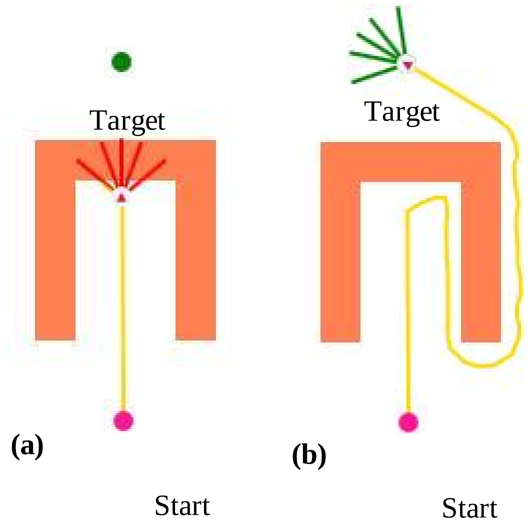


Fig. 6. Midpoint Repulsive Force effect.
(a) Without Midpoint Repulsive Force.
(b) With Midpoint Repulsive Force.

5.5. Off-Sensors Attractive Force

This force is proposed to give the robot an insistence to maintain its direction until it reaches a dead end or it goes so far from the target. Furthermore, this force is also used to enhance the performance of the robot around the corners and to increase the smoothness of the resultant path (reduces the oscillations of the motion).

This force is based on two classifications; classification of the motions of robot and classification of the sensors.

a. Robot's Motions Classification

The motions of the robot are classified here into three classes:

Class 1: Direct movement to the target (*DM*). The robot has an angle equal to zero relative to target point.
Class 2: Clockwise movement to the target (*CWM*). The robot tries to reach the target and avoids the obstacles by moving clockwise direction. The target is taken as the center of motion.
Class 3: Counter clockwise movement to the target (*CCWM*). The robot tries to reach the target and avoids the obstacles by moving counter clockwise. The target is taken as the center of motion.

b. Sensor's Classification

We divide the sensors except the zero degree sensor into two groups the left group or clockwise group (the -40 and -20 angle's sensors) and the right group or counter clockwise group (the 40 and 20 angle's sensors). Figure (7) illustrate this classification.

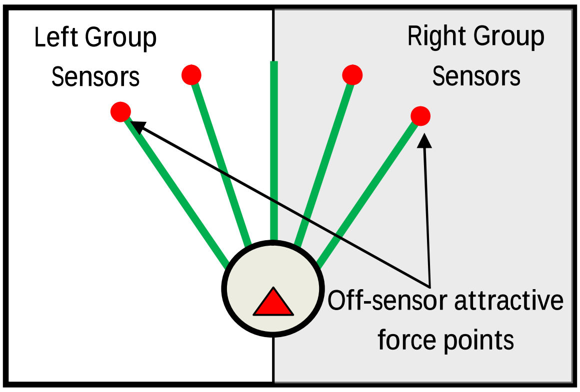


Fig. 7.Off-Sensor Attractive Force.

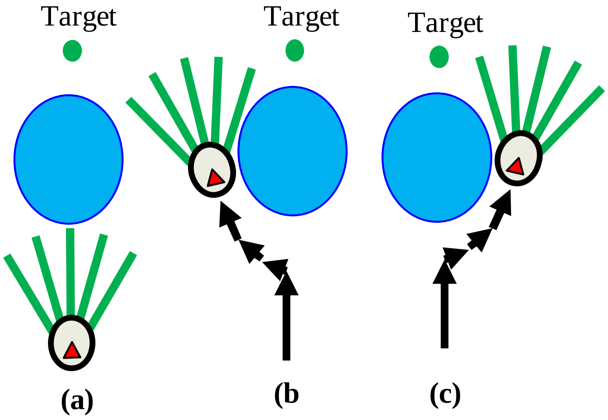


Fig. 8.Robot Motion Classification.
(a) DTT. (b) CWDT. (c) CCWDT.

The motion of the robot at the start point is DM and at this moment, the off-sensors attractive force is not calculated until the robot changes its direction (collision is detected). If a collision is detected, the robot due to the prime repulsive force is deviated. Then, the motion of the robot is checked whether it is CWM or CCWM. At this moment, the off-sensors attractive force is calculated for the group of sensors which is nearest to the target point. This off-sensor attractive force is calculated for each step of the robot according to the assigned group until the motion of the robot altered to the DM. This means that the robot will advance to the target point with the current detected motion (CWM or CCWM) until the direct motion of the robot DM is detected again. At this moment, the calculation of the off-sensors attractive force is stopped and the robot continues on its direct motion to the target. When a new collision detected again, then the algorithm is restarted in same way.

After the right group of sensors is specified, the off-sensor attractive force and its gradient are calculated for the specific two sensors as in equation (14) and (15).

$$Uatt_{Sen}(P_R) = \xi \sum_{i=1}^{2} d(P_R, P_{Seni}) \times SC_i \quad \ldots(14)$$

$$\nabla Uatt_{Sen}(P_R) = \xi \sum_{i=1}^{2} \frac{P_{Seni} - P_R}{d(P_R, P_{Seni})} \times SC_i \quad \ldots(15)$$

In (14) and (15) ξ chosen to be 1, P_{Seni} are the points of the off-sensor attractive force taken at the end of each sensor range as shown in Figure (7) and SC_i is a binary flag represents the condition of the sensor; 1 for off sensor and 0 for on sensor.

This force has another major importance where it reduces the effect of midpoint repulsive force.

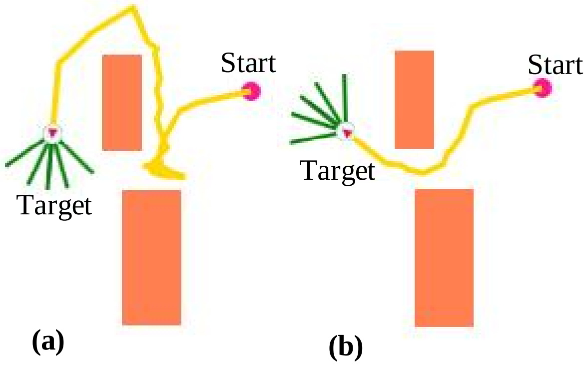


Fig. 9. Off-Sensors Attractive Force Effect.
(a) Without Off-Sensors Attractive Force.
(b) With Off-Sensors Attractive Force.

In fact, the midpoint repulsive force is calculated always even when the robot is far from the midpoint. This may direct the robot away from the target. So the off-sensors attractive force ensures that the robot will not go so far in its attempts to avoid the dead ends and U shape traps. Figure (9) shows the effect of the off-sensors attractive force.

i. Direction and Step Size

The attractive forces and the repulsive forces are used to obtain the direction of the robot only. The gradient of force is calculated according to equation (16).

$$\boldsymbol{F} = -(\nabla U_{att} + \nabla U_{rep} + \nabla Urep_{MP} + \nabla Uatt_{sen}) \qquad \ldots(16)$$

The direction of the robot is found according to equation (17).

$$\theta_R = tan^{-1}\frac{F_y}{F_x} \qquad \ldots(17)$$

When the direction of the robot is calculated, we need to calculate the step size of movement. The step size calculation is done according to two cases, these cases are;

Case 1: Free robot motion. In this case, the sensors detect no collision and the step size is initialized to distance equal to the sensor range (80 cm). The reason for this is that, in free robot motion all we need to ensure that there is no obstacle in front of the robot within range of the sensor only.

Case 2: When the collision is detected. The step size is taken as the summation of the maximum detected distance and the robot width.

ii. Near Target Behavior

Although the proposed algorithm is enhanced to overcome drawbacks in the classical algorithm, the algorithm still has some difficulties to lead the robot to special kind of targets. When the target lies near narrow corners and when the target lies between two closed obstacles. According to the algorithm, the robot may change its direction before the robot reaches the target because of the effect of repulsive force of the near target detected points as shown in Figure (10).

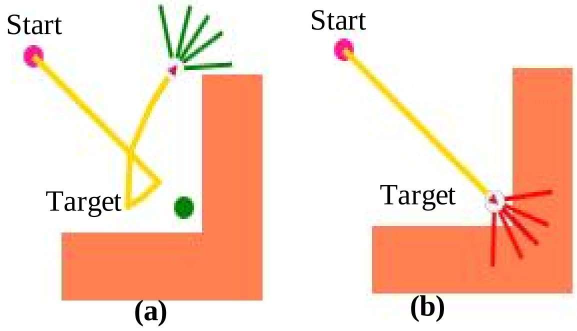


Fig. 10. Near Target Behavior.
(a) Without Near Target behavior.
(b) With Near Target behavior.

Thus, when the robot becomes at a distance from the target less than the sensor range, the behavior of the algorithm is changed. The midpoint repulsive force and the off-sensors attractive force will no longer active. The step size will be equal to the distance from the robot to the target. This will lead the robot to the target without any additional actions.

For better understanding of the proposed algorithm, the previous steps of algorithm are illustrated in flowchart shown in Figure (11).

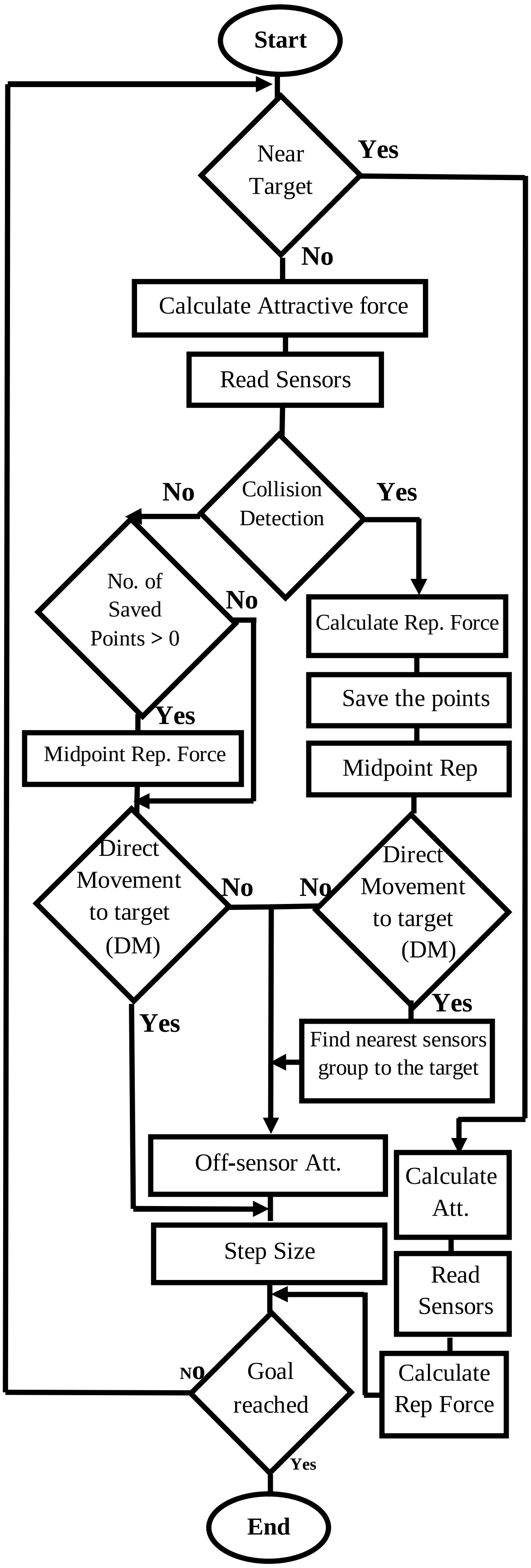


Fig. 11.The Flowchart of Proposed Algorithm.

6. Simulation and Results

This section is assigned to perform a simulation on some path planning problems using the proposed algorithm. Two examples with two different environments are studied. In addition, a comparison study is done between the proposed algorithm and the algorithm that is proposed in [2]. This simulation is performing via a VC++ using Direct2 library.

Environment 1: This environment has length of 6.3 m and width of 5.6 m. The results of the two examples are shown in Figures (12, 13).

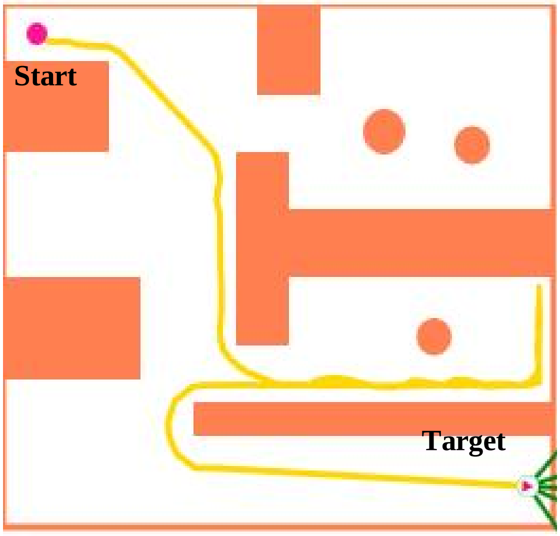


Fig. 12. Simulation Result of Environment 1, Example 1, Start point is (0.245m, 0.245m) and goal point is (6m, 5m).

Environment 2: This environment is generated randomly by random environment generator algorithm. The obstacles are represented by circles. There are 80 obstacles with radiuses in range of 0.12m to 0.9 m. The environment has length of 17.15 m and width of 14.7m. The results of the two examples are shown in Figures (14, 15).

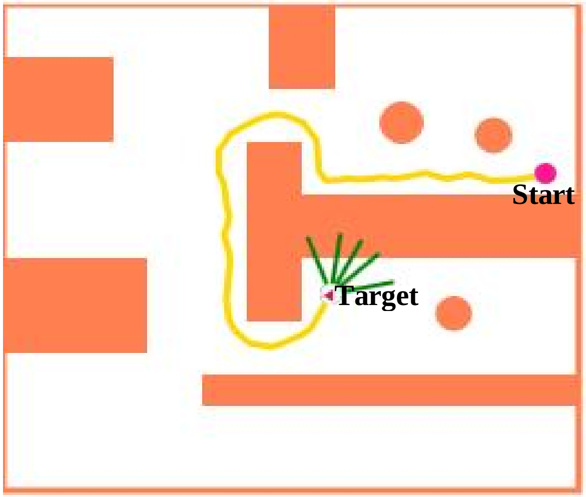


Fig. 13. Simulation Result of Environment 1, Example 2, Start Point is (6.07m, 1.88m) and Goal Point is (3.6m, 3.1m).

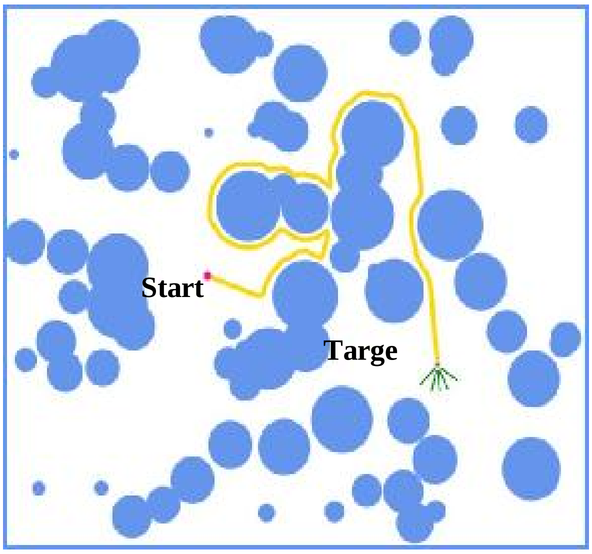


Fig. 14. Simulation Result of Environment 2, Example 1, Start Point is (6m, 7.3m) and Goal Point is (12.7m, 9.75m).

<u>Comparison Study:</u> This comparison is done between the proposed algorithm in [2] and our proposed algorithm. The proposed algorithm in [2] uses Q-learning algorithm and fuzzy logic to find the path to the target based on the reading of thirteen sensors.

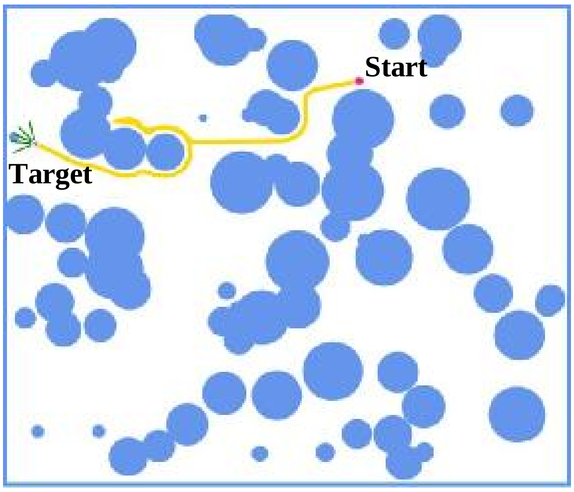


Fig. 15. Simulation Result of Environment 2, Example 2, Start Point is (10.7m, 2.3m) and Goal Point is (0.9m, 4.2m).

Two examples are taken for comparison. The results of the Q-learning algorithm are shown in Figure (16) and Figure (17). The two examples are re-simulated using our proposed algorithm and the results are shown in Figure (18) and Figure (19).

The comparison study shows that our proposed algorithm develops paths which are the same or better than the paths of the Q-learning algorithm. In addition, our algorithm does not need to use any artificial intelligent system like fuzzy or neural network.

Fig. 16. The Q-learning Algorithm Results, Example 1, [2].

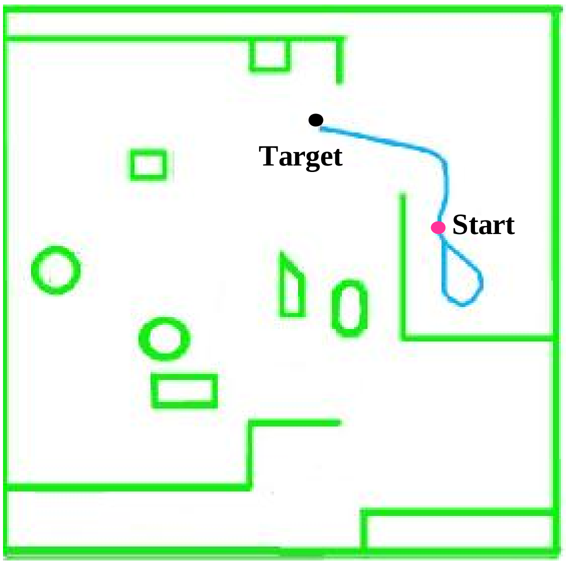


Fig.17. The Q-learning Algorithm Results, Example 2, [2].

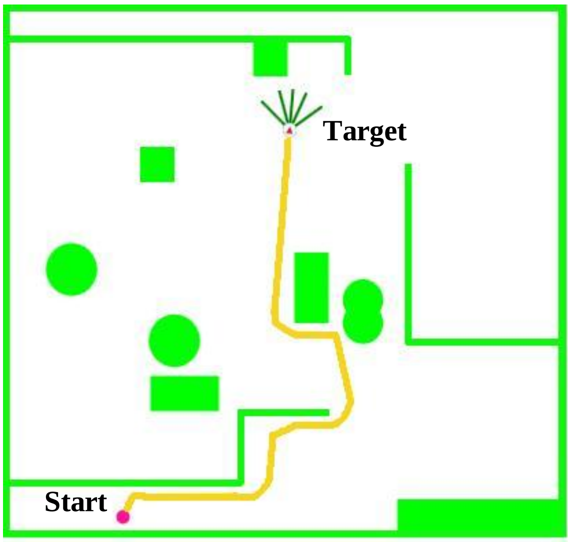


Fig. 18. The Re-Simulation of Q-Learning Algorithm Example 2 by the Proposed Algorithm.

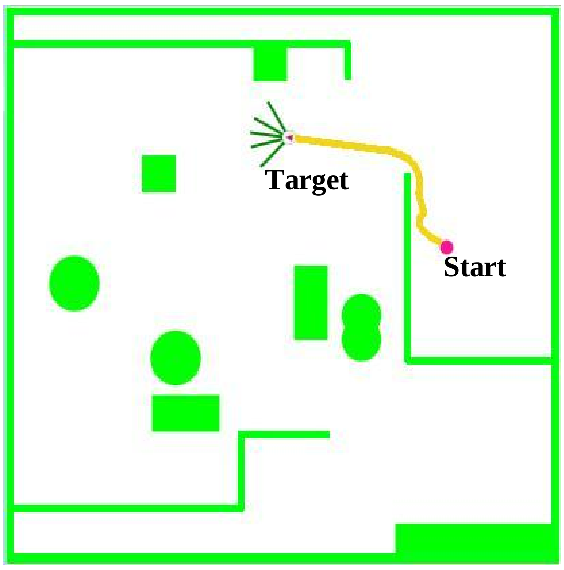


Fig. 19. The Re-Simulation of Q-learning Algorithm Example 3 by the Proposed Algorithm.

7. Conclusion

In this paper, we proposed an algorithm to solve the problem of finding a path between two specific points in the totally or partially unknown environment. The required data for the algorithm are; the start point, the target point, and the readings of five infrared distance meters which are fixed in the front of the robot within angles equal to $(-\frac{\pi}{9}, -\frac{2\pi}{9}, 0, \frac{2\pi}{9}, \frac{\pi}{9})$. The main points that are important to refer to for the proposed algorithm are:

- Since, the classical artificial potential field suffers from some drawbacks; we suggested secondary forces, the off-sensors attractive force and midpoint repulsive force. These suggested forces are merged with forces of classical artificial potential field. These additional forces are submitted to a certain rules and conditions, to ensure a smooth and safe path to the target.
- In addition, the proposed algorithm follows simple calculations and conditions without any searching or optimization method. Thus, it is possible to apply this algorithm on micro controllers like PIC or AVR micro controllers.
- The simulation results show that the proposed algorithm is fast and efficient. In addition, it overcomes the drawbacks and limitations of

traditional artificial potential field. The proposed algorithm has the capabilities like escapes from local minima, passes between closely spaced obstacles, damps oscillations in the presence of obstacles and damps oscillations in narrow passages.

- Finally, the proposed on line path planning algorithm always go to the target within minimum distance. Furthermore, the comparison study shows that our proposed algorithm is better than the algorithm that uses artificial intelligence system.

8. References

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تجنب العوائق للروبوت النقال باستخدام مجال القوى الاصطناعي المعزز

محمد جاسم محمد * **مصطفى وعد عباس ****
**، **قسم هندسة السيطرة والنظم/ الجامعة التكنولوجية*
*البريد الالكتروني: moh62moh@yahoo.com
**البريد الالكتروني: Mustaffa.waad@yahoo.com

الخلاصة

في هذا البَحثْ تَمْ تَقديمْ مُخطط مَجالْ القوى الأصطِناعيْ المٌعَزز. هذا المٌخطط أقترح لأيجاد الحَلولْ بِسرعَة عالِية وفَورية لمَشاكلْ تَخطيطْ طَريقْ الرُوبوتْ النَقالْ عِندمْا تَكونْ البيئة المَدروسْة تَحتوي عَلى عَوائقْ غَير مَعروفة المَواقع والأحجام . أن مَجال القوىْ اللأصطناعي التَقليديْ يُمثل كُلا مِنْ القوة النَبضية نُتيجةْ العائقْ المُكتشف و القوة الجَاذبة الناتِجة منْ الهَدف. هذهِ القوى مُمكنْ ان تُعتبر دَليلْ الأتِجاه الأساسي للرُوبوت النَقال. منْ ناحية ثانِية فانْ مَجال القوى الأصطِناعي التَقليديْ يَمتلك عِدة مَشاكل. ولذا أقتَرحنا قوتَين ثانَويتين واللتين سُمِيتا قوة نُقطة الوَسط النبضية وقوة الجَذب للمتحسس الخامل. هاتان القوتان الثانويتان والقوى الاساسية المحسنة قد تم دمجها للتغلب على المَشاكل مَثل النهاية المَيتة ومَصيدة حَذوة الفرس. أن الخَوارزمية المُقترحة تكتسب المَعلوماتْ عَنْ البيئْة الغَير مَعرُوفة بِواسِطة جَمعْ القراءات منْ خَمسْة مُتحَسِساتْ يَعمَلونْ بالأشعْة التَحتْ الحَمراءْ وبِمَجالْ أكتشافْ ٠.٨ مَتر. أنْ الخَوارزمِيْة المُقترحة قدْطُبقت على بيئتَيْن مُختلفتينْ كَذلكْ قَد تَم مٌقارنتِها مَعْ خَوارزمية أخرى. أن المُحْاكاة والنتائجْ التَجريبيْة تُؤكدْ أنْ الخَوارزميْة المُقترحْة دائما تُلاقيْ الهَدفْ المَطلوبْ. بَالأضافة الىْ ذَلك أن أداءْ الخَوارزمية جَيداً ويُوفيْ المُتَطلباتْ منْ حَيثْ تَقليلْ الزَمنْ والجُهد الحِسابيْ.