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Local Path Planning of a Four Mecanum Wheeled Mobile Robot Based on New Modified Ultrasonic Sensors with Experimental Implementation

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Abstract: This work aims to solve the local path planning problem of a four mecanum wheeled mobile robot in a static environment by using an improved artificial bee colony optimization (IABC) with an experimental implementation. Two improved equations are utilized to overcome the disadvantages of the standard bee colony (ABC) optimization. The first modification equation makes the number of the limits that done by the bees to change with each iteration instead of using a fixed limit value, while in the second modification, it has been designed an equation enhance the balance between the explorations well as exploitation processes. Two new modified ultrasonic sensors are designed to detect the obstacles that are found in the environment. Each modified sensor contains single transmitter and two. MATLAB/Graphical User Interface (GUI) software is used to simulate the theoretical results. The performance of the IABC optimization is compared with the ABC optimization in the case of avoiding four static obstacles and the simulation results are demonstrated that the performance of the IABC is better than ABC in terms of the path length and the computation time. To validate the efficiency of the IABC optimization, an experimental avoidance procedure is done based on the same conditions that are used in the theoretical avoidance. Also, a comparison is occurred between the adopted IABC and other algorithm and the results show the robustness of the IABC over the other algorithm.

Keywords: Mobile robot (MR), Local path planning, Improved artificial bee colony (IABC) optimization, Modified ultrasonic sonic sensor, Static obstacles.

1. Introduction

Mobile robots (MR) are utilized dramatically in the several applications such us in medical, military purpose, industries, space research and others [1]. Generally, mobile robot system is consisted of mapping, localization, and path planning units [2]. In the path planning, the robot needs to move from the start to the target points without collision with any obstacles that are found in the environment [3]. Path planning problem of the MR can be classified into global and local. If the information about the obstacles location, size, and speed are known to the robot before staring it's navigation, this problem is classified as global path planning. On the contrary, the problem is classified as local path planning [4]. Obstacles are categorized into static and movable (dynamic). The positions of the static obstacles are stationary, while the positions are changed in the case of the movable obstacles [5]. Many works solved the path planning problem of the MR by using different algorithms. Musa Matli et al [6], solved the path planning problem of a four mecanum wheeled mobile robot by using the follow- gap approach and fuzzy logic control. The authors used LIDAR system to detect the stati and the movable obstacles that are found in the environment. Rkaa T. Kamil et al [7] studied theoretically the static obstacles avoidance problem of the MR. The used a modified bee colony optimization to generate an optimal safe path followed by the MR from the start to the target points. Two scenarios were presented by the authors. In the first scenario, there are fifteen static obstacles with circular shape in the environment, while in the second scenario, there are twenty four obstacles. Anish Fatin H. Ajeil [8], applied hybrid algorithm consists of particle swarm optimization (PSO) and modified frequency bat (MFB) optimization to avoid static obstacles and dynamic obstacles in an unknown environment. The obstacles were detected by using twelve deployment sensors. Navid Toufan and Aliakbar Niknafs [9] adopted modified gray wolf optimization to solve the path planning problem of Khepera IV MR. The authors used V-REP simulator to model the robot and to present the results. Baoye Song et al., [10] studied the obstacles avoidance problem of the MR. They used particle swarm optimization (PSO) with high-degree Bezier curve. PSO was used to generate short safe path followed by the robot from the start to the goal points, while high-degree Bezier curve utilized to make the path more smoothness. T. A. Badmos et al., [11] adopted an improvement PSO to solve the problem of a non-holonomic MR. They applied a new equation for the weight parameter (w) and made it to change with each iteration. The authors used MATLAB software to simulate the algorithm and presented the theortical results. Ahmed Haj Darwish et al., [12] applied a modified bee colony optimization to avoid static as well as dynamic environments. They used eight ultrasonic sensors to detect the obstacles. MATLAB software was used to simulate the results, while Amigo MR was chosen by the authors in the experimental work of the obstacles avoidance. Harshal S. Dewang et al., 2018 [13] used adaptive PSO for avoiding static obstacles theoretically. They tested their adopted algorithm in a four environment. They made a comparison between the adaptive and the classical PSO and they concluded that the adaptive PSO generated path shorter than the path of the classical PSO. Weiren Shi et al., [14] solved theoretically the path planning problem of the MR by using Fuzzy-Neural Networks model. The inputs to the Fuzzy-Neural Networks model were the distances between the obstacles and the robot which are measured by a ten deployment sensors. A. Medina-Santiago et al., [15] studied the obstacles avoidance problem of the MR. They utilized multilayer perceptron neural network (MLPNN) as a control system in the avoidance process. Three ultrasonic sensors used to detect the obstacles that are found in the environment. Nizar Hadi Abbas and Farah Mahdi Ali [16] applied a modified bee colony optimization for solving the path planning problem of a MR. Three environments were chosen by the authors to test their avoidance algorithm. The first environment was contained four static obstacles, the second environment contained six static obstacles, and the third environment included twelve obstacles. All the obstacles that were found in the three environments are within circular shape.

This work concentrates on the local path planning problem of a four mecanum wheeled mobile robot with an experimental implementation. A new improvement artificial bee colony optimization (IABC) has been applied to generate short, save, and smooth path followed by the robot during the avoidance process. Two modified ultrasonic sensors are used to detect the obstacles that are found in the working environment. Each modified sensors consists of single transmitter and two receivers. MATLAB/Graphical User Interface (GUI) software is used to simulate the theoretical results. The performance of the IABC optimization is compared with the ABC optimization in the case of avoiding four static obstacles and the simulation results are demonstrated that the performance of the IABC is better than ABC in terms of the path length and the computation time. The experimental test of the obstacles avoidance process is achieved by the interface between the MATLAB software (PC) and Arduino microcontroller through Wi-Fi module. A comparison studies have been evaluated between the developed algorithm, the classical ABC and other state-ofthe-art algorithms. These studies are proved that the performance of the IABC optimization is better than the other algorithms.

2. Performance Criteria of the Avoidance algorithm

Performance criteria of the MR path planning is the search for optimal or a near optimal path followed by the MR from the start to the end points. In this work, the performance criteria has been contained two important topics. These two topics are the short path as well as the path smoothness. The short path is achieved by minimizing or decreasing the tracking length between the start and the end points. The cost function that is used to represent the short path can be written as below:

$$f_1\,(x,y) = d = \sum_{i=1}^{N-1} \sqrt{(X_i(t+1) - X_i(t))^2 + (Y_i(t+1) - Y_i(t))^2} \tag{1}$$

Where (d) is Euclidean distance between the start and the end point, x(i), and y(i) are the coordination of the via-points. Path smoothness implies the concept of minimizing or reducing the angle difference between the current and the next via-points that are produced by the avoidance algorithm. The cost function that has been adopted for path smoothness representation is expressed as:

$$f_2(x,y) = \sum_{i=1}^{N-1} d\theta = \sum_{i=1}^{N-1} tan^{-1}\left(\frac{Y(i+1)-Y(i)}{X(i+1)-X(i)}\right) \tag{2}$$

The total cost function is evaluated as:

$$(x,y) = 0.5\, f_1(x,y) + 0.5\, f_2\,(x,y) \tag{3}$$

The process of the via-points selection is depicted in figure (1).

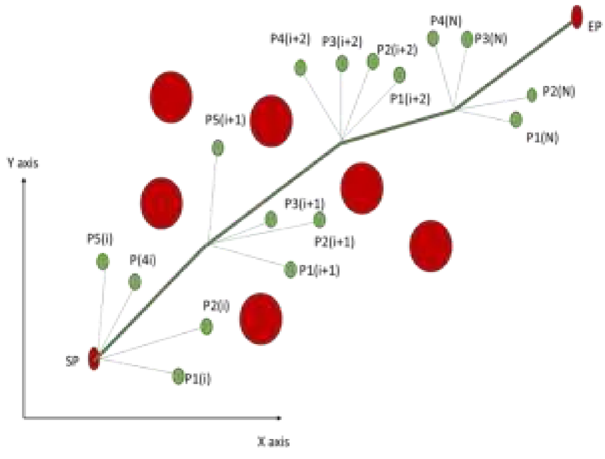

Figure (1). Via-points selection according to the total cost function

Standard ABC optimization

Artificial bee colony (ABC) optimization is a kind of the meta-heuristic algorithms. It was invented in 2005 by D. Karaboga. The bee colony is contained three types of the bees which are: employed, scout, and onlooker [17]. The main job of the employed bees is to search about a rich quality sources of the nectar amount and sharing the information to the onlooker bees. When the onlooker bees received the information about the rich food sources, they are starting to exploit these rich food sources. The employed bee becomes scout when it failed to enhance or increased the food quality. Equation (6) represents the feasible solution as below [17]:

$$x_{i,} = x_{min,j} + rand(0,1)(x_{max,j} - x_{min,j}) \quad (6)$$

Where i= 1,2…,SN, j= 1,2,…,D, D: is the number of optimized parameters, rand (0,1): is the real number having an interval [0,1], x_{max} represents the upper bounds of $x_{i,j}$, and x_{min} is the lower bounds of $x_{i,j}$. After that, the new solution which is denoted by vi(vi,1,vi,2,…,vi,D) is produced, and an updated solution has been evaluated by the equation (7) as [17]:

$$v_{i,} = x_{i,j} + \varphi_{i,j} \, (x_{i,j} - x_{i,k} \quad (7)$$

Where k ϵ [1, 2…,SN] , j ϵ [1, 2…..D] and is the real random number having an interval within [−1, 1]. Each employed bee is applied the greedy method between the nectar amount of (xi,j) and the nectar amount of (vi,j). If the nectar amount of (vi,j) is better than of (xi,j), (xi,j) is changed by (vi,j) and vi,j becomes the new population number. Otherwise, (xi,j) has been retained and the counter (i) increases by one. If the employed bees are unable to enhance self- solution within number of trails which is called "Limit", the solution is reinitialized by using Eq. (6) and the employed bees are became a scout bees.

3. Improvement Artificial Bee Colony (IABC) Optimization

In the standard ABC optimization, if the nectar amount cannot be enhanced by the employed bees within a number of trials "Limit", these bees have been became scout bees and their positions have been abandonment and they search for a new position randomly. In this paper, a separate counter of the failure at each solution has been adopted and a new equation for the limit variation at each iteration is applied instead of utilizing a constant limit value in each iteration. In the starting of the calculations, a lower limit value that denoted by "an" is evaluated by Eq. (8) as below:

$$an = \frac{Limit\ value}{D} \quad (8)$$

Through each iteration, "an" is increased until it's reached to the maximum limit value which has been referred by "ax". The formula that has been adopted to represent "ax" is:

$$ax = \frac{MCN}{D} \quad (9)$$

The target limit equation can be expressed as below:

$$Target\ Limit = an + fix\ (ax - an)e^{\frac{\frac{t}{T}}{2.718}} \quad (10)$$

Where (t) is the current iteration and (T) is the total iterations. Now, Eq. (10) is minimized the mathematical evaluations by changing limit value at each iteration instead of depending on a constant limit value i.e., (such us limit =100) through each iteration and this development made the algorithm faster to reach the required solutions. Another adopted modification is applied in this work to the new position equation i.e., (Eq.7) to improve the balancing process between the explorations well as exploitation processes. The parameter $\varphi_{i,}$ that is found in Eq. (7) is responsible for selecting the food source direction i.e., (either to left or right of the current food source (for x-axis) and either up or down to the current food source (for y-axis)). So, a new equation for representing $\varphi_{i,}$ parameter has been designed and it written as:

$$\varphi_{i,j} = 0.7\ rand(-1,1) + 0.3\ e^{\frac{-fit_i D}{t}} \quad (11)$$

From Eq. (11) that is maintained above, it can note that the parameter ($\varphi_{i,j}$) is not completely a random value as in Eq.(7) and this matter has been achieved a good matching between the explorations well as exploitation processes.

4. New Modified Ultrasonic Sensor Design

Obstacle detection is considered to be an important issue in the path planning of the MR. In this paper, the obstacles are detected by using two new modified ultrasonic sensor. Each modified sensor contains single transmitter and two receivers, Figure (2) illustrates the modified ultrasonic sensor.

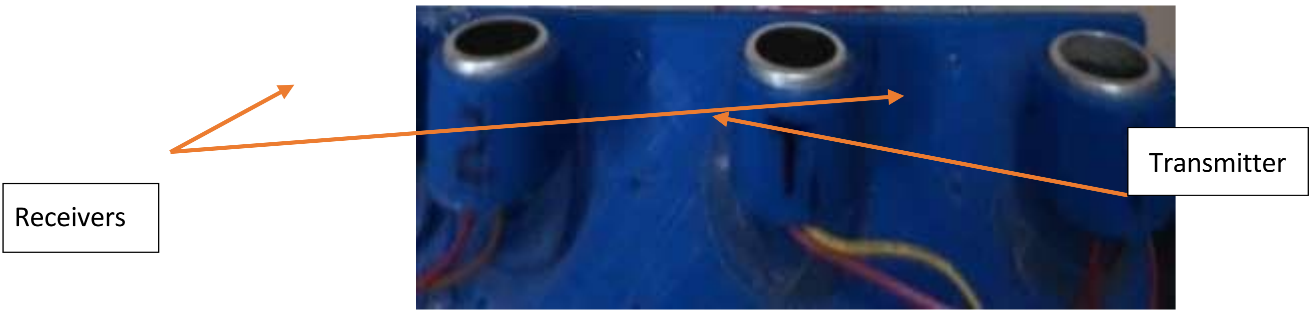

Figure (2). The modified sensor with single transmitter and two receivers

The two receivers (R_1 and R_2) are placed in equal distance from the transmitter (T_1). The main purpose of adding an additional receiver (R_2) is giving an extra sensing for the obstacles distance measurement. In this paper, two modified ultrasonic sensors are adopted and utilized to measure the obstacles distances from the robot, obstacles velocity, and the obstacles direction movements. These measurements (the obstacles distances from the robot, obstacles velocity, and the obstacles direction movements) cannot be obtained from a single traditional ultrasonic sensor (which is contained single transmitter single receiver) and this matter is considered to be the main reason that led to this development. The calculation of the distance (S_R) between the sensor and the obstacle has been expressed as:

$$S_{Ri} = \frac{v\ x\ t}{2} \tag{12}$$

Where i=1, 2, (v) is the sound velocity (340 m /s), and (t) represents the total time from the moment of transmitting wave until receives its. The time (t) in the Eq. (12) must be adjusted in terms of microseconds unit and it terms by (t_m) so, Eq. (12) has been written as:

$$S_{Ri} = \frac{340\ x\ t_m\ x\ 10^{-6}}{2} = \frac{17\ x\ t_m}{10^3} = \frac{t_m}{58.8} \tag{13}$$

5. Experimental Setup of the Robot

The actual four mecanum wheeled mobile robot is displayed in Fig.3. Each wheel has a nine passive rollers with ±45° and it has been actuated by geared DC-motor with encoder. Five primary electronics parts which are: control unit, actuators, sensors, communication part, and the power supply have been used in this work. Arduino AT mega microcontroller and two L298N (Hbridge) are utilized as the control unit. The type of actuators that are used in this work are four geared DC-motors with encoders. Four encoders and two modified ultrasonic sensors are represented the sensors that have adopted and utilized in this paper. ESP 8266 Wi-Fi module is used in this paper as a communication part between the Arduino AT mega and PC (MATLAB software). The data send and received by this Wi-Fi module. Four NC 18650B batteries have been used as a power supply unit and Fig.4 illustrates the connection between the electronics parts.

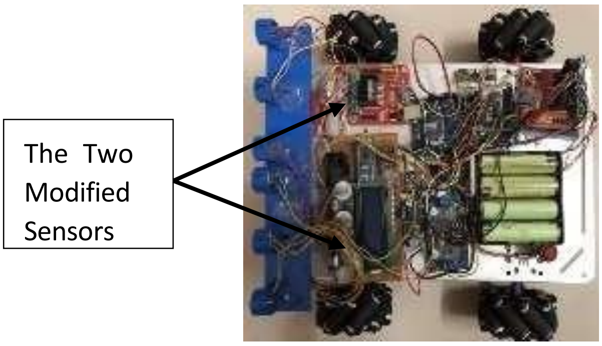

Figure. 3 The actual robot setup

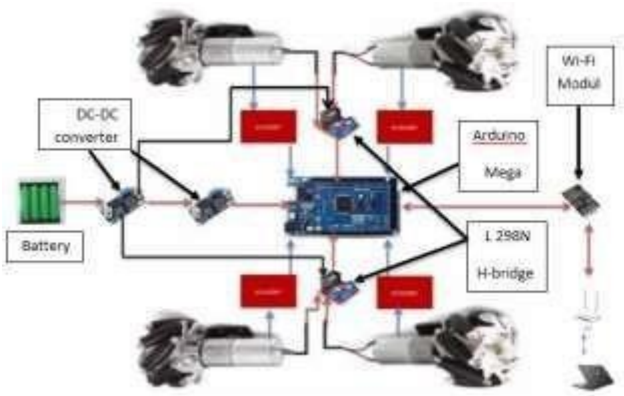

Figure. 4 The connection of the robot electronics components

6. Results and Discussions

This section includes the simulation and the experimental results of the local static obstacles avoidance. The area of the working environment is 300 x 300 cm^2. The number of the bees populations are 50, MCN is 100, and the number of iterations are 50. The starting point position is (0,0), while the target point position is (300,300) cm. The velocity of the MR is 10 (m/s).

6.1 Simulation Results of the Static Environment

MATLAB-GUI 2019b software has been used to implement the theoretical approach of the avoidance algorithm. The working environment contains four static circular obstacles with circular shapes and the position as well as the radius of each obstacle is tabulated in Table. 1 as below. Table. 1 Static obstacles parameters

Obs. Number	Radius (cm)	Position (x, y) cm
1	13	75,75
2	10	0,100
3	10	50,150
4	8	50,150

The best paths that are achieved by ABC and MABC optimizations are displayed in Fig. 5(A) and (B).

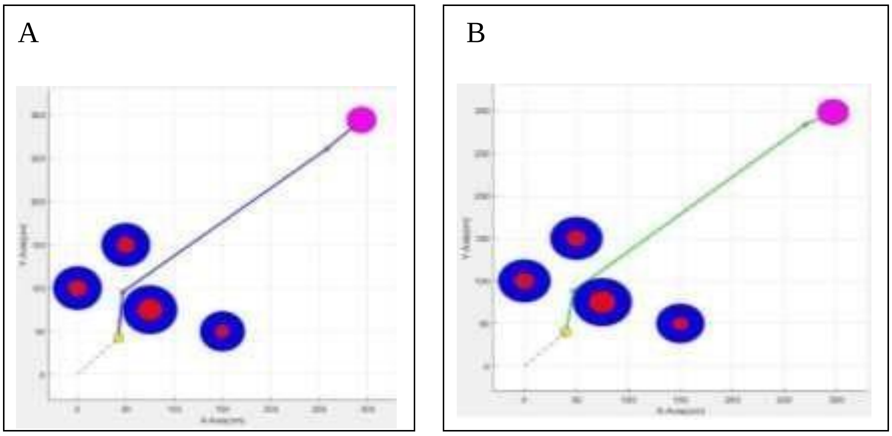

Figure. 5 Paths traveled by the MR (A) by using ABC, (B) by using MABC

It is clear from the above figure that the alternative paths that have been generated from the ABC optimization is marked within green color and the path that generated from the MABC optimization is marked with blue color. The alternative paths are straight lines so, the robot is accomplished the avoidance process with an omni-directional movements. The MR begins it's movement from point (0,0) towards the target point (300,300). The results of the two adopted algorithms are tabulated in Table. 2.

Table. 2 The simulation results that obtained from ABC and MABC optimizations

Avoidance Optimization	**Covered Path Length from SP to TP (cm)**	**Computation time (s)**	**Location of via points (cm)**
ABC (Fig. 5(A))	516.1542	25.9899	P1(48,82) P2(264,280)
MABC (Fig. 5(B))	485.3251	21.3521	P1(49,95) P2(261,258)

It is clear from Table. 2 that the path length that generated from MABC optimization is shorter by about 6% and faster by about 16%. I t can be concluded that the performance of MABC optimization is better than of ABC optimization because of the developments that are adopted in this work.

6.2 Experimental Results of the Static Environment

To validate the simulation results that obtained from MABC optimization, an experimental test in the case of static obstacles avoidance based on MABC optimization has been applied. In this work, the robot does not known the positions and the size of the obstacles therefor, the avoidance is accomplished depending on the two modified sensors data. It has been used four cylindrical boxes as stationary obstacles. The position and the radius of each obstacle are chosen similar to these parameters in the case of the simulation results. The images of the actual path followed by the MR during avoiding the static obstacles are depicted in Fig. 6.

Figure. 6 The actual path followed by the robot while avoiding static obstacles

The avoidance process is achieved by interfacing between Arduino microcontroller and MATLAB / GUI software through Wi-Fi module. The MR begins it's movement from point (0,0) to point (300,300) and the command of beginning this movement has been sent from MATLAB/GUI to Arduino microcontroller by Wi-Fi module and this matter represented in Fig. 6(A). The information about the distances between the obstacles and the robot are extracted from the modified sensors and sent from the Arduino to the MATLAB software. The decision to initiate the avoidance algorithm is done by MATLAB software. If the distance between the obstacle and the robot is less than 30 (cm) as shown in Fig 6(B), the MATLAB initiates the avoidance algorithms and sends the information to the robot/Arduino to leave the original path and followed the alternative paths as displayed in Fig. 6(C). The information that are sent from MATLAB to the robot/Arduino include the via-points locations as well as the robot speed during the alternative paths. The process of sending and receiving the data between the MATLAB software and Arduino is continued until the MR reaches the target point safely as iliustrated in Fig 6 (D) and 6 (E). The actual performance results of the MABC are tabulated in Table 3.

Table. 3 The actual avoidance performance results

Avoidance algorithm	**Covered distance (cm)**	**Computation time (s)**	**Via-points location (cm)**
MABC	490.01251	23.75141	P1(49,95) P2(261,258)

6.3 Comparison

Finally, our adopted avoidance method (MABC) is compared with the first case study of the work [8]. The type of the avoidance method that was used in [8] is particle swarm optimization (PSO) with modified frequency (MFB) optimization i.e., (PSO-MFB). The area of the working environment that was adopted in [8] is 10 x 10 m^2. In this comparison, the environment of work [8] is scaled to 100 x 100 cm^2 by multiplying the results of work [8] by a factor equals to 10 to obtained a good comparison between MABC optimization and PSO-MFB optimization. It has been utilized the same number of the static obstacle which are equal to five obstacles with the same positions as well as same radius. The traveling path that generated from MABC optimization and followed by the MR depicts in Fig. 7.

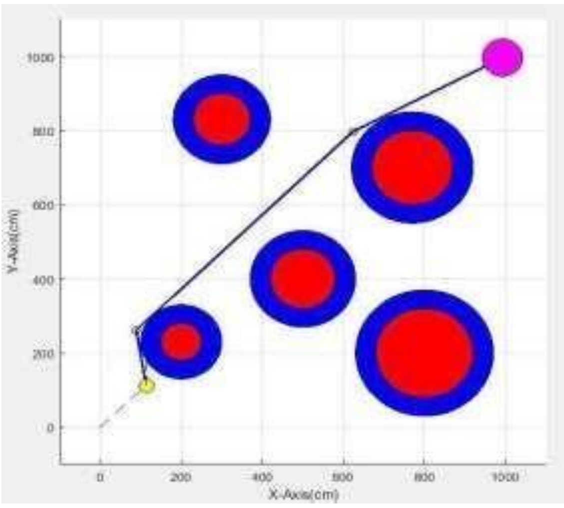

Figure. 7 Traveling path by the MR by using MABC optimization based on the environment of the work [8] The comparison results between MABC optimization and PSO-MFB optimization are listed in Tab. 4.

Table. 4 comparison results between MABC and PSO-MFB optimizations

Optimization Technique	Path Length (cm)	Time (min)
MABC	**1464.26**	**2.6666**
PSO-MFB	1477.85	3.48

It can conclude from the above comparison results, MABC that is adopted in this work generated path shorter by 5% and faster by about 6% and this giving an indication that the performance of the adopted MABC optimization outperforms the performance of PSO-MFB.

7. Conclusions

This work presents and solved the local path planning problem of a four mecanum wheeled mobile robot in a static environment with experimental implementation. The obstacles that are found in the environment are detected by using two new modified ultrasonic sensors. Each modified sensor contains single transmitter and two receivers and this matter makes to obtain synchronized measurements reading as well as reduce the number of the sensors that used to detect the obstacles. The avoidance algorithm that used in this paper is the modified artificial bee colony (MABC) optimization. Two modifications based on the standard ABC optimization are presented and described. The first modification makes the number of the limits change with each iteration instead of choose a fixed value, while the second modification enhance the balance between the explorations well as exploitation processes. The performance of the adopted MABC optimization is compared with the performance of standard ABC optimization and the simulation results are proved that the path that generated from MABC optimization is shorter by about 6% and faster by about 16%. Also, a comparison is made between MABC optimization and an algorithm technique used PSO-MFB optimization. The comparison results show the robustness of MABC optimization in solving the local path planning.

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