Real Time Navigation Approach for Mobile Robot

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Manuscript submitted October 30, 2015; accepted December 29, 2015.
doi: 10.17706/jcp.12.2.135-142

Abstract: Real time navigation is still challenge in mobile robotics. The challenge interacts with decision and optimization of obstacle avoidance and path distance respectively, when robot moves from initial position to target position in complex crowded environment. This paper develops the efficient navigational controller by using modified Firefly Algorithm (FA) which is studied over Normal Probability Distribution (NPD). It fulfills not only the said challenges but also minimizes the computational calculation and random moving of fireflies as additional advantage. The effectiveness of proposed controller has been compared with other navigational controller in terms of path optimality and it has been found that the proposed controller perform better.

Key words: Mobile robot navigation, firefly algorithm, path planning, normal probability distribution.

1. Introduction

Path planning is the most important task of mobile robot navigation when environment is uncertain and unpredictable. Many researchers provided the global and local path planning technique for effective navigation. The global path planning technique is used when the environment is known. The main disadvantage of global path planning is inability to adjust with the uncertainty. To handle the uncertainty present in the environment, the local path planning approaches like Fuzzy logic [1], Genetic Algorithm [2], Neural Network [3], Ant Colony Algorithm [4], Particle Swarm Optimization [5], Simulated Annealing [6], Cuckoo Search Algorithm [7] and many more is used for mobile robot navigation problem.

The present paper focuses the application of Firefly Algorithm [8] for the local path planning in presence of variety of static obstacle in complex crowded uncertain environment. In the year 2008, Yang presented the nature based metaheuristic algorithm inspired by flashing behavior of fireflies. Firefly Algorithm is new artificial intelligence approach is popularly used in the field of optimization and autonomous system. Here, a successful effort has been made in the field of mobile robot navigation by using Firefly Algorithm over the Normal Probability Distribution for path planning and optimization. The firefly algorithm is evolutionary technique which has ability to self-plan self-adaptation and self-organize. The characteristic like robustness and high convergence rate make it suitable to adopt the changing and undesirable condition of complex system. The ability to get better position over its initial position minimizes the number of iteration and make easier to get optimal path in minimum time. Due to its efficient features, now days it is widely accepted for solving the problem of fault detection in robot [9], economic emission dispatched problem [10], reliability-redundancy optimization [11], mixed variable structural optimization problem [12], cooperative networking problem [13], dynamic environment problem [14], combinatorial optimization problem [15], learning from demonstration problem [16]. To improve the effectiveness of the firefly algorithm some researcher used the Gaussian distribution function to increase the convergence speed [17] and some researcher modified the firefly algorithm to avoid random moving of the firefly algorithm when there is no brighter firefly [18]. Firefly algorithm is very efficient due to their ability of search for optimal solution which is required to solve science and engineering problem.

2. Basic Firefly Algorithm Structure

Bioluminescence is the process by which firefly emits the light and which work as signal system to attract other fireflies. The attraction of both male and female firefly is totally depends on the rhythm of flash light, rate of flashing of light and amount of time for which the flash of light is observed. The flashing light of fireflies is used as the objective function which is to be optimized and used to formulate new optimization algorithm. The attraction of one firefly towards the other is possible when the other is having the higher light intensity and this is the basic concept of working of firefly algorithm. The three basic rules of FA

1) All fireflies are unisex and are attracted to each other regardless of their sex.
2) The degree of attractiveness of a firefly is proportional to its brightness and thus for any two flashing fireflies, the one that is less bright will move towards to the brighter one. The distance between two fireflies will be less for the more brightness. The random move means equal brightness of the flashing fireflies.
3) The objective function is generated for evaluating the brightness of fireflies.

Let, β = Attractiveness of firefly, β_0 = Attractiveness of firefly at *r = 0*, γ = Coefficient of light absorption, x_i = Position of first firefly, x_j = Position of second firefly, *i* = first firefly, *j* = second firefly, x_i^k = current value of i^{th} firefly at k^{th} dimension, r_{ij} = distance between x_i and x_j, *d* = dimension, *t* = iteration, *r* = random number, α = randomization parameter.

Then,

Attractiveness of the fireflies is given by, $\beta(r) = \beta_0 \exp(-\gamma r^m); m \geq 1$

Distance between two fireflies is, $r_{ij} = \left\| x_i - x_j \right\| = \sqrt{\sum_{k=1}^{d} (x_i^k - x_j^k)^2}$

Movement of one firefly towards the brighter is, $x_i^k(t+1) = x_i^k(t) + \beta_0 \exp(-\gamma r_{ij}{}^2)((x_j^k(t) - x_i^k(t)) + \alpha(r - \frac{1}{2})$

3. Application of Firefly Algorithm for Mobile Robot Navigation

To know the environment, to localize position and to plan towards goal by avoiding obstacle is the main task of mobile robot. The sensor present in the robot makes robot easy to localize its position in environment and to detect the obstacle. The task of generation of optimal path is accomplished by using FA over normal probability distribution in complex crowded environment. If firefly refers as the population then its theoretical interpretation can be studied under Normal Probability Distribution. A probabilistic model is generated here for incorporating the general behavior of fireflies. The arithmetic mean, variance etc. are such statistical tools which are used as the empirical data for representing the decision of firefly's movements. This experiment is performed in the random environment and its outcomes are governed by continuous probability of the chance mechanism and the sample space. Here the firefly assigned with the random variable first then its random movement is defined over the range of possible values second and its frequency is Normal Probability Distribution finally. It's applying for the fireflies as the corresponding random variable continuously in following section.

3.1. Objective Function Formulation

This section generates the objective function for obstacle avoidance and optimal path generation in presence of n obstacles. Following are the FA based analysis for calculation of distance, attraction and movement between the robot and Goal.

Let, Arithmetic mean of attraction,

$$\overline{\beta(r)} = \frac{\int_{-\infty}^{\infty} r\beta(r)dr}{\int_{-\infty}^{\infty} \beta(r)dr}$$

Standard deviation of attractiveness,

$$\sigma_{\beta(r)} = \sqrt{\int_{-\infty}^{\infty} (r-\bar{x})^2 \beta(r)dr}$$

Then, Attraction over NPD,

$$N(\overline{\beta(r)}, \sigma_{\beta(r)}) = f(\beta(r)) = \gamma(\beta(r)) = \frac{1}{\sigma_{\beta(r)}\sqrt{2\pi}} \exp\left(\frac{-\frac{1}{2}(\beta(r)-\overline{\beta(r)})^2}{\sigma_{\beta(r)}}\right)$$

Let, Arithmetic mean of distance,

$$\overline{r_{ij}} = \frac{\int_{-\infty}^{\infty} r r_{ij} dr}{\int_{-\infty}^{\infty} r_{ij} dr}$$

Standard deviation of attraction,

$$\sigma_{r_{ij}} = \sqrt{\int_{-\infty}^{\infty} (r-\bar{r})^2 r_{ij} dr}$$

Then, Distance over NPD,

$$N(\overline{r_{ij}}, \sigma_{r_{ij}}) = f(r_{ij}) = \gamma(r_{ij}) = \frac{1}{\sigma_{r_{ij}}\sqrt{2\pi}} \exp\left(\frac{-\frac{1}{2}(r_{ij}-\overline{r_{ij}})^2}{\sigma_{r_{ij}}}\right)$$

Let, Arithmetic mean of movement,

$$\overline{x_i^k(t+1)} = \frac{\int_{-\infty}^{\infty} (t+1)x_i^k(t+1)dt}{\int_{-\infty}^{\infty} x_i^k(t+1)dt}$$

Standard deviation of movement,

$$\sigma_{x_i^k(t+1)} = \sqrt{\int_{-\infty}^{\infty} ((t+1)-\overline{(t+1)})^2 x_i^k(t+1)dt}$$

Then, Movement over NPD,

$$N(\overline{x_i^k(t+1)dt}, \sigma_{x_i^k(t+1)dt}) = f(x_i^k(t+1)dt) = \gamma(x_i^k(t+1)dt) = \frac{1}{\sigma_{x_i^k(t+1)}\sqrt{2\pi}} \exp\left(\frac{-\frac{1}{2}(x_i^k(t+1)-\overline{x_i^k(t+1)})^2}{\sigma_{x_i^k(t+1)}}\right)$$

It is already mentioned that the occurrence and chance in firefly's behavior is incorporated for using the

Normal Probability Distribution. There are the three fundamental reasons of selecting NPD for generating the proposed firefly algorithm. These are the followings:

1) The discrete probability distribution, i.e. Binomial, Poisson, and Hyper geometric can be approximated.
2) Large samples transformed into small.
3) Statistical Controller can be formed.

Firefly's behavior is studied over these characteristics corresponding to the first, second and third as uniform movement, efficient decision and error corrections respectively. Mobile robot is a logical decisional device hence it is easy to formulate and program the robotics dimension. Robot Collect the primary data of the observation and form the hypothesis which helps to generalization.

Let, R= Robot, G = Goal, x_R = Initial position of robot, x_G = Position of goal, r_{RG} = Distance between x_R and x_G. x_i^k = Current value of robot at K^{th} dimension.

$x_i^k(t+1)$ = Movement,

$N(\overline{\beta(r)}, \sigma_{\beta(r)})$ = NPD of attractiveness,

$N(\overline{r_{RG}}, \sigma_{r_{RG}})$ = NPD of distance,

$N(\overline{x_R^k(t+1)}, \sigma_{x_R^k(t+1)})$ = NPD of distance movements.

Constraints, if there is any obstacle

i.e. $r_{RG} \neq 0$

3.2. Algorithm

1) Robot starts.
2) By $N(\overline{\beta(r)}, \sigma_{\beta(r)})$, Robots traces the goal.
3) By, $N(\overline{r_{RG}}, \sigma_{r_{RG}})$, either, there is no obstacle.

Then,

By $N(\overline{x_R^k(t+1)}, \sigma_{x_R^k(t+1)})$, Robot moves towards the goal until $r_{RG} = 0$

Or, there is any obstacle, i.e. $r_{RG} \neq 0$

Then

a) Compute $Z_i = \dfrac{x_i - \overline{x_n}}{\sigma_n}$

b) Compute area under the normal curve from 0 to Z_i.

c) Compute normal probability distribution

$N(\overline{x}, \sigma) = f(x) = y(x) = \dfrac{1}{\sigma\sqrt{2\pi}} \exp\left(\dfrac{-\frac{1}{2}(x-\overline{x})^2}{\sigma^2}\right)$ 3.4. Compute expected frequency by,

Total frequency = Probability of Step 3.3

Set the normal probability distribution curve.

4) By, $N(\overline{\beta(r)}, \sigma_{\beta(r)})$, $N(\overline{r_{RG}}, \sigma_{r_{RG}})$, $N(\overline{x_R^k(t+1)}, \sigma_{x_R^k(t+1)})$

Robot moves towards the goal through following the NPD curve until $r_{RG} = 0$.

5) Robot stops.

4. Experimental Validation and Simulation Result

To prove the effectiveness of proposed FA based controller, various real time test has been performed on the Khepera robot in presence of variety of obstacle. The proposed FA based controller activates when robot detects the obstacle present in the path of the robot otherwise robot finds the goal directly. The fig. 1 gives the step by step generation of path from robots initial position to final position. Fig. 1(a) shows the initial position of the robot in the environment from which motion towards goal starts. The Fig. 1 (b), (c), (d), and (e) shows the how effectively robots detect and avoids obstacle by activating the FA mechanism. The robot is programmed by using C++ for path planning in real time environment.

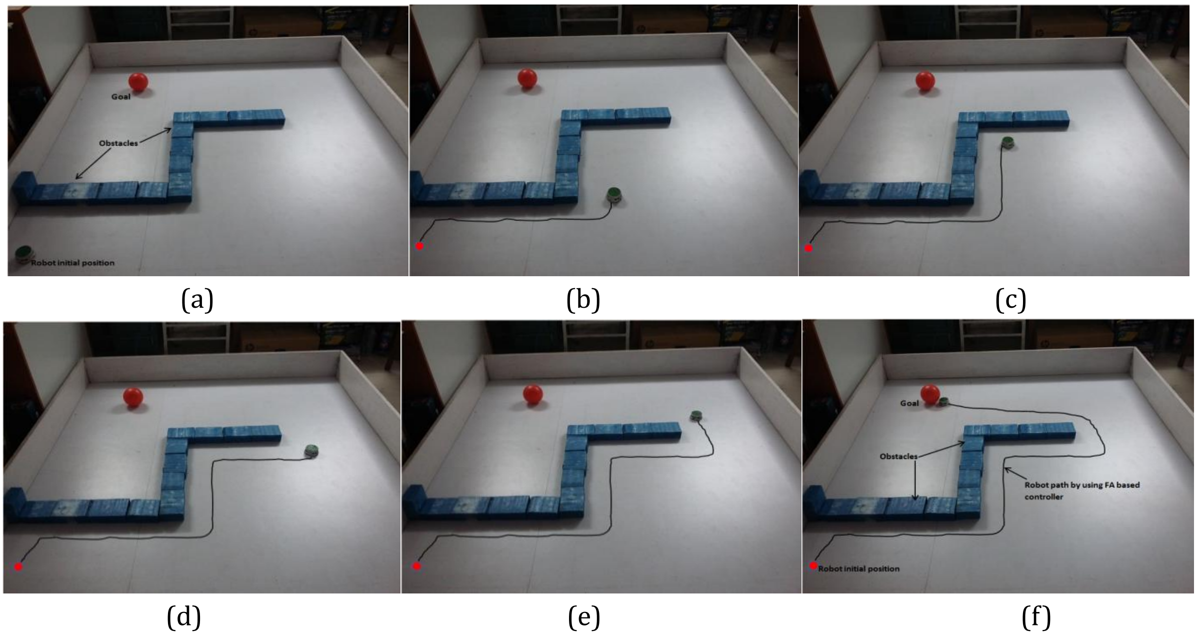


Fig. 1. Real time navigation of mobile robot using FA based controller.

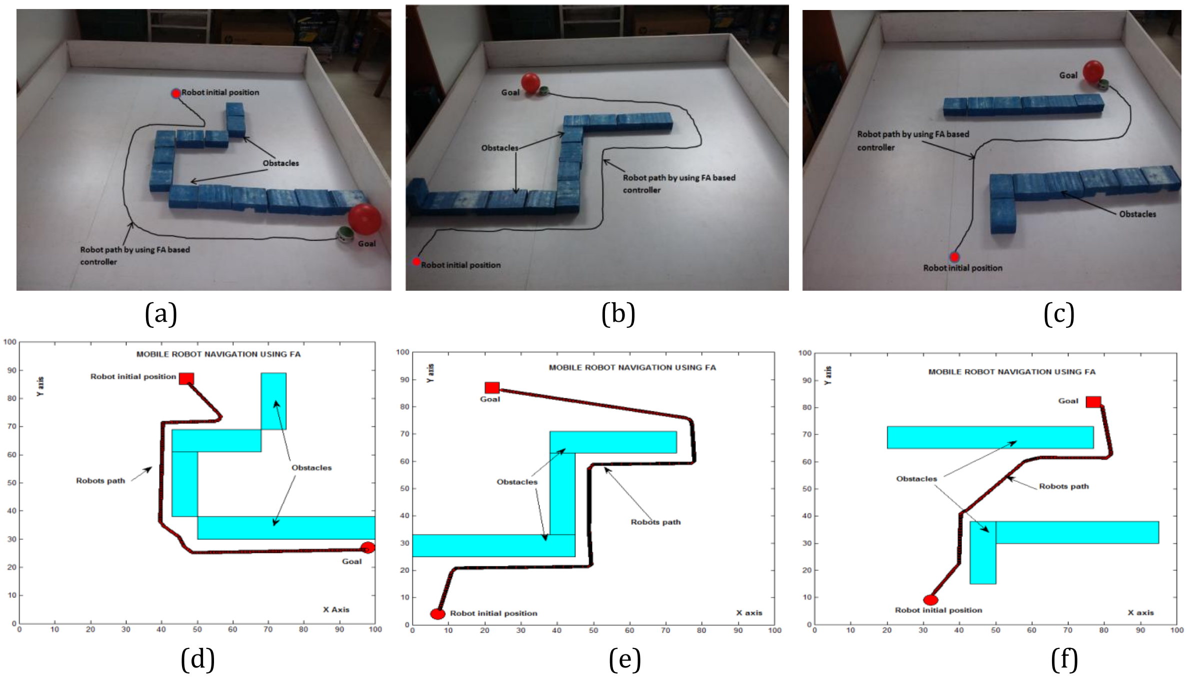


Fig. 2. Comparision of experimenatal & simulation environment.

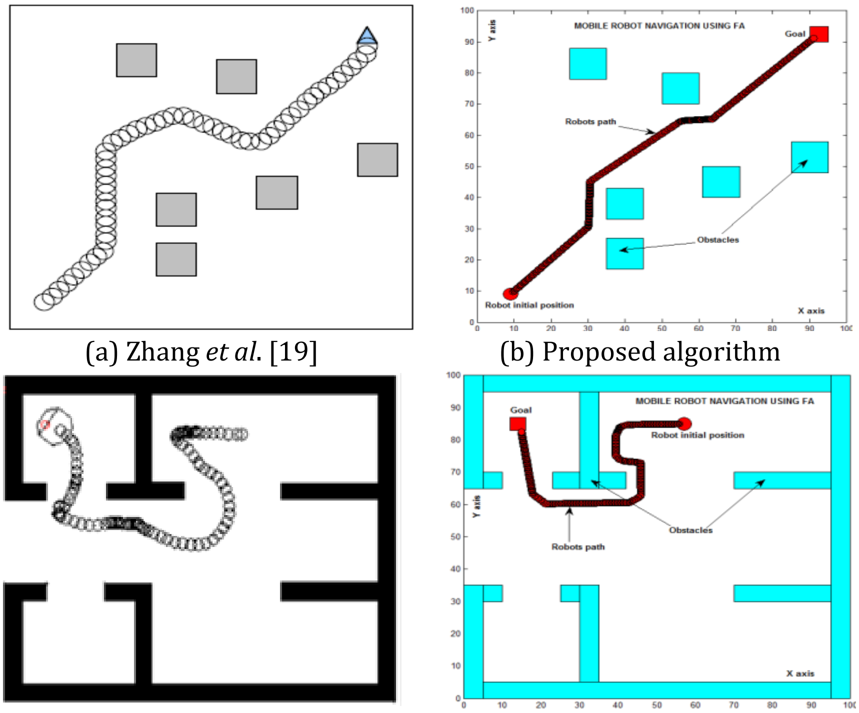
The simultaneous comparision of experimental path and simulation path has been analyzed on the basis of path length and time. It has been noticed that the simulation path is optimal and time requires for navigation is short as compared to experimental path. The following Table 1 and Table 2) compares the simulation path and experimental path on the basis of time and path length. Matlab R2008 has been used for the simulation purpose. The analysis of different environment in presence of variety of obstacle is shown in Fig. 2.

Table 1. Path Length Covered by Robot in Experiment and Simulation to Reach Target

Sl. No.	Path length in simulation (in 'cm')	Path length in real-time experiment (in 'cm')	% of error
Scenario-1	254 (Fig. 2(d))	267 (Fig. 2(a))	4.86
Scenario-2	322 (Fig. 2(e))	335 (Fig. 2(b))	3.88
Scenario-3	179 (Fig. 2(f))	190 (Fig. 2(c))	5.78

Table 2. Time Taken by the Robot in Simulation and Experiment to Reach Target

Sl. No.	Time taken by the robot in simulation (in 'sec')	Time taken by the robot in real-time experiment (in 'sec')	% of error
Scenario-1	13.7 (Fig. 2(d))	14.35 (Fig. 2(a))	4.52
Scenario-2	17.1 (Fig. 2(e))	18.69 (Fig. 2(b))	5.84
Scenario-3	9.95 (Fig. 2(f))	10.40 (Fig. 2(c))	4.32



(a) Zhang *et al.* [19] (b) Proposed algorithm

(c) *Wang et al.* [20] (d) Proposed algorithm

Fig. 3. Comparison of proposed controller with other approaches.

Comparison with other Artificial Intelligence Approaches

To prove the effectiveness of proposed controller, the comparative simulation analysis is presented with the other artificial controller. The Fig. 3(a) & 3(c) is other navigational approaches provided by Zhang and Wang respectively is compared here with the proposed controller shown in Fig. 3(b) & 3(d). The similar environment is produced for comparision by using Matlab R2008.

The data reflects that the proposed controller performs better than the existed navigational controller under the context of path optimality as shown in Table 3. Maximum path length saved by proposed contoller is upto 20%. The path shown in Fig. 3(b) and 3(d) is very close to boundaries of obstacle hence the proposed controller can be successfully use for robot navigation for complex crowded environment in presence of static obstacle. The FA approach saves path length and achieves the target within time limit.

Table 3. Comparision of Simulation Result in Terms of Path Length

Sl. No.	Path length covered by the robot in simulation (in 'cm') by proposed algorithm	Path length covered by the robot in experiment (in 'cm') by other AI technique	% of path length saved by proposed algorithm
Scenario-1	4.2 (Fig. 3 (b))	4.9 (Fig. 3(a))	14.28
Scenario-2	3.5 (Fig. 3 (d))	4.4 (Fig. 3(c))	20

5. Conclusion

The approach of efficient navigation has been developed using Firefly Algorithm. The proposed FA controller uses the Normal Probability Distribution to generate optimal path and to minimize the time of navigation. The NPD minimizes computational calculation by avoiding randomness of fireflies and iteration. The result given by proposed controller is effective when robot deals with the unknown environment. The simultaneous comparison with other artificial intelligence approach reflects the proposed controller outperforms in terms of optimal path and quality of solution. In future, the work may be extended for robot navigation in complex environment in the presence of dynamic obstacle.

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