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Accuracy and Convergence Analysis of uFA-FastSLAM for Robot and Landmarks Position Estimation

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Abstract. In autonomous mobile robots, Simultaneous Localization and Mapping (SLAM) is a demanding and vital topic. One of two primary solutions of SLAM problem is FastSLAM. In terms of accuracy and convergence, FastSLAM is known to degenerate over time. Previous work has hybridized FastSLAM with a modified Firefly Algorithm (FA), called unranked Firefly Algorithm (uFA), to optimize the accuracy and convergence of the robot and landmarks position estimation. However, it has not shown the performance of the accuracy and convergence. Therefore, this work is done to present both mentioned performances of FastSLAM and uFA-FastSLAM to see which one is better. The result of the experiment shows that uFA-FastSLAM has successfully improved the accuracy (in other words, reduced estimation error) and the convergence consistency of FastSLAM. The proposed uFA-FastSLAM is superior compared to conventional FastSLAM in estimation of landmarks position and robot position with 3.30 percent and 7.83 percent in terms of accuracy model respectively. Furthermore, the proposed uFA-FastSLAM also exhibits better performances compared to FastSLAM in terms of convergence consistency by 93.49 percent and 94.20 percent for estimation of landmarks position and robot position respectively.

1. Introduction

In autonomous mobile robots, Simultaneous Localization and Mapping (SLAM) is a demanding and vital topic. And in SLAM, state estimation is the problem, namely estimating the robot and landmarks position. The robot estimates the detected landmarks and its own position simultaneously. This enables an autonomous mobile robot to explore an unknown environment and build a map of the environment incrementally while simultaneously uses the map to estimate its own position [1].

SLAM problem has two primary solutions, one of them is FastSLAM where particle filter is used to estimate the robot position and EKF is used to estimate the landmarks position [2]. However, optimistic estimation of uncertainty are produced by FastSLAM in long-term [3], generating inconsistent estimation [2]. Therefore, a modified Firefly Algorithm (FA), namely unranked Firefly Algorithm (uFA) is used by Musridho et al. [4] to improve the performance of FastSLAM in terms of accuracy and convergence consistency, they named it uFA-FastSLAM.



In this work, original FastSLAM algorithm and uFA-FastSLAM algorithm are being analysed and compared in terms of the accuracy and convergence of robot and landmarks position estimation. Convergence analysis is detailed examination of the rate of convergence, where things tend to become together or meet at the same point. Two of three goals stated by Treichler [5] about why convergence analysis needs to be done are to prove that the convergence exists and to evaluate properties of convergence, such as value of convergence.

2. The uFA-FastSLAM

In previous work, a modified FA which is called unranked Firefly Algorithm (uFA) has been used to optimize FastSLAM [4]. The elimination of a process that ranks the fireflies based on their light intensity in FA developed by Yang [6] is indispensable. The reason is because it caused the values (light intensity) of the fireflies sent to different particles. While the input of FA, i.e. weight of particles in FastSLAM for light intensity of fireflies, have to be in the same order when they are being sent back to FastSLAM. The uFA is added into FastSLAM before the resampling phase to optimize the robot and landmarks position estimation.

3. Experimental Settings

MATLAB is used as the platform of this research, toolbox of FastSLAM which included the map of the environment is provided by Bailey [7]. It is selected because many works [2,3,8,9] have used the same environment map. In this map, uFA-FastSLAM by Musridho et al. [4] is compared with original FastSLAM by Montemerlo et al. [10] in terms of accuracy and convergence of robot and landmarks position estimation.

To avoid biased algorithm comparison, this research use the same parameters setting used by Musridho et al. [4]. The parameters are number of simulations, robot's velocity, robot's wheelbase size, control signal time interval, observations time interval, number of particles, number of loops, max generation and population of fireflies, the values are 50 runs, 3 m/s, 4:2 meter, 0.05 second, 0.2 second, 100 particles, 1 loop, 100 times and 100 fireflies.

4. Discussion of Accuracy and Convergence Analysis

The evaluation done by calculating the error of each result of the compared algorithms, namely FastSLAM and uFA-FastSLAM by using root mean square error (RMSE). There are two performance measurements, they are the robot position estimation error and landmarks position estimation error. This evaluation focuses only on the performance of the algorithms in the mentioned performance measurements and will not discuss about the computational complexity (time consumption).

The time step depends on the defined time interval and velocity of the robot, smaller time interval or lower velocity creates more time steps for the same environment map. It happens because the robot records every measurement in each time interval and lower velocity made the robot takes longer time to reach the last waypoint. The recorded measurements are then being calculated using RMSE. The analysis of the results are shown from Figure 1 until Figure 4.

The difference between the estimation results of FastSLAM and uFA-FastSLAM can be seen clearly in figure 1. Estimations done by uFA-FastSLAM remained in a line, which means that they are converged. Meanwhile the estimations done by FastSLAM are diverged as it moves further. This shows that the uFA-FastSLAM has successfully kept the estimation to converge every time landmarks are detected.

In terms of the error rate of the estimation, results of uFA-FastSLAM are better than the results of FastSLAM. The result from 50 simulations run can be seen in Figure 2. It was obtained by using RMSE for each run.

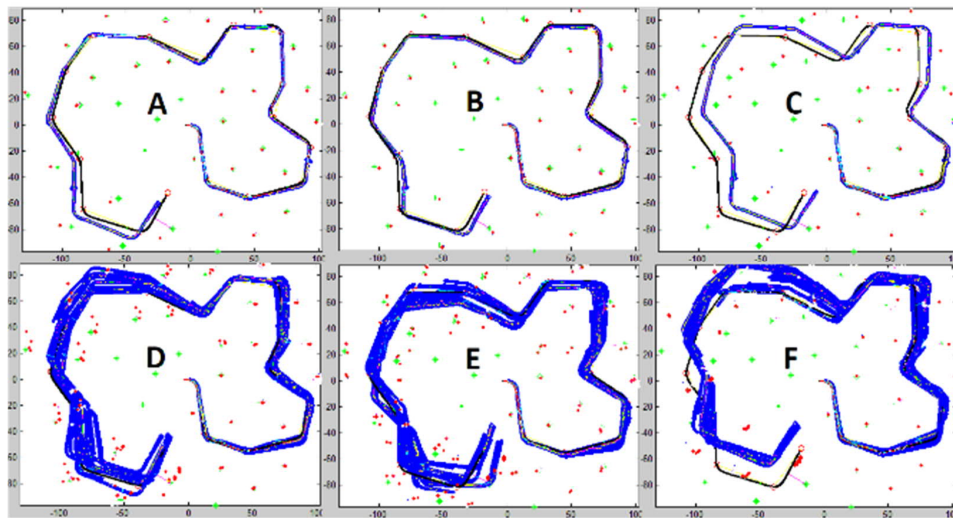


Figure 1. Results of Robot and Landmarks Position Estimation from Three Different Runs each for uFA-FastSLAM (A,B,C) and FastSLAM (D,E,F).

Comparison of the Average of Error can be seen in Table 1. The result is obtained through average of sum of each error, smaller value means higher accuracy.

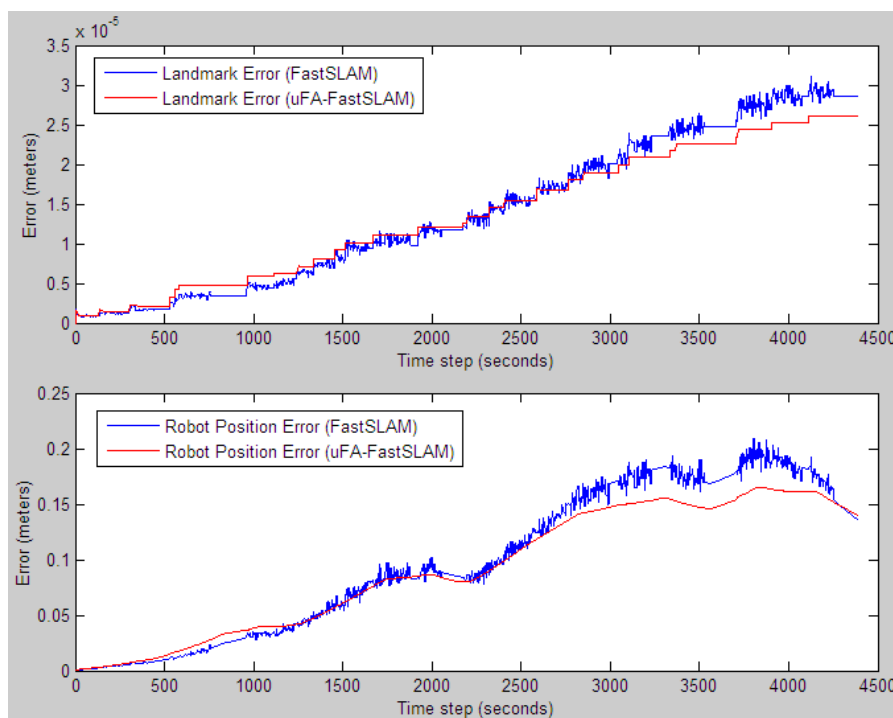


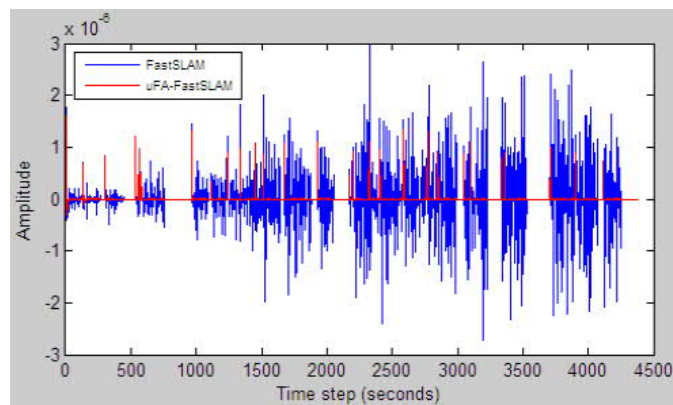
Figure 2. Comparison of Error Average from 50 Simulations Run between FastSLAM and uFA-FastSLAM: Landmarks Position Estimation (Top); Robot Position Estimation (Bottom).

Table 1. Average of Error.

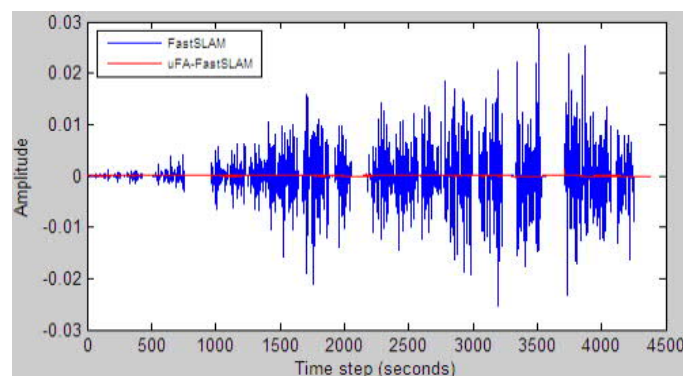
| Algorithm | Landmarks Position Error | Robot Position Error |
|--------------|--------------------------|----------------------|
| FastSLAM | 1.4149^{-05} | 9.96^{-02} |
| uFA-FastSLAM | 1.3682^{-05} | 9.18^{-02} |

To analyse the convergence of robot and landmarks position estimation, a MATLAB code named Amplitude Counter is created to count the fluctuations of estimation error per time step. The results can be seen in Figure 3 and Figure 4. The code yields a result of waveform-like graph.

As seen in figure 3, the error of landmarks position estimation of FastSLAM fluctuates significantly. The error keeps on changing, creating high ups and downs value. Meanwhile the error of landmarks position estimation of uFA-FastSLAM fluctuates only at some parts of the whole time step and almost not changing at most of the time steps.

**Figure 3.** Convergence Analysis using Amplitude Counter for Landmarks Position Estimation Error.

And convergence of robot position estimation is shown in figure 4. The difference between the waveform formed by the result of estimation error of FastSLAM and uFA-FastSLAM is clearly significant. The convergence of uFA-FastSLAM consistently remained in small amplitude the whole time step, far less compared to the amplitude of robot position estimation error of FastSLAM.

**Figure 4.** Convergence Analysis using Amplitude Counter for Robot Position Estimation Error.

Comparison of Average of Convergence from both FastSLAM and uFA-FastSLAM can be seen in table 2. It is obtained through the average of absolute sum of Amplitude Counter value to get the positive value for each movement. Smaller value means more convergence is maintained. Based on this result, uFA-FastSLAM is proven to be better in maintaining the convergence of the estimation.

Table 2. Average of Convergence.

| Algorithm | Landmarks Position Error | Robot Position Error |
|--------------|--------------------------|----------------------|
| FastSLAM | 1.05^{-07} | 9.26^{-04} |
| uFA-FastSLAM | 6.84^{-09} | 5.37^{-05} |

5. Conclusion

This work presented the accuracy and convergence analysis of robot and landmarks position estimation of an original FastSLAM and optimized FastSLAM, namely uFA-FastSLAM. The experiment used a selected toolbox and an environment map with several parameters setup. Using RMSE, the error rate of the estimations are calculated to see the accuracy of both algorithms. In addition, to get the value of convergence, the obtained RMSE is calculated with an equation created for this research which then named Amplitude Counter, it yields waveform-like graph. Then the average value of the result is calculated, this is the value of convergence. The proposed uFA-FastSLAM is superior compared to conventional FastSLAM in estimation of landmarks position and robot position with 3.30 percent and 7.83 percent in terms of accuracy model respectively. Furthermore, the proposed uFA-FastSLAM also exhibits better performances compared to FastSLAM in terms of convergence consistency by 93.49 percent and 94.20 percent for estimation of landmarks position and robot position respectively.

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