Troubleshooting indoor localization systems in underground mines

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Abstract

The object localization problem in an underground mine is rather complex. The hard working conditions and the complexity of indoor mine space are the reasons of many errors in the localization system installation process. This paper provides an approach to detect the errors in the landmarks installation positions. This approach consists of 3 algorithms for different types of the installation errors. We aslo proposed the simulator of the localization system itself. It is based on the Unscented FastSLAM model. This simulator is used to simulate localization system with installation errors to test the errors detection algorithms. The proposed algorithms demonstrated high accuracy via the simulator.

1 Introduction

Indoor localization systems are used to estimate an object position when the global localization systems such as GPS are not available. An underground mine is such a place. The satellite signal does not pass over the rock thickness. Indoor localization systems in underground mine are based on map of the mine itself and interaction with the mine infrastructure elements (landmarks). The tracked object estimates distance to landmarks and sends the results to a server. The object also may be equipped with IMU (Inertial Measurement Unit) to get more information about its trajectory. All information is sent to the server to compute the object position.

Because of the hard working conditions and the complexity of the indoor mine space many installation errors occurred. It is very hard to prevent all of them on the installation stage or detect them manually in the working system. There is the need to develop an automated system that detects these errors during an exploitation. In this paper we provide an approach to detect the errors. Also we developed the simulator of the underground mine localization system with the installation errors to test our algorithms via it.

The localization system simulator is based on the Unscented FastSLAM algorithm [1]. We use the SLAM approach to update landmarks positions to detect contradictions between their estimated and theoretic (initially given) positions. The mine itself is represented by the directed weakly connected weighted graph where the edges correspond to straight areas (tunnels) in the mine and the vertices corresponds to connections between them. A similar model was already used in underground mine localization problems in the literature [2]. We need to use the unscented transformation because of the special properties of the distance function on this graph space. This function does not allow to compute the Jacobian in the classic FastSLAM algorithm and we avoid it with the unscented transformation.

The rest of the paper is organized as follows.

In the section 2 we proposed the graph-based model of underground mine and the Unscented FastSLAM algorithm applied on it. We also provided tests of the simulator to show that it simulates the localization system with installation errors quite accurately to test the errors detection algorithms on it.

In the section 3 we provided the description of different types of landmarks installation errors. It was found that there are 3 common types of such errors. We proposed 3 algorithms to detect each type of errors.

In the section 4 we proposed our experimental results. We tested the algorithms via the simulator. We generated some underground mine graphs and also used some graphs of the real underground mine. It was found that algorithms show high accuracy for each type of data and for each type of installation errors.

2 Underground mine simulation

Brief description of base simulation idea.

2.1 Graph-based model

Formal mathematical definition of the model: graph description, definition of distance function, definition of the object position on the graph edge. The graph edges correspond to the strict areas of underground mine such as tunnels. The vertices correspond to the connections between these areas. The object position is represented by the point on the graph edge – each edge has a weight (tunnel length) and the shift between 0 and the edge's weight determines the position on the edge.

2.2 Unscented FastSLAM approach

This section must present the UFastSLAM approach on the graph-based space and explain the reasons of the unscented transformation usage.

The need to use the unscented transformation comes from the definition of the distance function between the points on the graph edges. The unscented transformation allows to avoid the Jacobian computation used in the classic FastSLAM approach. The derivative of the distance function cannot be computed analytically and this is the reason of the Jacobian computation impossibility.

2.3 Simulation tests

The detailed description of the simulation experiments with different graph. This section includes the experiments with the generated graphs and the graphs of the real underground mines. It should also show work process of the localization system with the installation mistakes (wrong initial position of the landmarks).

3 Errors detection

This section and its subsections contain detailed and formal definitions of the different types of landmark installation errors.

3.1 Shifted access point

Shifted access point is an access point that was placed on the right edge but wrong position on this edge. This section contains formal definition of this error and provides the algorithm to detect it.

3.2 Incorrect installation order

Installation order is incorrect when the access points are placed on the wrong edges – one access point replaced by another. This section contains formal definition of this error and provides the algorithm to detect it.

3.3 Defective access point

If an access point does not provide the signal – it's defective. This section contains formal definition of this error and provides the algorithm to detect it.

4 Experimental results

This section contains detailed description of the algorithms tests on simulation. It provides an algorithm accuracy on the different types of the mistakes detection on different underground mine graphs.

5 Conclusion

The approach of installation mistakes detection in underground mine localization systems was presented and tested via the simulation.

The proposed graph-based underground mine model represents underground mine as a directed graph where the object position is a point on the graph edge.

The location system simulation is based on the Unscented FastSLAM algorithm that allows to estimate position of the moving object without the Jacobian computation. The simulator was successfully tested on the simulated and real underground mine structures.

The errors detection algorithms was proposed and tested on the simulation. All of them provided high accuracy of the mistakes detection via the generated and real input data for all presented types of the installation mistakes.

References

[1] C. Kim, R. Sakthivel, and W. K. Chung. "Unscented FastSLAM: A Robust and Efficient Solution to the SLAM Problem". In: *IEEE Transactions on Robotics* 24.4 (2008), pp. 808–820. DOI: `10.1109/TRO.2008.924946`.

[2] R. Voronov, A. Moschevikin, and A. Soloviev. "Algorithm for Smoothed Tracking in Underground Local Positioning System". In: (2018), pp. 1–6. DOI: `10.1109/RUSAUTOCON.2018.8501664`.