TOPOLOGICAL MOBILE ROBOT ENVIRONMENT REPRESENTATION

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Abstract: This paper describes environment representations, used by mobile robots with focus on topological representation. The environment could be known by mobile robot, i.e. the environment map is known. Or the environment map is build through exploration of unknown environment. Environment representations, let us say maps are of three basic types - metric, topological or hybrid. Metric map represent geometrical relations of objects in environment, hence is more precise like topological representation. Topological representation is more convenient for planning and tasks execution. This paper deal with topological representation, their building and with them linked problems. One of the main problems not even during map building even by using of pre build map is localization problem. In case of topological-like maps, it is the problem of identification the actual robot occurrence place within map. For robot occurrence place identification are used combinations of more methods, e.g. landmarks selection, detection and recognition, history of occurrence places, triangulation.

Keywords: topological map, landmark, localization, triangulation

1 INTRODUCTION

The main task of mobile robotics is autonomous work in environment. Hence are required as much information about environment as possible. Information about mobile robot environment let us say environment representation is often named environment map, because actually it has in fact really form of map. Environment map building is closely linked with localization problem. Coherence and robustness of map actualizations depends on robustness of position estimation. In case of dynamical map building must be the localization with respect to already known map regions. Localization could be divided into global localization and position estimation. Global localization is performed with influence of global uncertainty which affects whole learnt or let us say till now learnt map. Local localization - position following is executed during map building and therefore is under influence of local uncertainty in position estimation. There are more map types which are often based on types of sensor data, are dedicated for different environment types, appropriate for different tasks. Localization problem is critical problem in each map type. In paper introduction are described basic used map types, next section deals with localization problem with focus on topological representation form.

2 BASIC MAP TYPES

There are three used map types – metric, topological, hybrid. According to which part of environment is represented by map, we distinguish local and global environment maps. Local maps represent near vicinity of mobile robot and global maps represent whole explored environment. Maps could be optimized for representation of static environment or changing – dynamical environment.

2.1 Metrical map

Metric maps are the most used environment maps in mobile robotics. They represent objects in environment based on their geometrical relationship. Most often are used two forms for representation of geometrical relationships between objects.
First form is based on Cartesian environment representation, often is used extended Kalman filtration. By map building is most frequently used fusion of information from odometry with data from other sensors sensing mobile robot vicinity (ultrasonic or laser range finders).
Second form of metric maps has form of occupancy grid map, which is very often used in various mobile robotic systems. Occupancy grid map consist of cells representing probability of which the place in environment is occupied or free.
Advantage of metrical map is possibility to achieve very precise environment representation, but at the same time the disadvantage is in severity of record capacity and computation effort in processing map data. The main disadvantage of metrical environment representation approach is, that it does not allow representation of symbolic entities, like doors, chairs, boards, etc.

2.2 Topological map

Topological map (Fig. 1) is form of environment representation, which represent environment based on significant features. It has form of graph, where nodes represent significant environment features or significant places and edges represent connections between features or places. Because of its advantage for planning is this map widely used. First approach of metrical map building is offline building – in this case is topological map build from before build metrical environment map (Thrun, *et al.*, 1998; Thrun, 1998). Second approach is online building, where the map is created directly by environment exploration (like in (Choset and Nagatani, 2001)). On building of this map type has uncertainty in position estimation no effect. But there is another major problem in identification and recognition of significant environment features, based on which is done the identification of nodes in before build map or in online build map.
Advantage of topological map is lower record capacity as needed for metric map, and therefore it is more suitable for exploration of larger environments. Main advantage is robustness against errors in robot position estimation in Cartesian coordinate system, because this information is not critical by building and using of this map form. By fully operational recognition and identification of environment features is planning in this case simpler.

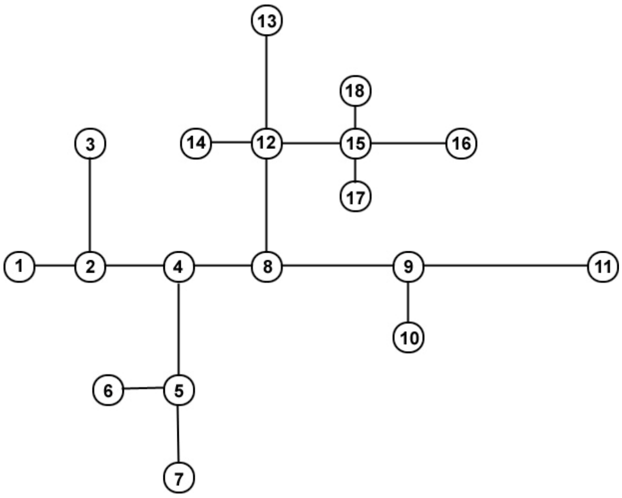

Fig. 1 Example of topological map form, where nodes represent rooms, crossroads or corridor ends

2.3 Hybrid map

Hybrid map (Tomatis, 2001) is combination of both previous map types. Like topological map, hybrid map consist of nodes and edges connecting nodes. In this case edges and nodes could be topological or metrical.

Hybrid map has advantages of both previous map forms, where metrical form ensure more precise environment description and topological form ensure robustness against errors in localization. Besides the localization problem rise here the problem of detection and identification of places, where must be done switching from metrical to topological form or from topological to metrical form. In fact it is switching between modes for path generation from place described topologically and mode for trajectory generation based on metrical information of given place (local level).

3 LOCALIZATION

By each of previous mentioned map types is main problem the localization problem. By each type it is another specifically problem. Localization problem is problem of finding correspondence between robot location in real world and robot location in environment map (Kortenkamp, *et al.*, 1998). Robot location in metrical maps is robot position and heading (x,y,φ), where by topological maps it is the actual robot occurrence node. Localization could be divided into two sub problems - local and global localization.

Local localization, let us say position following is problem of estimating robot location while robot is moving. Estimation of robot location is in this case possible by using integration of location increments in time, but the initial location must be known. Location increments are determined based on odometry information, but this information is affected by uncertainties - slippage and drifts of robot platform. Because of uncertainties in odometry is mainly used integration of odometry data using Kalman filtration. Kalman filtration suppresses effect of growing localization errors. Most suitable is using odometry information with combination of localization based on another environment information source. In such case is possible to make corrections of location estimation in points, which are known. That's how could be suppressed the effect of accumulative localization error, even by traveling longer distances. But this principle works only in case, where known points could be identified and recognized.

Global localization is the problem of robot location estimation under global uncertainties. This problem arises for example when location of mobile robot must be estimated in known environment map, but initial robot location (position and heading) is unknown. Global

localization approaches have two main advantages: First, they yield higher degree of autonomy, because the initial location is not needed to know. Second advantage is, that in case of known initial robot location is localization more robust.
Because of uncertainty in sensor data, majority of localization approaches use probability representation of robot location. So localization is not determination, but estimation of robot location. Most commonly used localization methods are extended Kalman filtration (EKF), Markov localization, Monte Carlo localization (Fox, *et al.*, 1999), and partially observable Markov decision process (POMDP), etc.

4 TOPOLOGICAL LOCALIZATION

Goal of topological localization is not to estimate robot location in Cartesian coordinate system, but estimation of actual robot occurrence place in topological map. The map of environment is useful when it truly describes environment. Therefore in topological map must be clearly known which place in map represents which place in environment. Already by map building is needed to acquire as much information about given environment place as possible, because of future place recognition. Hence are acquired identification marks of such environment place or vicinity of mobile robot, so that it is possible to differentiate such place from another explored environment places. This identification marks are landmarks or another features of environment, features of object in environment, like characteristically textures, room edges (convex or concave), doors, etc.
Only identification marks of environment places, objects, etc. are not sufficient for identification and recognition, because environment is mainly monotonous and places and object are often very similar (Fig. 2). Therefore is by localization needed as much information as possible. Besides could be used methods based on graph search, history of places (Remolina and Kuipers, 2004).

By satisfactory solved problem of localization or let us say estimation of robot occurrence place in map, appears question how to plan trajectory on local level in such environment place more precise. When we imagine that such place in map represent some room, then this is the problem of planning trajectory in room. Because for identification of such place – room are used different landmarks or environment features, they could be used even by more precise localization in local level – in room. There could be used some forms of triangulation methods. With help of triangulation method is possible more precise robot location estimation in such room, of course in coordinate system joined with coordinate system of landmarks.

Topological localization methods could be divided in these steps:

- Detection of surrounding landmarks in the environment
- Comparison of detected landmarks with landmarks recorded in map, landmark identification and recognition
- Actual robot occurrence place identification
- Using of triangulation for more precise robot location estimation, in place coordinate system

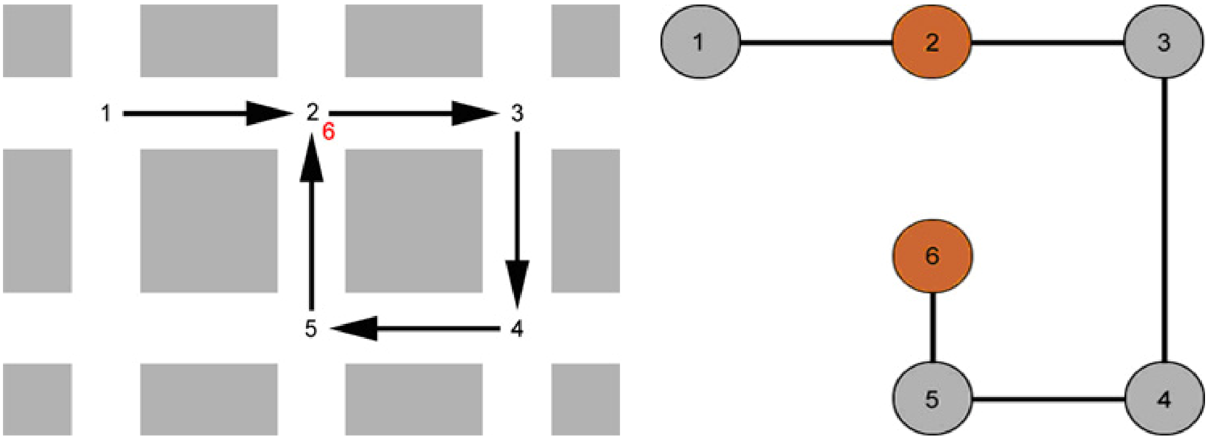

Fig. 2 Problem of place identification by topological map building. Left: robot environment exploration (only symbolical). Right: build topological map

4.1 Landmarks

Landmarks are important for place or objects identification, hence for localization in topological map. Landmarks are natural or artificial. Artificial landmarks are better for detection and identification, but it is necessary to make changes in environment – to add artificial landmarks. Artificial landmarks are suitable in unchanging environment, where the robot is executing repeating tasks.

In changing environment is adding of artificial landmarks into environment not effective. Besides there could be situations, where is adding of artificial landmarks not possible. Therefore are used methods based on natural landmarks. In case of natural landmarks it is more complicated task, because must be chosen which information about place or object in environment is important. Identification marks must be chosen so, that detection, identification and recognition of places or objects in environment is possible.

For robust and functional localization in different kinds of environment is necessarily combination of localization methods based on landmarks and methods based on graph search or robot occurrence places history. Environment where the robot is executing tasks, is often monotonous, many objects or places look similar. Hence recognition and identification of objects or places is ambiguous. Therefore is needed combination of different approaches for their recognition and identification.

4.2 Triangulation

Like was mentioned before, the landmarks, so some identification marks of environment places could be used for place identification, even for navigation inside places. Environment place often represent some room, where the trajectory must be more precise generated. For this purpose could be used landmarks, based on which is realized triangulation, so robot location computation. Robot location is determined in landmarks coordinate system, hence room coordinate system. For trajectory planning inside room is robot location determined in local coordinate system completely sufficient.

In order to triangulation possibility, is needed some minimal count of known landmarks. Also triangulation is sensitive to errors and therefore is better to use over determined system of landmark. In this way could be achieved better precision and some stage of robustness in robot location computation (Betke and Gurvits, 1997).

5 CONCLUSION

By using of metric map types is main problem in odometry error, which is affecting map building. Odometry error is critical also by using of before build environment map. Metrical representation form ensure precise environment description, it is based on description of geometrical relationships between object and therefore is vulnerable to estimation of robot location in Cartesian coordinate system. Furthermore are metrical maps more suitable for humans, not for autonomous mobile robot planning.
For planning and understanding of environment, like we people do, are needed another forms for environment description based on features, relationships or another obtained knowledge about environment. This description forms can not be named maps, because they represent environment in more complex aspect. Therefore better name is environment representation.
Topological or let us say graph environment representation types represent right way how to advance to environment representation used by humans. Furthermore, based on principles of this representation forms, could be created more developed description form for environment and world understanding.

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