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An Approach of Dynamic Object Removing for Indoor Mapping Based on UGV SLAM

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Abstract: The study of indoor mapping for Location Based Service (LBS) becomes more and more popular in recent years. LiDAR SLAM based mapping method seems to be a promising indoor mapping solution. However, there are some dynamic objects such as pedestrians, indoor vehicles, etc. existing in the raw LiDAR range data. They have to be removal for mapping purpose. In this paper, a new approach of dynamic object removing called Likelihood Grid Voting (LGV) is presented. It is a model free method and takes full advantage of the high scanning rate of LiDAR, which is moving at a relative low speed in indoor environment. In this method, a counting grid is allocated for recording the occupation of map position by laser scans. The lower counter value of this position can be recognized as dynamic objects and the point cloud will be removed from map. This work is a part of algorithms in our self-developed Unmanned Ground Vehicles (UGV) simultaneous localization and Mapping (SLAM) system-NAVIS. Field tests are carried in an indoor parking place with NAVIS to evaluate the effectiveness of the proposed method. The result shows that all the small size objects like pedestrians can be detected and removed quickly; large size of objects like cars can be detected and removed partly. *Copyright © 2015 IFSA Publishing, S. L.*

Keywords: Dynamic object removing, Indoor mapping, SLAM, UGV.

1. Introduction

As the development of mobile computing platforms, such as smart phone, pad, watch etc., indoor positioning and navigation applications for indoor Location Based Service (LBS) become more and more popular. A lot of technologies are utilized for indoor positioning, for example, WiFi, Bluetooth, digital broadcasting signals, ZigBee, magnetic field, A-GPS, etc.[1-4]. Most of exist indoor positioning systems make use of an simple sketch map for visualization. However, indoor map also plays an important role for practical indoor LBS applications. Indoor map has its own characteristic: (1) the structure is complex; (2) the layout changes frequently. For example, a large supermarket may have hundreds of shelves and these shelves are organized in certain layouts for customers' convenience. And after a few months the layout may be changed for promotion. Thereby, a measurable and up to date map is needed for further indoor LBS applications.

The SLAM technique is the process of building a map of an unknown environment by traversing it with range sensors (laser, sonar, etc.), while simultaneously determining the location on the map. It combines positioning and mapping with scan feature matching method in a single framework, and it is considered to be an effective method for positioning and environment-recognizing problems [5-7]. Thereby, compared with various mapping methods, LiDAR based simultaneous localization and mapping (SLAM) seems to be a fast and effective indoor mapping and updating method in a complicated GNSS-denied indoor environment. However, when mapping with LiDAR sensors, some dynamic objects like pedestrians or indoor vehicles may exist in the mapping area. Such dynamic objects must be removed in the mapping processing to improve the map quality. It is well known that positioning, mapping and detection and tracking of dynamic objects are related each other in a SLAM system [8-9]. The proposed dynamic object removing method of this paper is also a part of self-developed 2D LiDAR based SLAM system-NAVIS and the main purpose of NAVIS focus on mapping and update the indoor environment quickly [10-11].

The topic of detecting and tracking dynamic objects has been active for decades in robotics, and previously proposed solutions can be categorized as model-free approach and model-based approach. The model-free approaches is based on motion clues, regardless its shape, class or other semantic information. But it can only detect instantaneously moving objects [12]. On the contrary, the model-based approach is based on the priori knowledge of shape, class, etc. and some classified algorithms are applied for dynamic object extraction, such as Data-driven Markov Chain Monte Carlo [13], Probability Hypothesis Density (PHD) filter [14], Joint Probabilistic or Data Association Filter (JPDAF) [15].

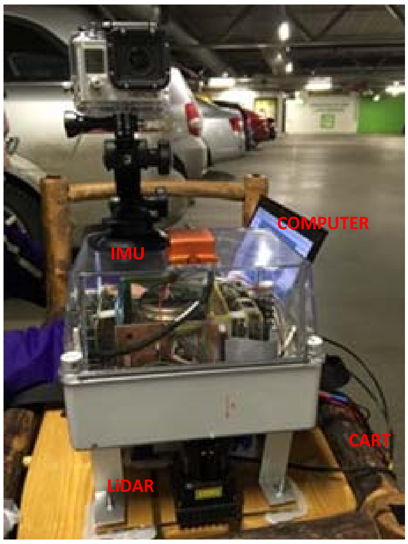
As a beginning work of dynamic objects removing for improving the NAVIS mapping system, the proposed dynamic object removing method of this paper utilizes a model free detecting and tracking approach called Likelihood Grid Voting (LGV). It takes full advantage of the high scanning rate of LiDAR mounted on a low speed moving UGV platform. The main contribution of this paper is that, an integrated framework of positioning, mapping and dynamic object removing is provided to build accurate and clear indoor maps efficiently.

The rest of this paper is organized as follows: Section 2 will introduce the NAVIS mapping system and the test scenarios. The dynamic objects in acquired data set also will be analyzed in this section; then the LGV algorithm will be described in details in Section 3; the mapping result after dynamic object removal will be discussed in Section 4; a conclusion will be drawn in section 5 at last.

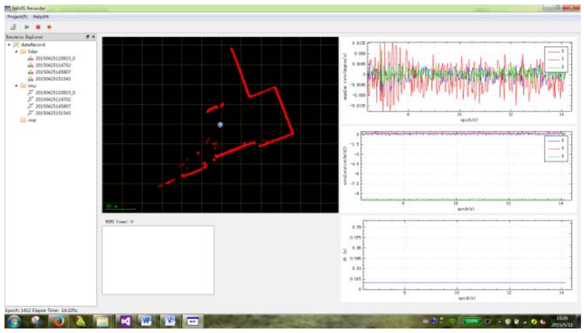
2. Mapping System Overview and Test Scenarios

2.1. Overview of Mapping System

The work of dynamic object removal is based on the NAVIS indoor mapping system that we have developed. Fig. 1. (a) shows the hardware of NAVIS, which includes an Xsens MTi-G IMU and a Hokuyo UTM-30LX-EW laser scanner. The scanning range of the LiDAR sensor is about 0.1 m to 30 m with 270º scan angle and its angular resolution is 0.25º. They were installed horizontally on a cart and connected with the data recording computer. The raw IMU and LiDAR data are recorded with recording software, which is shown in Fig. 1(b). Finally map building and dynamic object removal process is done with post process software shown in Fig. 1(c).



(a)



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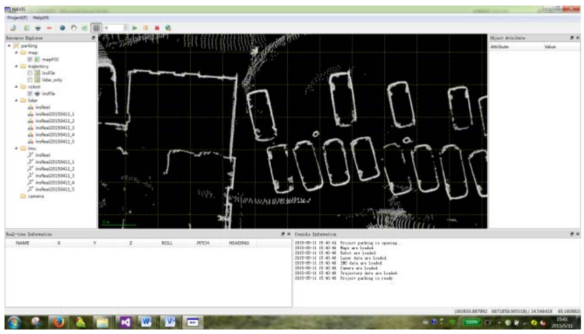
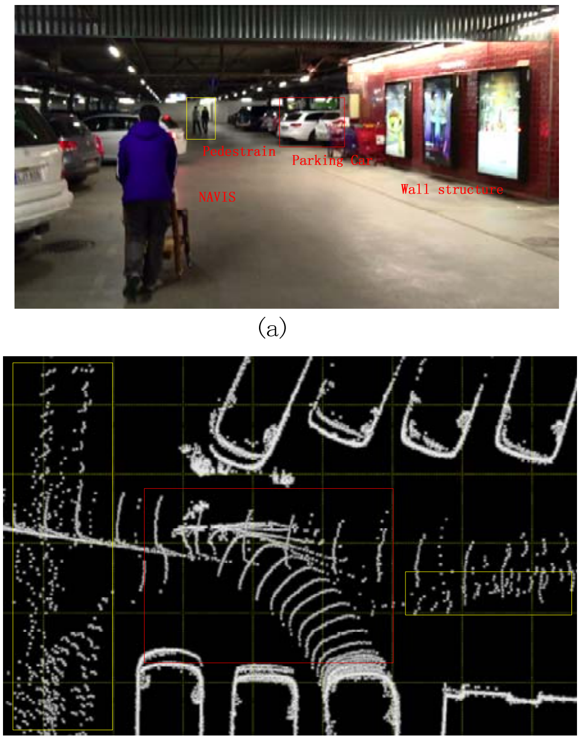


(c)

Fig. 1. (a) Hardware platform of NAVIS indoor mapping system, (b) Data recording software of NAVIS, (c) Data process software of NAVIS.

2.2. Test Scenarios and Dynamic Objects Removal Problem

The filed test scenario was selected at an underground parking place of a store. It is a typical complicated indoor environment with walking persons, shopping carts and cars etc., as is shown in Fig. 2(a). and Fig. 2(b) shows the mapping result without dynamic object removal. Pedestrians and moving cars are the main dynamic objects in this research. Areas in yellow and red rectangle show the LiDAR point cloud trajectory of pedestrians and moving cars, respectively. As it is shown in the map, such trajectories are not a part of static structures of environment, which have to be removed. Then, the problem is how to remove the dynamic objects, while keeping the good positioning from LiDAR scan matching in a SLAM framework, because positioning and mapping are affected by each other.



(a)

(b)

Fig. 2. (a) Underground parking place of a store, (b) Map result with dynamic objects.

3. Dynamic Object Removing Algorithm

3.1. Workflow of Map Building

The dynamic object removal algorithm is a part of the SLAM based map building process chain and the data process workflow is shown in Fig. 3. First, the observation data of IMU and LiDAR are utilized for positioning with multi-resolution likelihood grid map based scan matching and INS mechanism respectively, and then their positioning results are fused with Extend Kalman Filter (EKF) for the optimal position estimation in a loosely-coupled way. The details of the positioning algorithm are described in our previous work [16]; second, based on the estimated position and attitude, the LiDAR point cloud at current epoch is stored into the multi-resolution likelihood grid map, which can be used for LiDAR scan matching at next epoch; Next, the dynamic removing algorithm is applied on the current likelihood map at a certain time interval (for example:10 seconds) to filter the dynamic objects for final clear indoor maps; Finally, The likelihood map is exported with local coordinate when all the data processing is finished.

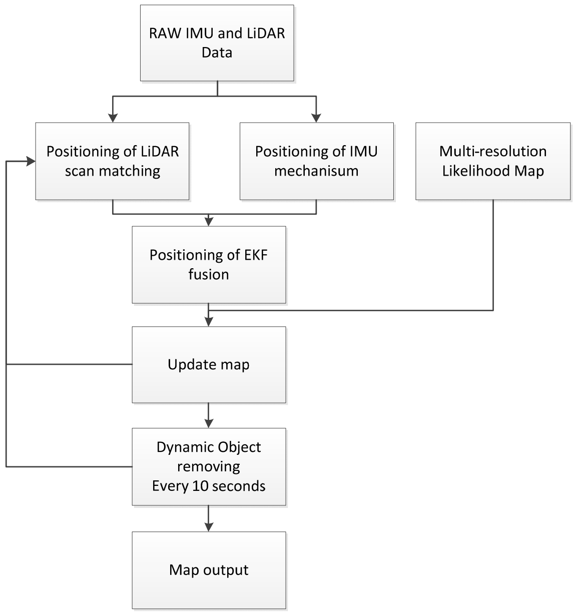


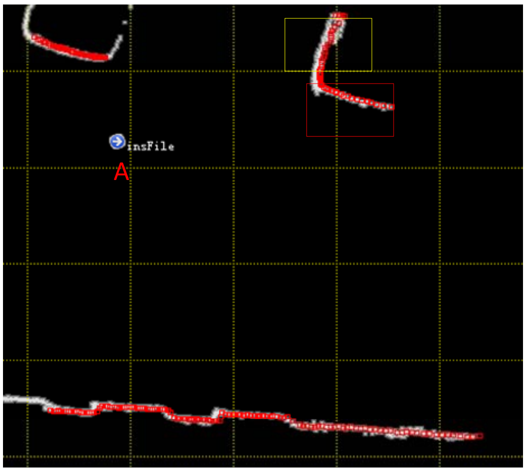
Fig. 3. The map building process workflow.

3.2. Likelihood Grid Voting Algorithm

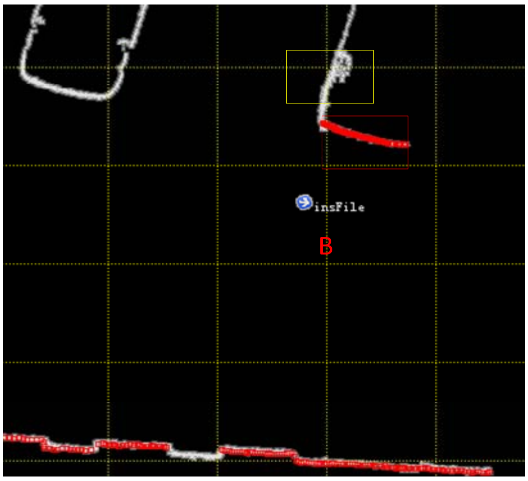
The proposed dynamic object removal algorithm called Likelihood Grid Voting (LGV) is a model-free method. It takes full advantage of the high scanning frequency of LiDAR, which is moving at a relative low speed in indoor environment. The LiDAR scanning rate is about 40 Hz. When the mapping cart is moving at a human walking speed of about 0.5 m/s in the indoor environment, as is shown in Fig. 4(a), the mapping platform moved from position A to position B (Fig. 4(b)), the object in red rectangle scanned by both of the two scans, while the yellow rectangle shows the changes of the two scans (red dots are laser range points). These data suggest that the laser scans on the same static structure will overlap several times in a given short period. On the contrary, the scanning count number on the dynamic moving objects will be less.

Then the principle of dynamic object judgment depends on the occupied scan count C at a certain grid cell position of the likelihood map. Thus, two types of information must be recorded by each patch of multi-resolution likelihood map: the likelihood value and the scan count C, as is shown in Fig. 5.

Likelihood value is used for mapping environment and positioning by scan matching; scan count C used for filter the dynamic objects. The pseudo-code of the algorithm is shown in Algorithm 1.



(a)



(a)

Fig. 4. Example of Laser Scan Overlap.

Algorithm 1. Pseudo-code of the LGV algorithm based on multi-resolution likelihood map.

Requires: 1. Multi-resolution Likelihood map M;
2.Maximum resolution level mLeve l of M
3. cell value C_{ij} in scan count grid of M
4.cell value L_{ij} in likelihood grid of M
Setting: scan count cretiea F
for each cell value C_{ij} in scan count grid of F with mLeve l
    if $C_{ij} < F$
      $C_{ij} = 0$
      $L_{ij} = 0$
    end if
end for
return map M

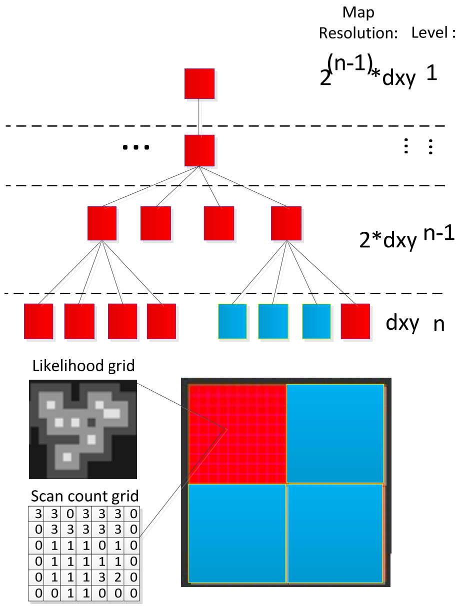


Fig. 5. Pyramid structure of the Multi-resolution likelihood map.

In this algorithm, pyramid structure of the Multi-resolution likelihood map is used for positioning with scan matching. We found that (1) if all the levels of map are filtered with the proposed dynamic removing algorithm, the positioning result may get worse, because some static structures are removed falsely. Therefore, only the maximum level of likelihood map is utilized for dynamic object removal, in order to guarantee the positioning accuracy. (2), the determination of scan count criterion F is also very important. If F is too large, more effective environment static structure could be removed wrongly. In this study, the sensor cart moves at human walking speed of about 0.5 m/s and F is set to 2. Fig. 6 shows an example of the scan count grid result with the removing algorithm.

Scan Count Grid

before

0	0	0	0	0	0	0
0	3	3	3	3	3	0
0	1	0	1	0	1	0
0	1	0	1	0	1	0
0	3	3	3	3	2	0
0	0	0	0	0	0	0

after

0	0	0	0	0	0	0
0	3	3	3	3	3	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	3	3	3	3	2	0
0	0	0	0	0	0	0

Fig. 6. Grid voting algorithm for dynamic object removing.

4. Results and Discussion

The proposed LGV dynamic object removing algorithm is a model free method, the result only depends on the laser scanning times on the same object. This section discusses the performance of the removal algorithm applied to different objects-pedestrian, vehicle and static structure, respectively.

4.1. Pedestrian Removal

Fig. 7 shows the map comparison result of the pedestrian removal. As it is shown that, because the height of LiDAR sensor is about 1 m, the shape of a pedestrian is short point cloud arcs, which are legs of human. In such situation, when a pedestrian walks normally, there are no overlapped laser scans basically and the effect of pedestrian removal is very well by the proposed algorithm.

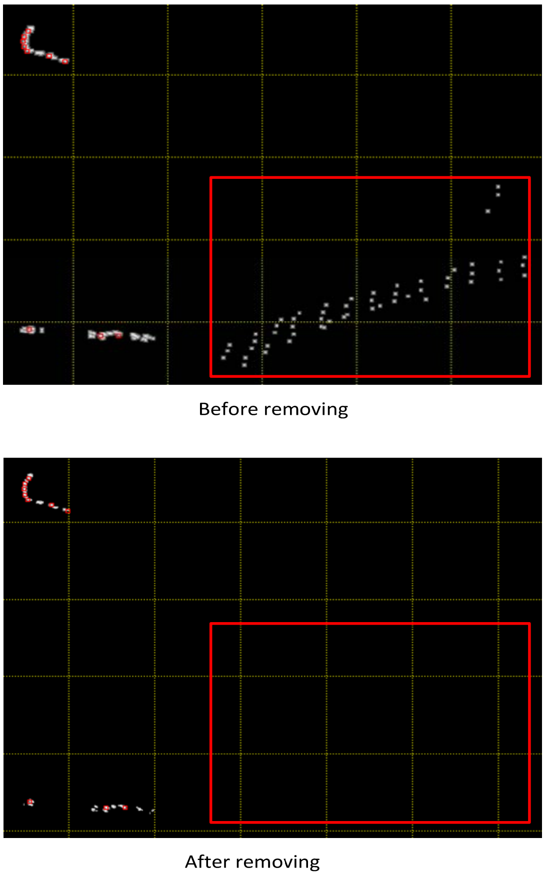


Fig. 7. Map result of Pedestrian Removal.

4.2. Vehicle Removal

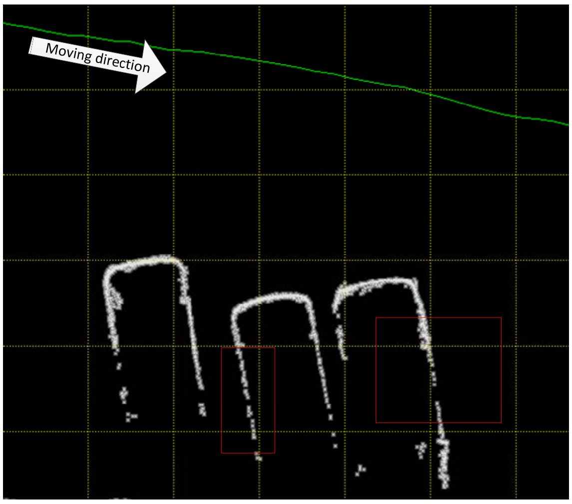
Fig. 8 shows the map result of moving car removal. In this scenario, the green line is the trajectory of NAVIS mapping platform. A car passed by the mapping platform at the same direction. The size of car is about 3 × 5 m and the point cloud trajectory is shown in the red rectangle, while, two stopped car and a wall are recognized as static structure in the scenario. The shape of a car is 'L' in each laser scan, when passing by the LiDAR sensor, and the map result shows that the bottom of moving car can be removed ,for there is not too much overlap laser scans. However, the sider of the car moves along LiDAR sensor on a straight line, there are more laser scan point cloud along the car side, which can be recognized as static structure wrongly.

Fig. 8. Map result of Vehicle Removal.

4.3. Map of Static Structure

In this study, the object shape is not taken into consideration in the model-free dynamic object detection method. The dynamic object removal result of the proposed method depends heavily on the scanning count. However, there are still some fixed structures that are scanned only once like dynamic objects and such static part are also be removed by the LGV algorithm. As it is shown in Fig. 9, when the mapping platform moving from left to right along the trajectory (green line), the stopped vehicle framework in red rectangle were also scanned only once. Thereby, they were removed recognized as dynamic object wrongly. Moreover, the multi-resolution grid likelihood map is not only used for mapping, but also used for positioning with scan matching. As it is found that if such static structures are removed, it will result in wrong positioning result with LiDAR scan matching. That is why only the maximum resolution map level is applied for mapping and other layers are used for positioning in NAVIS system.

In another way, the problem of static part removal can be resolved by slow down the mapping speed for scanning on static environment as much as possible with several laser scans.



Befroe removing

After removing

Fig. 9. Map result of static structure.

5. Conclusions/Outlook

In this paper, an indoor mapping system is introduced. It provides a unified framework of position estimation, static structure mapping and dynamic object removing. And the main focus of this study is dynamic object removing. A model free approach called LGV algorithm based on multi-resolution grid likelihood map is described. The core of such method is the overlap times of raw laser scans on same object. The result map proves that (1) the small size of dynamic objects like pedestrian can be detected and removed clearly; (2) large size objects like moving vehicles can be removed partly; (3) a small part of static structure could be recognized as dynamic objects wrongly. The scam matching positioning error caused by the wrongly removals can be corrected by other map layers, for the removal actions are only applied on the maximum resolution map layer.

As the main purpose of dynamic object removing is mapping the indoor environment. The proposed LGV algorithm can remove most part of the noise dynamic information and build clear maps automatically. Only a small part of the noise dynamic objects need be removed manually. The efficiency of mapping can be promoted.

In future works, the stochastic of the dynamic objects will be taken into considered: two or more mapping results of the same environment will be overlapped for helping dynamic object removal and keeping the static structure well.

Acknowledgements

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