論文の内容の要旨

Online SLAM and Moving Object Tracking on Streets with Vehicle-borne Mapping System

（車載マッピングシステムによるSLAMと移動オブジェクトの追跡手法に関する研究）

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Positioning technology is strongly demanded in many fields such as in mobile robot, vehicle localization and navigation, 3D mapping and so on. For vehicle localization and navigation, GPS is widely used. However, the localization accuracy is not satisfied in urban area due to occlusion problem caused by many tall buildings in the city. Recent years, Simultaneous Localization And Mapping (SLAM) has becoming a promising solution for vehicle localization with high accuracy, which can locate the vehicle in unknown environment only using onboard sensors, without any prior knowledge of the environment.

Laser-based SLAM in static environments has been solved, but laser-based SLAM in dynamic environments such as on urban streets involving many moving entities still remains challenging. For SLAM in dynamic environment, the most challenging problem is to distinguish the moving object from the background. A joint framework is proposed and popular to solve the SLAM and moving objects detection and tracking (MODT) problem at same time. This framework is proved to be mutual beneficial. However, this framework may also be affected by each other. For example, it may become unstable if an error occurs in SLAM or MODT. In a congested environment such as urban street, usually it is hard to detect moving objects successfully just by tracking due to occlusion and limited observation.

This thesis focuses on developing a robust and accurate laser-based SLAM and moving object detection/tracking algorithm for vehicle localization in urban environment. Meanwhile, as a unique application of SLAM and moving object detection, we also want to develop an automatic traffic data collection system on a moving vehicle platform in urban area.

In this study, the performance of SLAM is improved in two aspects. Firstly, a simple but effective strategy in grid map building is introduced. In mapping process, each grid in the map is incrementally updated and classified as occupied, empty or unknown, and then the information of the empty grid is used to detect moving object. In this way, the moving object can be detected and discriminated from the background more effectively, even without tracking. It reduces the negative influence caused by the existing of moving object and makes SLAM more reliable in dynamic environments.

Secondly, weighted point matching is proposed in scan matching process in SLAM. Different weight is assigned to each laser point based on local feature to improve the matching accuracy. A point far away is given a large importance value while a point nearby is assigned a small value. By using this strategy, in one hand, it reduced the matching error in SLAM in each frame and thus reduces the accumulative error in localization in large area. In another hand, it reduced the negative effect of nearby moving objects and enables SLAM more robust in dynamic environment.

The proposed SLAM algorithm is tested on a vehicle platform which equipped with only two horizontal laser scanners for SLAM and MODT, a camera and a GPS are for validation. The two laser scanner, LD OEM by SICK, which are mounted on both left and right side front of the vehicle, can cover a maximum measurement range of 150m with a horizontal view of 270° and angle resolution of 0.25°.In the experiment, we drove the experimental car on urban streets in Tokyo, with an average speed about 50km/h.

Fig 1 shows the final localization and mapping results by SLAM after finishing the total experiment course. The vehicle trajectory by SLAM is shown Google Earth in red colour, while the yellow line is the vehicle trajectory by GPS. From the zoomed view, it is obvious that the trajectory from SLAM is much smoother and more accurate than that of GPS. The total accumulative error of our SLAM algorithm is less than 3m after a 2.3km trip. We also conducted a contrast experiment to compare our proposed SLAM algorithm with the conventional SLAM method. The two SLAM algorithms mainly differ in matching process: the previous one assign different weight value for each laser points in matching while the later one treat all of the laser points equally. The water blue line is the result using the conventional SLAM method. It is obvious that the localization accuracy of the proposed method is much better than that of the conventional method.

Based on the SLAM algorithm and moving objects detection technology, we developed a novel Smart Probe Car system, which can automatically collect traffic data on a moving vehicle platform. Only two laser scanners are used in the system. One is a horizontal laser scanner mounted on the front of the car, which is used to locate the car by SLAM. Another one is a slant laser scanner mounted on the back of the car, which is used to build a 3D map of the environment. Based on the 3D map, the moving objected can be extracted from the background. Then, a novel method is proposed to estimate the speed of these cars based on their 3D profile. Our traffic collection system is shown in fig 2.

The performance of the developed traffic data collection system is validated with experiment on a congested urban street. Fig 3 shows an instance of our real time traffic data collection program. The SLAM, 3D mapping, vehicle detection and traffic data collection process are carried out at the same time in a real time way. The yellow line is the trajectory of the probe car, and the red point shows its current position. The speed of the probe car is estimated by SLAM and is shown in the top of this window. The detected cars are labeled in red color and their speed and size are shown at their location. As the probe car moving, the vehicles in the other lane are detected in the same way. The detected cars are counted and the total number is shown the right top of the window.

A number of detected cars and their parameter such as speed and size are shown in Fig 4. Their ID is the counted number in our traffic collection system. The clusters are extracted from the 3D map built by the slant laser scanner, while the corresponding image is from the video camera, which is just for reference and validation. The experiment results confirm that we can collect real time detailed traffic data with the proposed Smart Probe Car system.

However, there are still many challenges remain in real application. Further effort is needed to solve the accumulative error in SLAM in a much larger scale area. Fusing with other sensors such as GPS or camera could be a possible solution for this problem, which is supposed to be introduced in further study. In another hand, in traffic data collection, we just use the slant laser scanner information to estimate all the parameter of the detected cars. It is efficient but not robust enough. Since we also can detect the speed by tracking using a horizontal laser scanner, in future study, this kind of information also should be added into consideration, in order to make the estimation more reliable.

Figures

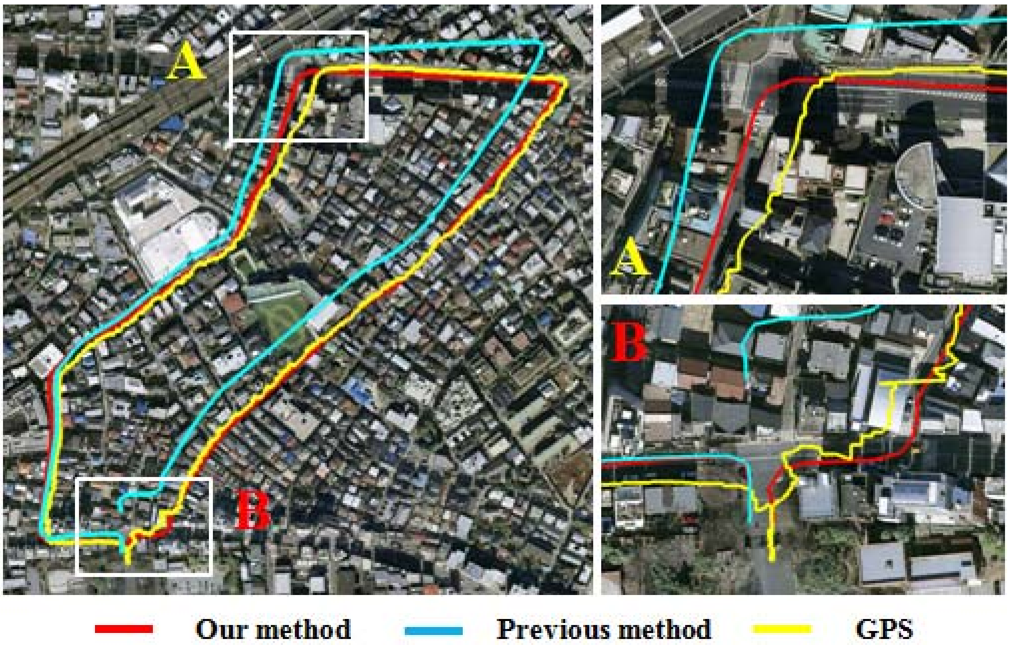


Figure 1 Comparative experiment of SLAM in urban area

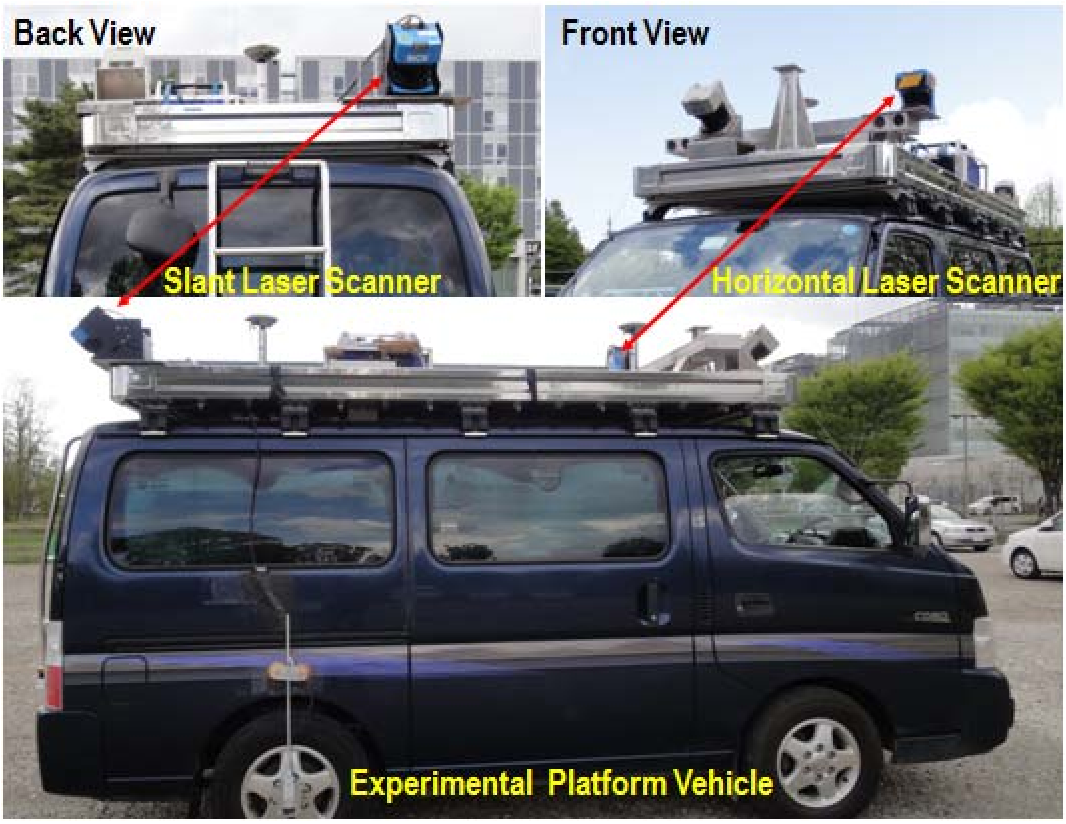


Figure 2 Test-bed vehicle for traffic data collection

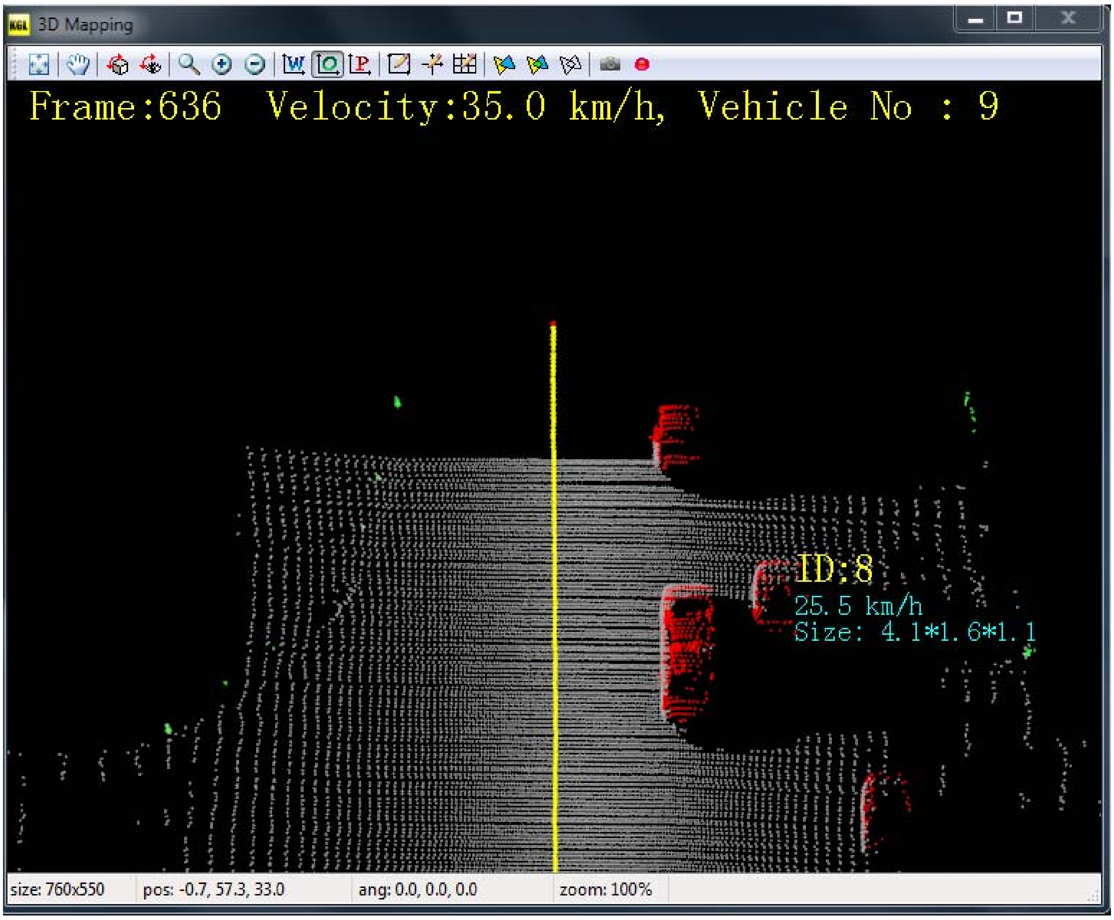


Figure 3 A instance of real time traffic data collection program

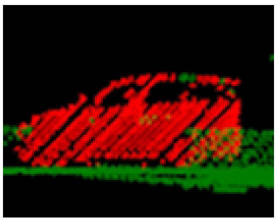
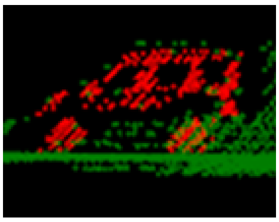
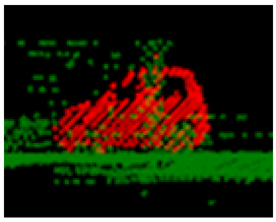
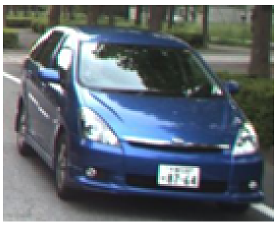
ID	1	2	3
Size (m)	5.0*1.8*1.7	2.8*1.5*1.8	3.1*1.6*1.6
Speed (km/h)	11.1	4.5	10.4
Cluster			
Image			

Figure 4 Samples of detected car and traffic data