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Supporting autonomous vehicles by creating HD maps

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Abstract
Maps are constantly developing, also, the newly defined High Definition (HD) maps increase the map content remarkably. They are based on three-dimensional survey, like laser scanning, and then stored in a fully new structured way to be able to support modern-day vehicles. Beyond the traditional lane based map content, they contain information about the roads' neighbourhood. The goal of these maps is twofold. Primarily, they store the connections where the vehicles can travel with the description of the road-environment. Secondly, they efficiently support the exact vehicle positioning. The paper demonstrates the first results of a pilot study in the creation of HD map of an urban and a rural environment. The applied data collection technology was the terrestrial laser scanning, where the obtained point cloud was evaluated. The data storage has been solved by an in-house developed information storage model with the ability to help in vehicle control processes.

1. Introduction

Autonomous vehicles need to be efficiently supported by maps. Satellite and inertial based positioning techniques can describe the coordinates and orientation of a vehicle with high accuracy. A map has to provide information whether or not particular lanes are allowed to be used by a given vehicle.

A research task involving high accuracy field surveying to create 3-dimensional map has been conducted. The paper describes this procedure in details. The map stores the lanes by their markers and contains all the necessary topological information. Finally, the use of the newly developed map model to be applied in autonomous vehicle control is demonstrated.

2. Environmental mapping

Terrestrial laser scanning (TLS) is one of the most effective data collection techniques in surveying. The technology is based on distance measurement, where the scanner emits laser impulses and the instrument measures the time and/or the phase difference of the returning signal. The scanner contains a glass prism rotating quickly around a horizontal axis resulting in vertical profiles of multiple points. By the rotation of the scanner around a vertical axis, the whole 3-dimensional neighbourhood can be surveyed. The result of the scanning is a point cloud with millions of points. Such scanners can have built-in or external camera that enables to "colorize" the point cloud. The point cloud prepared this way is easy to interpret even for non-professional users.

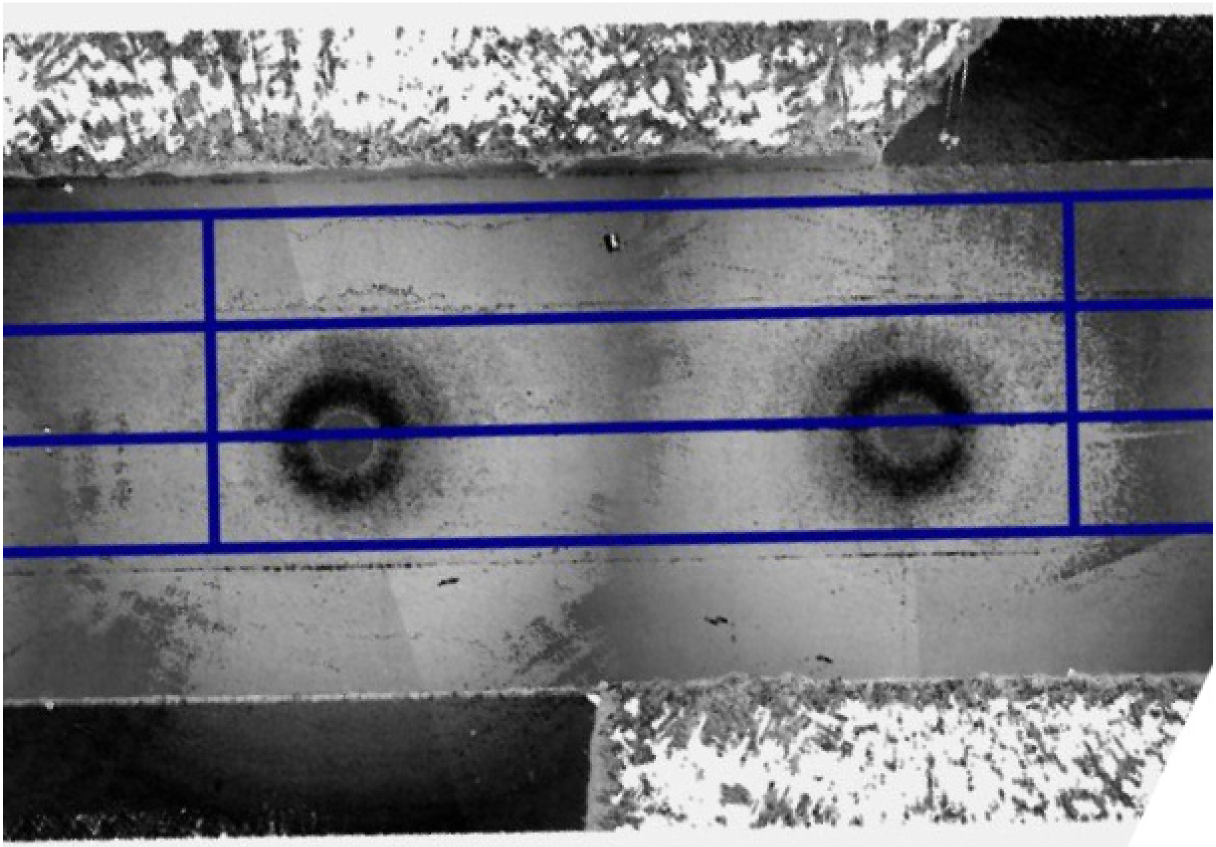
If the working area is larger than the scanner's measurement range, multiple stations, from which the separate point clouds are collected, are required. Then, these clouds have to be unified, which can be done by means of

- manually selected natural points being identifiable in multiple point clouds,
- using artificial markers (e.g. spheres) during scanning, then applying automatic or manual marker selection, or
- computationally intensive technologies (e.g. Iterative Closest Point (ICP) algorithms) for automatic point cloud matching (FARO SCENE SOFTWARE).

These point cloud transformations result in a single point cloud containing all the measured points. To reduce the redundancy, it has to be resampled (decimated). The obtained data set is unstructured and contains unnecessary and disturbing objects, like moving vehicles or pedestrians, too. This drawback can be eliminated during the cleaning and evaluation process (CLOUDCOMPARE). Some occlusions, because of parking cars, trees or bushes cause incompleteness of the data set; joining multiple point clouds, can reduce this effect.

There were two test sites where the mapping technology can be demonstrated. The first test site is in the campus of BME containing buildings, roads, parking lots and some green areas. This test site has significant height differences, so it is suitable to demonstrate the power of the 3-dimensional surveying and mapping concept. The second test site is in Tököl near to Budapest, where the road is in rural environment (no neighbouring objects, practically no elevation information). The test road has many lanes with relatively new lane markings, which are excellent for creating a test lane model.

a) Detail of the laser scanned point cloud of the BME campus



b) Evaluation of the lane markings in the point cloud of the Tököl test site (The scanner was in the middle of the dark spots)

Fig. 1. Laser scanning of the environment and the evaluation of the obtained point clouds

The field survey was executed by a Faro Focus3D 120 laser scanner~~,~~ which has a measurement range of 120 m, and is capable of 2 mm range measurement accuracy. The point spacing was set for 6 mm in 10 m. Fig. 1(a) illustrates the resulting point cloud in the BME campus.

The obtained laser scanned point cloud is in a local coordinate system which cannot be directly coupled to the vehicle navigation system; therefore, a GNSS (Global Navigation System of Systems) measurement was executed in order to transform the local system into a commonly used global reference system. The applied device was a Leica Viva CS10 controller with Real-Time Kinematic (RTK) capability and a GS08plus smart antenna. Thanks to the RTK-service, the achieved accuracy for the GPS-points were better than 2 cm.

In the evaluation phase, the required objects have to be defined. In the pilot study it would be demonstrated how the lane model can be elaborated and how it can support the control of an autonomous vehicle. As the basic objects were only the lanes, therefore the evaluation of the point cloud had its focus on the lane markings.

In this particular case, the easiest, fastest and highest accuracy evaluation is the manual one, so the visible lane markings were digitized in the top view of the point cloud. Since the point cloud is already in a global reference system, the digitized lane markers have global 3-dimensional coordinates.

Fig. 1(b) shows the point cloud and the digitized lane markings in the Tököl test site.

3. Data storage model

The primary goal of the map model is to support the vehicle's control during the autonomous drive. The most evident task is to view the current position and heading of the vehicle in the map. This task requires an exact position and a heading angle measured by the vehicle on-board system. The newly developed map model has to be able to receive these data and visualize them along with the prior surveying results (lanes). Since the map has to support decision by providing the potential lane changes (i.e. whether traveling is allowed on the parallel lanes or not), the map model needs to include topological information, too.

The topology for the lane model is, therefore, built on finite element mesh (FEM). The lanes in the map are split into convex quadrilateral mesh-elements (Fig. 2 right side)~~,~~ which can be used both in straight and curved road segments. The vehicle positioning, therefore, can be simplified this way: in which lane and in which part of the lane is the vehicle located. By using the finite element cells, the position will be given by the identifier of the relevant quadrilateral element.

The mesh element can store information about its neighbours, whether they can be reached or not. Fig. 2 demonstrates how the quadrilateral mesh is used for vehicle positioning and lane change control.

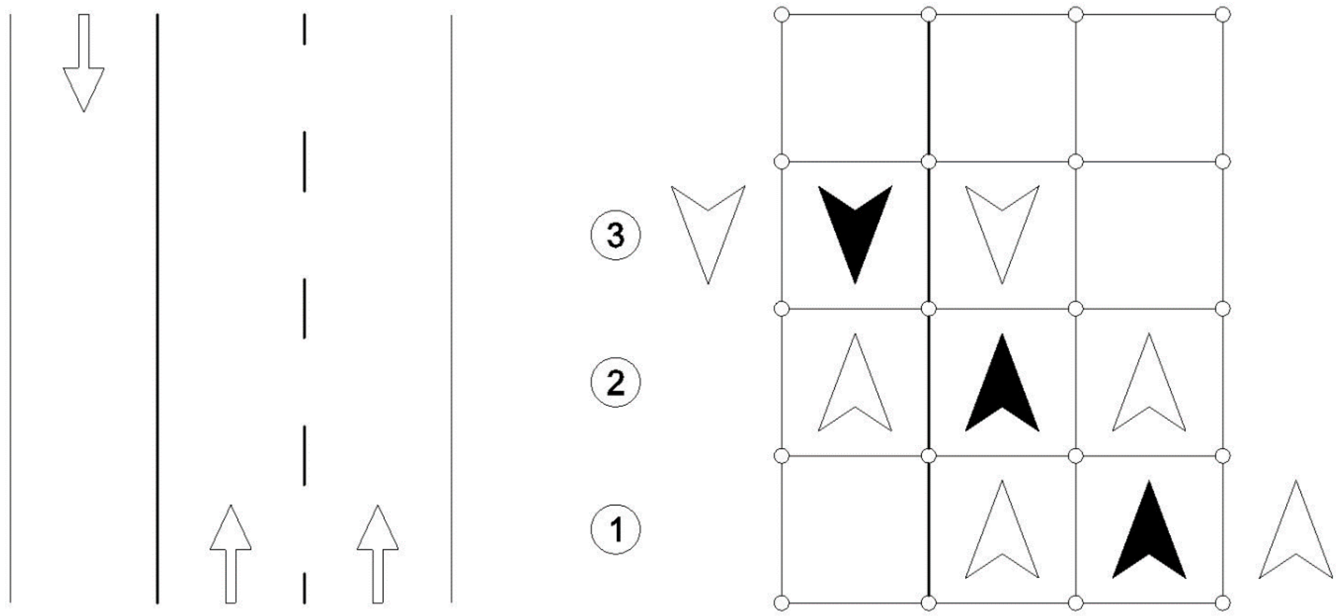


Fig. 2. Scheme and usage of the newly developed map model. Situation with the lane markings and the driving directions (left figure) and the corresponding topology with the mesh cells (right figure). Black arrows are for the analysed vehicles, white arrows for the possible lane changes. Numbers represent the scenarios

4. Usage of the HD map model

The developed lane based map model can also be interpreted as a function call: based on the previously surveyed data and the vehicle's position and attitude measured on-board, the map as the function returns the information whether the neighbouring lane cell can be reached or not.

To achieve this goal, the measured vehicle position must be projected onto the lane model and the only proper mesh element has to be selected. There is a useful technique applied in geoinformatical systems: all polygons (like the mesh elements) have Minimum Closest Rectangles (MCRs) defined by the minimum and maximum x and y coordinates, respectively. If a point location (as the vehicle's position) has to be defined, whether it is in the polygon or not, a simple logical test can eliminate the non-proper elements: the point must be in the MCR. If this condition is not fulfilled, the mesh element is ignored. Due to this technique, a very drastic mesh element elimination can be achieved. Therefore, a more exact, but slower decision can be made considering only the highly ranked candidates.

If the correct mesh element has been found, its neighbourhood information can be returned and the autonomous vehicle control mechanism can decide about the lane change.

The cases 1 to 3 in Fig. 2 has the results as it can be seen in Table 1.

Table 1. Lane change scenarios derived from the lane model

Case	Left lane change	Right lane change
①	✓	✖
②	✖	✓
③	✖	✖

✓ lane change is allowed. ✖ lane change is not allowed

5. Summary and conclusion

The newly developed quadrilateral finite element mesh of the lane model enables the control process of the autonomous vehicle to decide whether a connecting lane mesh cell can be reached or not. This procedure requires flexible and efficient meshing of the lanes-which can be derived from sophisticated field surveys, such as laser scanning. Creating a mesh model has to be done by an automatic procedure considering only the lane markings of the environment model. The automatic algorithm has to consider the changes of the lane geometry, i.e. number of parallel lanes. The next extension of the lane model could be the load of dynamic content, e.g. occupancy taken from traffic information.

Acknowledgement

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通过创建高清晰度地图来支持自主车辆

关键词
高分辨率地图
车辆导航
激光扫描
点云

抽象
地图不断发展，新定义的高清（HD）地图也显着增加了地图内容。它们基于三维测量，如激光扫描，然后以全新的结构化方式存储，以支持现代车辆。除了基于传统车道的地图内容，它们还包含道路附近的信息。这些地图的目标是双重的。首先，他们存储车辆可以行驶的连接，并描述道路与环境的关系。其次，它们有效地支持精确的车辆定位。该文件展示了城市和农村环境高清地图创建的初步研究成果。应用数据采集技术是地面激光扫描，其中获得的点云被评估。数据存储已经通过内部开发的信息存储模型解决 具有帮助车辆控制过程的能力。