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An offline path planning method for autonomous vehicles

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Abstract
Driving a road vehicle is a very complex task in terms of controlling it, substituting a human driver with a computer is a real challenge also from the technical side. An important step in vehicle controlling is when the vehicle plans its own trajectory. The input of the trajectory planning are the purpose of the passengers and the environment of the vehicle. The trajectory planning process has several parts, for instance, the geometry of the path-curve or the speed during the way. Furthermore, a traffic situation can also determine many other parameters in the planning process.
This paper presents a basic approach for trajectory design. To reach the aim a map will be given as a binary 2204 x 1294 size matrix where the roads will be defined by ones, the obstacles will be defined by zeros. The aim is to make an algorithm which can find the shortest and a suitable way for vehicles between the start and the target point. The vehicle speed will be slow enough to ignore the dynamical properties of the vehicle. The research is one of the first steps to realize automated parking features in a self-drive car.

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1. Introduction

Due to the recent revolution of science and technology, vehicles have more and more automated features or systems. Initially, the main motivation was to make driving easier or more comfortable, but world megatrends have oriented the development towards lower fuel consumption, higher traffic safety and reduced environmental impact.

To reach these future objectives, it is necessary to increase the level of automation of road vehicles. At the end of the decade, automated vehicles are going to appear in everyday transportation. Automated vehicles will overcome today's cars in efficiency, comfort, safety, velocity and traffic density. Connected cars have another advantage: with intelligent traffic control systems, traffic jams can be decreased or even avoided.

When talking about the motivation of automated driving one of the biggest expectation is a radical reduction of the accident number and their severity, as 94% of current traffic accidents can be traced back to the human drivers (ISO 2011).

Driving a road vehicle is a very complex controlling task, so substituting the human driver with a computer is a real challenge also from the technical side. Due to the new components and increased in-vehicle system complexity, vehicle testing and validation have become different from earlier ones. Testing the vehicle, the driver-controller and the traffic situations together requires new testing methods and strategies. The aim is the same as earlier: to guarantee road safety with reliable operation of the systems.

In this paper one of the first steps of the trajectory planning process will be discussed which is related to a university research (Gáspár et al., 2014). The vehicle now can do the lateral and the longitudinal control and it can solve some traffic situations for instance traffic jam assist. The next aim is to make the valet parking function and the main requirement of this new feature is to create a trajectory planner algorithm. The test vehicle can be seen in Fig. 1.

Fig. 1. Photo of the test vehicle

2. Trajectory planning layer

The trajectory planning process of automated vehicles has several parts. Apart from the curve on a map (Gu et al., 2013) it is necessary to take into consideration dynamical properties of a vehicle and the driving comfort of the passengers (Hult and Tabar, 2013).

Different features of automated vehicle require different complexity from the control algorithm. In many traffic situations it is enough to handle the vehicle as a point-like body and due to its low speed the accelerations can be neglected. An example could be a vehicle which is searching for a parking place. In this paper this basic approach is going to be analyzed. In further research, the sizes of the vehicle is not going to be overlooked and, for instance, in urban or in rural roads the speed planning also should be defined.

Another important aspect is the fixedness of the environment. When only one vehicle drives on the road it is enough to use a fix map. However, for example, in a car park where there are occupied and empty places, a map has to be changed; these are fixed obstacles. When there are other road users, moving obstacles have to appear on the map.

The trajectory planning process can be done in two types. If a vehicle has information about the environment (GPS, HD map, etc.), the path can be planned before the cruise on the coordinate system of the map. If there is no a pre-known map the vehicle can follow information from its sensors (real time path planning) (Chebly et al., 2015; Dolgov et al., 2010). In this case, the path is planned from the coordinate system of the vehicle. Of course, the two paths can transform one into another.

In this paper the curve planning part of the trajectory planning process will be discussed. Besides the maps are going to be fixed and there are not going to be other road users.

3. The applied map

The map of the pilot site was compiled based on combined survey with GNSS and terrestrial laser scanning technologies.

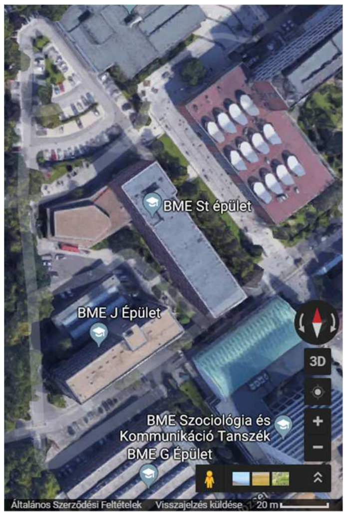

Fig. 2. The map of the applied territory (Google Maps 2018)

Terrestrial laser scanning was performed in April 2017 with a Faro Focus 3D 120S instrument, which has a 360° horizontal scanning and ~120 m range measurement capability. The geometrical resolution was set to 6 mm in 10 m. Several stations were applied to achieve less shadowing effect. The raw result was a unified point cloud having x,y,z coordinates and the received laser pulse intensity. Although GPS measurements enable to georeference the laser scanned data, for this study they were ignored.

Fig. 3. The applied map matrix

Then the point cloud was manually reduced on the surface height and all relevant object borders were drawn in Autodesk

AutoCAD environment manually. The obtained situation drawing was to be checked against topology and after accepting it, all polygons were filled by texture patterns considering that four layers are requested: (1) always available road surfaces, (2) potential parking slots, (3) surfaces not available for vehicles and (4) background (extension to minimal bounding rectangle).

Fig. 4. The applied binary map matrix

The topologically correct and layer-organized drawing was imported into QGIS, where further checks were executed, then shp format was exported. The 10 cm resolution final occupancy grid was derived by an in-house developed Matlab script. The resulted raster has a size of 2204 × 1294 elements, it can be seen in Fig. 3 and Fig. 4.

4. Pre-processing the map

The aim is to define the path which runs enough distance from the edges of the road. A solution can be to create a potential surface on the map where the potential means the distance from the edges. This potential surface defines a new matrix on the map which has a "mountain ridge" above the road. If the trajectory follows the ridge then the vehicle can realize the lane keeping function without observing the edges of the road.

To create the potential surface above the map a simple algorithm was used which is similar to those, which used in image processing (making paler the edges on a picture). The algorithm has a coefficient which multiplies the element of the matrix if it is more than zero and it has a neighbour which is less than one. The algorithm is iterative, the width of the road defines the number of the iterations. This process can be done on the matrix from eight directions (every internal element has eight neighbours).

The process and the results of the potential surface maker algorithm can be seen in Fig. 5.

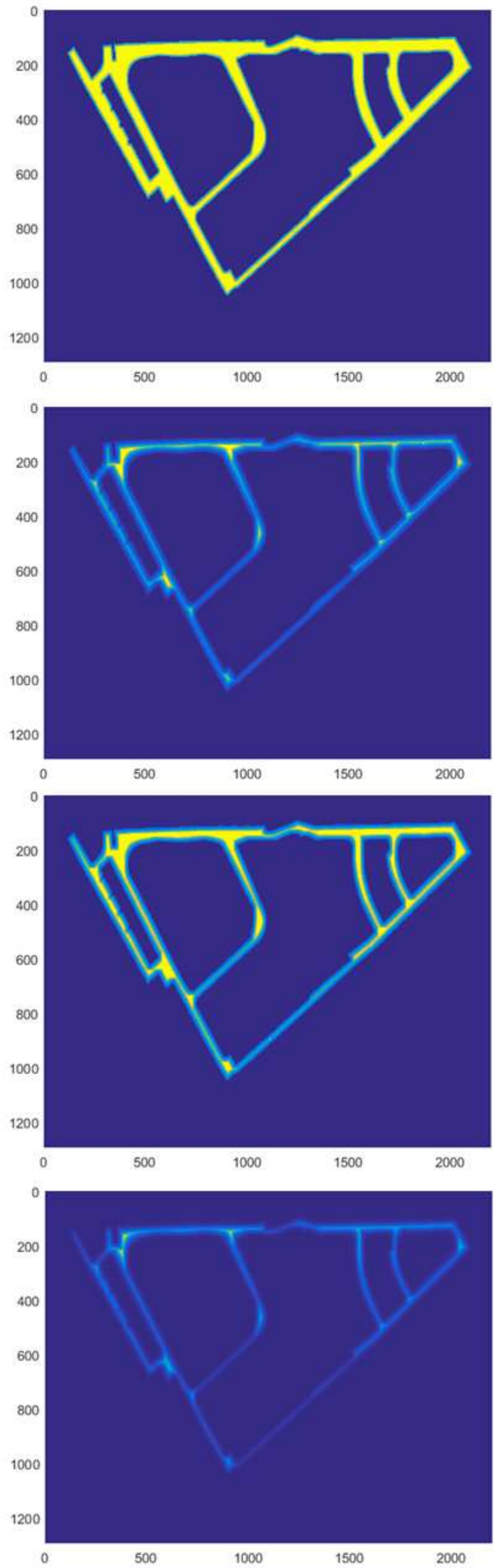

Fig. 5. The process of the potential surface making above the road

5. Finding the shortest path

The next step in the trajectory planning is the finding of the shortest path to the target place. The first method for this aim was the Dijkstra algorithm (Dijkstra, 1959). This algorithm calculates the shortest path between a starting node and all of the other nodes in a graph. The edges can be weighted which means the distance between the nodes. The graph can also be directed, in this case the directions define traffic rules on the map.

Matlab has several functions based on the Dijkstra algorithm, for this paper the "shortestpath" function is suitable (Mathworks, 2015). This function is faster than the original Dijkstra algorithm. To use the "shortestpath" algorithm for path planning the map matrix has to been converted to a graph. In the first approach the graph is not directed and from a general node there are eight ways to step: up, down, left, right with one meter distance and further four other ways diagonally with 2½ meters distance. In addition, the "shortestpath" function requires the numbers of the starting and the target nodes. With this method, the real shortest path can be calculated, which nearly always runs near the edges of the roads. To achieve a path on the middle of the road the values of the edges have to been modified. For this aim the potential surface gives a possibility: by the values of the potential surface the values of the edges can be calculated. Where the potential above the map is high (in the middle of the road) the values of the edges are lower. Where the potential above the map is lower (near the edges) the values of the edges are higher.

With an exponential equation the connection between the two quantities can be defined. The idea can be imagined if the potential surface handled as its opposite (multiplied by -1). Than the surface above the map is similar to a river bed, and the path should follow the deepest way.

After using the function, data have to been converted back to the number of the row and column in the matrix.

Some examples for the algorithm can be seen in Fig. 6 and in Fig. 7.

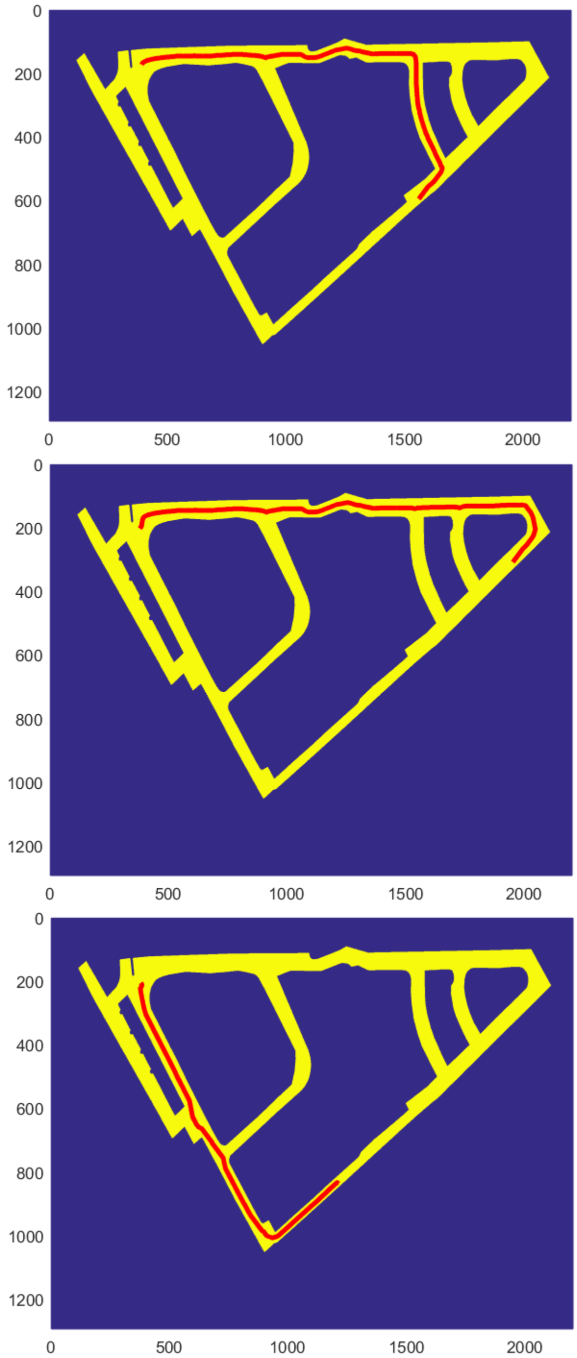

Fig. 6. Examples for the realisable paths

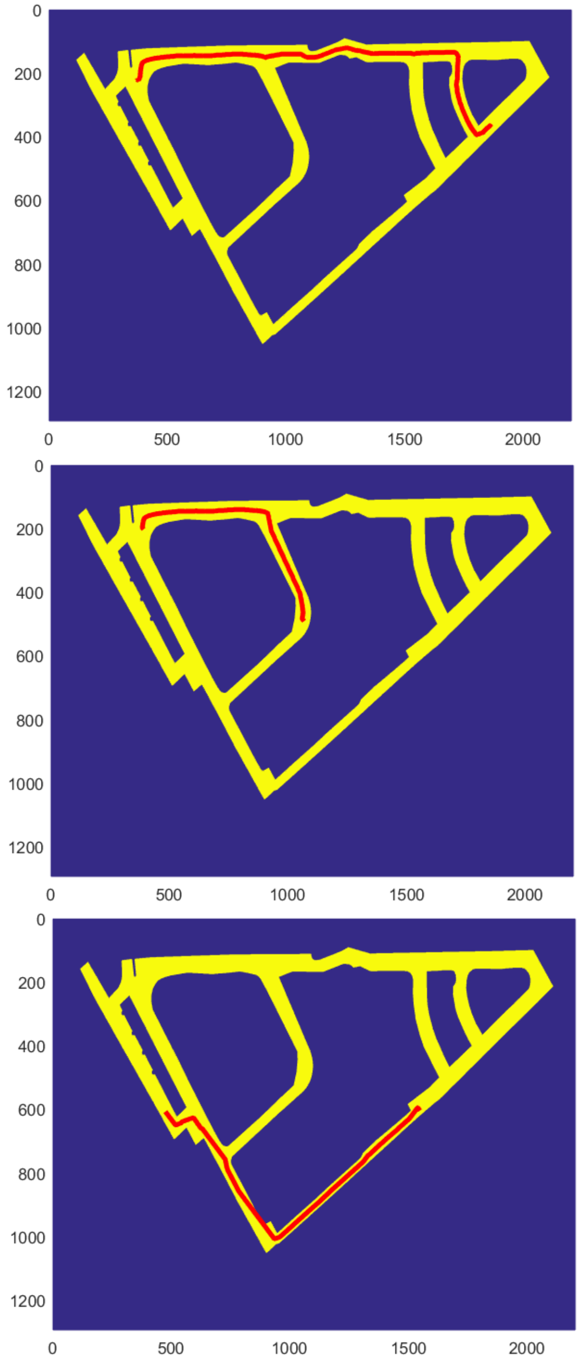

Fig. 7. Examples for the realisable paths

6. Concluding remarks

In this paper, a basic trajectory planner algorithm was presented for automated vehicles. The algorithm handled a point-like vehicle model and the obstacles on the map were fixed, there were not any other road users. The speed of the vehicle assumed to be enough slow to neglect the dynamical properties of the vehicle.

In the first section of the paper, the map making was presented. The map shows an existing area about as a binary matrix. The next step was to pre-process the map. With the filtering, a potential surface showed the distance from the edges on the roads. The potential surface was also given as a matrix. By the map and the potential surface a graph was generated where the nodes were the elements of the road-matrix, the edges were the distances between the nodes. By the potential surface the edges weighted: the distances were lower on the middle areas of the roads. By these pre-considerations the "shortestpath" algorithm gave as a result the shortest path between the start and the target node. The curve ran with an appropriate distance from the edges.

In further research, the applied graph should be simplified for faster computing. By directed graph the traffic rules can be considered. An example for that can be seen in Fig 8. Also an important step will be a collision checking and a use of a car model to check its capabilities with the required path. The final aim is to realize the valet parking function on the automated car of the university.

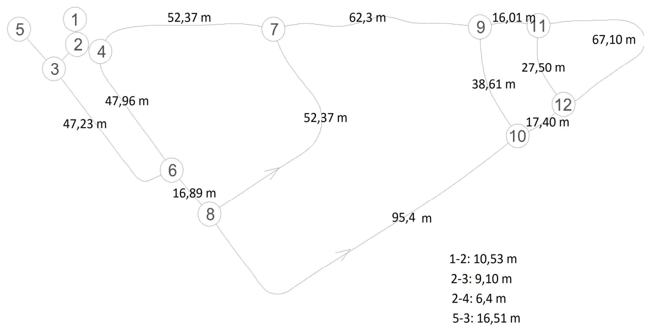

Fig. 8. A simplified directed map

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自主车辆的离线路径规划方法

關鍵詞
连接和自动车辆
自动驾驶
自动驾驶汽车
轨迹规划
路径规划

摘要
驾驶公路车辆在控制它方面是一项非常复杂的任务，用计算机代替人类驾驶员也是技术方面的真正挑战。车辆控制的一个重要步骤是车辆计划自己的轨迹。轨迹规划的输入是乘客的目的和车辆的环境。轨迹规划过程有几个部分，例如路径曲线的几何形状或路径中的速度。此外，交通状况还可以确定规划过程中的许多其他参数。
本文介绍了一种轨迹设计的基本方法。为达到目标，地图将以二进制2204 x 1294大小矩阵的形式给出，其中道路将由1定义，障碍物将由零定义。目的是制定一种算法，该算法能够在起点和目标点之间找到最短且适合车辆的方法。车速将会很慢，忽略车辆的动力特性。该研究是在自动驾驶汽车中实现自动停车功能的第一步