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Original Research Paper

Learning from the crowd: Road infrastructure monitoring system

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HIGHLIGHTS

- The paper proposes a system to autonomously and comprehensively monitor the road infrastructure condition.
- The designed methods could incorporate an automatic collection of ground truth data for supervised machine learning.
- The algorithms to compare trajectories are tested in terms of runtime.
- The results suggest to use a range search algorithm coupled with Euclidean distance.

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ABSTRACT

The condition of the road infrastructure has severe impacts on the road safety, driving comfort, and on the rolling resistance. Therefore, the road infrastructure must be monitored comprehensively and in regular intervals to identify damaged road segments and road hazards.

Methods have been developed to comprehensively and automatically digitize the road infrastructure and estimate the road quality, which are based on vehicle sensors and a supervised machine learning classification. Since different types of vehicles have various suspension systems with different response functions, one classifier cannot be taken over to other vehicles. Usually, a high amount of time is needed to acquire training data for each individual vehicle and classifier.

To address this problem, the methods to collect training data automatically for new vehicles based on the comparison of trajectories of untrained and trained vehicles have been developed. The results show that the method based on a *k*-dimensional tree and Euclidean distance performs best and is robust in transferring the information of the road surface from one vehicle to another. Furthermore, this method offers the possibility to merge the output and road infrastructure information from multiple vehicles to enable a more robust and precise prediction of the ground truth.

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1. Introduction

According to the German Federal Statistical Office in 2015 more than 10 billion of Euros were spent on road maintenance projects in Germany to repair road damages (Federal Statistical Office, 2016a). The condition of the road infrastructure is related to rolling resistance and therefore to the amount of CO_2 emissions of combustion engines. Moreover, it affects the range of electric vehicles, driving comfort, vehicle operating costs, and the economy of the country (Ahlin and Granlund, 2002; Molenaar and Sweere, 1981; Soliman, 2006). Faulty streets also have a great influence on the road safety (Ihs, 2004). The German accident statistics prove that more than 1200 accidents were related to road hazards in 2015 (Federal Statistical Office, 2016b). Many roads are regularly inspected by qualified staff to decrease the risk of accidents. A municipality must check the streets in regular intervals and repair all occurred damages in reasonable time. On high heavily busy roads, this happens several times a week, sometimes even daily. In larger cities, many trained inspectors survey the road network daily to log damages of any kind. Smaller communities normally face fewer resources to check their road infrastructure. However, such areas do not have fewer road kilometers that need to be controlled. The road network size in Germany of irregular investigated streets, such as country roads, has a length of 504,700 km and the size of frequently surveyed road, such as national highways, is only 176,800 km (Federal Statistical Office, 2013).

To improve the procedure and enable an autonomous road condition monitoring, we developed a method to estimate the road quality comprehensively and automatically in short and regular intervals. Therefore, we are able to detect many safety related road damages in almost real time. The method is based on a low-cost measurement device, which consists of an inertial sensor and a GPS sensor and is placed near the center of gravity of the vehicle (Masino et al., 2016). Based on a machine learning algorithm and statistics calculated from vibrations and dynamics of the vehicle the system can classify road infrastructure features and estimate the condition. A physical model, which needs lots of computational time and additional sensors at the suspension system of the vehicle, is not required. Since vehicles have different suspension systems, a machine learning model for one vehicle cannot be taken over to other vehicles. They must be trained manually to achieve a high accuracy of classification. Our method addresses this problem and presents an algorithm to collect the required training data automatically. It is based on a comparison of new trajectories to existing ones of trained vehicles.

The developed method can also be used to compare the output of already trained vehicles with each other to provide a more robust and more precise prediction of the road condition and to enable trend recognition by compare trajectory segments with the same location but different timestamps. Overall, with our proposed method, a periodic monitoring of roads can be guaranteed easily. Our system can strongly improve the road safety and quality at comparatively little expense while decreasing the manual and financial effort.

2. Relevant work

There has been research on road infrastructure monitoring based on vehicle sensors, such as accelerometers or acoustic sensors, and machine learning or filters, e.g., Chen et al. (2013), Eriksson et al. (2008), Masino et al. (2017a,b) and Seraj et al. (2016). However, to our knowledge no method has been developed to train new vehicles automatically based on the comparison of trajectories and to get a higher accurate prediction based on the fusion of the information from multiple vehicles.

2.1. *Recognition of street events*

In 2008 the Massachusetts Institute of Technology presented a system that recognizes potholes autonomously (Eriksson et al., 2008). For this purpose, seven taxicabs in Boston were equipped with measuring systems. For each taxicab, a triaxial acceleration sensor measured the vehicle dynamics with a sample rate of 380 Hz and the time, location, speed and direction were acquired from the GPS sensor with 1 Hz. The GPS sensor standard deviation was 3.3 m. The taxi fleet consisted exclusively of the model Toyota Prius from different years of construction. The taxicabs collected 2492 km road data within ten days. The following street event classes were considered good street, pedestrian crossings with thick paint, railway crossings, potholes, manholes, hard stops, turns. The data were labeled with the object, which was run over with the vehicle. A series of filters were applied to the data set to distinguish potholes from other events. Other classes like manholes could not be detected. To test the algorithm, it is applied to both the training data and the large data set from the taxicab fleet. After repeating these tests with random parts of the training data set, potholes could be detected with an accuracy of 92.4%. On well-conditioned roads, the false positive rate lay between 0.12% and 0.63%. On roads with potholes, the false positive rate increased to 14.0%. The algorithm detected 48 potholes in the big data set. A manual verification showed that 39 of these events were actual potholes.

RoADS System from 2014 was intended to recognize road damages and anomalies using smartphones, which were firmly attached to the windscreen of the test vehicles (Seraj et al., 2016). The smartphones had a three-axis acceleration sensor, a gyroscope and a GPS sensor, which were sampled at a frequency of 93 Hz. 45.9 km of road data were collected in two cities by using five different vehicles. In total 100.3 km were traveled. To generate the test data set different street events were run over and the passenger labeled all the important features with an audio recording. The collected data was preprocessed and divided into three classes.

(1) Severe events: sunken manholes, potholes and poorly preserved or heavily patched road sections.
(2) Mild events: all anomalies that occur on only one side of the vehicle, for example cracks, one side patches or one side bumps.
(3) Span events: all events, which extend over the entire width of the road, for example speed bumps, pedestrian crossings, expansion joints and large patched areas.

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