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Accurate lateral positioning from map data and road marking detection

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ABSTRACT

We are witnessing the clash of two industries and the remaking of in-car market order, as the world of digital knowledge recently made a significant move toward the automotive industry. Mobile operating system providers are battling between each other to take over the in-vehicle entertainment and information systems, while car makers either line up behind their technology or try to keep control over the in-car experience. What is at stake is the map content and location-based services, two key enabling technologies of self-driving cars and future automotive safety systems. These content-based augmented geographic information systems (GIS) as well as Advanced Driver Assistance Systems (ADAS) require an accurate, robust, and reliable estimation of road scene attributes. Accurate localization of the vehicle is a challenging and critical task that natural GPS or classical filter (EKF) cannot reach. This paper proposes a new approach allowing us to give a first answer to the issue of accurate lateral positioning. The proposed approach is based on the fusion of 4 types of data: a GPS, a set of INS/odometer sensors, a road marking detection, and an accurate road marking map. The lateral road markings detection is done with the processing of two lateral cameras and provides an assessment of the lateral distance between the vehicle and the road borders. These information coupled with an accurate digital map of the road markings provide an efficient and reliable way to dramatically improve the localization obtained from only classical way (GPS/INS/Odometer). Moreover, the use of the road marking detection can be done only when the confidence is sufficiently high (punctual use). In fact, the vision processing and the map data can be used punctually only in order to update the classical localization algorithm. The temporary lack of vision data does not affect the quality of lateral positioning. In order to evaluate and validate this approach, a real test scenario was performed on Satory's test track with real embedded sensors. It shows that the lateral estimation of the ego-vehicle positioning is performed with a sub-decimeter accuracy, high enough to be used in autonomous lane keeping, and land-based mobile mapping.

1. Introduction: map and localization in intelligent vehicles

The most prominent providers of digital content and operating system for mobile device, Google, Apple and Microsoft have announced their actions toward taking over the in-car infotainment system with their rival OS for mobile device and products dedicated to vehicles (CarPlay, Android Auto, and Windows Mobile) with a forecast of 420 Million cars connected by 2018 (Ropert 2014) (including users with only a smartphone). Applications with the most market penetration are the Geographic Information Systems (GIS) and navigation systems: people tend to use their smartphone instead of the car's dashboard. With Google Map and Street View product, Google is a step ahead, and now with their driverless car they paved the way for augmented data encoded in their map. Apple followed the way and is now driving vehicles around the world to collect data to improve the Apple Maps (Apple 2015). Recently, a consortium made of Audi, BMW and Daimler agreed to pay 2.5 billion euros ($2.7 billion) to purchase Nokia's digital mapping service "Nokia Here". The car makers feared that Nokia Here's technology, the most advanced digital map of the world's major road network, would fall into the hands of Google, Apple or even Uber (d'Onfro 2015), with risk of losing control of information systems inside the car that are vital to self-driving cars and future automotive safety systems (Boston 2015).

Unlike navigation services that people use to get to their destination, partially or fully self-driving cars need infallible information about the road ahead in real-time. A 3D high-definition digital representation of the road conditions updated dynamically. In this representation, vehicle's location (derived from its ego-localization) and road lane marking are critical-to-quality factors.

Ego-localization of a vehicle is a mandatory component of such intelligent vehicle or advanced driver assistance system. Direct applications range from navigation (automated driving or assistance) like smart parking solutions (Lan and Shih 2014), autonomous lane

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change system Martin et al. (2014), automatic overtaking Milanez et al. (2012), collision warning Chang, Tsai, and Young (2010) to cooperative maneuvers based on communications involving several vehicles Perez, Milanez, Godoy, and Villagra (2013). Three levels of accuracy can be determined, depending on the application: a standard navigation system would use a macro-scale map, an autonomous lane change system would need information at the ego-lane level (which lane is the vehicle in), while critical-to-safety systems or highly automated driving would require an accuracy of few centimeters.

Navigation systems embedded in cars or mobile applications (TomTom, GoogleMap) provide a map-matched position of the vehicle by correlating measurements from a GPS receiver to a digital map database. The accuracy of such satellite navigation devices is limited typically to 5 to 10 m, which comply to the requirements of a display system giving turn-to-turn navigation directions to the driver, other examples are fleet management systems through GPS-tracking or traffic jam assistant.

Ego-lane level accuracy is required to perform semi-autonomous driving tasks such as lane keeping, vehicle platooning, or cooperative systems applications (using vehicle-to-vehicle communications) such as collision-free trajectories prediction You et al. (2015) or extended map. It is also necessary for warning system such a lane departure or wrong way driver warning.

For a more advanced mode of automation such as highly automated driving, without real-time input from a human operator, localization at a microscopic level is required (lateral and longitudinal), especially at high speed. Self-driving cars or automated overtaking maneuvers, for instance.

2. Related works

So, vehicles localization is at the core of development and optimization of reliable transportation systems. Several types of sensors are commonly used in the automotive market. They can be classified into three types:

- relative positioning sensors: odometer, Inertial Measurement Unit IMU (gyroscope, accelerometer), steering encoder,
- absolute positioning sensors: GPS receiver, magnetic compass.
- One can add to this list perception sensors such as camera, Lidar, radar and sonar, which can be post-processed to evaluate the motion of the vehicle (visual odometry) and can therefore be listed as relative positioning sensors.

In order to improve accuracy and reliability of the localization, combining the output of different sensors is a requirement. Several data fusion methods are used: non-linear filtering, Kalman filters or Interactive Multi-Models (IMM) for instance. Most of them try to enhance GPS accuracy, especially in the case of poor satellites coverage area, signal blockage by buildings, multipath in urban canyon, atmospheric conditions, or dilution of precision. In this case, navigation is done by dead-reckoning (Milanez et al. 2012; Perez et al. 2013): odometer, IMU and steering encoder are used to evaluate the motion (yaw angle and traveled distance) of the vehicle and deduce its path.

Standard IMUs are effective enough to ensure an ego-lane level of accuracy GPS/IMU fusion is vulnerable to residual errors so a continuous monitoring of the process is necessary to guarantee that the quality of the vehicle positioning is acceptable: dead reckoning approaches suffer from integration errors that grow unbounded with respect to operation time.

To ensure robustness and accuracy, the trend amongst equipment manufacturers, car makers and research teams is to make use of heavy equipment. In the Urban Challenge DARPA 2007, all contender vehicles were equipped with several multilayer Lidar scanner, RTK-GPS military-grade IMU, radars, sonars, cameras… The course involved a 96 km (60 mi) urban area course, to be completed in less than 6 h. Rules included obeying all traffic regulations while negotiating with other traffic and obstacles and merging into traffic. The winner team of the challenge averaged approximately 14 mph (22km/h) throughout the course. All challengers managed to end the course, but such equipment is not affordable enough to make a notable market penetration in a near future.

Another example is the Google driverless car. It is able to do impressive automated tasks because Google had the resources to develop an extremely expensive mapping system encoding the exact three-dimensional location of streetlights, stop signs, crosswalks, lane markings, and other important aspects of a roadway. These maps are much more complicated than what one would find in an OpenStreet Maps or Google Maps though; a bank of sensors including a high precision RTK-GPS and a Velodyne Lidar scanner (70k$), need first to make repeated passes scanning the roadway to be mapped, and the data are labeled by both humans and computers. The process it currently uses to make the maps are too inefficient to work in the US country as a whole (Gomes 2014).

Low cost or close-to-market approaches can use visual odometry (Martin et al. 2014) or SLAM (Simultaneous Localization and Mapping) to correct dead-reckoning navigation, but these approaches still suffer from an accumulation of drift resulting in poor localization after a few kilometers have been travelled. A possible way to reduce this effect requires the driver to drive in loops, loop closures enabling a compensation for localization errors.

Recently, an interesting line of research has emerged that perform image based localization using large geo-tagged image databases acquired from specially equipped platforms LeBarz, Thome, Cord, Herbin, and Sanfourche (2015) Zamir and Shah (2010) (Street View data). Ego-localization is based on matching the image acquired from the vehicle's cameras to an image database. Although localization results are promising, the large image databases required for these systems make them expensive to build up and maintain for real-world applications.

Structural approaches using higher level features are less demanding in term of computation load assuming the road network has been surveyed accurately beforehand. They rely on ground markings such as arrows, speed limit, or texts (Nedevschi, Popescu, Danescu, Marita, & Oniga 2013; Ranganathan, Ilstrup, & Wu 2013; Wu & Ranganathan 2013), visual landmarks (Lategahn, Schreiber, Ziegler, & Stiller 2013), traffic signs (Qu, Soheilian, & Paparouditis, 2015) or lane markings (Kim, Chung, & Yi 2015; Schindler 2013; Tao, Bonnifait, Fremont, & Ibanez-Guzman 2013).

In Ranganathan et al. (2013) Wu and Ranganathan (2013) the absolute position of corners of ground markings (such as arrows, speed limit, or texts) were precisely surveyed and matched to corners detected by FAST with a camera in order to estimate its pose and location. In (Lategahn et al. 2013), a vehicle with a backward facing camera is used to create a 3D landmarks map of the environment. Landmarks are matched into the current image and back projection errors are minimized yielding a rough single shot pose estimate. IMU measurements are merged with past single shot estimates yielding the final ego-pose. In (Nedevschi et al. 2013), a method to improve global localization in an intersection is based on the alignment of visual landmarks with the information from an extended digital map. A stereovision system provides a detailed 3D perception of road landmarks such as lateral lane delimiter, painted traffic signs, curbs and stop lines. Combination of visual and enriched map of the intersection is done with a Bayesian network, yielding to a global localization with a sub-meter level of accuracy.

Recently, Tao et al. (2013) proposed an EKF-based algorithm fusing GPS, IMU and lane marking information: they have shown that the use of visual features can improve the lateral localization up to a centimeter-level accuracy (less than 30 cm). Their experimental