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# Robust and ubiquitous smartphone-based lane detection☆

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ABSTRACT

Lane-level positioning is required for several location-based services such as advanced driver assistance systems, driverless cars, predicting driver's intent, among many other emerging applications. Yet, current outdoor localization techniques fail to provide the required accuracy for estimating the car's lane.

In this paper, we present *LaneQuest*: an accurate and energy-efficient smartphone-based lane detection system. *LaneQuest* leverages hints from the ubiquitous and low-power inertial sensors available in commodity off-the-shelf smartphones about the car's motion and its surrounding environment to provide an accurate estimate of the car's current lane position. For example, a car making a u-turn, most probably, will be in the left-most lane; a car passing by a pothole will be in the pothole's lane; and the car angular velocity when driving through a curve reflects its lane. Our investigation shows that there are amble opportunities in the environment, i.e. lane "anchors", that provide cues about the car lane. To handle the ambiguous location, sensors noise, and fuzzy lane anchors; *LaneQuest* employs a novel probabilistic lane estimation algorithm. Furthermore, it uses an unsupervised crowd-sourcing approach to learn the position and lane span distribution of the different lane-level anchors.

Our evaluation results from implementation on different Android devices and driving traces in different cities covering 260 km shows that *LaneQuest* can detect the different lane-level landmarks with an average precision and recall of more than 91%. This leads to an accurate detection of the exact car lane position 84% of the time, increasing to 92% of the time to within one lane. This comes with a low-energy footprint, allowing *LaneQuest* to be implemented on the energy-constrained mobile devices.



## 1. Introduction

Recently, there has been a growing number of location-based services (LBS) that require knowledge of the car's lane position including advanced driver assistance systems (ADASs) [1], autonomous cars (e.g. the Google driverless car [2]), lane-based traffic estimation, electronic toll fee collection [3], predicting driver's intent [4,5], among others. However, current state-of-the-art outdoor vehicular navigation systems can only provide an accuracy of about 10 m in urban environments [6]. Hence, they fail to provide an estimate of the vehicle's exact lane (Fig. 1).

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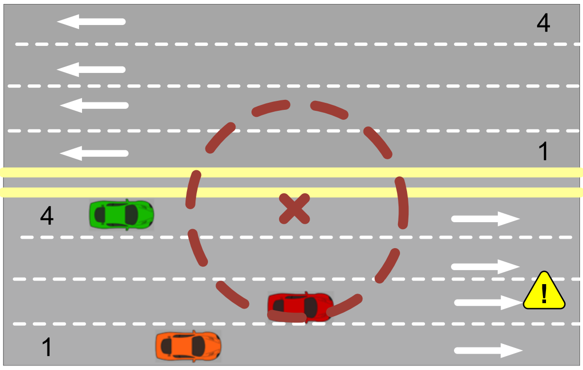


**Fig. 1.** Current outdoor localization technologies fail to provide enough accuracy to estimate the car lane position. The '×' mark denotes the GPS position and the circle the associated error. While the red car is moving in the 2nd lane, an error around 3 m moves its estimate to the 4th lane. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

A number of systems were proposed to provide lane-level localization accuracy [7–12]. However, these systems require special sensors to be installed on all vehicles (e.g. the RF sensors in [11]) and/or an expensive calibration phase (e.g. [7–10]), limiting their ubiquitous deployment. Computer vision based techniques, e.g. [12], use a camera to detect the lane markings. However, using an image processing solution raises accuracy challenges when road markings are unclear, line-of-sight is obstructed, and/or in bad weather conditions (e.g. raining). It also requires extensive energy and processing power from commodity smartphones.

In this paper, we present *LaneQuest*; a system that leverages the ubiquitous sensors available in commodity smartphones to provide an accurate and energy-efficient estimate of the car current lane. Starting from an ambiguous coarse location estimate, e.g. reported by the GPS, *LaneQuest* leverages driving events detected by the phone sensors to reduce this ambiguity. Specifically, *LaneQuest* uses the low-energy inertial sensors measurements to recognize unique motion events while driving such as changing the lane, turning right, or passing over a pothole. These events or "lane anchors" provide hints about the car current lane. For example, a car making a left turn most probably will be in the left-most lane; Similarly, potholes typically span only one lane, allowing detecting the lane of cars that pass by them. *LaneQuest* uses a crowd-sensing approach to detect a large class of lane anchors as well as their positions through the road network and the lanes they span, exploiting them as opportunities for reducing the ambiguity in lane estimation.

To address the sensors' noise, location ambiguity, and error in anchors location estimation; *LaneQuest* models the lane detection problem as a Markov-localization problem that combines the vehicle's motion events (such as changing lanes) with lane anchor detection in a unified probabilistic framework. We have implemented *LaneQuest* on different Android devices and evaluated it using driving experiments at different cities covering more than 260 km. Our results show that *LaneQuest* can detect the different lane anchors with an average precision and recall of 93% and 91% respectively. This leads to accurately detecting the car lane more than 84% of the time, increasing to 92% to within one lane error. Moreover, *LaneQuest* has a low-energy profile when implemented on top of different localization techniques.

In summary, our main contributions are summarized as follows:

- We present the *LaneQuest* architecture: an energy-efficient crowd-sensing system that leverages the sensed lane-anchors along with the vehicle's dynamics to provide an accurate robust estimate of the car's current lane position without any prior assumption on her starting lane position.
- We provide the details of a unified probabilistic framework for robust detection of the vehicle's driving lane position.
- We propose a crowd-sensing approach for detecting the road and lane position for different types of lane anchors. The proposed technique captures the inherent ambiguity in the crowd-sensing process.
- We implement *LaneQuest* on Android phones and evaluate its performance and energy-efficiency in different cities using different smartphone devices.

In an earlier work [13], we proposed a preliminary version of the *LaneQuest* system presented in this paper. However, in this paper we have extended the work in [13] significantly. Specifically, we propose a new lane estimation algorithm (*minErr*) to provide more robust and accurate estimates. The proposed method enhances the lane estimation accuracy by more than 20% compared to the method in [13]. In addition, it reduces the errors incurred during the transient period significantly. We also add a new curvature estimation method. The new method works with phones that do not support the gyroscope sensor and enables our system to cope with different heterogeneous devices. Moreover, we propose a new lane-change algorithm detection. The proposed algorithm improves the accuracy of detecting both left and right lane changes by 26.8% and 7.3% respectively as compared to the conference version.

The rest of the paper is organized as follows: we discuss the related work in Section 2. Section 3 presents an overview of the system architecture. Sections 4 and 5 give the details of the *LaneQuest* system and event detection framework. We discuss the different aspects of the system in Section 6. Section 7 provides our evaluation of *LaneQuest*. Finally, we conclude the paper and give directions for future work in Section 8.