IMU and Passive Resonator Localization System for Autonomous Vehicles

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I. INTRODUCTION

All-electric autonomous vehicles (AVs) carry many advantages over internal-combustion and non-autonomous modes of transportation. Existing obstacles to widespread adoption of electric AVs include limited battery energy storage, initial cost, and the current limitations of vehicle automation. One approach to addressing these issues is the development of "connected autonomous vehicles" (CAVs) [4]. CAVs can rely on communication with a network of other connected vehicles and information systems to determine the state of the vehicle and its surroundings. CAVs can also benefit from dynamic wireless power transfer (DWPT), sometimes called "in-lane charging." DWPT for electric vehicles uses a primary coil embedded in the roadway to transmit power to a secondary coil on the vehicle. DWPT mitigates the initial cost and limited battery energy storage of electric AVs by decreasing required battery capacity and providing opportunities to recharge without stopping the vehicle. DWPT relies on precise alignment between the coils (on a scale of centimeters), and this precise alignment requires accurate state measurements of the vehicle. Current AV technology has difficulty determining vehicle state in rain, snow, and other poor visibility conditions due to its reliance on visual line-of-sight sensors and imprecise or limited GPS.

A. Literature Review

Existing research on vehicle localization has considered systems that do not use line-of-sight sensors (LiDAR and cameras) or GPS. Cortes [1] developed a method to sense lateral misalignment in inductive power transmission wireless charging systems using received signal strength indicator (RSSI) measurements. Cortes's research focused on static charging systems, determining the impact of vertical and horizontal spacing of the primary and secondary coils on position measurements. The results show that misalignment direction can be determined consistently with RSSI measurements, but misalignment magnitude is difficult to determine from the non-linear signal output of the sensing coils.

In [6], a phase difference of arrival (PDOA) method is used with RFID tags to localize mobile robots in an indoor environment. Compared to using a RSSI method, the PDOA method proved through simulation to have less error. The PDOA method is less susceptible to multipath signal propagation. The researchers in [6] also implemented a Kalman Filter to fuse relative positioning data from encoders with the absolute positioning data from the RFID tags. In a similar study, Hekimian-Williams et al [3] conducted physical experiments that showed localization accuracy on a scale of millimeters is achievable with a RFID PDOA system. Hekimian-Williams et al indicated how physical experiment results are directly relevant to localization applications (as opposed to purely simulated results), but it should be taken into account that the physical experiment results may depend on ideal conditions.

Other work has focused on localization in GPS-denied or GPS-limited environments. Whitaker et al [5] conducted simulations to determine the performance of "self-describing fiducials" fused with IMU data via an extended Kalman Filter (EKF) for ground-vehicle localization in GPS-denied environments. Similar fiducials are commonly used with cell-phone cameras to give the phone information relevant to the marker location. Whitaker et al determined that such a system is heavily dependent on sensor quality, but the system could provide acceptable error levels even with a consumer grade IMU. Future work along this track could include incorporating fiducial location uncertainty into the model.

Costley and Christensen in [2] developed a navigation framework that incorporates LiDAR object detection with IMU measurements to work in GPS-limited environments. The LiDAR object detection and IMU measurements are fused via an EKF to estimate the state of simulated vehicle in an orchard. The paper provides a performance evaluation that compares the position estimate error covariance of the system with the LiDAR measurements and without LiDAR. The results show a minimum of 90% improvement in 3-σ deviation for the system incorporating LiDAR over the system that did not incorporate LiDAR.

B. Proposed Contribution

This work proposes a simulation to predict the performance of a localization system for road vehicles utilizing an industrial grade IMU and PDOA method using passive circuit resonators. The PDOA method will be similar to the technology used in [6] and [3]. IMU data will be used to propagate the state of the vehicle and PDOA data will be used for state updates. Data from both subsystems will be fused via an EKF to estimate vehicle state. Performance

will be measured by position estimate error covariance, and the system incorporating PDOA measurements will be compared to a system that uses only an IMU. The sensitivity of the design to measurement errors, road coil spacing, and vehicle coil configuration will be analyzed. After determining the performance of the proposed system, the feasibility of using such a system for DWPT alignment and general vehicle automation will be considered.

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