Autonomy for Mobility on Demand

Z. J. Chong, B. Qin, T. Bandyopadhyay, T. Wongpiromsarn, B. Rebsamen, P. Dai, S. Kim,
M. H. Ang Jr., D. Hsu, D. Rus and E. Frazzoli

***Abstract*— We present an autonomous vehicle providing mobility-on-demand service in a crowded urban environment. The focus in developing the vehicle has been to attain autonomous driving with minimal sensing and low cost, off-the-shelf sensors to ensure the system's economic viability. The autonomous vehicle has successfully completed over 50 km handling numerous mobility requests during the course of multiple demonstrations. The video provides an overview of our approach, with special comments on our localization and perception modules showcasing one such request being serviced.**

***Index Terms*— Mobility-on-demand, and self-driving car.**

I. Introduction

With the urban transportation infrastructures reaching their limit due to ever increasing personal transportation systems, mobility-on-demand (MoD) systems operating on shared resources are becoming a viable alternative [1]. While successful in increasing resource utilization, the systems usually suffer from resource depletion at less frequented stations. Although there have been many proposals to realize the MoD systems, a means of transporting the vehicles for the rebalancing trips remains an open problem.

Vehicle autonomy is considered as an efficient solution to automatically rebalance vehicles among stations with asymmetric resources, and enable a one-way vehicle sharing option in MoD systems. The ability of vehicles to drive autonomously in urban scenarios has matured as evidenced by the results of the DARPA Urban Challenge (DUC) [2]. However, the developed vehicles depend on a variety of sensors, some of which are prohibitively expensive while others are highly specialized, causing the deployment to be economically infeasible.

The main contribution of this work is to develop an autonomous vehicle testbed that, unlike most existing systems, uses minimal sensing and off-the-shelf components for attaining the same level of operational ability while making the system economically viable. The video shows the essential demonstrations of this work along with the MoD scenario.

Z. J. Chong, B. Qin, M. H. Ang Jr., and D. Hsu are with the National University of Singapore, {chongzj, baoxing.qin, mpeang, dyhsu}@nus.edu.sg.

T. Bandyopadhyay, T. Wongpiromsarn, B. Rebsamen, P. Dai, and S. Kim are with Singapore-MIT Alliance for Research and Technology, Singapore, {tirtha, nok, brice, peilong, sungwoo}@smart.mit.edu.

D. Rus and E. Frazzoli are with Massachusetts Institute of Technology, Cambridge, MA., USA, rus@csail.mit.edu, frazzoli@mit.edu.

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II. System Description

Currently we have a single vehicle providing MoD service between four stations. Passengers can request a pickup using a smart phone or a web interface. The request is sent to a scheduler running on a central server, which places the request at a proper position of the request queue so as to optimize the vehicle route and passengers waiting time. Once the vehicle finishes servicing a request, the scheduler forwards the next request on the queue to the vehicle.

A. Hardware

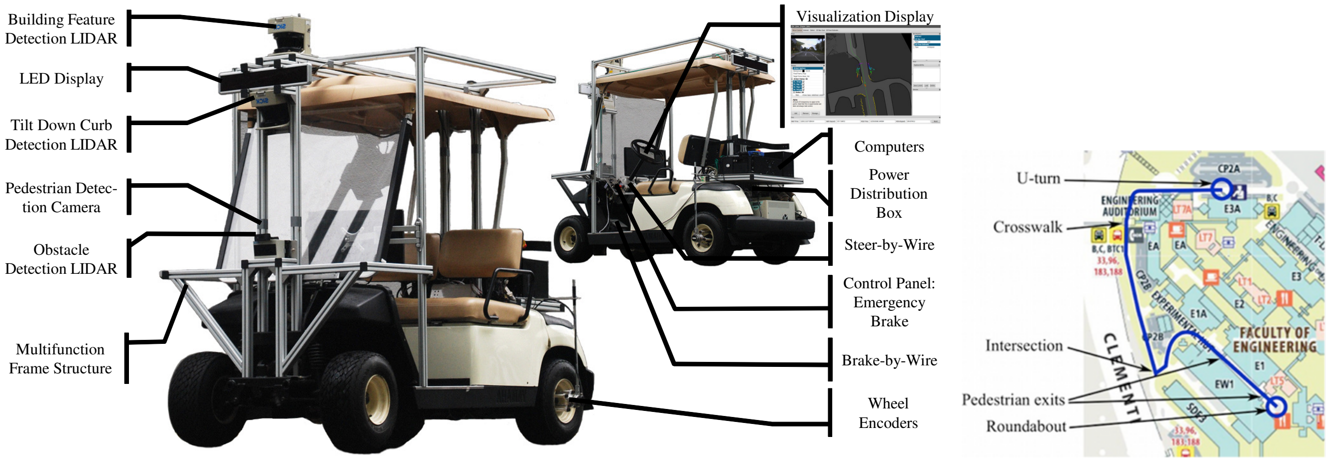
Our vehicle is based on an electric golf car, as shown on Figure (a). We utilize three 2-D LIDARs and a simple webcam to achieve required perception and wheel encoders and a dual axis gyroscope to measure the vehicle's speed and orientation. We actively avoid using GPS or expensive INS systems, or 3-D LIDARs to keep the vehicle costs down.

All computations are performed by two regular desktop PCs with Intel i7 quad-core CPUs running Ubuntu Linux. The software, from data acquisition to the navigation modules, was developed as a modular architecture using the Robot Operating System (ROS) [3] suite and using only open source libraries.

B. Perception

Autonomous driving requires the robust detection of static obstacles like road dividers as well as moving pedestrians and vehicles on the road. By using 2D-LIDAR, however, it is difficult to distinguish the kind of obstacles like lamp posts, pillars or pedestrians on the sidewalk. While many systems in DUC used an overhead 3-D LIDAR, it is prohibitively expensive for our purpose. Vision systems provide an economical alternative to detecting and identifying features but in many cases fail to provide sufficient distance information crucial to avoiding obstacles.

To overcome this problem, we developed a pedestrian detection system that combines information from a single planar laser-range finder and a simple webcam for pedestrian detection. The points from the LIDAR are clustered based on their spatial disparity. A subset of the camera image corresponding to potential pedestrian clusters are sent to a Histogram of Gradient (HoG) [4] based person detector for identification. More details are provided in [5]. Besides, such an approach could be generalized to detecting other objects, such as vehicles.



(a) Vehicle configuration

(b) Route of the autonomous vehicle

C. Localization

Robust localization is essential for autonomous navigation. Most autonomous vehicles depend on a combination of good GPS-INS systems. In an urban environment, however, the utility and accuracy of GPS for autonomous driving is limited by the multi-path problem and satellite occlusion due to high buildings, overhead driveways, and underpasses. A key component of our work is developing a vehicle localization system that is not dependent on the GPS or other expensive DGPS-INS systems. For this purpose, we utilize information from the road network itself that is usually available a-priori.

One of the most prominent features on an urban road is the curb. The lack of curbs indicate an intersection or a junction of two or more roads. The combination of curb and intersection features and their idiosyncrasies carry significant information about the urban road network, which can be exploited to improve vehicle's localization.

On our vehicle, curb information is observed from the tilted downward LIDAR, and fused with odometry information under the MCL framework. Our results prove that this system is able to yield precise localization and robust performance even in the presence of temporary occlusion from other vehicles and pedestrians. More details are in [6].

D. Navigation and Control

Since the vehicle navigates on a known road network, the navigation problem can be simplified by following predefined routes. Navigation is thus reduced to path following, which is implemented as a pure pursuit controller [7], and speed control.

The speed controller is made of three components: 1) a static speed profile hard-coded in the path definition, which takes into accounts information such as road condition, path curvature, etc., 2) a reactive component to stop in the presence of obstacles, and 3) a PID speed controller to achieve the resulting velocity command. The reactive component generates a velocity profile that causes the vehicle to slow down when an obstacle is detected in its trajectory, so as to stop a few meters in front of it. A rolling cost map centered on the vehicle, which incorporates information from the proximity sensors, is used for obstacle detection.

III. Conclusions and Future Work

We showed the feasibility of economically viable vehicle autonomy applicable to several interesting scenarios such as MoD services. Our vehicle has covered in total over 50 km autonomously servicing numerous requests from visitors and dignitaries during the course of multiple demonstrations held over the past six months. While the vehicle currently operates in a restricted section of the National University of Singapore campus, the route, as shown on Figure (b), has representative segments of a typical road network. In additional, being on campus, the vehicle has to be more conservative in dealing with other vehicles and potentially distracted student pedestrians.

Currently we are working towards increasing the number of stations serviced by this vehicle. We are also in the process of incorporating more autonomous vehicles to provide a more comprehensive MoD system. We believe that this is one important step towards future urban mobility with safe and convenient public transportation.

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