Mobility21

A USDOT NATIONAL UNIVERSITY TRANSPORTATION CENTER

Carnegie Mellon University

Penn
University of Pennsylvania

The Ohio State University

CCAC

# Towards a Smart, Safe, and Sustainable Sidewalk: A Quantitative Analysis on How Sidewalk Infrastructure Affect Personal Delivery Devices

Ding Zhao (0000-0002-9400-8446),
Zhiwei Steven Wu (0000-0002-8125-8227)

FINAL RESEARCH REPORT

Contract # 69A3551747111

**Problem:**

The deployment of Personal Delivery Devices (PDDs) has been troubled by the soaring cost of operations and the public's concerns about the safety and robustness issues potentially brought by the new mobility. As leading companies such as Amazon, Nuro, and Starships which have obtained permits to commercialize their PDDs fleets in many cities, it is urgent to investigate how to develop a safe and robust mobility system from both the ego-vehicle intelligence side and the sidewalk infrastructure side that is sustainable for companies to run their business and beneficial to the public.

The project aims to investigate 1) how the sidewalk infrastructure affects PDDs and residents, and 2) how to develop a safe and robust mobility system to deal with the constraints on the sidewalks. To this end, we aim to build a delivery robot to collect data of the sidewalk ecosystem in Pittsburgh and establish a multi-modal simulator for PDDs to train a safe and robust mobility system.

**Methodology and findings**

The first-stage task is to build a high-fidelity mobile robot platform to perform data collection and mobility functionality development and evaluation. We upgraded our existing four-wheel mobile robot platform for outdoor usage with the latest sensing systems, including stereo cameras, inertial measurement unit (IMU), solid-state LiDARs, wheeled odometry, and WiFi network communication. We finished the calibration of all these sensors, which can provide accurate 3D measurement of the surrounding environment of the robot, and also developed a complete data collection pipeline based on the sensors and the onboard computer in the Robot Operating System (ROS). Furthermore, we designed a real-time human-machine interaction interface and data visualization system so that we can facilitate the data collection process and instantly monitor abnormal situations.

The second task is to process the data collected from the mobile platforms. We digitized the physical real-world road information based on the LiDAR point cloud data, the IMU pose data, and the odometry data. We further denoising the sensory data, and combine them together to perform semantic 3D point cloud-based simultaneous localization and mapping (SLAM) to extract both geometric and semantic representation from the LiDAR sensor, including the 3D map and objects semantic meaning information along the sidewalk. We also developed a perception module, which can detect the dynamic obstacles, such as pedestrians, around the robot. The perception results can help to 1) enhance the mapping quality by filtering out dynamic obstacles and 2) record pedestrian trajectories so that we could investigate the influence of different delivery robot autonomous navigation policies on pedestrians. Particularly, we adopt an image-based deep learning method to perform object detection, which can run in a high-frequency in the onboard Nvidia Xavier computer. The built high-definition map and perception module can be used in many downstream mobility modules, such as re-localization, planning, and control. We can also utilize the 3D map date to analyze the effect of sidewalks to the mobility system.

Based on the processed map and the perception module. We aim to build a full autonomy stack. In particular, we implemented a three-level planning and control module. The first level is a global router, which can plan a collision free path based on static map and A* algorithm. The second level is a local planner that can generate smooth and safe trajectories based on the waypoints generated from the router, and we have implemented a sampling-based local planner - Dynamic Window Approach (DWA), and two optimization-based planners - iterative Linear Quadratic Regulator (iLQR) and Model Predictive Control (MPC). The third level is the controller that can convert the trajectory to motor commands of the robot. With the three-level planning and control module, we can enable the robot to navigate safely and autonomously in the campus. We have validated the implemented full autonomy stack on our physical robot.

We developed a digital-twin simulation environment for our robot based on the realistic Webots simulator. With the high-fidelity simulation environment, we are able to train learning-based planning algorithms in simulation that could be deployed in the real robot in the future. We demonstrate the robot's capability of achieving point to point autonomous navigation tasks around the CMU campus, which can safely and robustly react to surrounding obstacles. We also gave a demo to a group of legislators, including four senators, and it has been featured by the CMU Engineering Department [1].

We analyze the efficiency and the fairness of coalitions of autonomous vehicles. A simplified T-intersection was modeled, due to its scalability to more complicated environments, where coalitions of autonomous vehicles either followed society's traffic rules or acted in the self-interest of their coalition. This complex multi-agent planning problem was solved by utilizing SARSA, a model-free reinforcement learning algorithm, to learn the decision-making algorithm of an autonomous vehicle company. The efficiency, defined as how quickly the vehicles could exit the T-intersection, was first analyzed for the case where the self-interest actions were unregulated. The experiments showed that this could lead to potential detrimental effects on efficiency when an autonomous vehicle coalition was not the majority in the queue. To understand how implementing a fairness regulation would impact the efficiency and fairness of these interactions, reward shaping was used to regulate the learned selfish behavior. The experiments demonstrated promising results that efficiency could be maintained, if not improved, while improving the group fairness. The corresponding paper will appear at the 2022 International Conference on Intelligent Transportation Systems (ITSC).

We also provide theoretical models that provide insights on the use of algorithms that may affect different sub-populations (e.g., residents in different neighborhoods and the communities) [2]. In the context of PDD, algorithms and predictive models may be used to determine whether PDD should be deployed in certain regions of a city, which may depend on a wide range of factors, including sidewalk quality, traffic flow during different times of the day, and the availability of curb space for parking. Our theoretical model analyzes how the heterogeneous deployment costs across different communities influence the delivery company's deployment policy.

The team has been working on a white paper with ITS America on a white paper on PDD to further disseminate the findings of this project and make a social impact.

## Conclusions

By analyzing the efficiency and the fairness of coalitions of autonomous vehicles, as they act in their self-interest of their group, we discovered that there may be detrimental effects on efficiency, although that may not be the intent of the autonomous vehicle decision-making algorithm. The experiments demonstrated that with a fairness regulation efficiency could be preserved, and even improved, while improving the fairness. Moreover, this illustrates that implementing a fairness regulation within the decision-making algorithm is a promising solution.

## References:


[1] https://www.instagram.com/p/CV5j7QJIC9q/?utm_source=ig_web_button_share_sheet

[2] Keegan Harris, Daniel Ngo, Logan Stapleton, Hoda Heidari, Zhiwei Steven Wu. Strategic Instrumental Variable Regression: Recovering Causal Relationships From Strategic Responses. The 39th International Conference on Machine Learning (ICML 2022)