Proceedings of the Second International Conference on Automotive User Interfaces and Interactive Vehicular Applications
(AutomotiveUI 2010), November 11-12, 2010, Pittsburgh, Pennsylvania, USA

Semi-Autonomous Virtual Valet Parking

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ABSTRACT

Despite regulations specifying parking spots that support wheelchair vans, it is not uncommon for end users to encounter problems with clearance for van ramps. Even if a driver elects to park in the far reaches of a parking lot as a precautionary measure, there is no guarantee that the spot next to their van will be empty when they return. Likewise, the prevalence of older drivers who experience significant difficulty with ingress and egress from vehicles is nontrivial and the ability to fully open a car door is important. This work describes a method and user interaction for low cost, short-range parking without a driver in car. This will enable ingress/egress without the doors being blocked by neighboring cars.

Categories and Subject Descriptors

H.5.2 [**INFORMATION INTERFACES AND PRESENTATION (e.g., HCI)**]: User Interfaces – *interaction styles, prototyping, user-centered design.*

General Terms

Design, Experimentation, Human Factors.

Keywords

Driver-vehicle interaction, remote driving, parking.

1. INTRODUCTION

1.1 Overview

The demographics of aging and disability are leading to an increasing need for drivers to egress and enter their vehicles from a remote location. Increasing the number of accessible parking spaces is not a tractable solution. This suggests there is value in a *Virtual Valet* that mimics regular curbside valet service.

The aging of the population is a well-known issue. For older drivers, limitations in motor abilities cause significant problems in entering and exiting vehicles [5]. Among the frail older population, a large number only use vehicles as passengers. About 50% of one large sample reported difficulties getting in and out of vehicles [16]. While some passengers can be dropped off by the driver before parking in order to permit greater enter/egress space, it may be undesirable to leave some classes of passengers alone (e.g., Alzheimer's, young children, etc.) while a car is parked. Furthermore, restrictions in rear visual field of view due to neck mobility impairments may reduce safety when backing up.

In the past 30 years, there has also been a six-fold increase in the US population of wheeled mobility users [8]. Within this population, about a quarter drive and almost a third do not live in areas with public transit services. Particularly relevant is that the "growth in wheelchair users has occurred over and above the growth of the total population" (p. 3) and this "growth far exceeds the growth in the older population" (p. 15).

Large vehicles, like vans, are particularly attractive to people who use wheelchairs due to modification options that allow ramps to be installed for easy roll-in boarding. Drivers who use wheelchairs and can transfer on their own, on the other hand, find that two door models are best for entering and exiting and loading and unloading their chairs. The doors of these models are very wide and having only one door on each side makes it possible to get the chair into the rear of the automobile. Yet, trends in automotive design are reducing the number of vehicles that have wide doors and enough space in the rear compartment to store a wheelchair.

The need for large enter/egress space and/or larger vehicle sizes severely limits parking options and reduces physical access. Likewise, many wheelchair users can recount times when they were blocked from entering their car due to neighboring vehicles. Automated parking garages [10] are a potential option, but they are cost prohibitive for installation in homes and only make the spots within the garage accessible. A solution that is not reliant on special locations supports greater destination options and is more robust to changes in residence and employment.

Automated parallel parking and docking alongside curbs was demonstrated by this research group in the mid-1990's [7] and became a market reality ten years later. We seek a similar impact where this proof of concept demonstrates technical feasibility, thus spurring action by the automotive community. It is worth noting that sensitivity to liability and safety issues has led to semi-autonomous parallel parking solutions, rather than the fully autonomous method demonstrated (e.g., driver must keep foot on brake pedal and supervise). This has led to interesting research questions on how to provide similar supervisory authority when the driver is not behind the wheel and possibly out of sight.

1.2 Universal Design

In addition to literature reviews and experiences from prior work, the team met with end users, clinicians, and experts in aging, disability, policy, advanced vehicle control, machine perception, driver-vehicle interaction, and wheelchair transportation safety. One of the key observations to arise from discussions was that the problems related to driving within both the aging and disabled communities can be decomposed into a set of common denominator tasks. The basic fact is that *task-specific* levels of

AutomotiveUI'10, November 11-12, 2010, Pittsburgh, Pennsylvania
ACM 978-1-4503-0437-5

competence are needed in core driver capabilities, regardless of *what* is leading to the need. In other words, the solution for a valet-style approach should be designed so that it is valuable and effective for all users, rather than being a single use design that supports the needs of drivers with a specific medical diagnosis.

2. FUNCTIONALITY

2.1 Interaction Model

There are potential problems that need to be avoided when designing interfaces for mobile systems. McGovern [11, 12] studied rate-controlled ground vehicles (e.g., dune buggies with video cameras) and reported operator problems including slow driving, imprecise control, loss of situational awareness, poor attitude and depth judgment, and failure to detect obstacles. He also concluded that many vehicle failures (collision, roll-over, etc.) were traceable to these operator problems. Enthusiasts have integrated an iPhone with an actuated car and demonstrated intuitive teleoperation but their released videos clearly show the interaction requires significant attention by the operator [19].

Thus, basic teleoperation of vehicles may be greatly aided by systems that reduce the need for continuous manual control. These same methods may also reduce errors in real-time manual teleoperation [1] and reduce weaknesses under communication constraints [18]. These findings suggest that manual teleoperation may not be adequately robust or safe for the general population. This is reinforced by the general chaos found in most parking lots. As such, more appropriate techniques for interaction with remote mobile systems need to be developed.

Prior work has demonstrated teleoperation via a PDA interface utilizing technology developed for other mobile robots. For example, one mode of interaction involved clicking on a video of the forward scene to create waypoints [4]. However, most of these methods involve interaction demands higher than basic supervisory control and were designed by and for roboticists. A survey of regular drivers comparing manual parking, parking by taxi drivers, and autonomous parking revealed some apprehension to autonomous parking and the need for the driver to have override ability [3]. The literature, our experience, and input from end users during our early meetings suggest the right model is supervisory control that allows driver intervention where the vehicle also has the ability to sense and react to obstacles.

2.2 Semi-Autonomous Requirements

Factors relating to parking scenarios and the desire for robustness to a wide range of parking locations define the scope for autonomy. This leads to a set of requirements that influence the design process. Specifically, a virtual valet must be able to:

- Operate without any infrastructural support.
- Use a robust localization system that enables the system to operate even when GPS signals are lost (e.g., parking garages).
- Include short-range obstacle detection and avoidance.
- Navigate autonomously at controlled low-speed.

3. SYSTEM DESCRIPTION

3.1 Test Vehicle

The concept of Virtual Valet was implemented and tested using Navlab 11, which is a Jeep Wrangler that has been extensively modified to support our research (Fig. 1). Navlab 11 is equipped with a variety of sensors for short-range and mid-range obstacle detection, including six SICK LMS 2-D laser scanners, a custom vehicle state measurement system based around GPS, inertial, and odometry sensors, and various cameras, all mounted on a reconfigurable sensor rack. A small array of on-board computers record and analyze sensor data.

Figure 1. The Navlab11 vehicle.

3.2 Vehicle Control

The vehicle control system is based on a tiered architecture, similar to the one described in [6]. The first layer is behavioral control, which provides low-level control and monitoring of all the sensors and actuators. The second layer is the executive layer, which selects a set of behaviors that must be executed to achieve a task (e.g. traverse a path, park the vehicle, pick up a passenger, etc) and computes the trajectory based on initial setup and desired coverage. The third layer is planning, which determines long-term goals within the constraints imposed by available resources.

Navlab 11 has been equipped with brake, throttle, and steering actuators that allow the control system to change the movement or direction of the vehicle as needed. Each actuator is monitored and guided by an embedded closed-loop controller that receives commands from a high-level control module (Fig. 2).

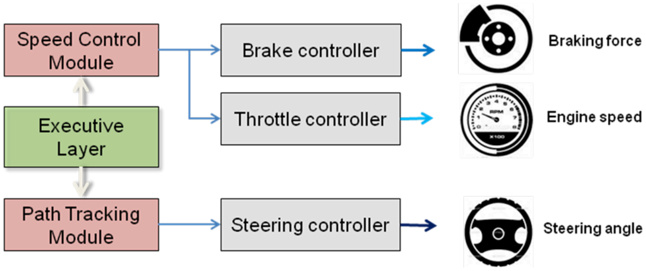

Figure 2. Three independent controllers are used to modify the vehicle's speed and direction.

The speed control module issues throttle or brake pedal position commands to the corresponding controllers needed to maintain the desired speed. Similarly, the path tracking module issues steering angle commands that modify the vehicle's direction of motion and allows it to track the desired path.

For robust localization without GPS, the vehicle uses a combination of scanning SICK LIDARs and odometry sensors to position the vehicle inside a parking deck. These structures provide strong and stable features suitable for SLAM (Simultaneous Localization and Mapping) algorithms that are able to determine vehicle pose with great precision. Likewise, this obviates the need for parking lot infrastructure (e.g., beacons, etc).

Through this architecture, the executive layer is capable of producing sequences of behaviors that provide the functionality needed for the Virtual Valet. For example, as illustrated in Fig. 3, the vehicle stops to drop a passenger at a certain location, then makes a U-turn and drives back until it finds a parking spot. After parking, and upon receiving a passenger pick up command, the vehicle backs up, leaves the parking spot, and returns to the same location to pick up the passenger.

For this simple example, the vehicle's path is learned through demonstration with selective improvisation. When executing the drop off maneuver, the vehicle stops at a precise position and orientation to accommodate the passenger, which is important for scenarios involving wheelchair ramps. The vehicle should stop at the drop-off location since this location implicitly has no roadside barriers to block ramp deployment (e.g., signposts, etc). Once complete, the vehicle will turn around and position itself along a trajectory that will allow it to search for an empty parking spot.

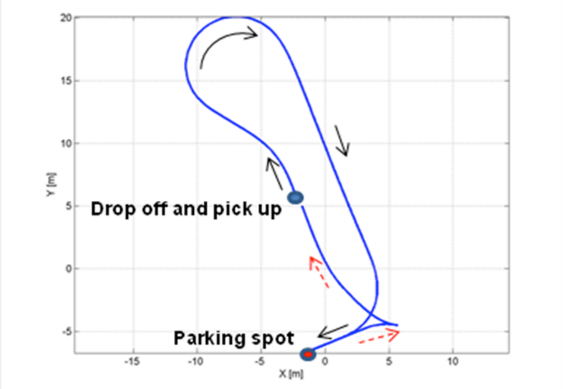

Figure 3. Path tracking experiment. Multiple behaviors are used in a coordinated fashion to drop off a passenger, park the vehicle, and return for passenger pick up.

For this example, all the spots were mapped into the vehicle's memory a priori and the LIDAR detected empty spaces. Knowing the geometry of a parking lot in advance is plausible through server-based SLAM repositories (indoors) and work on identifying spots from public overhead images (outdoors, e.g., [15]), although it is conceivable that a more complete system will have the capability to detect ground markings. In our case, this ability was secondary to our objective and not included. Since the interaction model is supervisory and the LIDAR is not a perfect sensor, the vehicle stops and awaits operator approval of the parking space before proceeding.

The system then improvises a trajectory to the parking spot, using the tracking algorithm to interpolate a smooth curve to the final orientation. A similar procedure is used to recall the vehicle to the pick up point. The team has not focused on issues related to control policies and high-level planning and are deferring these to other work (e.g., [2]).

3.3 Obstacle Detection

While our model includes operator override, the aforementioned literature demonstrates the need for vehicle-based obstacle detection and avoidance. For this system, the vehicle detects unsafe conditions, pauses motion, and prompts the user to confirm that it is safe to resume. Unsafe conditions primarily come about through static and dynamic obstacles, such as pedestrians and vehicles, which intersect the intended path of the vehicle. We use a custom architecture for vehicle-borne LIDAR sensing of pedestrians and vehicles originally developed for the cluttered environment around transit buses [9, 13, 14, 17]. In addition to detection and tracking static and moving obstacles, a collision model computes the likelihood of impact over the near term, providing a ready metric of the hazard level of the current situation. If the hazard level exceeds a tunable threshold, the vehicle will stop and prompt the user to inspect the situation using the user interface.

4. Autonomy and User Interaction

The autonomy and user interaction are intimately linked. As described in the previous section, the vehicle's autonomy is limited to a very small subset of possible maneuvers. The average person cannot safely execute these maneuvers safely under full remote control. Situational awareness is poor, and the target user for this application may have dexterity limitations, thereby making manual control more problematic. Also, commercialized systems will likely use wireless communications that are not reliable enough to guarantee safe operation.

Desire for override authority notwithstanding [3], current technology is not ready to exclude the human from the control loop. Perception systems are still error-prone. For example SICK LIDARs often have trouble detecting black vehicles that have extremely low albedo in the infrared. Of greater concern is the general difficulty of autonomy in unstructured situations, which is sometimes the case in parking lots, as opposed to highways where the behavior of vehicles are much more predictable. At this time, keeping the human in the loop is a requirement.

Figure 4. 180 Degree FOV image provides a human friendly interpretation to the LIDAR data processed by the vehicle.

While LIDAR is the primary sensing modality, it is not suitable for human interpretation. Figure 4 shows an example view with LIDAR overlay (green dots), and the more narrowly focused human interface, currently implemented on and iPod Touch. The main display shows 60-degrees of forward view at a time and can be panned using figure gestures left and right to reveal a full 180-degree FOV image. The video feed from a single camera is used for rear viewing when the vehicle performs a backing maneuver.

Swiping up or down intuitively toggles between forward and back video, echoing the convention of checking a rear-view mirror. Video is transmitted via WiFi datalink, however in practice, we expect the datalink will be whatever is most suitable for the user (e.g., 4G wireless, DSCR, etc).

As described earlier, the vehicle's motion is defined as series of learned and improvised paths. The transition from one path segment to another is governed not only by the robot's completion of the prior segment, but also by the human user's input via three buttons in the upper part of the user interface. In keeping with the importance of easily understood mental models, the control system is a simple state machine:

> **Go:** When not in motion, the Go button is illuminated. The user must use this to explicitly command the vehicle to being execution of a trajectory. For example, after the user gets out of the vehicle, they must signal the vehicle to begin the parking spot search maneuver. Once a spot is found, the user must also signal the vehicle that the spot is acceptable.
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> **Stop:** Upon movement the Go button disappears. The user can stop the vehicle if they detect an impending unsafe condition by pressing the Stop button. Similarly, the vehicle can enter this state autonomously. The UI reflects this state change by illuminating the Resume button.
>
> **Resume:** Only when the resume button is pressed will the robot again begin executing its trajectory.

At this time, we keep the Stop button active at all times and a safety driver sits in the driver's seat, providing redundant safety. Designing abort in deployed systems is an area for future work.

A video demonstrating the system in use is provided here: http://www.ri.cmu.edu/~navlab/persistent/

5. FUTURE WORK

There is survey evidence that drivers have apprehension to automated parking when compared to manual parking by the driver and parking by taxi drivers [3]. However, briefings to end users about the Virtual Valet project have been overwhelmingly positive. We suspect the difference between abstract descriptions to concrete embodiment is producing an effect. Therefore, the next steps for the team will be demonstrations of the system paired with traditional feedback methods (e.g., focus groups, etc) to identify the sources for such apprehension and how the user interaction may be adapted to resolve such issues.

6. ACKNOWLEDGMENTS

This work is based on research supported by the National Science Foundation under Grant No. EEEC-0540865.

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