SMOOTH: Improved Short-distance Mobility for a Smarter City

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ABSTRACT

OSU SMOOTH (Smart Mobile Operation: OSU Transportation Hub) is an autonomous vehicle test bed that aims at providing intelligent transportation systems research for the first and last mile of an individual's commute. It augments current public transportation infrastructure by providing users with access to a heterogeneous network of on-demand autonomous vehicles. We use demand and usage data to provide optimized scheduling and dispatching services, which provide passengers access to multiple choices of transportation through different automated shuttle sizes and speeds. The system has been designed to maximize the replicability and scalability for future city-wide deployments. It conforms to the National ITS Architecture to maintain the benefits of possible cooperation with other subsystems of ITS.

CCS CONCEPTS

•Information systems → Information systems applications;

KEYWORDS

Autonomous vehicle, intelligent transportation system, cloud computing

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1 INTRODUCTION

To promote the utilization of public transportation, it is important to improve its accessibility. The Control and Intelligent Transportation Research (CITR) Group at The Ohio State University (OSU) and Center for Automotive Research proposed the SMOOTH system to provide the first mile/last mile transportation solutions to reduce the extra time and hassle the commuters face[7]. To be a part of the regional ITS (Intelligent Transportation System) architecture, SMOOTH is designed to give all individuals access to multiple choices of transportation. Its vision is to provide seamless connection between the residences or work place and public transportation, especially for those who are elderly, injured, those who have a disability, or otherwise have limited mobility. This concept of connection contains two aspects: the first one is that it provides transportation facilities in hardware; second, it is a software platform developed with standards to support interoperability and with open interfaces ready to be embedded in the regional ITS.

Related solutions to the problem include aTaxi¹ which works with autonomous golf carts to provide a network of automated vehicles to replace traditional taxi service. Unlike this project, SMOOTH seeks to augment current transportation needs rather than replace existing infrastructure. Another system called CityMobil2[1] is being developed with automated shuttles. This system is potentially more expensive to deploy than smaller vehicles. These shuttles may also be under-utilized if individuals in a community do not share enough common destinations. The smaller vehicles proposed by SMOOTH seek to create a more personal, customized solution. Feeder[8] provides a ride sharing system of human driven vehicles to pick passengers up at existing transportation access points to new stops which are closer to their destination. A first and last mile transportation service deployed in the campus of National University of Singapore[4] utilizes existing infrastructure to detect pedestrian. This particular system bears the most similarities with our SMOOTH system, especially in terms of object detecting and tracking technologies used in autonomous vehicles side.

SMOOTH adapts a multi-tier B-S web architecture and a mobile-first designed web portal for access to autonomous vehicles. Utilizing a cloud-based application platform, it implements the functions

¹<https://www.us-ignite.org/globalcityteams/actioncluster/bRAyH96RNRKpZXGdK3FmXQ/>

of three ITS subsystems: Personal Information Access, information Service Provider and Transit Management. Based on the communication equipment installed on the SMOOTH vehicles, the fleet of vehicles shares requests, tasks and road information.

To ensure that the system is economically feasible, we exploit prior knowledge of the environment and take configurable approaches according to different user scenarios. The multi-disciplinary research team adopted components designed for pedestrian detection and avoidance, intersection handling, and navigation.

The rest of this paper is organized as follows. An introduction to typical use cases of the system is described in Section II. In Section III, the general architecture of SMOOTH is discussed, including the details of the corresponding ITS subsystems. In Section IV, the modules of one autonomous vehicle as part of the larger system are described. In Section V, the knowledge enriched map, which helps to alleviate the load of perception, is discussed. Section VI comments on the future work involved in the next phase of this project. Conclusions are also drawn in this section.

In the first phase of tests in 2015, OSU Transportation Hub demonstrated the concept with two different types of fully-automated vehicles covering personal-use and shared-use scenarios. Routes with both simple and complex traffic/pedestrian patterns are being developed as part of the next phase, in collaboration with the City of Columbus, and it partially funded by the NSF EAGER program.

2 USER SCENARIO

When a traveler wants to travel using SMOOTH, they open the SMOOTH hub web application. After logging into the system, they can start scheduling their trip according to their needs and requests. The users/travelers input their start address or use their current location as the start point, and input their destination address. The SMOOTH system then matches the nearest SMOOTH vehicle stations around the start address and the end address. If a route serviced by SMOOTH is matched, the system will assign a vehicle to pick up the traveler. If not, the system queries routes and it schedules one that is serviced by other transit systems. Currently, the alternate services are OSU Trip², COTA³ and CAR2GO⁴. The system generates directions for the whole trip for the traveler, who are connected through SMOOTH to the other transit systems. This type of operation aligns well with a smarter city of the future, as proposed by the Smart City of Columbus, and forms a crucial component in multi-modal transit.

After the request is confirmed, the Smooth will assign a vehicle to take the traveler to the destination directly, or in the alternate case, to a bus stop or to a CAR2GO parking lot. After the traveler gets off from the bus or CAR2GO, if they are not at their destination yet, another SMOOTH vehicle will pick up the passenger to complete the remaining leg of the trip. When the pickup task is finished, the vehicle returns to the local hub to wait the next passenger.

If the passenger is a regular/repeat user, the system keeps history records of requests and solutions. The system will recommend the frequently used routes for the passenger.

Figure 1: Use Case.

The system provides two different classes of vehicles: scooter and golf cart. Each request is assigned a different vehicle for a given passenger according to availability and the options selected by the passenger. From the request to the arrival of the vehicle, there exist a time interval. During this period, the system can still accept other passengers' requests to make a ride-sharing pickup for the four passenger golf cart.

Figure 1 describes five use cases, ordered from the simplest to the most complicated one. In the simplest use case, the vehicle is waiting at a station near the start address of the request from the passenger, when the passenger is on board, the vehicle drives from the origin station to another SMOOTH station near the destination address. The routes between stations are setup with a predefined navigation and map database, which makes sure that autonomous driving processes smoothly. Although it will certainly make the walking distance shorter, the passenger still needs to walk to the station to take the SMOOTH ride. It is unrealistic to set up many stations to make the gap very short. So the vehicles are equipped with the autonomous route planning ability for the short trip between homes or workplaces of passengers to the station. In the cases 3, passengers are picked up at their home or work place near the SMOOTH stations, then the vehicle navigates back to the station that it started from, follows the fixed route to a station near the destination address, and then finally navigates to the destination. The whole trip is divided into three spans, which require different control strategies.

The original intention is to resolve the last mile problem of transit, so SMOOTH is designed to cooperate with other transit modes by integrating its service to a multimodal transit plan. If there is no one-leg SMOOTH route between the start address and the end address, the SMOOTH system provides a multimodal transit solution for

²<http://trip.osu.edu/bustime/home.jsp>

³<http://www.cota.com>

⁴<https://www.car2go.com/US/en>

the passengers. The SMOOTH vehicle will take the passenger to a bus stop, then passenger takes the bus to another bus station, and another SMOOTH vehicle from a nearby smooth station will come to pick up the passenger to the destination. When many passengers make requests near the same place like a community or a shopping mall in a short time span, it increases the complexity, like the use case 5. It will be ineffective to arrange scooters to pick up many passengers. SMOOTH merges the requests together, and sends out golf carts to pick up passengers. In many occasions, multiple passengers go to a common event, a shopping mall, or other community attraction. Many people will wait there to be picked up. Multiple vehicles will be tasked to come to the pickup location. So the SMOOTH vehicles need to share their tasks, communicate with each other, approach the pickup point in order, and line up. People can take any vehicle to go, because vehicles share their request information.

2.1 THE ARCHITECTURE OF SMOOTH

The growing Intelligent Transportation Systems (ITS) industry is crucial across the globe as cities try to reduce congestion, reduce emissions, and meanwhile offer better services to their citizens. In the ITS industry, open standards play a critical role in helping government organizations to save costs by integrating solutions, and reduce the risks of building or procuring new systems. It also establishes a common platform to enable future innovation.

The US National ITS Architecture ⁵ is one of the ITS standards that logically and physically describes ITS, and it is gaining traction across the world. The common framework helps practitioners, engineers, and product developers to plan, define, and integrate intelligent transportation systems.

As a subsystem of a Smart City, the design of SMOOTH is based on the national ITS architecture. A reciprocal Transit Management Subsystem includes other SMOOTH services that are provided to other ITS systems and customers:

- (1) The information provider subsystem not only provides information for SMOOTH itself, but also provides information for other systems. For example, it can provide information to trip planning apps.
- (2) SMOOTH also supports other agent to make requests (cooperation with other systems), in addition to responding to the traveler. For example, a third-party company (for example, a travel agent) can make a request for their customers.
- (3) It will support point-to-point services, which means that it will not only pick up passengers from and carry them between bus stops, it will also support routes between bus stops and doorsteps.

The Figure 2 shows the architecture of SMOOTH, a multi-tier and mobile-first design as a web portal for access to vehicle and for requesting ride service. The three tiers as follows: Personal Information Access, Information Service Provider and Transit Management. It is designed as a B-S web architecture, as shown in Figure 3, and it constitutes the SMOOTH Hub. Utilizing a cloud-based application platform called Meteor ⁶, SMOOTH hub allows the development

Figure 2: the Architecture of SMOOTH.

Figure 3: the Web Architecture of SMOOTH.

of a centrally hosted website which can be accessed from desktop and mobile device alike without loss of functionality or additional development time.

2.2 Personal information access

The first tier is Personal Information Access (PIA), which is the client side, and it provides the capability for travelers to receive formatted traffic advisories from personal portable devices, or desktop computers anywhere over Internet. Passengers log into the system, input authorization information, make a request for travel, and manage their requests. The map GUI will show the real time status of the requested vehicle and the passenger's request information. The key function of it to provide routing information and allow users to select those transportation modes that satisfy their individual needs.

The PIA also tries to acquire the passenger's location if the devices are equipped with GPS or GSM-station-based location systems, or just location functions provided by map servers. Simple

⁵<http://www.iteris.com/itsarch>

⁶<https://www.meteor.com>

displays providing schedule information and imminent arrival signals are also provided. This basic information is extended to include multi-modal transit information including traffic conditions and transit schedules. Like Google Maps directions, users input the addresses where the trips start and end. The system automatically searches available routes. The addresses are converted into GPS coordinates first, then the system searches the nearest SMOOTH station.

Because route planning takes significant computing time, the historical planning results are saved in a database, which boosts the planning process in repeat requests. SMOOTH also stores the historical request records which are used to learn the travel habits of specific passengers without storing personally-identifying data. Based on the cloud platform of SMOOTH, the system can make more effective schedules and plans for the passengers in the long term.

2.3 Information Service Provider

The second tier is the Information Service Provider (ISP), which is the web server that collects, processes, and stores passengers' requests. It includes Traveler information management, Trip planning, Traffic data collection, Request and Ride sharing and Multi-modal cooperation. According to the ITS architecture, it is an implementation of service package ATIS05: ISP Based Trip Planning and Route Guidance.

Traveler information management provides functions to manage user registrations and enrollments, and manage user request records. It provides a billing system to charge the users for pickup services. When users make a request using the route that the system provided, the trip planning module in the ISP will make a more specific plan to arrange specific vehicles to pick up a given passenger. The planning algorithm goes over the vehicles that serve a particular SMOOTH route, and for each vehicle calculates the available time for the request to choose the earliest available vehicle to provide service. As a system that can be integrated in the ITS architecture, the ISP provides data collecting, fusing and repackaging functions, which collect information from transportation systems, and redistributes this information to other systems in the region and other ISPs. SMOOTH interfaces with CAR2GO and OSU Trip system through the web portal, collects transportation information such as routes scheduled, station locations and availability of parking spaces. OSU Trip and CAR2GO both provide web service APIs to provide the information on their facilities such as vehicle location, route data, prediction data, etc. With an authorized access key code, SMOOTH makes HTTP requests for data and receives XML responses from their web servers. Since COTA does not provide a similar API, the system collects information from the COTA website and inputs into the database of SMOOTH. This module also plays the role of information redistribution, which provides a bridge between the various transportation systems. The function is implemented by web API to other systems. Information provided includes transit schedule information, ride matching information, and parking information. Reservations for future request services are also provided in the implementations. Information is provided to the traveler through the Personal Information Access

Subsystem, and to Transit Vehicle Subsystem through available communications links.

2.4 Transit Management Subsystem

The third tier is the transit logic system: Transit Management Subsystem (TRMS), which communicates with the ISP to execute requests of passengers and execute administrator commands to manage transit vehicles, routes and paratransit operations. It provides operations, maintenance, customer information, planning, and management functions for the transit property. It spans distinct central dispatch and garage management systems and supports the spectrum of flexible route and paratransit services. Route management is a very important function of the subsystem, which includes: route navigation data file management, vehicle assignments for a route and route availability assessment.

SMOOTH is designed to provide carefully planned route files for the vehicles. Route files include waypoint and arrays of checkpoints which are the marked GPS positions used to guide the vehicle, such as reference positions which can be used as destinations, the stop line positions the vehicle should stop, and the traffic light positions where the V2I communication will start to receive the traffic light signal. If the traffic light is not equipped with the communication mechanism, the video based detection system can be used to detect the light color. Each checkpoint contains the location, expected speed, or expected action information.

The vehicle management module tracks the vehicle status in real time. It implements the ITS service package APTS01- Transit Vehicle Tracking. It also collects operational and maintenance data from transit vehicles, manages vehicle service histories, and assigns maintenance plans and personnel to vehicles and routes. As the system uses electric vehicles (EVs), charging is the most important task for maintenance. The SMOOTH system also considers the scheduling of vehicles from the perspective of the charging characteristic.

TRMS communicates with transit departments and other operating entities such as emergency response services and traffic management systems. It receives special event and real-time incident data from the traffic management subsystem. It interfaces with the Emergency Management Subsystem to allow coordinated use of transit vehicles to facilitate response to major emergencies or evacuations. In addition, the subsystem supports transit security features. This includes monitoring silent alarms, both passenger and operator initiated, on-board transit vehicles. It also includes the capability to support transit vehicle operator authentication and the capability to remotely disable a transit vehicle. The subsystem includes the capability to monitor for a transit vehicle being off the assigned route.

2.5 The database

We use the non-SQL database, MongoDB⁷, to store data. The main reason for choice of MongoDB is that it is free and its efficient concurrent buffer reading and writing ability. It is also easy to deploy. The vehicle status will be updated every two seconds in real time. Although the MongoDB is a non-SQL database. It still

⁷<https://www.mongodb.com>

Figure 4: Data Model for SMOOTH.

supports relational data relationships. The following Figure 4, a brief E-R model, describes part of core data model of SMOOTH.

3 THE AUTONOMOUS VEHICLE

Autonomy in transport vehicles have varying degrees of dependence on the infrastructure. Systems with heavy infrastructure dependence typically need pre setup and are more suitable for controlled environments. Fully autonomous vehicles, which rely on powerful perception system to detect the environment, such as Google driverless car⁸, can handle dynamic and adversarial scenarios. However, fully autonomous vehicles bear heavy price tags for their sensing and perception systems. In this project, we investigate the balance between the heavily infrastructure-dependent and the fully autonomous approaches according to different use cases in order to build an affordable intelligent transportation system, which leads to different hardware and software configurations.

3.1 Hardware

Two types of pilot vehicles have been constructed, a single passenger mobility scooter and a four passenger golf cart. Both types of vehicles are equipped with some common hardware, primarily for the wireless communication between vehicles and back to the centralized base station and GPS localization. For the complex use cases, we equip it with LIDAR, camera, IMU and RTK GPS, as shown in Figure 5. But for the simpler use cases, the vehicles are equipped with only low-cost sensors: web cameras, odometer, general IMU and GPS. Pyroelectric infrared sensors are used in the simplest solution as an extra safety measurement to detect pedestrians in case other sensors do not successfully detect the targets. If the infrared sensor detects pedestrian but others sensor do not, the vehicle will stop and pop up message windows to inquire the passenger, or transfer image to the server station to make a decision when there are no passengers on the vehicle.

3.2 Software

The software architecture includes five main modules: perception, mapping, localization, planner and controller. Those modules implement onboard schedule, maintenance, monitor and route guidance

Figure 5: SMOOTH Equipped Four-person Golf Cart[7].

functions. The configurations are different for different use cases to avoid unnecessary computing load.

Perception module takes as an input the raw data from the sensors. Detection algorithms extract features (e.g., pedestrian and other moving and stationary objects) from the raw sensory data. As the system adopts modular methods, the classification and tracking algorithm are applied to track and predict the obstacle's dynamic behaviors. Since the system uses knowledge enriched maps, which embed background knowledge of environments, the above algorithm can process only the data from a region of interest (ROI) to reduce the computing load. In addition to those sensors for autonomous navigation, battery sensors are installed to schedule charging activity.

The mapping module maintains the global map of the environment that is updated to current road situation by SMOOTH on the server side. The road information comes from two sources: one is the server side data collected from traffic authorities and other ITS system. The other is collected as the vehicles report obstacle information to the server if the perception system on board judges something to be a static obstacle, such as a parked vehicle on the side of the street. The server will broadcast the information to let vehicles update their maps. The global map is acquired through digital map edition tools with high precision DGPS. For complex use cases, where the preset map is not available, the system uses Google Maps direction service and slow down the speed of the vehicles to allow the perception system process more sensor data. The localization module incorporates the data received from the GPS, LIDAR and odometer to provide an estimate of the current state (position, velocity and heading) of the vehicle.

Planner module is in charge of computing an obstacle-free path, satisfying certain traffic rules, all the way to the goal. In the case where the vehicle is driving on a preset route, on which the vehicle is supposed to follow the checkpoints strictly, the planner calculates a route only from one checkpoint to the next to avoid the obstacle overhead, with possibly a two-checkpoint horizon. In complex use cases, the route planner needs to generate routes originating from its very position rather than a known node on a preset route. In this case, Google Maps directions are used to generate routes. The route planner has to locate the vehicle coordinates on the map first to find the next approachable route and location in the direction map for the vehicle.

⁸<http://www.nytimes.com/2010/10/10/science/10google.html>

Figure 6: the Knowledge Enriched Map Base.

For the control module, we adapt the motion planning algorithm called a setpoint scheduler that is based on a more realistic model of vehicle control [2]. The model computes a sequence of setpoints that allows the vehicle to change motion behavior smoothly via empirical performance profiling of the PID controller for the brake and speed regulator. The setpoint scheduler searches for a feasible trajectory for the vehicle based on a descriptive model of the PID controllers performance. The algorithm constructs a feasible setpoint schedule such that the vehicle arrives at the position at specified time and velocity. Finally, the controller module is responsible for computing the actuator commands, to the physical actuators so that the vehicle can reach the pick-up and drop-off position in time.

4 KNOWLEDGE ENRICHED MAP

Most traditional digital maps only contain geometrical and topological information[3]. The information provided in these maps are not sufficient for autonomous vehicles. For example, speed limit, flatness, lane center information are needed for driving a vehicle. So in the SMOOTH project, we introduce the knowledge enriched map which includes different levels of related knowledge for autonomously driving, based on the RNDF format[5]. The RNDF maybe the most famous route definition file format that serves as a digital description of the urban areas in the real world. It specifies the network of road segments and free-travel zones accessible to the autonomous vehicles. The route network consists of a number of segments, each one including one or more lanes. A lane is defined by a series of waypoints in latitude and longitude coordinates. Intersections are defined by pairs of exit and entry points. The RNDF also provides locations of stop signs and checkpoints, lane widths and lane markers information. Beside road segments, the RNDF specifies free-travel zones to represent parking lots and obstacle fields. The zone area is represented as a polygonal boundary by perimeter points. A zone may include one or more parking spots, each specified by a pair of waypoints. As we can see from the definition of RNDF, the checkpoint is the basic element in the map. Our proposed knowledge enriched maps extend RNDF with the definition of checkpoint with corresponding perception model, and the knowledge base, as show in figure 6. For example, the

knowledge enriched map adds checks point near traffic lights. It means that when the vehicle approaches the point, it will find the traffic light in the captured image. So the checkpoint-related image model can provide information for the video-based traffic light recognition module, which can help to locate ROI, reduce the traffic light recognition errors[6].

5 CONCLUSION AND FUTURE DIRECTIONS

SMOOTH is built with a modular architecture that conforms to the National ITS Architecture. Its implementation also heavily depends on mobile web technologies, which are proven to work at scale. Currently two testing phases are being executed and planned on the OSU campus to test the functionality and scalability of the proposed system. Two vehicles, a single passenger mobility scooter and a four-passenger golf cart, have been retrofitted with control hardware and sensing equipment in order to integrate them into the SMOOTH architecture. Two scooters and another golf carts will join the project that will allow us to test the most complicated/all use cases in the near future.

The most important maintenance activity for electric vehicles is charging. The solution for charging management needs to be considered, which includes battery monitoring and charging subsystems. The vehicle needs to make and execute autonomous charging plans according to its variety of riding tasks. To further reduce running costs, the technologies for shared charging stations are needed. Locating the charging station and parking in the exact position to connect to the charging hub are also needed to be researched. The goal of maintenance technologies development is that once it is deployed, it keeps running without care.

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