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Automated Valet Parking enabled by Internet of Things: A pilot site realization and validation at Brainport, the Netherlands

Louis Touko Tcheumadjeu[1a*], Emi Mathews[2], Arjan Teerhuis[2], Qinrui Tang[1a], Jorge Garcia Castano[3], Marcus Gerhard Müller[1b], Thomas Lobig[1a], Philipp Lutz[1b], Jongseok Lee[1b], Robert Kaul[1a]

1. German Aerospace Center (DLR), Institute [[a]TS and [b]RM], Germany

2. TNO, the Netherlands

3. Vicomtech, Spain

* Corresponding author e-mail: [louis.toukotcheumadjeu@dlr.de]

Abstract

An automated valet parking (AVP) service which vehicles drive and park by itself is presented in this paper. Seamless integration of subsystems such as parking management system, Internet of Things (IoT) platforms, automated driving vehicles, micro-aerial-vehicle and road-side cameras provided by different stakeholders to a working solution is aided by introduction of IoT to the core of the system design. Technical realization of the AVP service with its architectural components and interacting subsystems are explained in the paper. Piloting and testing activities carried out to validate the system prove the merits of the proposed solution.

Keywords:

Automated valet parking, Autonomous driving, Internet of Things, IoT platforms

Introduction

Internet of Things (IoT) stands for an updated vision of the Internet where uniquely identifiable “things” get connected to internet services enabling seamless communication, contextual services and data sharing between them. It is bringing radical changes in the traffic and transport industry, where the traffic information collected from IoT devices such as vehicles and infrastructural units can be analysed to support the decision making in the transportation field. Bringing IoT to autonomous driving (AD) vehicles and advancing AD functionalities through it is an active research topic. In this paper, we look at one of the advanced AD functionalities offered by self-driving vehicles called automated valet parking (AVP) and how IoT can enable and enhance this functionality.

AVP stands for a valet service offered by a self-driving vehicle driving and parking by itself after the driver has left the car at a drop-off point probably near the entrance of the building, and retrieves the vehicle when he/she wants to leave the site. AVP has been previously studied in [1, 2]. In this paper, our focus is on a novel solution that brings IoT to AVP and explains its merits, such as easy sharing of information (vehicle and parking spot statues), supporting advanced routing and scheduling services, and more efficient and cost-effective parking.

AVP has been developed as part of the European Union project AUTOPILOT [3] (AUTOmated driving Progressed by Internet Of Things) with the objective to bring together knowledge and technology from automotive and IoT value chains to develop IoT-architectures and platforms which bring AD towards a new dimension. AUTOPILOT IoT enabled AD cars are tested at six large-scale pilot sites in Finland, France, Italy, the Netherlands, South Korea and Spain. The AVP solution presented in this paper is the one developed and tested at the Brainport site in the Netherlands.

AVP storyboard

A new AVP service has been introduced where users can leave/retrieve their car at the doorsteps of the building where they plan to visit and let the car drive and park automatically at a nearby parking lot. Figure 1 explains a typical use of this service. Bob, a user of the AVP service arrives at the drop-off station and uses the app in his smartphone to use the service. On entering the credentials the app connects to the parking manager to check for a free parking spot in the nearby parking lot. The fixed cameras at the parking lot notify the parking manager on the occupancy status of the parking lot. Unfortunately, on this very busy day all parking spots monitored by the fixed cameras are reported as occupied. Hence, the parking manager seeks the assistance of drones that are employed to support AVP. Drones can check the status of the parking spots not observable by the fixed cameras or provide an accurate status of the parking spots in case of conflict resolutions. The drone sets off its flight and finds a free parking spot. The parking manager assigns it to Bob's car and the routing service provides the route information. Bob accepts the suggested parking spot and sends his car to park using the App. Car drives automatically to the dedicated parking spot and parks. Bob goes to his appointment and gets the confirmation once the car has been parked. After the meeting, Bob retrieves his car using the App.

Step 1: Arriving at the drop-off position

Step 2: AUTOPILOT-AVP App requesting a parking spot

Step 3: Fixed cameras updating parking spot occupancy status

Step 4: Drone searches and confirms a free parking spot

Step 5: App displays the route to the parking lot

Step 6: Automated parking at the parking spot

Figure 1: Typical use of AVP service

AVP IoT architecture

The AVP IoT architecture developed for the Brainport pilot site is depicted in Figure 2. It is built on standard IoT architectures with key features such as openness, flexibility, interoperability between IoT platforms. It consists of three main parts: 1) the AVP applications, which contains services to the AD vehicles and users such as parking management, user management and routing services, 2) IoT platforms, which enables the IoT functionalities such as device management, context management, process and service management, semantics, analytics and security, and 3) things, which includes IoT devices such as AD vehicles, Roadside Unit (RSU) cameras, and MAVs and AVP smartphone App.

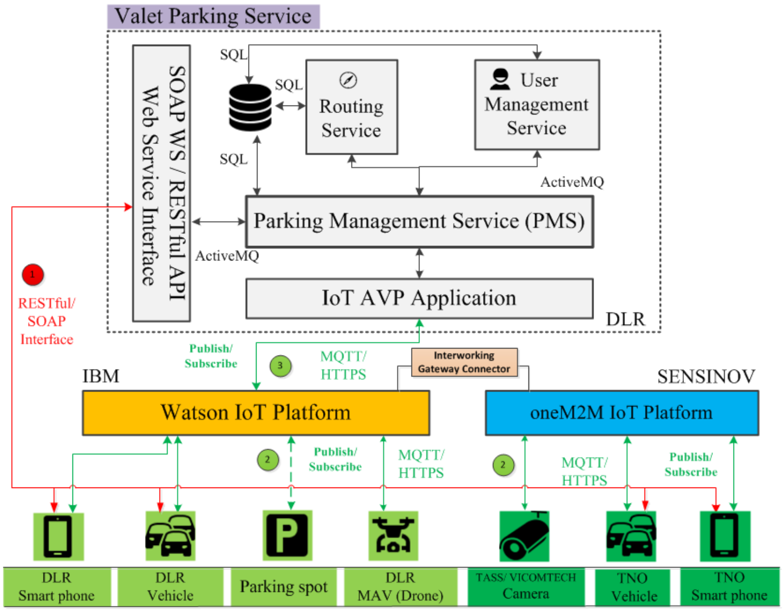

Figure 2: IoT system architecture of the automated valet parking use case in Brainport

AVP applications: Parking Management Service (PMS) manages one or more parking sites, keeps an up-to-date status of parking lots and makes their reservation. It interfaces with the IoT AVP Application that makes the external communication with IoT platforms over MQTT or RESTful interface [4].

IoT platforms: AUTOPILOT project supports a federated IoT platform architecture, which means that several layers of IoT platforms are supported and they can be deployed on a variety of physical infrastructures. Two cloud-based IoT platforms are employed in the Brainport AVP pilot realization, namely Watson IoT Platform from IBM [5] and oneM2M platform from SENSINOV [6].

IoT devices: AD vehicles considered in the AVP includes two pilot vehicles provided by the German Aerospace Center (DLR) and Netherlands Organisation for applied scientific research (TNO), respectively. The AD vehicles publish event messages and receive command messages to/from the IoT platform during the *parking* and *collection* processes.

IoT platforms' interworking gateway

Two cloud-based IoT platforms, Watson IoT and oneM2M work seamlessly in the AVP pilot site, compared to the contribution described in [2]. A bidirectional interworking gateway connector allows the interoperability between the two platforms. This is achieved by setting oneM2M as an interoperability platform and using oneM2M interworking gateway for connecting other platforms (i.e. Watson IoT) to it. The interworking gateway is configured to share selected data types of other platforms with the interoperability platform. Such data will then become accessible to all the connected IoT platforms through the interoperability platform.

AVP IoT information flow

A schematic view of the AVP IoT information flow implemented in the Brainport pilot site is shown in Figure 3. Data is exchanged using AVP data model developed based on the SENSORIS [7] and DATEX II [8] standards.

- D1: Camera AVP Event Data, namely parking spot occupancy and obstacle data are published to oneM2M platform. The PMS subscribed to this information gets it from the Watson IoT platform through the interworking gateway.
- D2: Vehicle AVP Command Data, namely *park* or *collect* the AD vehicle, initiated from the users Apps goes to PMS which publishes it to the Watson platform. DLR vehicle directly subscribed to it receives it from the Watson platform whereas TNO vehicle gets it from the oneM2M platform.
- D3: Vehicle AVP Event Data, namely vehicle status and position estimates, being published to the Watson and oneM2M platforms by the DLR and TNO vehicles, respectively is received by PMS by subscribing to it from the Watson platform. It is then processed and published to the Watson platform

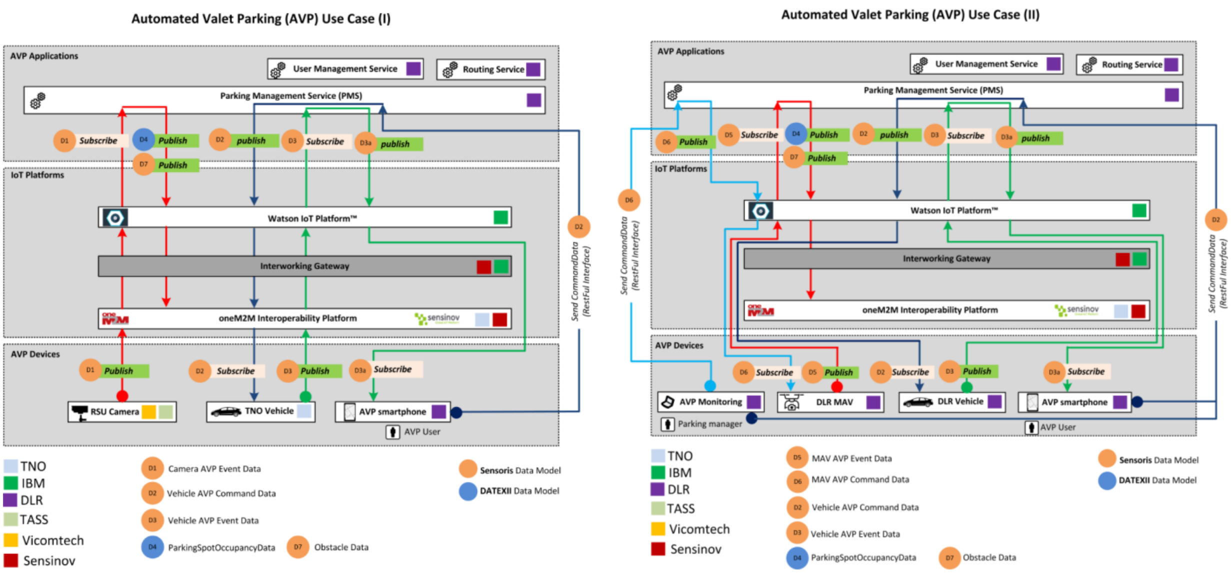

Figure 3: AVP IoT information flow

which is subscribed by the app and show live updates of vehicle status to the users.

- D4 and D7: Parking Spot Occupancy and Obstacle Data received by the PMS from the RSU cameras are processed and published to Watson and oneM2M IoT platforms for external applications to use.
- D5: MAV AVP Event Data are published to the Watson IoT platform and PMS which subscribes to them, processes and publishes as in D4 and D7.
- D6: MAV AVP Command Data: AVP Monitoring unit initiates the command to fly MAVs. PMS receives this and publishes the command data to the Watson IoT platform. MAV subscribed to this

command receives it and acts accordingly.

Vehicle Platforms

Two connected and automated vehicle prototypes from DLR and TNO have been used in the Brainport pilot site for AVP (see Figure 4). In this section the integration of IoT technology in vehicle and the adaptation of autonomous function to enable the IoT based autonomous driving are described.

TNO / TASS + TUe Toyota

DLR‘s prototype Volkswagen e-Golf

Figure 4: Connected and automated vehicle prototypes in Brainport pilot site

Automation functions adaptation in vehicle to enable IoT autonomous driving

The DLR prototype FASCarE is a fully electric Volkswagen e-Golf. The vehicle was modified to allow access to OEM sensors and actuators for longitudinal and lateral control and equipped with additional hardware. This includes radar and laser sensors, a differential GPS system, several industrial PCs for running the AD functionality, a 4G communication unit and a custom dashboard display.

The software was only slightly adapted, e.g. an IoT gateway module was added. The main human machine interface (HMI) for the user is the Valet Parking App, the in-vehicle HMI was mainly used for testing and debugging.

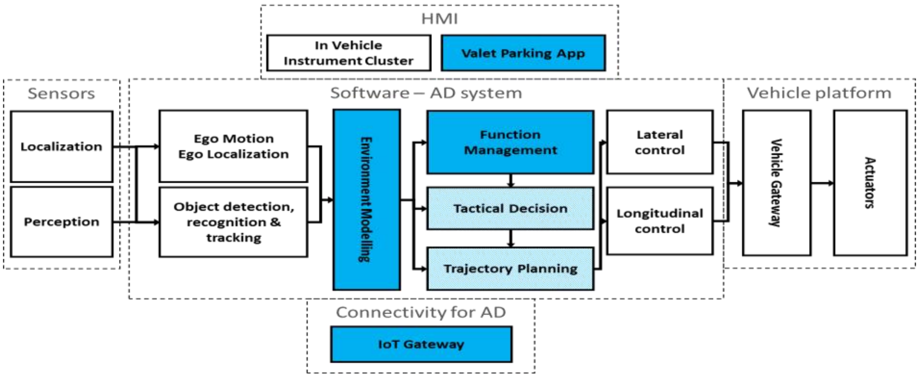

Figure 5: Adaptation of autonomous functions in DLR’s vehicle prototypes

The trajectory planning is based on optimal control. It respects speed limits and avoids obstacles. An additional trajectory planning mode for reverse parking was added for the use case.

The function management module acts as a higher-level control centre for trajectory planning and other function modules below, setting planning goals and switching modes of control. The function management handles communication with the IoT platform; it provides a translation of parking commands from the AVP Parking Management System into sequenced goals for the trajectory planning.

The main contributions involves the development of HD-map functions (and related to that: the localization), the modification of the existing supervisory control that handles the commands to the system and the addition of a IoT gateway function to connect the in-vehicle AVP-application to an external IoT Parking Service.

Integration of IoT technology in vehicle

The final DLR architecture is based on ROS and the proprietary DLR Dominion Environment IPC platform. ROS is best suited for sensor fusion tasks and also integrates the IoT client module, while Dominion is better suited for high frequency real-time control tasks and AD planning.

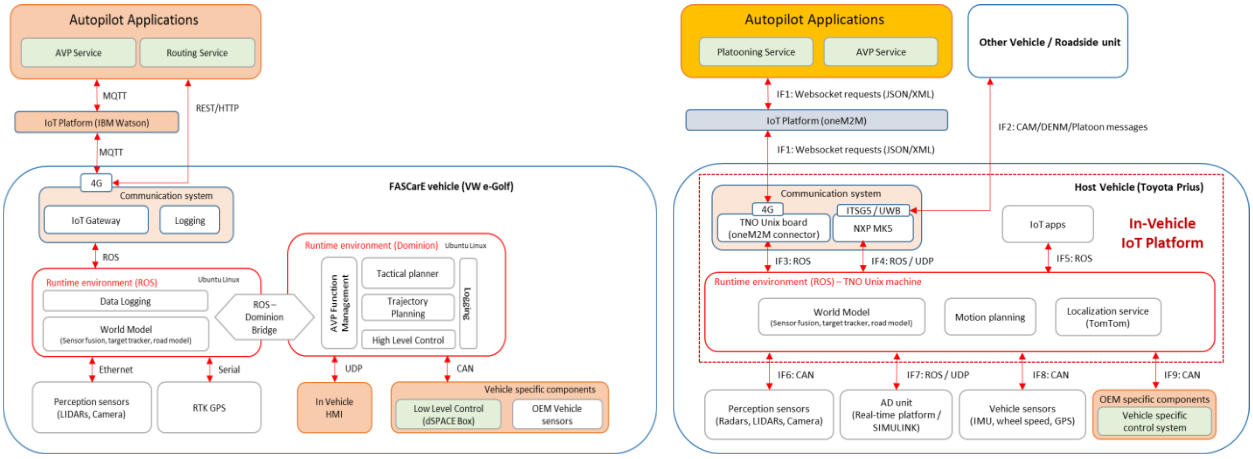

Figure 6: IoT software components architecture diagram of the DLR and TNO vehicles respectively

The in-vehicle control software for TNO vehicle is developed within the ROS-framework. All sensors and actuators are, either directly over Ethernet or via a CAN-gateway, connected to the ROS-network. Within this network, the AVP-application is divided over several nodes, all having their specific functions namely localization, object tracking, path planning, path tracking controller and IoT gateway.

The Micro-Aerial-Vehicle (MAV)

The task of the MAV is to autonomously observe the status of particular parking spots. The use of a flying platform is especially useful in scenarios where it is difficult or inefficient to install road side cameras. This can be in cases where the parking spot structure is built up temporarily and on rough terrain, like sometimes found on festivals. It can also be used in scenarios, where the road side cameras have failed or are uncertain about their observation due to occlusions or other difficulties.

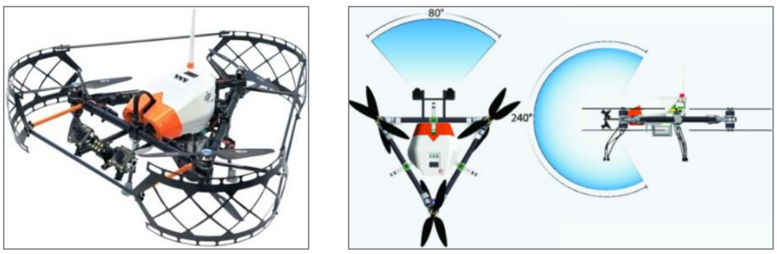

Figure 7: MAV and stereo camera setup and field of view

The MAV used in this paper is equipped with two pairs of stereo cameras, which consists of four wide-angle cameras. The camera setup provides an approximated 240° vertical field of view as illustrated in Figure 7. The arrangement of the cameras and the separate control of them make the system well suited for outdoor scenes with high dynamic range situations. For navigation the MAV is using a visual-inertial approach which is described in [9].

The MAV is waiting for a command from the parking management system at its starting position on the ground. Once the MAV receives the request to check the status of a particular parking spot, it flies to it and takes an image of the parking spot. The image is sent to a base station, which is running object detection software to determine whether the parking spot is occupied. Then the result is sent to the IBM Watson IoT platform. The Parking Management Service receives the status and MAV telemetry data over MQTT and processes this information for decision-making. After the image was processed, the MAV is flying back to its starting position.

The Road Side Unit (RSU) camera

To support AVP, panoramic and multi-sensor road side cameras are installed in the area where the autonomous vehicles are driving and parking. The cameras are located throughout the environment at different positions, from the drop-off point, the lanes/access roads to the parking lot. The road side camera network is responsible to provide information of different video analytics, which will be published in the IoT. Specifically, the role is to provide the status of parking spots and detections of static obstacles disabling any driving area. To do this, video streams are transmitted to a back-office processing server where the video analytics are executed in multiple instances, one instance for each tuple camera-analytic. All detected events are formatted using specific data models and, subsequently, sent over to a high-level communication entity, which then publishes the oneM2M platform.

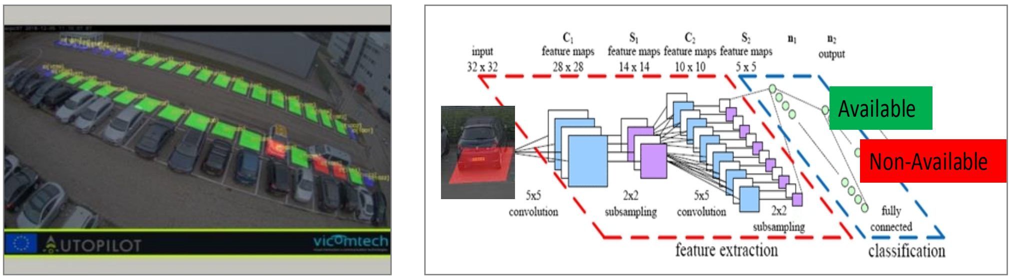

Figure 8: AVP road unit camera and parking lot detection visualization

The free parking spot detection module is composed by two different parts. Localization of parking spots is the image region which corresponds to each parking spot. Assuming that the road side camera is static, this task has been manually performed using an image annotator application where each parking spot is defined by 4 corners. Once all parking spots are annotated, metadata are stored in a configuration file. Then, a parking spot monitor application is in charge of the classification of parking spots to determine if they are occupied or available using a convolutional neural network (CNN). Figure 8 shows a snapshot of the parking spot monitor application where the status information can be differentiated by means of three colours: green means the parking spot available, red means occupied and blue means unable to be classified since the accuracy of the parking spot is too low.

The static obstacle detection module combines short-term and long-term background models to extract static foreground objects. Once the static obstacle monitoring starts, information including its GPS location is periodically transmitted to the IoT by using specific data models. Similarly, when the static obstacle is removed from the environment a last message is sent to notify that the driving area is again available.

AVP piloting and technical evaluation in Brainport

AVP pilot site

AVP pilot site in Brainport located at the Automotive Campus, Helmond is shown in Figure 9. Visitors to the campus can leave the car at the drop-off point in front of the campus and the car will drive to the parking lot at the back of the campus and park there. Vehicle can use two routes highlighted in blue colour and the access roads to the parking lot are monitored by five cameras as shown in Figure 9. Additionally, two cameras are installed in the parking lot to cover that area.

Figure 9: AVP test site and equipment in the pilot site Brainport

AVP piloting activity and results

The piloting activity has started in September 2018 and will be continued until June 2019 in dedicated piloting weeks in every quarter of the year. The first piloting week in September 2018 verified that components and interfaces work according to specification and validated that the integrated system is suited for piloting. At the second piloting week in December 2018, user acceptance test was carried out with several nontechnical end users from the Automotive Campus tested AVP service. Users sit inside the car to experience the autonomous driving and parking while a safety driver explains the onscreen visualizations to them. In the next round, they move to the demo booth to see the working of the system from the backend visualizations. The pilot runs were completed successfully and based on the feedback received from these users further improvement of the system is carried out.

Figure 10: MAV parking spot occupancy detection, left: occupied, right: free

During four piloting rounds, the MAV received commands to check the occupancy status of two different parking spots which were once occupied and three times unoccupied. In all these runs, the MAV detected the occupancy status of the parking spot correctly. Figure 10 shows a visualization of the object detection by the MAV; the dot shows where in the image the occupancy status is evaluated on.

AVP validation experiments

In addition to piloting activities, for technical evaluation of the system we have defined following test scenarios, which will be executed in several rounds (at least 20 rounds) during the test week of June 2019.

1. Autonomous drop-off (DO) / pickup (PU) with TNO and DLR vehicles without or with obstacle
    - Without obstacles: vehicle takes the shorter route from/to drop-off / pick-up zones
    - With obstacles: obstacle is present before the driving and vehicle takes the longer route
2. Parking spot (PS) occupancy and obstacle detection in different traffic and weather conditions with RSU camera or the MAV
3. Routing service: calculation of optimal route a) without obstacle (see Figure 12), b) with obstacle when RSU camera or vehicle detects obstacle prior to navigation (see Figure 13), and c) with obstacle but detection after setting off.

Figure 11: Road network and parking spots (PS)

Figure 12: Route A - shorter route from the DO to PS without obstacle

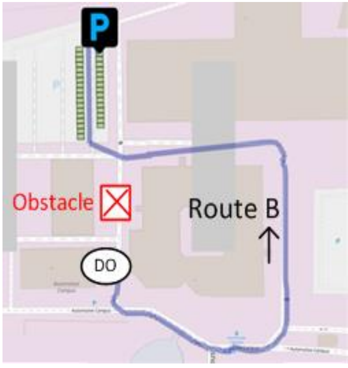

Figure 13: Route B - longer route from the DO to PS with obstacle on the shorter route

The key performance indicators (KPI) that will be measured during the subsystem tests are accuracy, reliability, and robustness, whereas the KPIs measured during the integrated tests will be parking duration, percentage of successful autonomous driving, and percentage of successful autonomous parking.

Conclusion and outlook

The technical solution of the AVP enabled by IoT is presented in this paper. The seamless integration of multiple (IBM Watson and oneM2M) IoT platforms, multiple (DLR and TNO) AD vehicles, smartphone Apps, MAV and RSU cameras into a valet parking service is enabled by IoT. Piloting activities and technical tests confirmed the success of our solution. The ongoing work is to improve the user experience based on the feedback received and apply the solution in more challenging scenarios.

Acknowledgment

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