Automated Valet Parking enabled by Internet of Things (IoT)
Brainport Pilot Test

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AVP Storyboard

Automated valet parking (AVP) service where vehicles drive and park by itself

The car is enabled (through IoT) to drive autonomously
• from the drop-off (DO) point to a parking spot (parking scenario),
• and to return to the pickup (PU) point (collection scenario) to the driver on command using mobile App
AVP Implementation

**Option 1: without IoT**

- Parking spot exploration is needed

  - Road Network (HD digital map)
  - AD Car
  - AVP mobile App
  - Parking spot Infrastructure

**Option 2: With IoT**

- No need of parking spot exploration

  - MAV: Micro Aerial Vehicle (Drone)
  - MAV
  - Stationary detection
  - Mobile detection
  - Obstacle detection
  - Parking spot Occupancy detection

**IoT + 5G**

- IoT concept of AVP development
- IoT Interface implementation on the IoT devices and application side to allow the communication with the IoT platform
- IoT (standardized) data model specification for all involved IoT devices (vehicle, MAV, RSU camera, etc.)
- Adaptation of automation functions in the vehicle to support IoT data
- Define the communication workflow between system components
**IoT Technology and Autonomous Driving**

**AUTOPILOT Project:** Bringing Internet of Things (IoT) to autonomous driving (AD) vehicles and advancing AD functionalities

- **Devices:** IoT vehicle, IoT smartphone, MAV equipped with cameras
- **Actions of application:** publish events/commands to the IoT platform, subscribe events/commands
- **Actions of devices:** publish events to the IoT platform, subscribe commands
- **Action of Platform:** acts as broker, receives and manages information from IoT devices and applications, provides the information to the data subscriber.
AVP IoT based System Architecture

- **AVP applications**: contains services such as parking management, user management and routing services

- **IoT platforms**: enables the IoT functionalities such as device management, context management, process and service management, semantics, analytics and security
  - IoT platforms’ interworking gateway: Watson IoT and oneM2M IoT Platform Interoperability

- **Things**: includes IoT devices such as AD vehicles, Roadside Unit (RSU) cameras, and MAV (Drone) and AVP smartphone App

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Figure: IoT system architecture of the automated valet parking use case in Brainport
System components and IoT Communication Interface

User Management Service
Parking Management Service (PMS)
Routing Service
Valet Parking Service

Vehicle data
User data
Parking data
IoT Platform
Obstacle data
MAV data
Camera data

RestFul Interface
IoT Platform Interface

IoT Gateway
AVP App (GUI)

IoT Gateway
Parking Maneuver Service
Motion Planning Service

IoT Gateway
Processing Unit

IoT Gateway
Processing Unit
AVP Data Models

- AVP data model consists of
  - **IoT Event data models**
    - Standardized SENSORIS data model has been extended to support information specific to AVP
    - MAV and RSU camera data models are based on SENSORIS data model
  - **IoT Command data models**
    - to model the command message for vehicle and MAV

Example of AVP vehicle IoT event message "PositionEstimate"
AVP Vehicles Platforms
Connected / Automated Vehicle Prototypes

PS Brainport: TNO / TASS + TUE Toyota Prius

PS Brainport: DLR's prototype Volkswagen e-Golf

PS Brainport: NEVS's prototype

DLR vehicle sensors

Bosch Camera
- Lane detection
- Traffic signs
- Object detection

NOVATEL SPAN-CPT
- GPS + Compass
- IMU
- DORPS (local reference)

DRL IPS-Box
- Optical 3D-vision
- WS
- LiDAR

Ultrasonic Sensors
- Near range detection ≤ 5m

BMI Linkbird
- V2X Communication

SMS Radar
- Blind Spot detection
  - Length: 8m
  - Azimuth: ± 70°
- Rear objects
  - Length: 120m
  - Azimuth: ± 9°

IBEO Laserscanner
- 4 LIDAR + Fusion ECU
- Length: 150m
- Range: 85°

Bosch Radar
- Front objects
  - Length: ~180m
  - Azimuth: ± 8°

IoT software components architecture diagram of the DLR vehicle
RSU-Camera Application
Stationary Detection

Free parking spot and obstacle detection

- RSU-Camera are installed on the parking area and the driving area and act as IoT devices

- **Task:**
  1. To provide the status of parking spots and detection of static obstacles (PEDESTRIAN, VEHICLE, BICYCLE ...) disabling any driving area
  2. To publish the detection information into the IoT platform

<table>
<thead>
<tr>
<th>RSU Camera detection Information</th>
<th>Effect on the Automated Valet Parking</th>
</tr>
</thead>
</table>
| Extension of Routing and PMS services capability | - Dynamic routing to parking location;  
- Optimizing complete parking operation  
- Benefit of the IoT platform as standardised middleware to publish and subscribe the data |
MAV (Drone) Application

Mobile Detection

Free parking spot detection
- MAV and ground-station PC act as IoT device
- Custom coaxial tricopter designed by DLR
- Equipped with two pairs of stereo cameras

Workflow:
1. Receives IoT command from PMS to check the status of particular parking spots
2. Flying autonomously to the parking spots and taking an image
3. Sending the image to a base station
4. Publishing results to the IoT platform
5. Flying back to the starting position

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<td>- Optimizing complete parking operation</td>
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<tr>
<td></td>
<td>- Benefit of the IoT platform as standardised middleware to publish and subscribe the data</td>
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</table>
AVP Smart phone Application

AVP mobile App

- Developed with Android API
- Consists of SOAP web services and IoT interface
- Supports vehicle “Parking” and “Collection” scenarios
- Provides information about the valet parking process to the user.
Brainport Pilot Site (The Netherlands)
Test location: Automotive Campus, Helmond

AVP test site and equipment in the pilot site Brainport
Brainport Pilot Site (The Netherlands)

Use Cases | Brainport
--- | ---
Automated valet parking | X
Highway Pilot | X
Platooning | X
Urban Driving | X
Car/Ride Sharing | X
Car Rebalancing | X

- **Fibre Backbone**
- **In-Vehicle IoT Platform**
- **ITS-G5 RSU**
- **DRL Drone**
- **Commercial eNB (Helmond)**
- **TNO eNB**
- **MEC Node with oneM2M IoT Platform**
- **MEC Application Platform**
- **Pre-5G Core Network (TNO)**
- **Rest API**
- **Pre-5G MEC (TNO)**
- **Pre-5G Core Network (TNO)**
- **Tactical Data via LTE (100ms+)**
- **Time-Critical Data via G5 (10-20ms)**
- **Local Breakout**
- **Image Processing**

**Use Cases**:
- Automated valet parking
- Highway Pilot
- Platooning
- Urban Driving
- Car/Ride Sharing
- Car Rebalancing

**Platforms**:
- FiWARE Broker
- Watson IoT Platform™
- oneM2M Interoperability Platform
- HUAWEI Platform
- Pre-5G Core Network (TNO)
- TNO eNB
- MEC Node with oneM2M IoT Platform
- MEC Application Platform
- ITS-G5 RSU
- A270 & P-Automotive Campus

**Image Processing**

**Rest API**
Data management

- During the technical tests log files of the system components have been collected in CVS file format and uploaded into the CTS server.
- These data have been used for the technical evaluation of the AVP use case in the three pilot sites.

<table>
<thead>
<tr>
<th>Data Management / log files</th>
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</thead>
<tbody>
<tr>
<td>Vehicle state log data</td>
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<tr>
<td>Vehicle Positioning system</td>
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<tr>
<td>Vehicle dynamics</td>
</tr>
<tr>
<td>Driver vehicle Interaction</td>
</tr>
<tr>
<td>Environmental sensors relatives</td>
</tr>
<tr>
<td>Vehicle IoT communication log data</td>
</tr>
<tr>
<td>Vehicle IoT event message (PositionEstimate)</td>
</tr>
<tr>
<td>Vehicle IoT event message (VehicleAVPStatus)</td>
</tr>
<tr>
<td>Vehicle IoT Command message</td>
</tr>
<tr>
<td>RSU IoT communication log data</td>
</tr>
<tr>
<td>RSU Camera IoT event message (Parking spot occupancy)</td>
</tr>
<tr>
<td>MAV IoT communication log data</td>
</tr>
<tr>
<td>MAV IoT event message (Parking spot occupancy)</td>
</tr>
<tr>
<td>MAV IoT command message</td>
</tr>
<tr>
<td>Platform IoT Communication log data</td>
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<tr>
<td>IBM IoT log message</td>
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<tr>
<td>oneM2M IoT log message</td>
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Platforms Interoperability

- Two cloud-based IoT platforms are employed in the Brainport AVP pilot realization, namely Watson IoT Platform™ from IBM and OneM2M platform from SENSINOV.
- A bidirectional interworking gateway connector allows the interoperability between the two platforms.
Automated Valet Parking - Technical Evaluation

The car is enabled through IoT to drive unmanned to a parking spot, and to return to the driver on command.

This offers:
- Comfort service to car drivers (no time lost finding a parking spot)
- More efficient use of space on parking lots (cars can be parked closer)
- Less damage to cars during parking
- Optimization of logistics and reducing congestion in and towards parking area
- More efficient use of EV charging spots

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<tr>
<th>No.</th>
<th>KPI</th>
<th>Measurement</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>KPI-1</td>
<td>Parking duration</td>
<td>seconds</td>
<td>Drop-off scenario: Time from drop-off point until vehicle is parked (parking spot). Pickup scenario: Time from parking spot until the vehicle reached the pickup point.</td>
</tr>
<tr>
<td>KPI-2</td>
<td>Detection performance of free parking spots (Parking spot occupancy)</td>
<td>RSU Camera</td>
<td>1) Detection performance of free parking spots:</td>
</tr>
<tr>
<td>KPI-3</td>
<td>Reliable information of the driver about the parking process</td>
<td>duration</td>
<td>Delay between the message transmission from the message generation in the vehicle to the message reception at the AVP mobile APP interface</td>
</tr>
<tr>
<td>KPI-4</td>
<td>Detection performance of object/obstacle on the road</td>
<td>manually, correctness of the object detection through the AV-vehicle or RSU camera RSU Camera Detection performance of obstacle detection in the danger area.</td>
<td></td>
</tr>
<tr>
<td>KPI-5</td>
<td>Parking</td>
<td>Evaluate if the cars are parking 100% of the times properly and never cause damages during the test scenario</td>
<td></td>
</tr>
<tr>
<td>KPI-6</td>
<td>Technical complexity of the implementation</td>
<td>Evaluate the technical complexity of the implementation, also analysing the different cases (outdoor / indoor).</td>
<td></td>
</tr>
</tbody>
</table>

No. Topic | Research Questions | Hypotheses | KPI |
---|---|---|---|
1 | Time saving | Can the system decrease the time a user needs to park their car? | Since the user does not need to be present during the parking maneuver, less time will be required. | KPI-1 |
2 | Can the system reduce the total parking maneuver time? | The total time of the parking maneuver is less with the AVP system than driving manually. | KPI-1 |
3 | Does the AVP system improve user security? | Since the user does not need to be present during the parking maneuver, it is impossible for him to suffer any damage during it. | KPI-2 |
4 | Does the AVP system improve pedestrians’ security? | Since the autonomous parking area will be isolated, there will be no users in it reducing the risk of accident. | KPI-2 |
5 | Does the AVP system improve VRU security? | The IoT will allow the detection of VRU before it enters the range of the car’s sensors, allowing the system to react earlier. | KPI-2 |
6 | Energy efficiency | Is the energy consumption reduced when using the system? | The reduction of time and optimization of routes will cause a reduction in consumption. | KPI-7 |
7 | Maneuver precision | Can the AVP system carry out the parking maneuver with the same or higher precision than that obtained manually? | The system is accurate enough not to compromise the integrity of the vehicle. | KPI-7 |
8 | Maneuver information | Does the user have real time information during the maneuver even though he is not present? | The app informs the user in real time of the state of the vehicle during the maneuver. | KPI-5 |
AVP Demonstration (Automotive Campus, Helmond)

AVP Use Case has been tested at different pilots and successful demonstrated at the 13th ITS European Congress in Helmond (June 2019)
Thanks for your attention!

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AUTOonomous driving Progressed by Internet Of Things
Video
Smart Mobility, Empowering Cities