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Automated Vehicle Operational Scenarios and 5G Based Experimental Trials in the City of Trikala, Greece

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Abstract— *Automated vehicles is one of the more exciting areas of the automotive industry today. The general perception is a fully automated car where the driver can handle other matters while the car is driving by itself, and this will start becoming reality within the next years [1],[2.] Therefore, the possibility to provision road vehicles unmanned and on demand will have an important influence on the development of new mobility concepts. This paper highlights the basic concepts of an automated car operational functionalities, including a static multi-camera scheme, an operator interface with a map-based fleet tracking management, and a cellular 5G network-based communication architecture for video transmission. The purpose of the work carried out was to specify technical requirements for the design and implementation of a prototype system for a normally automated vehicle. The existence of standards has been investigated and have been adhered in the development and implementation of the system. An interface towards the automated vehicle has been created together with a control center which can monitor vehicle activity during its path.*

Keywords— *5G communication; Autonomous vehicles; CAN BUS, Control Centre; controller; lidar equipment; GPS; Road Side Units.*

I. Introduction

The objective of the system is to be able to control an automated vehicle without being in the physical vicinity of it. This will be done by relaying information to the operator from the vehicle such as video streams and sensor data. The operator will also be able to send control inputs to the vehicle in order to be able to remotely immobilize it [3]. The presented implementation consists of functionality and software that can be used for teleoperation control and can be run on a regular personal computer. Unlike the traditional vehicles, self-driving cars utilize a combination of advanced sensors, such as stereo cameras and long- and short-range radars, and lidars, to monitor and respond to their surroundings. These sensors can generate a huge amount of data per second.

Self-Driving Shuttle navigates 100% without human input. It can detect surroundings by using a variety of techniques such as radar, Lidar, GPS, odometry, and computer vision. Sensory system as "eyes", provide driverless bus ability to identify appropriate navigation paths, as well as obstacles and relevant signage. Computer, which so-called "brain", allows connection of diverse subsystems involving sensor, positioning, navigation, locomotion, motion control, energy, and communication. The system allows vehicle to recognize, analyse, and operate automatically, enabling shuttles to execute obstacle avoidance, passing, overtaking, and giving way, which is believed to enhance the transporting efficiency and safety. In this paper, we provide an outline of AVINT project (Automated Vehicles INTegrated within the urban context) funded by the Greek Secretariat of Research and Technology (GSRT-www.gsrt.gr) under the EDK program. Participants of the project are e-trikala (www.e-trikala.gr), Technical University of Athens-Institute of Communications and Computers (www.iccs.gr) and SPACE HELLAS SA (www.space.gr).

The aim of the project is to study the urban traffic situation in Trikala and to build an automated bus line connecting the city centre with the Trikala University Faculties terminal, in a route of 7.850 km, via a viable service, which can be seamlessly integrated with the urban transport network and provide bus priority. The path is shown in the following figure.

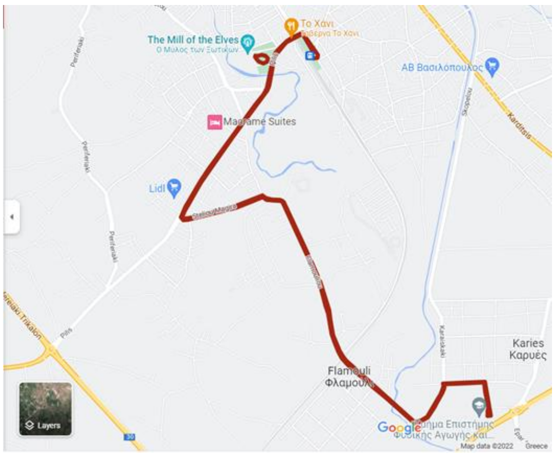

Fig. 1. Path within Trikala, Greece urban context to be followed by the automated van

The research project 'AVINT' focuses on the integration of autonomous vehicles within the urban context through a real-life demonstration in the city of Trikala in Greece. The participating partners study the urban transport context in Trikala city and will implement a transportation line supported by autonomous vehicles in a full integration mode with the city transport network within mixed traffic without dedicated lane. The real-file demonstration includes three phases: a) pilot phase without passengers and an operator on-board, b)

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trials with passengers and an operator on-board and c) passenger trials with no operator on-board.

As described earlier, the vehicle serving the specific lane shall be automated. This implies that the vehicle is capable of independent navigation and locomotion in an urban environment, within real traffic conditions among mixed vehicle traffic. The automated vehicle will not have the need for a human driver/operator inside the vehicle (in phase C – see below) and the actual driving is executed mostly without human intervention. Human intervention is expected and allowed to take place remotely to go over limited number of unforeseen, escalated or difficult driving conditions. Also, physical human intervention by the vehicle is expected to be managed under accidents, daily maintenance like charging, and other similar limited number of events that stop the actual service and cannot be overcome with remote driving. The fleet of buses shall operate in a non-segregated environment alongside mixed traffic as set out by the Greek law.

Human intervention is required to be handled remotely via the communication with a remote-control centre which will have real-time monitoring and supervision of the fleet of autonomous vehicles to overcome limited unpredictable, scalable or difficult driving conditions and involves limited remote operations such as braking and immobilization of vehicles [4]. The vehicle shall be able to accommodate people with wheelchairs. The access should be facilitated both on entering and leaving the vehicle and during travel providing safety. The vehicle will communicate with the route traffic lights in a vehicle coordination scheme allowing a green wave. Specific proximity sensors are and will be installed on the respective traffic lights to allow a traffic light manipulation (turn to green) upon vehicle approach (50 meters). High level architecture is illustrated in the figure below.

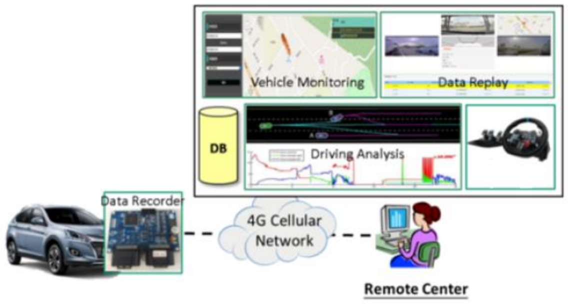

Fig. 2. High Level Architecture

The project is divided in three phases:

A) test phase – no passengers – a security operator on board: this is a testing phase for the project,

B) initial phase – passengers – a security operator on-board: this is the initial pilot phase,

C) final phase – passengers – no security operator on-board: this is the final project phase.

Vehicle needs to be able to operate in all three phases, even this implies changes in vehicles speed. [7] For phases B and C a reliable solution should be developed for i) an emergency button at the remote-control centre which is able to stop the vehicle in real time conditions and ii) remote execution of overtaking manoeuvres from an operator at the remote control centre.

A. Basic Requirements

The basic operational requirements of the project are outlined below:

Self-driving. Only manual intervention or remote takeover in emergency situations. The vehicle should support wheelchair access for persons with disabilities and ensure safety during operation

The Central control centre, 5G real-time feedback of vehicle-mounted video, 5 cameras, front and back, left and right, plus internal, and emergency call phone should be built. Instant emergency stop button is installed in remote control centre.

The vehicle can communicate with the traffic signal light, allowing the vehicle to pass with green light priority. The traffic light and Roadside Units are deployed together, and the signal control is realized when the vehicle reaches 200 meters.

The vehicle speed should be guaranteed to be 25Km/h maximum.

The vehicle needs to be equipped with the same monitoring system as the remote-control centre, including audio and images from the vehicle.

Reliable safety solutions are required to solve accidents caused by communication failures and to avoid traffic accidents.

The specific data that the control centre interacts with the vehicle terminal needs to have an API JSON information structure sample.

Green wave passing enable needs to be provided and the interaction protocol between traffic signal control and vehicles needs to be determined.

B. Evaluation Vehicle

The testing vehicle that is used for the prototype is a conventional Peugeot e-traveller van equipped with a variety of additional sensors such as an IMU (Inertial Measurement Unit) to measure orientation, LiDAR (Light Detection And Ranging) sensors to measure distance to surroundings and centimetre precision positioning using RTKGNSS (Real Time Kinematic - Global Navigation Satellite System).

The van shall have automated capabilities implemented and can follow a pre-recorded path with the position, orientation, and desired speed of the truck at discrete waypoints along the path, called breadcrumbs. Actuators and interfaces for steering and controlling brake and throttle are available.

The in-vehicle controller processes and fuses data of these sensors to provide the best possible perception around the vehicle. With the support of perception and decision logic functions, the command unit develops a control path to be followed. A monitoring unit will evaluate the route planning for safety and consistency. The central controller’s task is to process the data (data fusion), do the path planning, and to translate into commands for steering, braking, acceleration, park brake and the vehicles’ accessories (lights, blinkers, horn) The responsibility for correct command execution will be given to external organs, devices, and actuators external to the Electronic Control Unit (ECU). The ECU will provide interfaces for: power supply both internal and external, CAN bus and Ethernet.

All communication busses allow for bidirectional communication, and they interact with the vehicle communication interfaces. In this way, the ECU will have access to all the information available and can interact with every subsystem. For inputs and outputs, all the data that the ECU will process is fed in and out via communication signals based on CAN BUS standard.

The vehicle-road communication can realize collaborative interaction between the vehicle and traffic light infrastructure. Roadside equipment RSUs installed at intersections are connected to roadside infrastructure such as traffic signal machine, providing reliable and effective operation and traversal.

II. Remote Control Solution for Vehicle Monitoring

The possibility to provision road vehicles unmanned and on demand will have an important influence on the development of new mobility concepts. Remote image control will significantly increase the security of automated van with a critical mission to accomplish its path to the set destination.

Respecting the current Greek legislation, a remote control center will be developed by the project. In this remote control center a live feed of cameras surrounding the vehicle shall be provided using 5G communication. Thus 5 cameras within the van shall be installed aiming at providing a live feed (one looking in front, two on each side mirror, one looking at the back of the vehicle and one on the vehicle ceiling showing the vehicle interior). In addition, an emergency phone VoIP line shall also be provided within the vehicle. The following sections outline the basic monitoring concept, including a static multi-camera design, and cellular 5G network based video transmission architecture.

A conventional vehicle operating as a pre-test car shall be used for the trials and shall be wirelessly monitored. With respect to the possible travelled distance of the vehicle, the communication infrastructure needs to cover a wide area. To avoid a proprietary solution, mobile Internet is a sufficient way of using an already established infrastructure. Fortunately, the network coverage for cellular connections is constantly growing and the available transmission speeds are increasing.

SPACE HELLAS along with project's partners has thoroughly worked to this respect. Firstly, a 5G cellular connectivity device should first be able to integrate the hardware and offer enough firmware flexibility to set up automation rules. Besides, having a stable, reliable connection is crucial for real-time remote monitoring in such missions. The rugged and durable design of 5G router can sustain the van's vibration and wide temperature ranges. The operator who remotely monitors the van needs to understand the vehicle's surroundings. According to directives, the following are required:

1 horizontal view angle in the front of the vehicle

2 side cameras mirror views

3 rear camera view

Bandwidth and latency are the most important criteria for the choice of the communication architecture. The 5G cellular router is the ideal option for this solution, as it handles real-time, continuous heavy data throughput with a guarantee of ultra-low latency. This router can establish 5G network connectivity, making it possible to reach ultra-high upload speeds of up to 900 Mbps, and that's just what smooth live streaming requires.

Transmitting the raw images in color over a 5G cellular communication link would require reducing the data rate, so the video is video encoded. On the operator side, the images are decoded and displayed on a wide-angle screen with a field of view similar to the vehicle's.

Using a wired connection, cameras connect to a DVR (Digital Video Recorder), which in turn connects to a 5G cellular router, providing required connectivity. A dual-SIM 5G router offers stable and reliable internet access in a moving vehicle with automatic failover, ensuring network continuity even if the primary connection is lost. Having a backup connectivity option with a different operator reinforces the security of this solution, as any minute of lost communication poses an increased risk. The Control Center connects to the cameras installed in the van via secure VPN connection. The 5G router offers a variety of VPN services to choose enabling us to meet all solution requirements. An encrypted connection protects the data from viewing or altering by third parties for malevolent purposes, so the live camera footage and the recordings can safely reach the Control Center monitoring server.

The topology of the solution is like the one illustrated in the following figure [10]:

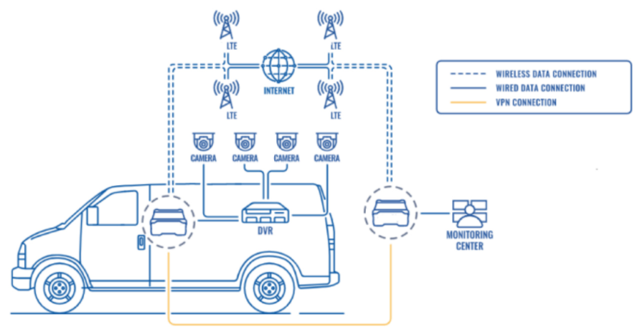

Fig. 3. Topology of the wireless camera monitoring solution

The benefits of the above-mentioned solution are summarized below:

- Router offers a 5G connectivity with automatic dual-SIM failover that is ideal for providing seamless back up connectivity.
- The rugged and durable design of 5G router can sustain van's vibration and wide temperature ranges.
- Using one of the multiple available VPN services in 5G router, encrypted secure remote access from the Control Center to the van is established.

Besides, SPACE HELLAS has designed a solution with a live map that gives a visual real-time representation of the vehicle in the system, including vehicle status, stops, pickups/drop-offs, and routes (including any deviations). By clicking on any of the vehicles on the Live Map, critical vehicle data (vehicle ID, speed, direction, location, status) can be viewed. This data is also logged for data analytics and reporting, and this data is available (in real-time) through the required API. The Platform can also use real time data from sensors (LIDARs, IMU, odometry, cameras). These data can be made available via APIs, but they are also available for presentation in the platform, along with live vehicle location, vehicle status, and more.

The platform infrastructure is designed for stability, scaling, resilience and mitigating common issues that lead to outages while maintaining recovery capabilities. Furthermore, it maintains redundancy to prevent single points of failure and is able to replace failed components. In the case of an outage, the platform automatically restores customer applications and databases as the platform is deployed across multiple data centers.

III. Results

We are currently in the process of evaluating the network connection of the test bed for use case deployment. As part of this activity, we evaluate latency and throughput between moving connected vehicles and 5G network. For the greater part of the measurements, latency stays under 60 milliseconds, and there are only some network blind spots (e.g., sharp turns obstructed by natural or human-made obstacles such as hills or buildings respectively) along the pre-defined path vehicle has to cover, that may increase the latency beyond this value. Latency of up to 60 milliseconds is sufficient for small-scale controlled tele-operated driving as well as mission parameter relay from off-board software to the bus. In addition to network latency, we shall evaluate the data freshness of a video signal. Data freshness measurement includes the whole processing and transmission chain and is therefore a true end-to-end performance metric. For our application, we stream video from a camera inside the vehicle to a remote screen. Data freshness is defined as the time difference between an event happening in front of the camera, e.g., an obstacle appearing on the road, and the event being monitored at the control center.

IV. Conclusion

In this paper we presented the requirements to achieve unmanned vehicles through automated driving. Several challenges create constraints in the deployment of autonomous vehicles for providing automated mobility on demand services. We have studied initial steps for automated tests under 5G communications to enable. Nevertheless, there are several technical [8] [9] economic and social challenges that need to be addressed before the large-scale deployment of high or full automated road transport systems occurs. The system presented relies on the transmission via wireless networks of video/audio streams of the vehicle surroundings to the control center allowing a human operator to remotely sense the environment and monitor the vehicle in a safe, controlled and cost-effective way.

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