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Design of Autonomy System for Military Operational Platform

Paula Mierzejewska[1], Krzysztof Fudala[2], Jakub Forysiak[3], Szymon Madziara[4], Jakub Felcenloben[5], Piotr Krawiranda[6]
Born Electric Sp. z o.o., Lodz, Poland

Abstract: The article provides detailed explanation of a military vehicle autonomy system. It focuses on the design of a 2-axis, off-road operational platform with autonomous drive for military purposes. The autonomy system is based on the sensor such as LIDAR, depth camera and infrared camera. The paper provides information on the hardware selection and its functions in the system, as well as the software. The article focuses on the schematics of the system and the software modules.
Keywords: Autonomy system, military platform, autonomous drive, autonomous vehicle, lidar

1. Introduction

Technological development has a crucial impact on the automotive industry. Theevolution of the vehiclesprovided increase in the safety, ergonomics and practicality. Modern vehicles allow easy, comfortable and quick transportation. However, increasing demand and needs of the potential users force manufacturers to constantly develop their solutions. The automotive companies constantly compete to win the customers.Contemporarily, one of the main goals of the transportation industry is development of the autonomous systems influencingsafety and comfort of driving. Initially the vehicles were controlled thoroughly by a human. However, with increasing automationinthe world the role of a human driver has decreasing trend [1-4].

Based on the NHTSA (National Highway Traffic Safety Administration in the USA) there are distinguished five different levels of automation:

- level 0 (driver only) – all functions of the car are under complete control of a human driver,
- level 1 (assisted) – only one function is automated (ex. cruise control), but the driver must remain attentive at all times,
- level 2 (partially automated) – more than one function is automated, but the driver must remain attentive at all times,
- level 3 (highly automated) – the automation of the driving functions allows driver to engage safely in other activities,
- level 4 (fully automated)–the vehicle does not require a human driver at all, it can drive itself.

According to society of automotive engineers (SAE) there is considered a 6-level classification (Figure 1).

SAE Level	SAE Name	SAE Narrative Definition	Execution of Steering/ Acceleration/ Deceleration	Monitoring of Driving Environment	Fallback Performance of Dynamic Driving Task	System capability (driving modes)	BASt Level	NTHSA Level
Human Driver monitors the driving environment								
0	No Automation	the full-time performance by *the human driver* of all aspects of the *dynamic driving task*	Human Driver	Human Driver	Human Driver	N/A	Driver only	0
1	Driver Assistance	the *driving mode-specific* execution by a driver assistance system of either steering or acceleration/deceleration	Human Driver and Systems	Human Driver	Human Driver	Some Driving Modes	Assisted	1
2	Partial Automation	Part-time or driving mode-dependent execution by one or more driver assistance systems of both steering and acceleration/deceleration. Human driver performs all other aspects of the *dynamic driving task*.	**System**	Human Driver	Human Driver	Some Driving Modes	Partially Automated	2
Automated driving system ("system") monitors the driving environment								
3	Conditional Automation	*driving mode*-specific performance by an *automated driving system* of all aspects of the *dynamic driving task* - ***human driver* does** respond appropriately to a *request to intervene*	System	**System**	Human Driver	Some Driving Modes	Highly Automated	3
4	High Automation	*driving mode*-specific performance by an *automated driving system* of all aspects of the *dynamic driving task* - ***human driver* does not** respond appropriately to a *request to intervene*	System	System	**System**	Some Driving Modes	Fully Automated	3/4
5	Full Automation	full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	**System**	Some Driving Modes		

Figure 1. Levels of autonomy [5]

So far there has not beenachieved a level of 3 or higher in a serial production, however there have been presented prototypes by several manufacturers. Some of the automotive companies plan on launching level 3 vehicles on the market in 2021 (Figure 2) [6].

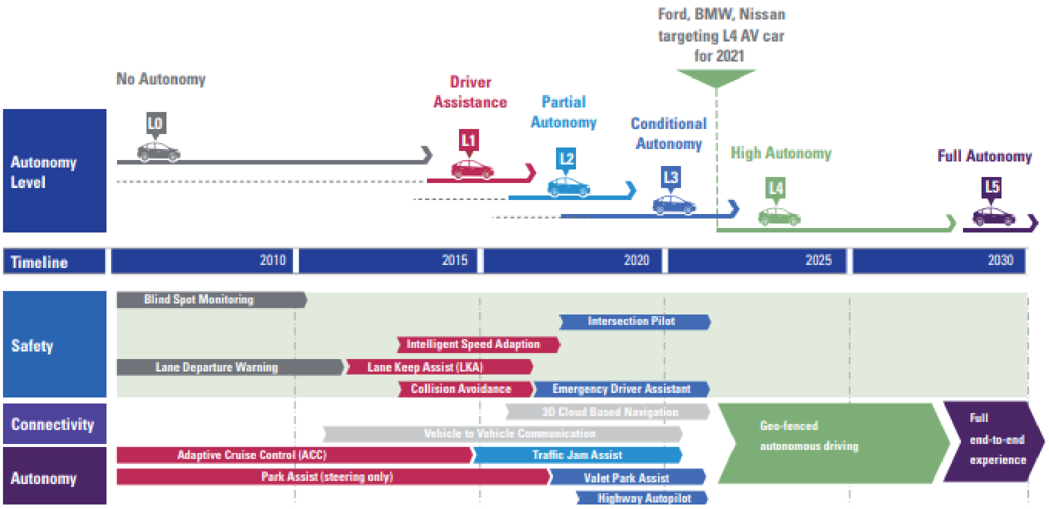

Figure 3. Autonomy level timeline [6]

2. Vehicle Description

In order to build an autonomous military operation platform the research of the market-launched vehicles was done. It was concluded that the best base for creation of the autonomous off-road vehicle is a Utility Vehicle. UTV is a 4-wheelvehicle, mainly designed for off-road and cargo purposes.Thanks to its construction the UTV are characterised by good manoeuvring properties and capability to overcome obstacles such as demanding, uneven terrain. Furthermore, they are well-adjusted to transporting relatively high loads.

The UTV chosen for the platform development was Polaris Ranger XP 1000 EPS (Figure 4). It is characterised by dimensions 3.05 x 1.58 x 1.96 m and weight of 66 kg, while it can carry up to 680 kg. Polaris Ranger has a double-wishbone suspension and 4x4 drive powered by 999cc internal combustion engine [7].

Figure 4. Polaris Ranger XP 1000 EPS [7]

After modifications the vehicle will be propelled by an electric motor powered by lithium-ion batteries.

3. Sensors Selection

The designed autonomy system bases on different sensors and transmitters. Due to the requirements, the autonomy system will include devices such as infrared camera, depth camera, lidar, GPS, router and computer allowing it to identify obstacles and drive along defined route. The sections presents the selection of the devices for the autonomy system and the results of their testing.

3.1. Lidar

Lidar (light detection and ranging) is a device used for detection and recognition of the surroundings and its elements. Based on the gathered data there is created a point cloud picturing the actual setting. The requirements for the lidar sensors were defined as follows:

- Operation mode: capable of working on a moving platform,
- Adjusted to mounting in a vertical position,
- Outside coverage [m]: min. 100,
- Horizontal sampling range [˚]: 360,
- Sampling rate [points/sec]: min. 100 000,
- Number of channels: min. 16

There was performed a market research and lidar model - Ouster OS-1 - was chosen. It was full-filling all of the requirements and was offered at the lowest price.
The parameters of the lidar Ouster OS-1 are presented below:

- Weight [g]: 380
- Coverage [m]: 120
- Sampling rate [points/sec]: ~ 300 000
- Horizontal sampling range [˚]: 360
- Vertical sampling range [˚]: ± 33

Furthermore, the device is equipped witha built-in accelerometer allowing more precise orientation of a point cloud in the space regardless of the platform inclination.

The research on lidar showed that the objects are recorded in the most precise way for up to 20 metres.The device allows imaging the elements of the surrounding very well (trees, bushes, buildings).It was also noticed that the material type (ex. glass, mirror) and colour (black, white) influences the recorded point cloud. Furthermore, there was not observed a substantial impact of the weather conditions on the recorded point cloud.

3.2. Infrared Camera

The infrared camera is used as a vision sensor during difficult lighting conditions, for instance at night. The requirements for the infrared camera include:

- Output: USB,
- Light wavelength range [µm]: 8-12,
- Visual range [˚]: min. 40,
- Sampling frequency: 30 Hz.

The leading manufacturer of infrared cameras is FLIR company. According to the specification FLIR ADK camera is the best solution for automotive industry, hence a perfect product for autonomous platform. The parameters of the chosen platform are presented below:

- Pixel Pitch [µm]: 12,
- Spectral Band [µm]: 8-14,
- Thermal Sensitivity [mK]: < 50,
- Operating Temperature [°C]: -40 to 85,
- Array format: 640 x 512,
- Frame Rate: Full Frame (30 & 60 Hz selectable),
- Sealed Design: IP69.

Performed research of the camera showed that it has high effectiveness in case of objects generating heat as a result of biological or mechanical processes such as humans and vehicles. The device also clearly records the elements of the surrounding such as trees and buildings. The thermal camera works best in low-temperature conditions, where emitted heat is better visible. The highest effectiveness was obtained for the tests in forested rather than urban areas.

3.3. Depth Camera

Depth camera is responsible for providing both image data that are used for image segmentation (for example finding roads), but also a cloud points similar to one produced by lidar.

The requirements for the depth camera include:

- Output: USB 3.0,
- Minimum distance [m]: 0.5,
- Maximum distance [m]: 10,
- Frames per second [fps]: min 30

Having performed the research it turned out that the only depth camera full-filling the requirements is ZED camera. It has the best parameters and is characterised by various resolutions. The parameters of the camera are presented below:

- Minimum distance [m]: 0.5,
- Maximum distance [m]: 20,
- Frames per second [fps]: 15/30/60/100,
- Resolution: 4416x1242, 3840x1080, 2560x720, 1344x376,
- USB 3.0 plug.

The experimental tests showed that the device works best in spacious surrounding with good lighting. The objects are recorded well for small distances (approximately 5 metres) and with increasing distance the recognizability of the objects decreases. The performed research did not show any crucial impact of the weather conditions on the camera records.

3.4. Image Processing Unit

Image processing unit is a computer responsible for processing signals from the cameras and lidar in the real time and identifying the objects. The required parameters for the computer are as follows:

- Gigabit Ethernet for collecting data fromlidar,
- CAN bus for connecting with other autonomous system elements,
- Ports: 2x USB 3.0 or USB - C for collecting data from cameras,
- RAM: > 8 GB.

Analysis of the platform requirementsand products available on the market resulted in choosing Nvidia Jetson Xavier computer as the best solution for this particular application. The device is dedicated to image processing for the purpose of autonomous systems in vehicles.

- Processor: 8-core ARM v8.2 64-bit CPU, 8MB L2 + 4MB L3,
- Graphics card: 512-core Volta GPU with Tensor Cores,
- Ports: PCIe x1, USB 2.0, UART (for Wi-Fi/LTE) / I2S / PCM / CAN, HDMI 2.0, eDP 1.2a, DP 1.4, USB-C x2,
- Wireless connection: Bluetooth 4.2, IEEE 802.11 ac,
- RAM: 16 GB,
- Disc: 32 GB

3.5. GPS

In order to process the autonomy function, it is compulsory to determine the geographical coordinates. Hence, there was performed a market research on the available solutions for the designed platform.

The requirements for the GPS:

- CAN interface,
- Supported global navigation systems: GPS, GLONASS, BeiDou, Galileo,
- Suitable for military applications.

The research showed that the most practical solution is GPS Duro. The parameters of the chosen device are presented below:

- Maximum temperature [°C]: 85,

- Minimum temperature [°C]:-40,
- Size [mm]: 130 x 130 x 65,
- Interface: UART, CAN,
- Global navigation systems: BeiDou, Galileo, GLONASS, GPS, SBAS,
- Suitable for militaryapplications.

Testing of the GPS showed that the device is characterised by very high precision. The recorded coordinates coincide very well with the travelled route on the map. According to the manufacturer the horizontal precision is 0.75 m and it was confirmed during the tests. Furthermore, in the repeatability test the results were highly consistent (up to 6^{th} digit after the decimal point).

4. Autonomy System Design

There are few scenarios of utilization of the autonomous vehicle created during the project:

- Transportation from point A to B based on GPS localization
- Patrol of the area
- Scanning the area

What is more, all of the data from vehicle should be visible in cloud application, where user can also browse through historic data. Therefore the design of the system needs to be adjusted to mentioned requirements. The system must be divided into modules based on devices that will host them. The schematic of the system is presented on following figure.

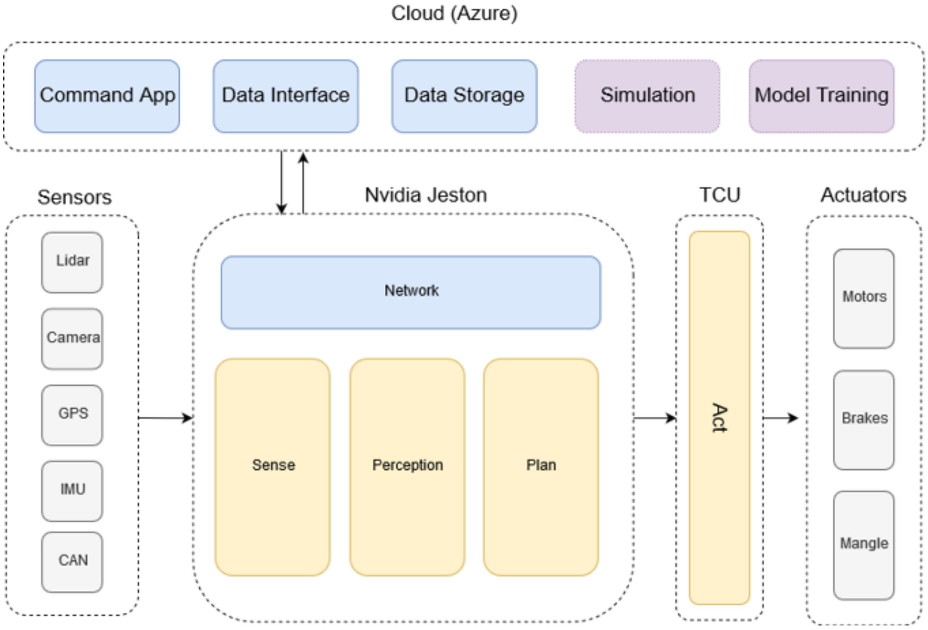

Figure 5. Schematic of the system

The cloud part will be responsible for gathering data from vehicle, storing them and visualization. It is based on the popular Microsoft Azure cloud solution. Moreover, web application will send the initial goal to the vehicle so it will know what the current task is.

The main algorithm of autonomy is placed on the Nvidia Jetson. It will be responsible for the analysis of sensors' data, planning the trajectory and checking if the goal was reached. The software modules of the autonomy system are presented on the following figure.

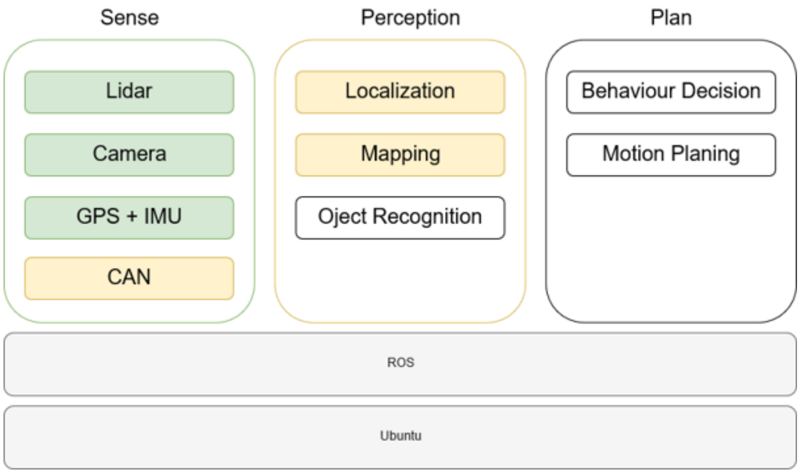

Figure 6. Software modules of the autonomy system

Sense module is gathering data from sensors and processes data to acceptable form for the perception module. Perception module localizes the vehicle in space and maps the surroundings – prepares the complete map of environment for the plan module. Plan module decides where it should ride and sends proper signal to Act module, placed on TCU board.

To properly test the autonomous vehicle, algorithms should be tested using simulation. The main goal is to mock data in as realistic way so the simulation will be as close to reality as possible. Therefore, only two modules changed were Sense and Act, the plan and perception remains as in the vehicle. This allows to test algorithms in the best way.

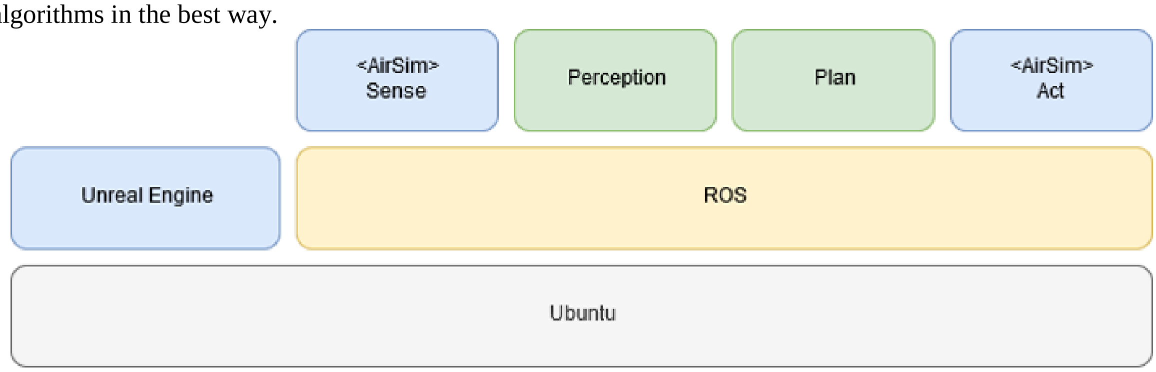

Figure 7. Simulation system topology

5. Conclusions

This publication could be a guide for future constructors seeking inspiration in the area of sensors collection and design of the system. The presented design allows to fulfil the requirements – thanks to modular approach the final solution can handle a great variety of tasks set by the users. It is a base for creation of more specific vehicles.

The testing module allows to test the algorithms in the realistic conditions, even for some cases that are difficult to induce in real world (for example extreme weather conditions). Thanks to cloud solution the testing can be done remotely from any place in the world, which is a huge facilitation for autonomous vehicle's creators.

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