Autonomous vehicle from TUL in Liberec scored points in the European Commission competition

A team of students and academic staff from the Department of Vehicles and Engines FME TUL and the Vehicle Department NATI TUL designed an autonomous vehicle for transporting cargo under challenging conditions, which impressed the European Commission evaluators. The design used modern design approaches such as topological optimisation.

The Technical University of Liberec (TUL) has already joined the electric vehicle platform for the Czech Republic in 2022, and from January 2024, it will also become a member of the steering committee. It will thus address the issue of electromobility together with strong leaders such as Škoda Auto, ČEZ, Prague Energy and CTU Prague, among others. Study programmes have opened her path focused not only on traditional but also on new directions of technical education and also by the successfully completed interdisciplinary project Modular Platform for Autonomous Chassis of Specialized Electric Vehicles for Transport of Cargo and Equipment (ANTeTUL), which was supported by the European Union and the Ministry of Education and Science of the Czech Republic through the Operational Programme Research, Development and Education.

One of the project results is a working model/demonstrator of an autonomous vehicle for transporting cargo under challenging conditions. The European Commission has selected the project as one of the finalists of the prestigious "Regiostars 2023" competition, which recognises the best projects supported by European funds. The self-driving platform has made its way among 228 competitors from all over Europe. The European Commission has been launching the Regiostars competition for 15 years to promote projects funded by European funds (under the Interreg Europe cross-border cooperation support programme). The evaluation of the last edition took place on 16 November 2023 in Ostrava and 30 finalists were selected from 228 applicants in six categories, including four Czech projects. (One of the six awards went to ProFem, a Czech non-profit organisation working to improve the situation in the field of domestic and sexual violence.) Liberec's ANTeTUL project, which is a self-driving modular platform for work in various workplaces and in the field, was selected by the European Commission in the A Connected Europe category, where it was joined by four other international projects for the Regiostars award: the Danube Cycle Plans (Interreg Danube), Diglogs (Interreg Italy-Croatia), Dynaxibility4CE (Interreg Central Europe) and Interreg Central Baltic.

The interdisciplinary team worked on the project under the leadership of Assoc. Michal Petru, Head of the Department of Machine Parts and Mechanisms of the Faculty of Mechanical Engineering TUL (FME TUL) and the Research Department of the Institute for Nanomaterials, Advanced Technologies and Innovations (NATI TUL), since 1 September 2018 and the project was officially completed on 30 January 2022. "At the beginning of May 2023, we were invited by the Ministry of Education, Youth and Sport CR to apply for the national round of the competition. There, evaluators in the Czech Republic selected four projects to represent the Czech Republic in the preliminary round, from which the European Commission then selected the finalists. The fact that we have been selected as a finalist in the prestigious Regiostars 2023 competition and then among the top five European projects in our category shows that our ANTeTUL is a significant research achievement. We defended our project in Brussels during the European Weekend. We

did not win the first prize, but, as the European Commissioner Elisa Ferreira said, of the five selected, virtually all can be considered winners," says Assoc. Michal Petrů.

Autonomous platform for cargo transport In the ANTeTUL project, the interdisciplinary team did not focus on an autonomous vehicle for road traffic but on electromobility that will help people and increase their safety in various workplaces and the field. *"We set four research goals: the development of lightweight materials for frame structures and other structural components, steering based on the momentum of individual wheels using electric drives, battery management and autonomous driving,"* explains Assoc. Petru added that the team has gradually developed three innovative generations of autonomous electric utility platforms. They are called Generation 0, which was preceded by Generation 0' (a derivation of zero), the size of the toy car on which autonomy was tested, and the validated data was then used to develop the much larger Generation 1 platform, measuring 3,850 × 1,925 × 1,005 mm. This utility autonomous electric platform is designed for transporting cargo in large halls and warehouses, for example, in mines and fields or in forests on uneven ground and unpaved ground. It weighs around one tonne and can carry at least the same weight. It is programmed for a speed of around 40 km per hour, but of course, it has to move more slowly in difficult terrain. Lightweight construction, unique gearbox The entire vehicle design was designed from the outset to achieve low weight.

The team, consisting of students and academic staff from the Department of Vehicles and Engines FME TUL and the Vehicle Department NATI TUL, used modern design approaches such as topological optimisation. "In the design of the axle arms and drawbar, topological optimisation helped us to achieve significant weight savings in the parts while maintaining the strength properties of the parts," says the head of the department, Dr. Robert Voženílek. Aluminium alloy weldments and weldments made of high-strength chromium-molybdenum tubes are used in the frame construction. Part of the frame is also made of composite elements; it is a hybrid composite (a combination of different fibres, for example, carbon, glass or textile). The hybrid composite of the frame was supplemented with nanoparticles of fly ash, which, in a small percentage ratio, significantly increased the elastic properties of the material used. A small single-speed gearbox also meets the requirements of a lightweight construction without differential with atypical joints in the form of glued wheels on the shaft. "It was developed by our students. They used gears used in the gearboxes of conventional passenger cars but made a significant contribution to reducing the overall volume of the gearbox by about a quarter compared to similar commercially available gearboxes. This gearbox is compact and is literally tailor-made for an autonomous platform," says Dr. Robert Voženílek.

Battery management is a new way of storing cells. A significant proportion of the weight of the platform is the battery, according to Ing. Pavel Jandura, Ph.D., from FM TUL, which is roughly one-third. But the question is how batteries will evolve in the future, what boxes will be made for them and what they will need to be stored in. According to Pavel Jandura, the research team had no plans to develop a new electrochemical battery design. They focused on how best to use known electrical energy storage technologies and their adaptation for specific practical applications of utility platforms, with a view to achieving the required capacity and performance for a given application. "One of the goals of this development was to find a way to keep battery cells at an optimal temperature. We wanted the battery to be mechanically robust yet lightweight and to incorporate effective temperature management. As part of the project solution, weight savings of up to 40% can be achieved for selected components of the battery

box. We have developed a new way of housing prismatic format battery cells using 3D printing methods and composite materials using ultra-thin and high-performance quadriaxial fabrics. During the project, the possibility of using the electrical properties of carbon fabrics as a heating element was verified. As a result, certain parameters of the battery were improved so that the platform could achieve the required range," says Dr. Jandura. However, he admits that the challenge of deploying composite materials lies in mastering the technology to mass produce the required shapes.

In general, today, the cost still does not compare favourably with established conventional design and manufacturing methods using lightweight metal materials. "However, it should be pointed out that this is true for the case of land-based electric vehicles, where the resulting weight of the battery box or the whole vehicle is not critical for its practical application. If we move into the area of flying vehicles, typically the eVTOL category, then weight, on the other hand, plays an absolutely crucial role here, where extremely lightweight yet strong composite materials are still the only technical solution for the practical implementation of such vehicles," he points out, while also reminding that range is a variable that depends not only on the energy stored in the battery but also on how the car is loaded, the terrain it is driving in and the prevailing weather and weather conditions. *"For land vehicles in general, range dependency is significantly affected by conditions. Operating a platform on a paved and level surface will be significantly different in terms of energy consumption than in a forest or in mines and hilly terrain that is heavy to traverse, where the distance travelled can drop significantly. The battery box is designed so that, in principle, the car can travel around 100 km,"* explains Dr Jandura, adding that the entire system can be adapted to a specific environment. On flat terrain, it makes sense to lighten the vehicle by reducing the number of batteries without compromising its functionality and performance. Multi-level steering This vehicle is equipped with several "senses" or sensory systems. Thanks to these and the multi-stage control system, the vehicle is equipped with a certain degree of autonomy, i.e. the ability to make its own 'decisions' and drive itself.

A control system has several hierarchical levels, where, generally speaking, the higher level gives commands and some aspects of autonomous behaviour to the lower layers of control. For example, the chassis design is such that the vehicle is divided symmetrically into quarters – each of the four wheels has a separate actuator for directional control and its suspension system. This gives the vehicle excellent manoeuvrability even in small spaces. *"Each wheel receives a command from a higher layer to turn to the correct position and turn in the desired direction. These commands are generated by the control system by evaluating the combined data from the various sensors that the vehicle uses to sense its surroundings. At the same time, a higher layer determines the desired speed. Everything is geared towards meeting a specific global goal. And its fulfilment depends on how it is specified and on the specific commands given by this higher layer,"* explains Assoc. Jaroslav Hlava from the FMI TUL added that *„during the development of the vehicle, a large number of different sensor systems were experimented with, including, for example, several differently filmed cameras: classic video cameras and depth cameras, with the help of which it is possible to obtain information about the position of the vehicle even in a situation where there is no GPS signal available. This means indoors or in the narrow passages between tall buildings typical of industrial sites.*

These experiments were mainly carried out on Generation 0, which was purposefully developed for easy preliminary validation of various control strategies that could be transferred to the final

Generation 1 platform. Based on position information, the vehicle can be steered in a feedback loop to follow a desired path and traverse operator-specified coordinates within the space it is moving through. "An alternative to this approach is a tracking mode of driving, where the vehicle follows a person, another vehicle, or other moving object. Ultra-wideband (UWB) technology has been used for this purpose, allowing information on the position of the tracked object or person to be obtained using a very low-power microwave signal, which is advantageous from an electromagnetic compatibility point of view.

Both steering options can be combined with lidar sensors that scan the area in front or behind the vehicle and provide information about static or dynamic obstacles. Since the control system has a mathematical vehicle model, it can estimate whether the obstacle can be avoided or whether the only possible response is to stop safely," says Assoc. Hlava. And as doc. Petrů, the information does not have to be processed only by the systems on board the vehicle. They can be passed on to a higher-level cloud, which will receive information about the complicated situation and try to resolve it. There is also the challenge of addressing the platform's ability to communicate with other systems, creating robotic autonomous teams where the different systems take turns in activities.

Scientists developed their own software

Liberec developed its own software to control the platform, which, as is evident from the previous text, has several levels. An integral part is a cloud-based superstructure that provides real-time evaluation of selected signals and prediction of required control interventions using machine learning principles. The cloud also houses complete telemetry data logging and a web-based user interface for monitoring and remote management of the autonomous vehicle. The second level is on-board control, ensuring the safe movement of the vehicle along its route. The control at this level was developed using the Matlab/Simulink environment. *"In it, it is possible to intervene very flexibly in the structure of the control system, while the implementation in the on-board control system takes advantage of the possibility of automatic code generation directly from this environment without the need for lengthy and inflexible manual programming,"* explains Assoc. Hlava.

Two modes

During the development of the control system, two basic modes of operation were developed and tested: tracking a specified path from point A to point B and Follow-me mode, or tracking a person or moving object. "The goal of achieving autonomy in tracking the path is to achieve a behaviour where no one needs to be on the path. The platform performs its tasks completely autonomously, such as transporting cargo. It registers and evaluates any unexpected obstacles on the route and can adjust its path accordingly," explains Assoc. Mcha Petrů. If the vehicle switches to follow-me mode, it follows an operator or object identified by an ultra-wideband beacon. This model is also intelligent and, therefore, reacts to obstacles accordingly. According to doc. Petru, this is an attractive option not only for industry but also for medical and assistance or delivery services. "I think this mode could be very interesting for the defence industry and the military as well," suggests Assoc. Michal Petrů.

Collaboration with local companies and foreign partners The ANTeTUL project was focused on pre-application research, so it was not primarily intended for deployment in industry. Nevertheless, it has significantly impacted the Liberec region, where companies have conducted

tests in specific industrial environments, buildings, halls, warehouses, outdoor spaces, fields, and paved and unpaved soils. It is also essential for the whole of the Czech Republic and the European Union. One of the project's indicators was the obligation to create national and international memoranda of cooperation – the team signed 19 of them in total. "We have gradually established cooperation with 25 countries not only in Europe but also in Asia, America and Australia. During the summer, we presented our research to research organisations and universities in England, e.g., UKRI (Innovate UK), UTAC, Birmingham CASE Automotive Research and Education Centre, Smart Mobility Living Lab London, and others. In December, I attended a very intensive meeting in India to discuss further research collaboration in electric mobility. There is no doubt that autonomous vehicles are changing the world of logistics. Our modular autonomous electric vehicle will help support the irreversible transformation of logistics by contributing innovative solutions based on modern scientific knowledge. It will help increase transport productivity and safety levels and ultimately lead to a reduction in environmental impact, " says Michal Petrů, noting that the team has registered five international patents and written 136 scientific publications concerning the project.

Practical application

The research team has worked with several companies in the project and some of them have already announced their interest in the autonomous platform. As it was developed and built under the operational programme call, it is not possible to produce it. Still, it would be possible to produce a modified form of utility chassis that could be used, for example, in road cleaning. "Companies producing machinery and equipment for cleaning roads, corridors and warehouses have expressed interest. We can also consider vehicles that cut grass along roadsides. I imagine autonomous or semi-autonomous platforms being used effectively in companies such as Alza or Amazon. There are also positive signals from some agricultural companies. Our system would find a perfect application in rescue work. The Czech Post and other suppliers have shown interest in the Follow-me mode," says doc. Petrů. He admits that the development is expensive, but the construction itself does not have to be so expensive. According to him, the assistant could be built for tens of thousands of crowns. At present, he says, such a vehicle would cost 200,000 to 250,000 crowns, but with cheaper sensors and a motor, it is possible to reduce the price by up to 100,000 crowns. "In countries where important components such as sensors, batteries or drives are manufactured, these components can be much cheaper. But we do not currently manufacture many components for autonomous electromobility in the Czech Republic or Europe, so we have to pay extra for them," he points out.

Student engagement, relevance to teaching

According to doc. Petru, this project will support the development of technical education and advanced study of autonomous electromobility. In this context, he recalls the significant contribution of students, especially PhD students in technical disciplines, to the project's overall success. For example, a student from the Faculty of Mechanical Engineering contributed significantly to developing the single-stage gearbox, and students from the Faculty of Mechanical Engineering TUL and the Faculty of Textiles TUL collaborated on the frame design or the preparation of composites. The students of the Faculty of Mechatronics have solved fundamental elements of hydraulics and have been significantly involved in the development of control systems, especially in the implementation of algorithms on a programmable automaton. They have also been effectively engaged in the development of battery management. This contributes significantly to the improvement of professional teaching and the direct link between education,

science and research. "*By getting involved in scientific work, young people gain valuable information, get access to the latest scientific knowledge and can strengthen university science teams. On the other hand, we are faced with the problem that companies are highly interested in such experts. They can easily overpay them and drag them to themselves. Given the remuneration opportunities at universities and the current grant vacuum, universities are losing out on capable and promising researchers*. Thanks to the ANTe-TUL project, I have travelled extensively and presented the results of the project in a number of countries. I have become convinced that the level of technical education at universities in the Czech Republic is outstanding and respected in the world. Czech technical universities have a reputation in the world and are globally respected for producing not only top graduates in particular types of studies but also significant innovations and patents; therefore, the study of technical disciplines deserves more support and, of course, a substantial number of students and graduates," says Assoc. Michal Petrů.

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