Drone-to-Vehicle Integration of Data: Design Concept and Application to Vehicle Automation System

Viktar Beliautsou[1], Aleksandra Beliautsou[1], Valentin Ivanov[1],
Binh-Minh Nguyen[2], and Hiroshi Fujimoto[2]
[1]Technische Universität Ilmenau, [2]The University of Tokyo

Modern vehicles are characterized by a high degree of environmental perception and automation. This is made possible by the development of new motion control and driver assistance systems as well as new methods for sensor-based detection of driving parameters. However, the functionality of commonly used visual and wave-based sensor systems, such as cameras, radars, etc., can be limited when installed in a vehicle, as some obstacles fall into the blind zone due to the road profile or other road users. It is also difficult to detect road-specific parameters such as gradient, slope or surface condition with on-board vehicle sensors. A method to improve the vehicle's detection capabilities can be proposed by extending the information channels with additional sensors by mounting them on an asisstent drone. This article presents a framework for drone-to-vehicle collaboration that enables the integration of data from drone sensors into the vehicle motion control. The article gives an overview of the system, the technology created for the implementation and the challenges to be overcome by integrating the different components. The hardware implementation of the drone and the integration of the data into the vehicle control unit are presented. The proposed approach allows the vehicle to view the road from different angles and detect changes in road conditions from a distance. It extends the capabilities of the vehicle motion control. The effectiveness of the developed framework is experimentally validated with electric vehicle's velocity control and traction control on low-friction surfaces.

Road parameter estimation

Thanks to recent advancements in actuators, computational hardware, and communications [1-3], transportation has become many features essentialy extending its functionality. Typical examples are autopilot technology, airborne urban mobility, and smart roads, that essentialy contribute to more reliable and user-friendly mobility automation.

A vehicle automation system cannot be realized without the ability to monitor road parameters (Fig. 1), which are being frequently changed in real-time operation. Therefore, various methods have been developed to identify road parameters using on-board sensors, e.g., driving stiffness estimation [4], camera-based detection of road irregularities [5], Light Detection and Ranging based (LiDAR) obstacle detection [6].

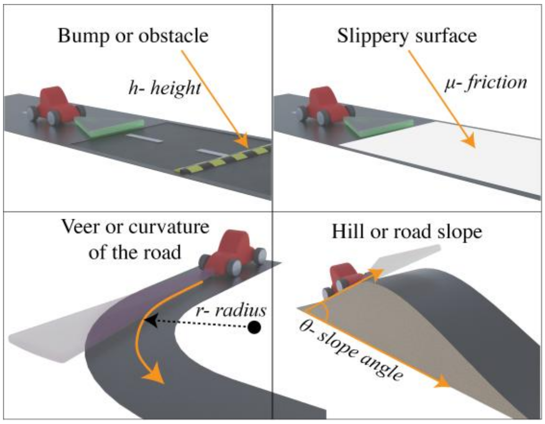


***Figure 1** Road parameters important for vehicle motion control and automation.*

In addition, the road parameters can also be determined using devices installed in the road infrastructure or in a vehicle travelling ahead. To facilitate interaction with in-vehicle systems, communication technologies from the areas of Vehicle-to-Everything (V2X) and the Internet of Things can be used. In [7], a variant of such interaction using crowd sensing was demonstrated, utilizing infrared temperature sensors, humidity sensors, quasi-electrical static sensors, cameras, Global Positioning System (GPS), etc. Wireless nodes were used for communication both in the vehicle and at the roadside. The studies [8] and [9] show the use of sensor data from vehicles driving ahead. In addition, vehicles can exchange information with each other (V2V) or receive information about accidents, weather conditions, etc. via V2X communication channels. Some concepts suggest using images from satellites or aerial vehicles flying over the road [10].

Motivation: Vision expansion for vehicle

The task of road parameters estimation has the following challenges which need to be solved.

Firstly, new vehicle control concepts will require new sensor functions. Unfortunately, attempts to extend the number and variety of sensors will not automatically improve the performance. Increasing the number of sensors in a vehicle is not always advisable and can lead to signal interference within a single vehicle or between vehicles nearby, as the range sensors of oncoming vehicles can detect each other, for instance light beams of the LiDAR, leading to false alarms.

Secondly, an important problem with the use of stationary observation sources is that it is complicated to cover the entire roadway. This can lead to a critical situation in which the problem area is not visible to such a station. It is not always possible to increase the number of stations, as this would increase infrastructure costs.

Stationary road monitoring has a decisive disadvantage: the monitored route always remains the same, and it is not possible to measure off-road or roadside sections in order to drive on unprepared terrain. This can be crucial in the event of a road accident if a problem area has to be avoided. After a natural disaster, a route for special vehicles must be created when clearing roads. In this case, communication between vehicles or fixed stations may not provide the necessary information.

Thirdly, estimating road parameters using on-board sensors can lead to latency caused by sensors' response dynamics and data processing time. For example, in [4] the driving stiffness is determined as an index of road friction using the recursive least squares (RLS) algorithm. This algorithm requires the implementation of three other algorithms: driving force observation based on motor torque and speed, vehicle velocity estimation and slip ratio calculation. The convergence of the individual estimates takes a certain amount of time. An example of the electric vehicle driving stiffness determination is shown in Fig. 2, where the vehicle accelerates and drives onto the low-friction surface after 2 seconds. However, the estimated driving stiffness only converges from the high friction to the low friction values after 2.5 seconds. This latency could affect the performance of motion control methods that require real-time updating of the driving stiffness and/or road friction coefficient.

The above problems motivated the authors to develop a new way to improve the ability of vehicles to detect road parameters without increasing the number of on-board sensors and to simultaneously overcome limitations related to positioning, the field of view, and the installation angle by placing the sensors on the vehicle.

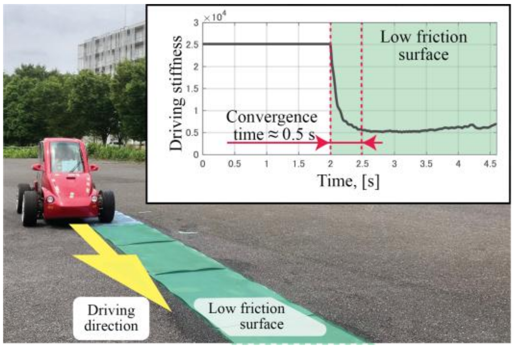


***Figure 2** Example of latency in real-time driving stiffness identification.*

Drone-to-Vehicle Integration of Data

The proposed approach presents a new platform for vehicle sensors that enables a vehicle to assess the information in front of itself with the help of an unmanned aerial vehicle (UAV) or a drone. It allows the flying drone to assist the vehicle when the vehicle's on-board sensors are unable to measure the environment, and the road infrastructure has also no data about the area. The platform should not only improve the quality of measurement technology in the vehicle, but also enable new strategies for vehicle automation (Fig. 3).

Another application is the improvement of driving comfort, e.g. the selection of an appropriate mode for (semi-)active suspension. After measuring the road profile in front of the vehicle, the active suspension can be adjusted before hitting a bump.

The drone can also be used to replace estimated values in vehicle control units with direct measurements or more accurate estimates. For example, one of the most important parameters that a vehicle must take into account is the coefficient of friction between the tyres and the road, which cannot be measured directly. Even if the coefficient of friction is calculated correctly using an estimator, the processing of estimated value can be delayed. This delay can be compensated for by using a drone that can recognise and predict the road condition from a distance.

The platform can be used to determine the type of the road surface, the profile and gradient of the road or to define a route through unknown terrain. The platform's applications are related not only to conventional road vehicles but also to special transportation, e.g., rescue vehicles for rubble removal and evacuating people after an earthquake. The existing

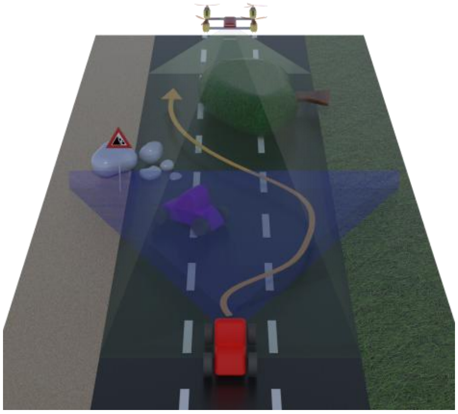


***Figure 3** Comparison of the fields of view of vehicle (blue) and drone (green).*

infrastructure may be severely disrupted and communication between units may be overwhelmed by the amount of information. The use of a drone in such a situation will provide vital information that will certainly reduce the time required for rescue operations.

In summary, the introduction of a UAV platform for vehicles has the potential to increase safety, support complex algorithms for unmanned driving and offer unique opportunities for specialised vehicles operating in rough terrain in an unfamiliar environment.

Implemented prototype platform

This study considers the drone-to-vehicle platform, schematically shown in Fig. 4. The drone is equipped with two types of sensors: the sensors that measure the environment, and the sensors that are used for drone navigation. The drone's on-board computer collects sensor measurements to process and identify the road parameters. The identified parameters are sent to the vehicle's computer via the Internet or a local network. The computer processes the required data and sends them to the vehicle's control unit where the control algorithm is performed.

Sensors related to the environment perception

Drones can carry a variety of sensors that can measure the environment. The most typical are cameras, LiDARs, radars, etc. On the one hand, these sensors are considered as the payload of the drone. On the other hand, they are also relevant for the vehicle control tasks. By combining data from different sensors and indirect measurement methods, some values can be measured that are difficult or impossible to capture with the required accuracy using the sensors in the vehicle. For example, data on the reflectivity of the road and the weather conditions can be used to presume which section of the road is covered with a film of water or an ice crust. Such measurements are possible because of the favourable view of perspective of the drone, as it can be located exactly above the surface, provides a sufficient distance for the operation of such sensors.

An important requirement for some sensors is the need for a stable installation, such as minimization of vibrations, static position and similar requirements. Of course, when installing such sensors on the drone, movements or vibrations cannot be fully eliminated, as even a slight gust of wind will cause the drone to change its position. To minimise this negative effect, special platforms are usually used that make it possible to stabilise the load independently of the drone's frame.

Sensors related to the navigation

Drones are also usually equipped with an inertial measurement unit (IMU), a global positioning system (GPS) and other sensors for precision landing and obstacle avoidance during flight. With modern satellite navigation systems, the position of any object can be precisely determined. However, the accuracy of positioning with a conventional GPS may be not sufficient.

Data transmission from drone to vehicle

Once the drone has received the data, it should be processed and transmitted to the vehicle. There are two possible scenarios for the use of drones. If the drone is being considered as an infrastructure object, then it will transmit data to a cloud server that can then distribute and provide all this data to the users. In this case, the drone is part of the road infrastructure and monitors the road as needed. It is not necessary to set up a new communication channel for the drone, it is sufficient to consider the drone as a new sensor in the infrastructure.

The second possible application, which can be defined as an aerial assistant or a drone accompanying a vehicle, involves two communication channels: drone-to-vehicle and vehicle-to-drone. The main purpose of data transmission from the vehicle to the drone is to provide the drone with information about the estimated trajectory of the vehicle and path planning. The

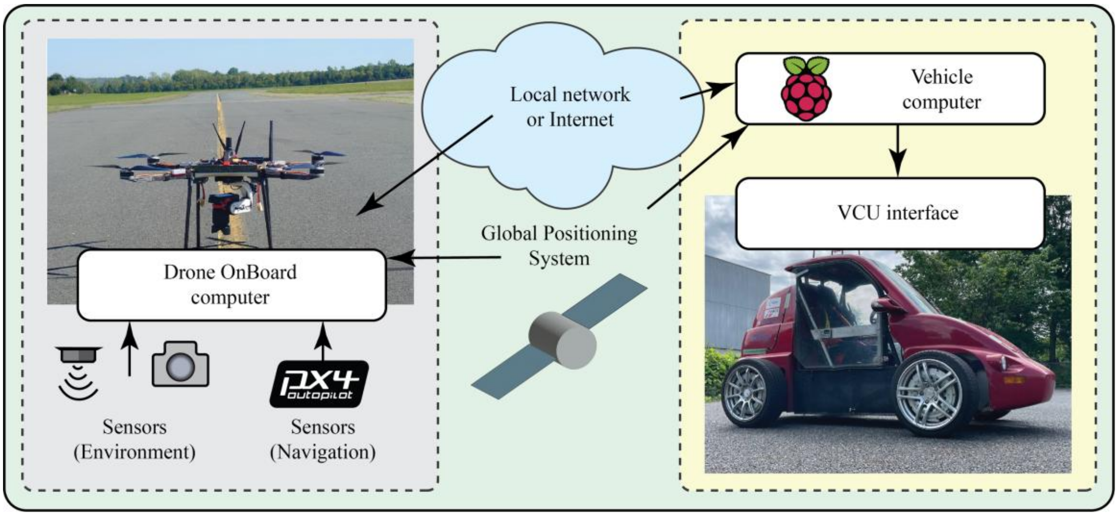


Figure 4 *Proposed platform with experimental drone and electric vehicle. Components on the grey background executed on the drone, and on the yellow background on the board of the electric vehicle.*

vehicle requests data, sends a command to launch the drone and confirms receipt of the required data. The data transmitted from the drone to the vehicle will mainly consist of the collected data. When recording, the target data should be synchronised with the drone's position data.

There is a variety of standards and protocols for organising such communication. One possibility is to install a router that sets up a wireless Wi-Fi network. Modern network standards make it possible to establish a high-speed connection over a distance of 1 km [11]. This range is sufficient for the intended tasks. For transmission data to the longer distances, the other networking technologies may be used. Another option is to connect the drone and the vehicle to the internet. This can slow down the connection, but completely removes the obstacle of communication distance.

Platform implementation

The proposed platform was implemented in a real experimental system developed by the authors' research groups. The drone is equipped with a camera that records the image of the road for further detection of obstacles, as well as a distance sensor working on LiDAR technology. The LiDAR sensor module is for application on drones and has a measuring range of 0-40m. The sensor operates at 850nm central wavelength and records readings at a frequency of 1000Hz with a resolution of 1mm. The drone has four motor-propeller actuators and is controlled by the Pixhawk 4® flight controller and equipped with on-board computer for the sensor data processing and router for the communication. The electric vehicle is driven by four in-wheel-motors and is equipped with the dSPACE-Autobox control system.

The system enables the vehicle to view the road situation from a different angle and makes the navigation task particularly clear, as can be seen in Fig. 3. The image of the terrain from a height looking down makes it possible to obtain data that already represents a map, and after assigning eventual trajectories on the map, it is possible to select the most suitable trajectory. Other functions can be achieved through a combination of sensors to determine non-measurable parameters that directly affect the behaviour of the vehicle. The distance at which the drone overtakes the vehicle can be used to compensate for communication delays, sensor and data processing times and the vehicle's reaction time. This is very useful for complex algorithms that require high computational effort and for processing large amounts of data. An example of the calculation of the overtaking distance during emergency braking is presented in the authors' recent studies [12].

Since during the experiment the vehicle and the drone will move in the test site, and interruption of communication or external devices should not interfere with data transmission, the local Wi-Fi network was protected by the WPA2-PSK protocol. The consistency of actions and correctness of data was confirmed after the experiment by the measurements obtained.

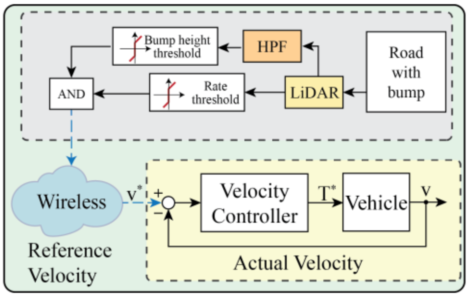


Figure 5 *Bump detection and speed control system. Components on the grey background executed on the side of the drone, and on the yellow background on the part of the electric vehicle.*

Application 1: Bump detection for automated speed control

First, the proposed platform is applied to a system that can automatically control the speed of the vehicle when passing a bump (Fig. 5). The drone analyses the road profile and determines the coordinates where the bump is located. The bump height is also measured in this way. Computer simulations of the vehicle model were carried out to determine the most comfortable speed pattern of the vehicle when driving over the test area. This allows the vehicle to pass the bump with less vertical oscillations. Specifically, the drone flies along a predefined flight path over an obstacle. When the drone begins to fly the route, the drone's computer analyses the road. The vehicle control system begins to accelerate to a certain speed and the drone accelerates further and overtakes the vehicle at a predefined distance. Then, the velocity of the drone and the vehicle are equalised. The drone constantly analyses the road and searches for an obstacle. Once the obstacle is found, the vehicle control system changes the expected speed profile. Near the coordinates where the obstacle is located, the vehicle must slow down until it reaches the appropriate speed to pass the obstacle.

To determine the obstacle and its height, a combination of a high-pass filter and logic conditions with thresholds adjusted based on experimental data is implemented. The diagram in Fig. 5 illustrates this method.

To evaluate the aforementioned strategy, real-time experiments were conducted at the Kashiwa Campus of the University of Tokyo. A proportional-integral vehicle speed controller (VSC) was implemented to outputs the motor torque. Let D_b be the distance from the vehicle to the bump, the longitudinal speed's reference value v^* is determined as

$$v^* = Q_v(s)v_s,\ v_s = \begin{cases} v_l & \text{if } D_b \le 0.5m \\ v_h & \text{otherwise} \end{cases} \tag{1}$$

where $Q_v(s)$ is a low-pass filter of velocity set point v_s, which is to make sure that the speed reference does not changes sharply from the high value v_h to the low value v_l.

Experimental results with the bump height of 5 cm, $v_h = 1\,m/s$, and $v_l = 0.5m/s$ are shown in Fig. 6. On this plot it is

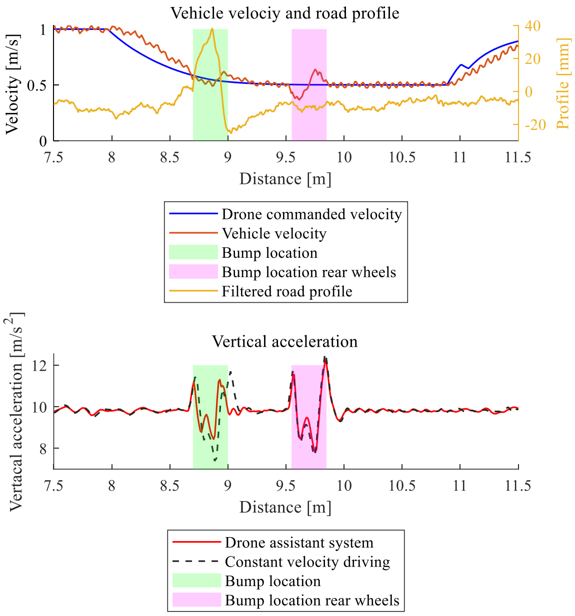


***Figure 6** Experimental results for bump detection.*

seen that bump is located correctly, and vehicle brakes before the bump, so the vertical acceleration was decreased and ride comfort was enhanced. In comparison with the constant velocity driving, the root mean square deviation of the drone assistant system was reduced by approximately 20%.

Application 2: Traction control on low friction surface

The second option investigated is to use the system as an estimator for wheel slip and traction control tasks. The idea is that the drone recognises where the surface with low friction is located and transmits this information in a timely manner to the vehicle control unit responsible for traction control (Fig. 7). The drive/brake torque can be generated correctly if the position of a surface with a low adhesion coefficient on the road is defined.

The drone is equipped with a camera, LiDAR and a computer that processes the data in real-time. The computer vision tool identifies irregular areas of the road surface and LiDAR readings assess the reflectivity of the surface. The data are analysed using the Look-up table for identification of the areas with low friction. The precise position of the low friction segments is identified by combining the data from image segments classified with a neural network and the reflectivity measurements of the road surface. After detection, the coordinates related to the low friction area were found are stored in the vehicle's memory and the vehicle performs motion planning. The drone transfers to the vehicle the speed reference v^* and the estimated road friction coefficient $\hat{\mu}$ through wireless communication. Fig. 7 schematically illustrates the above described process.

The control system is designed hierarchically. The output of the VSC is the driving force command F^*. By tracking the estimated driving force $\hat{F}$ with F^*, the driving force controller (DFC) outputs the desired slip ratio y, which is mapped to y_c after the limiter. The wheel speed reference ω^* is calculated as

$$\omega^* = (1 + y_c)\frac{v}{r} \qquad (2)$$

with the wheel radius r. Then, the wheel speed controller (WSC) is to output the driving torque command. Based on the wheel dynamics, the driving force observer (DFO) is realized as

$$\hat{F} = \frac{1}{r}Q_{dfo}(s)\left(T^* - Js\omega\right) \qquad (3)$$

with the low-pass filter $Q_{dfo}(s)$, and the wheel moment of inertia J. A detailed explanation on DFO as well as DFC and WSC can be found in [13].

The core of the vehicle system is the slip ratio limiter (SRL). The upper-bound of the SRL is determined based on the tire

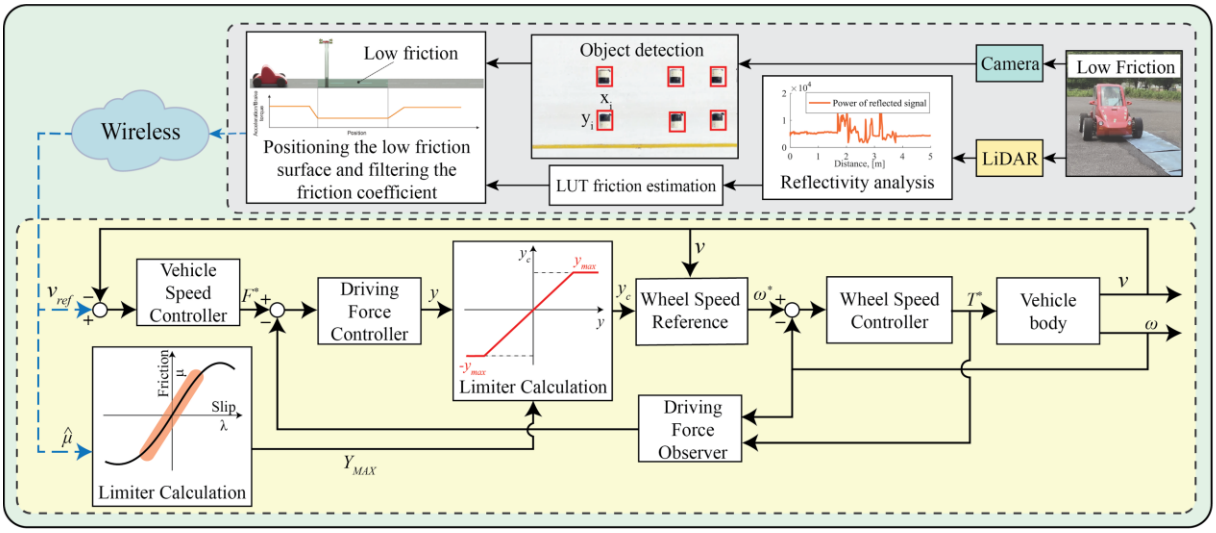
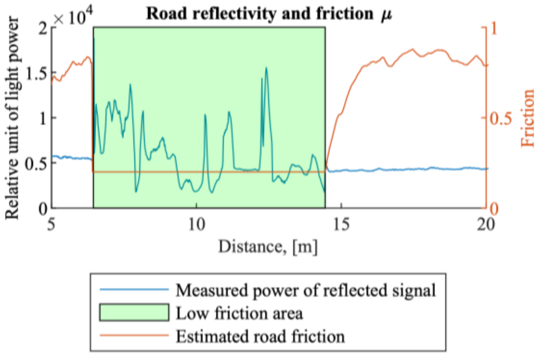
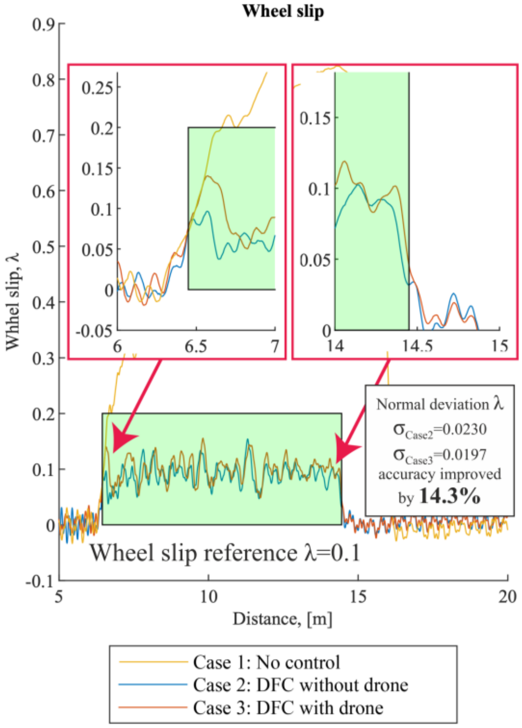


***Figure 7** Road condition identification and driving force control system. Components on the grey background executed on the side of the drone, and on the yellow background on the part of the electric vehicle.*



(a) Identification of road friction coefficient.



(b) Wheel slip ratio.

Figure 8 *Experimental results of traction control.*

force characteristics of the vehicle in accordance with the friction coefficient $\hat{\mu}$. The upper-bound value maintains the tire force in the linear region, thereby, preventing the dangerous slip phenomenon.

To evaluate the above strategy, real-time experiments were conducted as follows. The low friction plate made from polymer materials is covered with water to make the surface slippery. The drone sends a speed pattern to the vehicle system such that the vehicle accelerates from the high friction surface and enters the slippery surface. Thanks to the drone's vision system, the measured power of reflected signal can be obtained. Consequently, the road friction coefficient can be identified quickly with minimum latency, as it can be seen in Fig. 8a.

For comparison, three traction test cases were performed (Fig. 8b). In case 1, the driving force control was not utilized. This means the motor torque was directly calculated from the driving force command as $T^* = rF^*$. Thus, the wheel suffered a large slip phenomenon as the vehicle entered the low friction surface. In case 2, the proposed DFC system was utilized, and the wheel slip ratio was maintained at the safe value of about 0.1 during the acceleration on the slippery surface. During the case 3 the DFC system with the reference friction coefficient $\hat{\mu}$, dynamically adjusted according to the data measured by the drone, was used. This scheme is presented in Fig. 7.

The experimental results in Fig. 8a show correlation between LiDAR reflectivity measures and estimated friction of the road by the implemented algorithm. In contrast to the determination of the traction coefficient by the wheel response, as shown in Fig. 2, Fig. 8a shows that the detection of the decrease of the friction coefficient is performed rapidly, in a few milliseconds, which undoubtedly allows a better and more precise control of the wheel slip. Fig. 8b shows the wheel slip measurements that were collected during the proposed experimental control cases. Wheel slip during case 2 and case 3 reaches the optimal value $\lambda = 0.1$. However, in case 3 normal deviation of the λ during the DFC with drone assistance is $\sigma_{\text{Case2}} = 0.0197$, when the baseline DFC control in case 2 showed $\sigma_{\text{Case3}} = 0.0230$. Thus, slip control performance is increased by 14.3% using drone-based control in case 3. Moreover in the Case 3 actual increase of wheel slip λ happens earlier and keeps longer, as shown in zoomed subfigures.

Discussion

After the experiments presented in the previous section and the implementation of the drone with sensors, it can be confirmed that the drone can detect the relevant road parameters accurately enough and transmit them to the vehicle. The accuracy and performance are sufficient to improve the vehicle's on-board systems. However, the real world implementation of such a system would require the consideration or resolution of design issues.

One of the biggest and most important problems is the short flight time of the drone. The use of wires significantly limits the manoeuvrability of the drone and affects the maximum weight of the target load and stability. Therefore, the system must be designed in such a way that the drone can be recharged quickly enough or that it is possible to change the batteries. However, the ability to change the battery will complicate the design of the drone and the road infrastructure.

Given the rapid development in the drone industry, new types of batteries or propulsion systems may be developed in the next few years that allow for longer flight times. However, drones can already carry out flight missions lasting around half an hour and reach velocity around 30 m/s, which may be enough to cover a critical road section.

The positioning of the drone in relation to the vehicle and the positioning of the vehicle in relation to the road can also be a weak point of the system. Although the drone enables the recording of data with a higher accuracy than the position sensors, the resolution of the data is significantly lower.

Advanced sensors, such as RTK GPS, can achieve positional accuracy of several centimetres, but require a base station to transmit the corrections.

Severe weather conditions such as snow, rain or fog affect the accuracy and can also prevent the drone from taking off if the electronics are not sealed. Strong headwinds or crosswinds can significantly reduce the drone's flight time or navigation speed. But the weather conditions can also affect the sensors performance installed in the vehicles. These problems also exist with vehicle sensors and were mentioned in the studies [14], [15].

Modern drones have advanced autopilot functions that allow the drone to fly autonomously, avoid obstacles and follow behind or in front of the vehicle. However, this is not always possible. The more complex the terrain, the higher the probability that such a system will fail. In densely built-up cities, for example, the drone will be able to navigate much more slowly or not at all due to the complexity of the scenario and a large number of obstacles in the way, as well as blocked navigation data transmission from ground stations or satellites. The drone is also equipped with numerous electronic components that need to be redundant to reduce the risk of failure, which affects the maximum payload weight.

As mentioned in the introduction, the drone can also transmit data to multiple vehicles. If it is necessary to give a group of vehicles access to the surface map, a server must be organised to systematise the data received and forward it to the vehicles on request. This element also introduces an additional delay and can be a vulnerable connection that can fail or whose access is interrupted. In such a case, this can be a problem for both the drone and the vehicles.

Undoubtedly the integration of the drone into the vehicle's systems introduces the potential risk that this system could malfunction, or this communication channel could be used to hack into the vehicle. Thus, the vehicle will have to verify the authenticity and correctness of the data, as well as use security features that will protect the communication channel. In the case where the drone is considered as a sensor for the infrastructure, and a number of cars may have access to the drone's interface or commands, a management model that prioritises tasks and solves data access problems should be developed.

Some operational scenarios may require a longer range for data transmission, e.g. exploration of a terrain several kilometres away. In this case, it can be assumed that the data transmission rate does not need to be high, and other communication methods can be used, e.g. telemetry or digital video transmission.

These challenges apply not only to drones in the proposed concept, but also to many other examples of unmanned driving, UAVs and device-to-device communication, but these aspects have a strong impact on the possibility of integrating a drone as an external sensor for automotive systems.

Conclusion

The presented research proves the possibility of the aerial drone development for the application in the vehicle motion control systems. The use of drone data is proving to be useful for adapting algorithms for chassis and steering operation, substituting data calculated in the vehicle by drone measurements, as well as for scanning unknown terrain and route planning.

In this study, a LiDAR and camera-equipped drone was developed to generate surface maps. The system was implemented to transmit data from the drone to the vehicle and to control the vehicle based on the data received from the drone. Real-time experiments also confirm that it is possible to control the vehicle with a flying drone and that the data from the drone makes the vehicle motion safer and more comfortable.

The proposed platform can be easily extended to other tasks such as autonomous lane change control and obstacle avoidance. The architecture of the platform can be easily extended to other vehicle types as well as to complex control methods with preview and learning functions. Future work of the authors will address the challenges of the system as well as further experiments to improve the performance and efficiency of the proposed system.

Acknowledgements

The research leading to these results was funded by the European Union under the Horizon 2020 (H2020) Research and Innovation Programme under Grant Agreement No. 872907 (OWHEEL).

This work was supported in part by the JSPS KAKENHI Grant Number JP23H00175, and the Nagamori Grant.

We would like to thank Mr. Ueno (e-Mobility and Control Lab, the University of Tokyo) for his support in obtaining the experimental results.

References

[1] M. Sato, G. Yamamoto, D. Gunji, T. Imura and H. Fujimoto, “Development of Wireless In-Wheel Motor Using Magnetic Resonance Coupling,” IEEE Transactions on Power Electronics, vol. 31, no. 7, pp. 5270-5278, 2016.

[2] K. Strandberg, T. Olovsson and E. Jonsson, “Securing the Connected Car: A Security-Enhancement Methodology,” IEEE Vehicular Technology Magazine, vol. 13, no. 1, pp. 56-65, 2018.

[3] M. Noor-A-Rahim et al., “6G for Vehicle-to-Everything (V2X) Communications: Enabling Technologies, Challenges, and Opportunities,” Proceedings of the IEEE, vol. 110, no. 6, pp. 712-734, 2022.

[4] K. Maeda, H. Fujimoto and Y. Hori, “Four-wheel Driving-force Distribution Method for Instantaneous or Split Slippery Roads for Electric Vehicle,” Automatika, vol. 54, no. 1, pp. 103-113, 2013.

[5] J. -K. Lee and K. -J. Yoon, “Temporally Consistent Road Surface Profile Estimation Using Stereo Vision,” IEEE Transactions on Intelligent Transportation Systems, vol. 19, no. 5, pp. 1618-1628, 2018.

[6] J. Choi et al., “Environment-Detection-and-Mapping Algorithm for Autonomous Driving in Rural or Off-Road Environment,” IEEE Transactions on Intelligent Transportation Systems, vol. 13, no. 2, pp. 974-982, 2012.

[7] G. Sato, A. Sakuraba, N. Uchida, and Y. Shibata, “A new road state information platform based on crowed sensing on challenged

network environments," Internet of Things, vol. 18, p. 100214, 2022.
[8] J.-P. Langstand and M. Rabi, "Learning to cooperatively estimate road surface friction," arXiv preprint arXiv:2302.03560, 2023.
[9] L. Gao, J. Mitrovich, C. Beal, W. Bai, S. P. Maddipatla, C. Chen, K. Jerath, H. Haeri, L. Sinanaj, and S. Brennan, "Boxes-based representation and data sharing of road surface friction for cavs," Data Science for Transportation, vol. 5, no. 2, p. 9, 2023.
[10] J. Sun, G. Gui, H. Sari, H. Gacanin, and F. Adachi, "Aviation data lake: Using side information to enhance future air-ground vehicle networks," IEEE Vehicular Technology Magazine, vol. 16, no. 1, pp. 40–48, 2021.
[11] "IEEE Recommended Practice for Local and Metropolitan Area Networks--Part 19: Coexistence Methods for IEEE 802.11 and IEEE 802.15.4 Based Systems Operating in the Sub-1 GHz Frequency Bands," in *IEEE Std 802.19.3-2021* , pp.1-79, 26 April 2021, doi: 10.1109/IEEESTD.2021.9416944.
[12] V. Beliautsou, A. Beliautsou, and V. Ivanov, "Road Parameter Estimation with Drone-Vehicle Communication," SAE Technical Paper 2023-01-0664, 2023, https://doi.org/10.4271/2023-01-0664.
[13] T. Ueno, H. Pousseur, B. M. Nguyen, A. Correa Victorino and H. Fujimoto, "Proposal of On-board Camera-Based Driving Force Control Method for Autonomous Electric Vehicles," 2023 IEEE/ASME International Conference on Advanced Intelligent Mechatronics, pp. 424-429, 2023.
[14] J. Vargas, S. Alsweiss, O. Toker, R. Razdan, and J. Santos, "An overview of autonomous vehicles sensors and their vulnerability to weather conditions," Sensors, vol. 21, no. 16, 2021. [Online]. Available: https://www.mdpi.com/1424-8220/21/16/5397.
[15] F. De Ponte Muller, "Survey on ranging sensors and cooperative techniques for relative positioning of vehicles," Sensors, vol. 17, no. 2, 2017. [Online]. Available: https://www.mdpi.com/1424-8220/17/2/271.

Viktar Beliautsou (viktar.beliautsou@tu-ilmenau.de) is a PhD student at Working Group on Smart Vehicle Systems at Technische Universität Ilmenau, Germany. He received his bachelor's degree in Aviation System design and his master's degree in Mechanical Engineering. His research interests include UAV systems, Control Engineering, vehicle motion control, VTOLs, and Aircraft design.

Aleksandra Beliautsou (aleksandra.beliautsou@tu-ilmenau.de) is currently a PhD student and a research assistant at Systems and software engineering group at Technische Universität Ilmenau, Germany. She received her bachelor's degree in Aviation Science and her master's degree in Computer Science. Her research interests include model-based teams engineering, decision making, conceptual aircraft design,6yy and UAV systems.

Valentin Ivanov (valentin.ivanov@tu-ilmenau.de) Working Group on Smart Vehicle Systems at Technische Universität Ilmenau. He is SAE Fellow and coordinator of several European projects in road mobility.

Binh-Minh Nguyen (nguyen.binhminh@edu.k.u-tokyo.ac.jp) is an Assistant Professor with Department of Advanced Energy, the University of Tokyo. His main research interests include glocal control, robust control, and their applications to electric vehicles, flying vehicles, and power systems.

Hiroshi Fujimoto (fujimoto@k.u-tokyo.ac.jp) is a Professor with the Department of Advanced Energy, the University of Tokyo. His main research interests include control engineering, motion control, nano-scale servo systems, electric vehicle, motor drive, visual servoing, and wireless motors. He is a Fellow Member of the IEEE, and a Senior Member of the IEE of Japan.