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Embedded Hardware and Software Design of Omnidirectional Autonomous Robotic Platform Suitable for Advanced Driver Assistance Systems Testing with Focus on Modularity and Safety

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***Abstract*—**This paper deals with the problem of using Autonomous Robotic Platforms (ARP) for the ADAS (Advanced Driver Assistance Systems) testing in automotive. There are different possibilities of the testing already in development and lately, the ARP are beginning to be used more and more widely. ARP discussed in this paper explores the hardware and software design possibilities related to the field of embedded systems. The paper focuses in its chapters on the introduction of the problem in general, then it describes the proposed prototype concept and its principles from the embedded HW and SW point of view. It talks about the key features that can be used for the innovation of these platforms (e.g., modularity, omnidirectional movement, common and non-traditional sensors used for localization, synchronization of more platforms and cars together or safety mechanisms). In the end, the future possible development of the project is discussed as well.

***Keywords*—**ADAS Systems, autonomous robotic platform, embedded systems, hardware, localization, modularity, multiple robots synchronization, omnidirectional movement, safety mechanisms, software.

I. Introduction

FLAT and overrunable ARP are beginning to be used in the automotive for testing of the ADAS. Solutions that can be found between the ADAS systems are for example adaptive cruise control, automatic parking, blind spot monitor, emergency driver assistant, lane change assistance or pedestrian protection system. More information about the systems can be obtained from [1]-[3]. To test these systems, the ARP needs to be equipped with an ADAS testing target (also called a dummy). A dummy can be a pedestrian, a cyclist, a balloon car or similar. The dummy is mounted on top of the platform and then the scenarios according to the Euro NCAP (European New Car Assessment Programme, [4]) standards can be performed. For example, there is a scenario to test the automatic emergency braking (AEB) of a car where the platform moves with a dummy of a different car in front of a tested car and then suddenly brakes to a halt with a defined deceleration. Then the car's reaction is measured and evaluated again according to the Euro NCAP standards. The platform requirements are described in these standards as well.

There are several more or less ARP in the development already (see [5]-[8]). The goal of this paper is to show how to design such a large embedded system from the hardware and software point of view, how to maintain its reliability and safety. Also, it explores possibilities that can be used to make the ADAS testing more automatic, such as implementing omnidirectional movement to the platform, focusing on its modularity, keeping the safety at high level and using common sensors for localization with good enough precision. The possibility how to implement more of these platforms to perform more complicated scenarios is outlined as well. The platform must be resistant against being driven over by a car and must preserve low profile from the ground so it can be ignored by the sensors used in automotive. Mentioned safety mechanisms are very important because the platform is heavy (over 100 kg) and can reach high speeds (in the end even up to 80 kph). Modularity of the platform enables fast modifications, servicing, battery exchange, cleaning, etc. The development should lead to the platform which is synchronized with the tested car and which also enables cooperation of more such platforms.

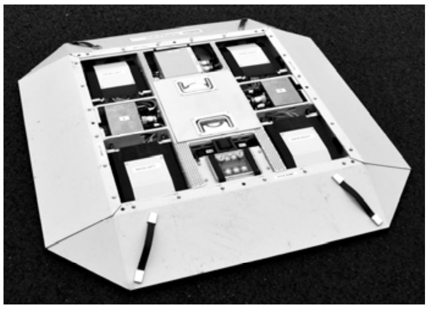

Fig. 1 Prototype of the ARP

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The research is tested on the prototype that is simultaneously being developed in the company Valeo Autoklimatizace k. s. It serves as a testing device itself to implement the ideas described in this paper and it is also used for ADAS testing of the new sensors that are designed in the same company. This prototype is shown in Fig. 1. This paper deals with the embedded systems part of this project as it is the main research field of the first author. The mechanical design, that the prototype is built on, can be found in [9]. Also, the subject has been already introduced in [10], where its background is described in more detail.

II. Embedded Hardware Design Proposal

First, the proposed hardware solution with its key features is described. The whole system does not contain just the ARP device itself but it consists of several devices connected over the wireless network. This concept can be seen in Fig. 2. There are the PC which runs the PC Application, the Base Station, the Kill Switch Button and the ARP. Each of these units has its own XBee module that provides a wireless connection to the other units (ARP has two of them – one for the control unit and one for the kill switch system).

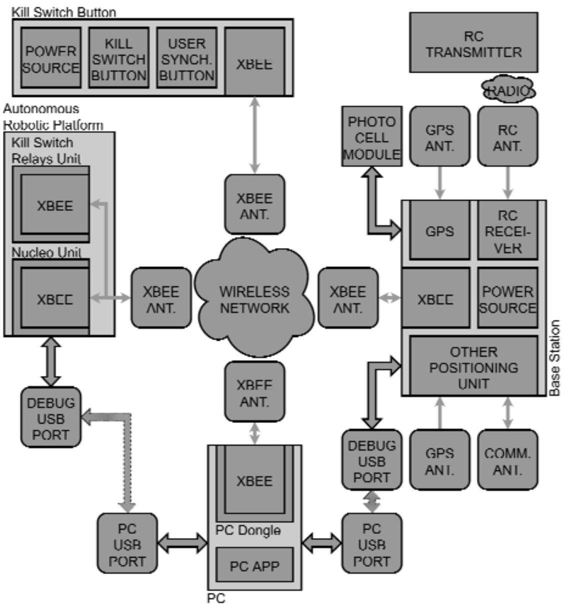

Fig. 2 Block schematics of the whole system

PC Application runs on a PC or a laptop and provides a user interface to the whole system. It can set its parameters, visualize its data or control its behavior.

Base Station is a device that has a role of the coordinator of the whole system. It controls the wireless communication and it has its own GPS. It makes a reference coordinates point of the system. It has connection possibilities to the other components that provide the user control. There is the RC receiver that can be paired with the RC transmitter to control the ARP manually. Then it contains connection to a photocell synchronization module which can synchronize the ARP with the VUT (Vehicle Under Test).

Kill Switch Button device contains emergency button called a kill switch which provides a possibility to stop the ARP in case of malfunction. It disconnects the drivers of the engines which causes the platform to brake to a halt electrically, then it can activate the braking servos (if mounted) for a mechanical braking and finally, it disconnects the power from the whole ARP through its main switch. Since this safety mechanism is wireless, it all works on the principle – while there is a signal, the system works. Additionally, this device has the user synchronization button which can be used to trigger scenarios manually on the same principle as the photocell does.

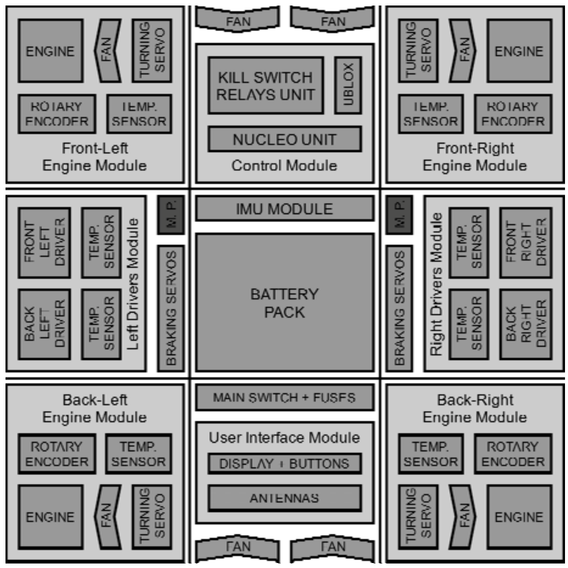

Fig. 3 Physical schematics of the ARP

The platform (Fig. 3) consists of the battery pack with the main switch, the Control Module, the IMU Module, the User Interface Module, the Drivers Modules and the Engines Modules. MCU in the Control Module communicates with the other wireless devices. It also gets data from the platform sensors (IMU Module, GPS with its antenna and Hall Sensors embedded in the engines). It can then control the platform's movement through the communication with the Drivers Modules that control each engine by the embedded PID controller.

A. Safety

There is the stand-alone Kill Switch Relays Unit as a part of the Control Module. It uses its own XBee to communicate with the Kill Switch Button. It works as a hardware safety mechanism. It stops the whole system as described in the section with the Kill Switch Button functionality.

B. Modularity

The next key feature of the ARP concept is its modularity from the mechanical and embedded hardware point of view. It can be seen in Figs. 2 and 3. The mechanical modularity is important for the maintenance of the device, the fast changing of a battery pack or wheels modules. The modularity in the electrical hardware goes hand-in-hand with the mechanical design. It is necessary so that the different pieces of hardware, which are changeable, work together. Also, it helps to provide safety to the whole design since each block checks the functionality of the blocks it is connected to.

C. Wireless Communication

The proposed wireless communication in the system uses XBee modules that provide the complete wireless solution. DigiMesh protocol (based on ZigBee) is used (see [11]). The main advantage over the classic point-to-point communication is that the wireless devices are able to retransmit information over the network using several hops, so it is not necessary for all the devices to see each other. This is useful in case of poor signal or bigger distances during the tests. The rate of the lost messages is slightly higher (as the bandwidth can be filled with more retransmits), but overall reliability of the communication is better.

D. Omnidirectional Movement

The Engines Modules (in Fig. 3) give the ARP a unique possibility of the omnidirectional movement, which can be useful for performing various scenarios. A diagram of the movement possibilities is shown in Fig. 4. The modules consist of the wheels using In-Hub BLDC engines. The wheels are attached to the module with a vertical spindle which makes the turning possible. It is controlled by a servomechanism with a gearing giving it the turning angle of -45° to 45° for every wheel. The ARP can drive forward, turn in the car's manner, turn with both front and back wheels, rotate around the centre vertical axis, etc. This solution also safes the vertical space so the platform can preserve the overall low height.

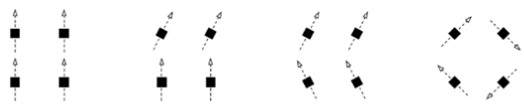

Fig. 4 Possibilities of the ARP movement

III. Embedded Software Design and Ideas

This section focuses on the software proposition. It is designed to be as modular as possible to maintain a robustness and an order in the large embedded system and the key aspect is its reliability. Wireless communication is equipped with a handshake mechanism plus it is controlled by watchdog timers. Wired communications are controlled by checksums (computed over the messages) and watchdog timers as well. Every task in the processing loop has its priority (e.g. the engines communication is more important than sending data for a visualization). Tasks that are not needed to be processed in one iteration can be divided into multiple blocks.

The example of the code design is shown in Fig. 5. It represents the infinite control loop of the Control Module triggered by its hardware timer, which periodically sets the "Proc. iteration requested" flag.

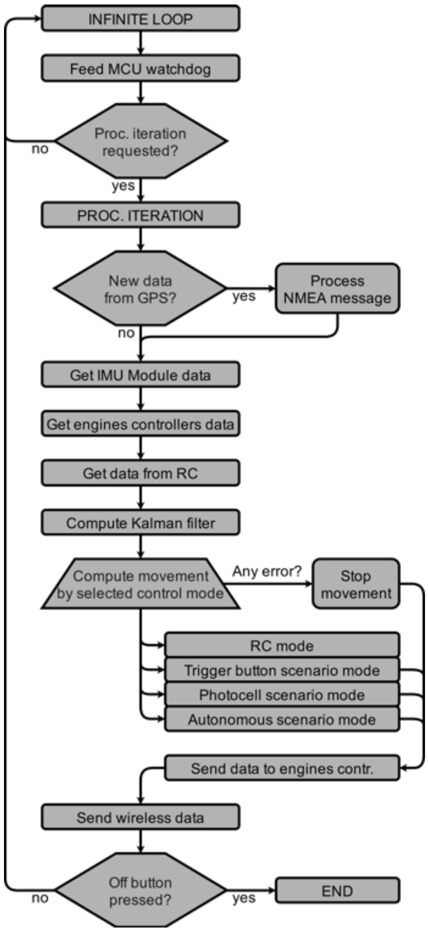

Fig. 5 Block diagram of the ARP control unit

A. Safety

Watchdog timers in the MCUs firmware control that every processing iteration is finished by a given time. If any part of the code or system starts malfunctioning, it is detected by its timer and the proper error state is set. Any error in the system means that the movement of the platform is stopped. This safety mechanism works as a continuous diagnostics tool and it puts the possibility of a false movement to the minimum. Then there is always the last possibility in the platform's manual kill switch button as shown in Chapter II.

B. Localization

Localization of the ARP is the main possibility where there is a space for future improvements and applying new ideas into the field. So far, the platform is used for basic scenarios with the pedestrian or cyclist dummy. These scenarios are short and repetitive with straight trajectories, which means that an odometry is sufficient for the localization of the platform. Then the platform is controlled through the PID controllers (one for the distance and one for the deviation from the straight trajectory). This localization method accumulates an error growing with time so it cannot be used for more difficult trajectories. In the future, localization based on the Kalman filtering is planned to be used. The platform is already equipped with the necessary sensors (see Chapter II). Also, the idea to use two ordinary GPS units (one is stationary on the Base Station) to compensate the error of the moving one (it is on the ARP) is going to be tested. Other sensors such as ultrasonic distance measurement or detection of the movement against the surface on the principal of the optical mouse are going to be evaluated, too. With this improved localization, there is going to be space for implementing better position control such as the state feedback controller.

C. Synchronization of Multiple ARPs

Final feature, which is discussed in this chapter, outlines an idea of platforms cooperation and synchronization. Later, when the autonomous driving gets to a higher level, one platform does not need to be sufficient for the ADAS testing. The platform is designed from the beginning to be able to be synchronized with other platforms or cars. The idea is to use the Base Station as a cloud connecting the network of possibly more platforms and the VUT equipped with its own positioning unit together.

IV. Conclusion

The paper shows improvements that can be used in the concept of ARP and it introduces ideas in the field that are related to the platform's modularity, reliability and safety of the system, localization of the platform, its movement possibilities (e.g. omnidirectional movement) and synchronization between the platform and a car or even more platforms if necessary.

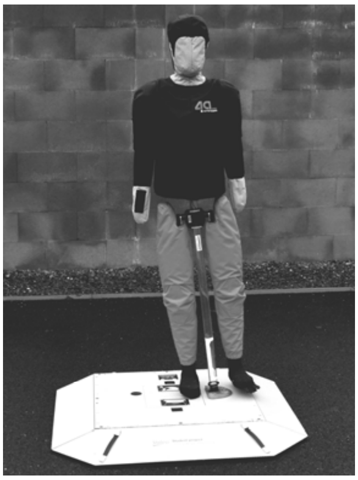

Fig. 6 Prototype with the mounted pedestrian

The subject is discussed from the embedded systems point of view and the research of this paper led to the successful completion of the prototype which was possibly due to the cooperation with the company Valeo Autoklimatizace k. s. in Prague and its research team in the project Opportunities for Students – Valeo R&D Program. The mechanical construction was developed in the same company and it was inspired by [9]. The prototype is shown with the mounted pedestrian in Fig. 6. This prototype is already actively used to test the ADAS systems and in the future, it will serve as a tool to validate other design possibilities focused mainly on a more precise localization using the Kalman filtering and a better autonomous control based on the state feedback controller.

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References

[1] J. M. Blosseville, "Driver assistance systems, a long way to AHS," 2006 IEEE Intelligent Vehicles Symposium, Tokyo, 2006, pp. 237-237, doi: 10.1109/IVS.2006.1689634.

[2] C. Laugier, "Some key technologies for the next car generation," 2014 13th International Conference on Control Automation Robotics & Vision (ICARCV), Singapore, 2014, pp. 1-2, doi: 10.1109/ICARCV.2014.7064482.

[3] P. Giusto, S. Ramesh and M. Sudhakaran, "Modeling and analysis of automotive systems: Current approaches and future trends," 2016 4th International Conference on Model-Driven Engineering and Software Development (MODELSWARD), Rome, 2016, pp. 704-710.

[4] Euro NCAP, "The Official Site of the European New Car Assessment Programme" (online), copyright: Euro NCAP, 2018, available at: https://www.euroncap.com/en.

[5] ABDynamics (online), copyright: Anthony Best Dynamics Limited, 2018, available at: https://www.abdynamics.com/en.

[6] DSD (online), copyright: DSD, Dr. Steffan Datentechnik Ges.m.b.H., 2014, available at: http://www.dsd.at/index.php?lang=en.

[7] 4activeSystems (online), available at: http://www.4activesystems.at/en.

[8] Unmanned Solutions (online), copyright: Unmanned Solutions, available at: http://www.unmansol.com.

[9] J. Német, "Dynamická platforma pro nesení lehkého cíle pro testování systémů ADAS," Prague, 2018, master thesis (in Czech), Czech Technical University in Prague, Faculty of Mechanical Engineering.

[10] O. Lufinka, "Princip autonomních robotických platforem (ARP) používaných pro testování ADAS systémů," Elektrotechnika a informatika 2018, Elektrotechnika, elektronika, elektroenergetika, Pilsen, 2018, pp. 81-84.

[11] DIGI, "DIGI XBEE S2C 802.15.4 RF MODULES" (online), copyright: Digi International Inc., 1996-2018, available at: https://www.digi.com/pdf/ds_xbee-s2c-802-15-4.pdf