Conceptual model of the automated pedestrian simulation system for unmanned vehicles and ADAS systems testing

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Abstract. This article is devoted to the issue of creating the concept of an automated system for simulating pedestrians on the road surface, intended for testing unmanned vehicles and active driver assistance systems. The article examines in detail the prerequisites for the creation of such a system and its relevance for Russia. The existing analogues of this system are demonstrated, their strengths and weaknesses are analyzed. A conceptual model of the system is proposed, its functional capabilities are described, the design of the main units and components of the system is presented. Two possible options for the operation of this system during testing are considered: at regulated and unregulated pedestrian crossings. Variants of test methods in accordance with the named options are proposed.

1. Introduction
The modern development of unmanned vehicles is carried out in two main areas:
• introduction and expansion of the functionality of various driver assistance systems (which are currently standardly equipped with cars of all classes);
• creation of methods and control systems for fully BPS (which are currently at the stage of testing prototypes, including operational ones).

A modern car contains many electronic driver assistance systems with varying degrees of automation of the driving process. They include systems for cruise control, directional stability, collision avoidance, parking distance control, preventive preparation for an accident, etc. These systems take over part of the car control functions, for example, the functions of automatic speed control, acceleration, braking, taxiing, engine and transmission operating modes. Due to this, in some conditions (for example, when driving on a motorway), the car can move autonomously, and the driver can not interfere with the driving process. Further improvement and expansion of the functions of driver assistance systems provides an increase in the autonomy of the car, bringing it closer to a completely unmanned vehicle [1].

In 2014, the Society of Automotive Engineers (SAE) decided to standardize the requirements for these systems and dividing them into 6 levels according to the degree of their automation [2]. Currently, on public roads in Russia, you can find cars not higher than 3 levels of automation, which are not yet autopilot, but the system is already equipped with many different software and hardware that control the car under the driver's control. At the moment, Russia is already testing level 4 unmanned vehicles on public roads with a driver inside. So, in 2019, 35 auto-pilot cars of the joint work of Mobis and Yandex Hyundai Sonata engineers have already appeared on the roads of Moscow, and in March 2020, their number has already increased to 100 cars.
For the active implementation of driver assistance systems, especially in the context of using them as control subsystems for unmanned vehicles, it is advisable to develop methods for testing and testing them to obtain reliable information about their technical characteristics. One of the active driver assistance systems is the pedestrian detection system, testing of which is an urgent task, since it is directly related to the safety of all road users [3].

2. System for detecting pedestrians on the road surface
The people safety on the roads is one of the most important aspects of road traffic. Car manufacturers are increasingly looking to protect everyone involved. An important aspect here is the prevention of collisions between cars and pedestrians and cyclists.

For the first time such systems were used on Volvo cars in 2010. The system currently has various variations such as Subaru's EyeSight, Volvo's Pedestrian Detection System (PDS), TRW's Advanced Pedestrian Detection System (APDS). Let's take a closer look at the PDS system presented on Volvo cars. The PDS Pedestrian Detection System is used to reduce the risk of a collision between a vehicle and a pedestrian. Pedestrian detection near the vehicle is its main function. In this case, the system automatically reduces the speed, which reduces the impact force in the event of an imminent collision. The system performs such functions as: detection of people in the direction of the vehicle; warning the driver about the risk of collision; automatic reduction of vehicle speed. After detecting a pedestrian on the radars of a car, the system automatically calculates what the position of a person will be at the moment of close proximity to the vehicle. Then a signal is sent to the driver on the car display. If the system determines that there is a risk of collision, an audible alarm sounds. When braking, the PDS system enhances its action by applying emergency braking. If the driver does not respond to the signal, the system is triggered automatically and stops the car by itself. At the moment, the PDS system guarantees complete traffic safety at a speed not exceeding 35 kilometers per hour. At higher speeds, the system reduces the force of the impact by reducing the vehicle speed. But there is a significant disadvantage, it lies in the fact that recognition of people at night or in conditions of poor visibility is difficult [4].

3. EuroNCAP tests for detection of pedestrians on the road surface
The EuroNCAP (The European New Car Assessment Program) is a European committee for conducting independent car crash tests with an assessment of active safety and passive safety. NCAP is paying close attention to tests involving pedestrians. This is closely related to developments in the field of unmanned vehicles, because most pedestrian tests are done to test a smart braking system that is unattended. To detect pedestrians, Euro NCAP tests different types of scenarios:

- a pedestrian or cyclist crosses the path of the test vehicle (figure 1);
- a pedestrian or cyclist walks / drives in the same direction as the vehicle (figure 2);
- a pedestrian or cyclist crosses the road onto which the test car is turning (figure 3);
- a pedestrian or cyclist is behind and the car is going in reverse (figure 4);

The first two scenarios are selectively repeated in low light conditions as well. For trials in which a pedestrian or cyclist walks or drives in the same direction as the vehicle, there are also several scenarios: a pedestrian walks in the center of the road or is displaced to one side.

There are 3 kinds of scenarios with a pedestrian crossing the path tested by a vehicle (figure 5,6):
- an adult running from the driver's side of the vehicle (a pedestrian runs at a speed of 8 km / h, the speed of an approaching car is 20-60 kmph);
- an adult walking from the passenger side (a pedestrian runs at a speed of 5 kmph, and the speed of an approaching car is 20-60 kmph);
- a child runs in front of cars on the passenger side of the car (a pedestrian child runs at a speed of kmph, the speed of an approaching car is 20-60 kmph);

For tests in which a pedestrian or a cyclist crosses the road onto which the car is turning, two types of tests are used: the car turns to the right or to the left. These two versions of the same scenario present
different problems due to the relative angles and distances between the test vehicle and the pedestrian [5].

The tests use a specially designed pedestrian target on a platform that has articulated limbs to simulate a person's walking. According to the specification, male and 6-year-old mannequins are used for the tests. Pedestrian mannequins meet such requirements as: the presence of an installed platform; directional following the path; the ability to reach speeds up to 15 kmph; impact resistance up to 60 kmph with minimal vehicle damage; reconstructability for retesting.

Figure 1. A pedestrian crosses the path of a test vehicle

Figure 2. A pedestrian walks / drives in the same direction as the vehicle

Figure 3. Pedestrian crossing a road into which a car is turning

Figure 4. Pedestrian crossing a road into which a car is turning

Figure 5. Test with an adult walking on the passenger side

Figure 6. Test with a child running in front of cars
The crash test dummy (figure 7) has a controlled platform with programmable speed and trajectory following capability. The mannequin has a modular assembly system, so it has a fast recovery time. The dummy rail is detached from the platform on impact, and the knee joints are designed to adjust its position. They flex on impact to minimize damage. The pedestrian platform holds an impact-resistant, lightweight pedestrian dummy that attaches with magnets. The dummy has high acceleration typical of real pedestrians and can reach speeds of up to 15 km/h. The mobile platform (figure 8,9) has dimensions of 840x1115x90 mm, a reinforced drive structure, and minimal radar and visual signals.

At the moment in Russia there is no certified domestic equipment for conducting such tests, and there are only prototypes.

4. Development of the concept of an automated system for imitating pedestrians on the road surface

When developing the concept of an automated pedestrian imitation system (the APIS), it is necessary to consider the requirements:

- compliance of the system with the requirements of the ISO 19206-2 standard [6,7];
- the height of the movable platform should be no more than 70 mm, so that in an emergency the platform would pass freely under the vehicle;
- the mass of the movable platform should not exceed 30 kg;
- in a frontal collision with a car, the dummy should be disconnected from the cart in order to reduce damage to the dummy and the vehicle upon impact;
- a pedestrian dummy must be equipped with heating elements to simulate infrared radiation of the human body;
• movement of the dummy is carried out in both directions;
• pedestrian speed must be up to 10 km / h with the possibility of regulation;
• movement of the mannequin should be carried out from left to right and from right to left;
• for the system to work in autonomous mode, it is necessary to provide for the detection of a car in the area of a pedestrian crossing;
• the system should exclude a collision of a pedestrian with a vehicle moving or stopped at a pedestrian crossing.

At the initial stage of the development of APIS, the two most typical scenarios of the behavior of a pedestrian on the carriageway are considered: a pedestrian crossing at a regulated pedestrian crossing (figure 10) and a pedestrian crossing at an unregulated pedestrian crossing (figure 11).

Based on the formulated requirements, the APIS concept was developed, which implies the presence of the following components: a movable platform with a dummy; dummy rotation system; system for detaching the mannequin from the cart; heating system for dummy parts; UMV detection unit. Each component of the system is discussed in more detail below.

5. **Movable platform with a mannequin**
A movable platform with a dummy (figure 12) includes: a movable cart (1), a drive unit (2), a cable tension unit (3), a dummy (4), a dummy rotation system (5), a heating system for dummy parts (6), a system for detaching the mannequin from the trolley (7).

![Figure 10. Scenario of a pedestrian crossing a regulated pedestrian crossing](image)

![Figure 11. Scenario of a pedestrian crossing an unregulated pedestrian crossing](image)

![Figure 12. 3D model of a platform with a mannequin](image)
Movable trolley (figures 13, 14, 15) is a mobile platform on casters designed to install mannequins on it and simulate the movement of a mannequin on a pedestrian crossing. The bogie frame is flat, it consists of 4 spars and 2 cross beams. The connection between the frame elements is made by means of fasteners for the structural profile. Trolley suspension is not provided. The bogie frame material was a 40x20 mm structural aluminum profile. Polyurethane casters were chosen as wheels for the trolley. The wheel is mounted on a smooth shaft on two bearings; positioning on the shaft is carried out by means of the presence of bushings. The shaft itself is fixed in supports, which are installed on the side members, and the supports are installed on a threaded connection. Also, a dummy rotation mechanism is mounted on the trolley, thanks to which, when it approaches the end of the transition, the dummy has the ability to turn.

The tension of the cable (figure 18, 19) is carried out by means of the tension knot. It is a spatial frame mounted on a metal sheet, inside which there are two rolling rollers fixed in bearing assemblies. The rollers are stacked discs mounted on shafts. The top of the frame is covered with a 3 mm sheet steel cover. The tensioning unit is mounted on a support sheet, which is reinforced with concrete blocks for immobility. From above, the tension unit is covered with a PVC plastic cap covered with a decorative film. All sheet metal parts are covered with moisture resistant enamel.
The adult mannequin (figure 20) is a foam rubber manikin on a steel wire frame. The child mannequin (figure 21) is a fabric-frame mannequin with the ability to dismantle the arms and legs.

![Figure 20. Adult pedestrian mannequin](image)

![Figure 21. Baby pedestrian mannequin](image)

6. Manikin turning system

The turning system (figure 22, 23) is one of the main components of the system, thanks to it, the manikin turns at the end points of the transition when starting the reverse movement "facing" in the direction of travel. To solve this problem, a dummy rotation system was developed. The development was complicated by the fact that the trolley itself is not driven, as a result of which no power sources and batteries are installed on the trolley, which would help equip the swing system with an individual drive. Therefore, the energy of the main traction drive installed in the drive unit is used to rotate the bogie. The principle of operation is that the cable is attached not to the mobile cart itself, but to the turning mechanism, and when the movement starts at one of the end points of the route, the mechanism is activated due to the high inertia of the cart with a dummy, due to which the turn is carried out. The dummy turning system includes: a toothed rack on a slider sliding along the groove of the bogie spar; two bearing assemblies to ensure low friction when turning the platform; bottom disc with toothed wheel; the upper disc, on which the swivel plate is mounted, on which the mannequin is mounted.

![Figure 22. 3D-model of the turning system](image)

![Figure 23. Manikin turning system](image)
7. System for detaching the mannequin from the trolley
In the process of testing the BPTS, situations may occur with the knocking down of the dummy by a vehicle. In this case, if the dummy and the mobile trolley are a single rigid structure and do not have the ability to disconnect, in the event of a frontal collision of the UMV with the dummy, an emergency situation may arise with damage to all the components of the APIS, as well as the UMV itself. To avoid such consequences, a system was developed that provides for the detachment of the dummy from the cart in case of a frontal collision with the UMV.

The system includes a reinforced dummy frame and a magnetic holder for mounting the dummy on the turntable. The reinforced frame is a structure of a profiled aluminum corner, designed to provide additional support for the mannequin in an upright position during movement. The magnetic holder consists of permanent neodymium magnets installed in the sole of the mannequin's shoe to mount it on the swivel plate. The frame was installed only on adult mannequins, since they have greater cantilever and windage. Children's mannequins remained stable without a frame. In the event of a frontal collision, the dummy is detached from the platform and falls on the asphalt in front of the vehicle that hit it, without damaging the APIS and UMV units.

8. Heating system for dummy parts
The manikin heating system is designed to simulate the infrared radiation of the human body, so that it will be visible in the infrared range. The components of the system are installed in the face of the mannequin, as well as on the arms, to simulate the thermal radiation of open areas of the human body in winter. The heating system for one dummy should include: a power supply for the heating elements; flexible heating element for gloves "palm" (figure 24); flexible heating element on the "face" (figure 25).

![Figure 24. Flexible heating element for palm gloves on the mannequin](image)

![Figure 25. Flexible heating element on the "face"](image)

9. UMV detection unit
Designed to determine the location of the UMV relative to the APIS. The block is equipped with optical barriers (photo-gates), allowing to determine the entry of the UMV into the APIS zone.

10. Conclusions and Future work
The implementation of the concept embodied in the described system will allow testing unmanned vehicles and active driver assistance systems in the conditions of test sites. The purpose of the system is to work out the algorithms for automatic registration and development of the response of the control system of an unmanned vehicle to the appearance of a pedestrian on the roadway along the route of the vehicle. Given the high interest of the scientific and technical community of the country in the development of unmanned vehicles, the development and implementation of this system looks like an important and demanded task.

Currently, the automated pedestrian simulation system on the road surface has been implemented in the form of a conceptual prototype, and test tests of the concept have been carried out. At the moment, work is underway to modernize the drive unit, and a universal methodology for testing unmanned vehicles and active driver assistance systems is being developed in order to introduce ASIP into the test.
ranges for unmanned vehicles. In the more distant future, this system may be certified for testing active driver assistance systems in order to certify vehicles.

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