The structural model of automated leveling system for a construction machine

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Abstract. Realization of road construction works at a high-quality and modern level is associated with significant requirements for accuracy and speed. In the manual mode, it is no longer possible to carry out the leveling process in accordance with these requirements. Therefore, a topical task is to automate the process of leveling the roadway using modern information technologies. Automated control systems for road construction equipment can improve the quality of performed work on terrain profiling and increase the life of the roadway. The article presents a structural model of the automated leveling system for the grader, reflecting the processes of interaction between subsystems and the relationship between them. The obtained results can be used to develop hardware and software systems for the control of road-building equipment.

1. Introduction
The construction of roads today is not inferior to the construction of buildings in complexity and importance. One of the main operations during construction is the leveling of areas according to the project height level. Achieving the required accuracy in the manual mode of control of construction equipment without additional equipment is almost impossible. The expensive special high-precision equipment, leveling systems, is applied for such road-construction works. The leveling system is a software and hardware platform consisting of attachments that is capable of automatically controlling the position of the executive machinery (EM) of the machine in real time, installed on the working body of road-building equipment. The system should solve the functions, assigned to it, in a timely and accurate manner throughout the entire period of operation with minimal financial and time costs. The use of road construction equipment without leveling systems no longer meets modern standards and construction requirements, and construction crews that do not use leveling systems are not allowed to build critical facilities such as federal highways, runways, stadiums, fields, parking lots and much more [1].

In road construction, the weather conditions for the use of the roadway have a major influence on durability. The main destructive effect on the roadbed introduces the appearance of hollows in the layers of road pavement, which are formed under the action of water with uneven laying of layers of road coating. Leveling systems allow more accurate layering of the pavement layers, which contributes to a more uniform distribution of the load on the road. Improving the accuracy of layer-by-layer surface profiling increases the degree of resistance to moisture and contributes to drainage. An important feature of using the leveling system is to reduce the number of passes of a road-construction
machine in the profiling mode from 10-15 to 2-3 times. Reducing the passes reduces the number of spent machine hours, contributes to fuel savings and shortens the construction time.

2. Relevance

With all the variety of leveling systems and without using control automation tools, achieving high quality of the roadway is an extremely long and laborious process. The weak link in the work of the system is the speed of a person’s reaction to alerts about a change in the position of EM, loss of attention and concentration. Whatever the accuracy of the positioning of the system, a person is not able to receive the surface quality specified by the system from a single pass of the site. Therefore, the leveling systems are able to increase the speed of planning work, and automatic systems allow to get the maximum quality from road-construction equipment [1].

The use of automated leveling systems on road-building equipment allows to obtain the highest quality result when working on any models of equipment [2, 3].

Lack of attention is given to the issues of formalization and optimization of road construction equipment management processes, the development of mathematical and algorithmic software for designing automated leveling systems. Without sufficient theoretical study of this issue, it is impossible to implement competitive automated systems that are not inferior in their functionality to foreign analogues.

As part of this study, the development of a structural model of an automated leveling system for road construction equipment applied for further design and implementation is considered. The use of an automated leveling system will make it possible to exercise control over the position of the working body, to regulate the speed of road-building equipment, and to optimize the useful power expended to perform the work.

3. Comparative analysis of various types of levels

At the first stage of formalizing the structure of the developed system, it is necessary to determine the optimal type of leveling system. There are various types of leveling systems on the market, which are divided into groups according to the type of technology on which they are based: ultrasonic, laser and GPS.

A comparative analysis of various types of technologies led to the following conclusions:

- ultrasound systems are the simplest to implement, however, preliminary surface preparation is required for their effective use, and the width of the profiled surface cannot exceed the width of EM of the road-construction machine, which makes streaming construction impossible;
- laser leveling systems ensure the flow construction of wide areas of the coating; the disadvantages of such systems include the refraction of laser beams when moving from one atmospheric environment to another, dispersion of a laser beam at large distances, signal instability, and the need for protection for the operator's eyes;
- GPS leveling systems require appropriate GPS equipment for their work, communication with a fixed point and with a road-construction machine; they have a high cost and requirements for operator qualifications. The advantages of this type of system include the ability to control a large number of equipment at the same time, the signal resistance to interference from overlapping by surrounding equipment, trees or small buildings.

4. System decomposition

The developed leveling system is based on the principle of operation of the laser leveling system. The choice is made on the basis that this system allows streaming construction at the work site, does not require additional external communication with devices and long-term training of operators. The use of a laser leveling system with a rotational laser is in most cases sufficient for building objects, since the laser plane of the level is built on a radius of up to 1500 meters when using a laser up to class 3b [4].
The analysis of the components of the leveling system allowed us to formalize its structure in the form of a model consisting of 4 subsystems (Fig. 1): laser plane building, searching and controlling a laser plane (LP), automation of the control of working parts of a construction machine, visualization.

![Figure 1. Block-scheme of automated leveling system for road-construction machine.](image)

Work with the system is described by a simple algorithm for performing successive stages and does not require high qualification or long training. The interface is simple and intuitive.

A surveyor enters data into the system through a data entry module. This module is a cross-platform application designed specifically to work with the system. When entering the application and selecting the mode for setting the position of the laser plane, the surveyor enters the current elevation position to the base of the subsystem for LP construction, the angle of the axis relative to the vertical, the direction of the subsystem for LP construction relative to the zero position, the speed of rotation of the laser beam. The application is connected by an intranet interface with LP builder subsystem and LP search and control subsystem [5].

The design positioning module receives the data entered by the surveyor in the application, and performs the installation according to the obtained coordinates. Servomotors with encoders and hall sensors with neodymium magnets are used for precise positioning. Positioning is carried out automatically by the system.

When installing the subsystem for LP construction in the design position, the control signal enters the module for constructing LP. The module consists of a rotation speed control system and a laser positioning system. The rotation speed control system allows you to set different speeds, control it according to the data from the application. The rotation speed is controlled by the encoder. The laser turns on automatically after reaching a stable rotational speed. The laser positioning system includes a laser and a set of prisms required to calibrate a laser point at different distances. Calibration is carried out through the application in the "Calibration" mode. The subsystem for LP construction is fully configured by the surveyor. After switching on the laser, the system is ready for operation.

The next step is to configure the LP search and control subsystem. The operator of the road construction machine through the application, in another mode, performs data input to set the EM position of the road machine. The information is transmitted to the data transmission module, then to LP control module. LP control module reads the position of EM through the module positioning, calculates the trajectory and speed of movement from the current position to the design and transmits...
data to the automation subsystem and the visualization subsystem. The subsystem consists of a processor for information processing from photosensitive sensors and is equipped with an intranet interface for interacting with peripheral devices [6].

The automation subsystem receives data about the required transfer through the data input module, and transmits data to the automated control module. When the position of EM changes, the data transmission module sends information via the data transmission module to the visualization subsystem [6, 7]. The subsystem consists of a control unit installed in the operator’s cab of road construction equipment. The actuators are connected to the system of hydraulic cylinders of the road machine and allow the automatic workflow, if necessary, you can turn off the automation system.

The visualization subsystem is a display installed in the operator’s cab, which is used to enter adjustments and adjust equipment manually, equipped with a wireless interface for interacting with peripherals. Input/output of information implements through the data transfer module. The visualization module is responsible for creating a realistic display of the position of EM on the display of the visualization subsystem [6]. The Input/Output module provides additional functions for adjusting the workflow [7].

Thus, the developed leveling system is based on a modular construction principle and is a set of independent subsystems, which makes it possible to use them on almost all models of bulldozers, motor graders and excavators on the world market, as well as to complement the already used leveling systems.

5. Practical implementation

On the basis of the obtained structural model, a prototype of an automated leveling system is designed, the results of which are presented in Figure 2.

The developed prototype includes LP builder and receiver. The LP builder includes a control panel that allows you to set the modes of the builder, duplicating the functionality of a mobile application.

A series of tests was carried out to test the adequacy of the developed structural model and prototype. The constructive requirements for the developed prototype were the following:

- Packaging should provide the possibility of transportation by road in a closed carcass.
- Prototype of the module should ensure the uninterrupted operation within the temperature range from -10 to +35°C.
Prototype of the module must withstand a fall on compacted soil from a height of not more than 1 meter.

Prototype of the module should provide an angle of inclination of the laser plane of no more than 30 degrees.

Used engines must provide a rotational speed of at least 30 Hz.

The developed prototype was tested under laboratory conditions and proved its efficiency. A sufficient rotation speed was 30 rpm using LP plotter in the room. At such speed, the prototype can be compared with the usual rotary separator, available on the market in the average price segment. The radius of the laser plane reached 40 meters outside in clear, rainy weather. 5 mW laser was used. The laser point was visible without the use of special equipment. Such result makes it possible to use the system, both for internal and external works.

The disadvantage of the developed system was the use of a mirror reflecting surface with an internal wall of reflection. When using a mirror surface, a significant attenuation of the laser beam was noticed, caused by a strong dispersion when it hit the reflective surface. During the study, it was decided to switch to use of a special pentagonal lens - pentaprism.

The speed of rotation of the laser beam was needed to increase to at least 200 rpm for the normal functioning of the level with the LP receiver. At such speed, 2-3 laser points are projected onto the translucent receiver screen every second, and the position of LP is mathematically calculated.

Further, after determining the position of LP, the system calculates the vertical deviation from the center of focus, which is converted into a control action for the lifting mechanism of the tripod. This method is the initial setup and search for LP. Further, all coordinates and deviations are transmitted to the mobile device with the installed application and duplicated on the operator's screen in the cab. This principle turned out to be the most convenient, since the receiving and radiating devices can be at a considerable distance from each other, and the intranet interface is able to connect devices at a distance of more than 100 meters without direct access to the Internet.

Thus, during the tests and subsequent improvement of the prototypes, the following indicators are received, presented in Table 1.

| Indicator                                | Required value                        | Received value  |
|------------------------------------------|---------------------------------------|-----------------|
| Positioning accuracy                     | no more than 50 mm per 100 m          | 45 mm per 100 m |
| Laser plane update rate                  | not less than 30 Hz                   | from 30 Hz to 4000 Hz |
| Resolution of applied matrix             | not less than 1920x820                 | 3280x2464       |
| Maximum angle of displacement of laser plane from the horizon | not less than 30 degrees | Up to 35 degrees |
| Permissible operating temperature        | from -10 to + 35°C.                   | from -20 to + 40°C. |
| Receiver diameter                        | no more than 30 cm.                   | 11 cm           |
| Receiver height                          | no more than 40 cm.                   | 15 cm           |

Thus, all specified requirements for prototypes are met in full.

The article deals with the creation of leveling systems, presents the principles of the most common systems, their use on construction sites. A comparative analysis of the most common leveling systems was carried out, their strengths and weaknesses were analyzed, on the basis of which it was concluded that the implementation of such systems allows reducing financial and time costs during road construction works, as well as to increase the durability of the road coating due to a exact elevation of each layer.
A block diagram of an automated leveling system was developed, which includes four main subsystems: the construction of a laser plane, the search and control of a laser plane, automation and visualization. Each subsystem includes a set of interconnected modules that ensure the correct operation of the system as a whole.

Based on the presented structural model, the software and hardware of the prototype automated leveling system was developed. Further research will be related to the formalization of the algorithm of the leveling system, the implementation of the necessary mathematical support and software that will improve the quality of the profiling of the road coating.

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