**Keywords:** leveling system; construction equipment; algorithmic support; system analysis

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# DEVELOPMENT OF A LEVELING SYSTEM FOR CONSTRUCTION EQUIPMENT

**Summary.** The quality of the roadway has a significant impact on the ability of drivers to drive their vehicles. Violation of the integrity of the coating, its geometrical parameters (shape), and the condition of the surface of the coating adversely affect the behavior of drivers, does not allow for correct driving of the vehicle, and leads to the occurrence of traffic accidents of varying severity. The current problem in the implementation of road construction works is to increase the level of automation of construction equipment and increase the accuracy of profiling. The article considers the main types of leveling systems, the scope of their application, advantages, and disadvantages. Based on the conducted analysis, the recommendations are formulated for the developed automated leveling system, its structure, and principles of functioning. The main components of the leveling system, their functions, and the connections between them are considered. The scientific novelty of this article is to develop an original algorithm for the functioning of an automated leveling system. It includes the main stages of the profiling process: installation by a laser plane, determination of its position, adjustment of the position of the working element of construction equipment, and differs due to the necessary mathematical support for the implementation of the laser plane control process. The algorithm allows one to develop software that implements the basic operations of managing the profiling process.

## 1. INTRODUCTION

Numerous studies have shown that one of the main causes of road accidents is the condition of the roadway [1 - 3]. When the quality of the road deteriorates, driving a vehicle becomes more complicated and requires more attention and cognitive resources from the driver [4].

Therefore, the task of improving the quality of the road surface due to the profiling of the high-altitude levels of the surface of the road surface is the actual transport problem. It can be considered an important factor in road safety as the state of the roadway is one of the key environmental parameters on the road that affects all road users.

The construction of roads today in complexity and importance is not inferior to the construction of buildings. Road construction works all over the world are performed using special equipment. One of the main operations in construction is the leveling of areas according to the projected altitude level. It is practically impossible to achieve the required accuracy in the manual control mode of construction equipment without additional equipment.

The expensive special high-precision equipment is used for road construction works such as leveling systems. The leveling system is a software and hardware platform consisting of attachment implements that are able to automatically control the position of the machine’s working element in real time and are installed on the working element (WE) of road construction equipment. The system must solve the tasks assigned to it in a timely and accurate manner throughout the time 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 teams that do not use leveling systems are not allowed to build especially important facilities such as federal roads, runways, stadiums, fields, parking lots, and many other objects [5, 6].

The leveling system displays data on the position of the working element of the road-building machine in the operator's cabin in real time and with sufficient accuracy for construction [7].

The article deals with the issues arising in the design and application of the automated leveling system. Also, the existing on the market varieties of leveling systems, their distinctive features and methods of working with them will be considered.

## 2. CLASSIFICATION OF LEVELING SYSTEMS

Currently, the market has various types of leveling systems, which are divided into groups according to the type of technologies on which they are based: ultrasonic, laser, and GPS.

**Ultrasonic leveling systems.** The simplest in terms of implementation are ultrasonic leveling systems. They are based on the ability of ultrasonic sensors to determine distances to objects. In practice, to work with such a system, it is necessary to equip the working element (WE) of the road construction equipment with attachment implements with ultrasonic sensors, and along the linear construction site to establish altitude marks connected at the same level by a string line. The use of an ultrasonic system allows not being distracted from the work of the operator of a road construction machine because the data on the deviation of WE from the project position are immediately displayed on the monitor in the cabin. Instead of marks, one can use any reference object, for example, a border [8].

The distance between the marks should be equal to the width between the attachments installed on WE of the road construction machine. In operation, the attachment fixes the distance between the ultrasonic sensor and the string line and displays the data on the screen of the operator of the road construction machine.

Ultrasonic systems simplify the profiling process, but it takes a lot of time to set the height marks and tension of the string lines when profiling the surface.

**Laser leveling systems.** Another common type of leveling systems is laser leveling systems. The principle of their work is based on the construction of a laser plane and the use of photosensitive elements that can fix its position.

There are two main types of laser leveling systems that differ in the principle of construction of the laser plane. Levels with a flat laser are distinguished by simple designs, but a complex lens that dissipates the laser beam, turning it into a plane. They have a short range and low cost. Rotational levels have a more complex design, which allows one to rotate the prism, creating a laser plane. They have a greater range and are expensive. Rotational levels are mainly used during construction.

The level is set on a tripod on the height measured from the benchmark when working. Light-sensitive attachment implements are mounted on WE of road construction machines. When moving, the attachment fixes the change in the position of the laser plane, and the offset data are transferred to the monitor in the operator's cabin [9].

The laser leveling system allows streaming construction of wide sections of roads and buildings. This means that the earthmoving machines on the site can work on one set altitude. The work of the surveyor is facilitated because when using a laser system, the permanent presence of a surveyor at a construction site is not required [6, 8, 10].

You only need to install a laser level in the project position when using a laser leveling system from a surveyor, and then the system automatically monitors the profiling process. One laser level covers an area of up to 800 m in diameter [8, 9].

The advantages of this system include the ability to monitor the position of WE of all construction machines on the site, equipped with receivers of the laser plane.

The disadvantages of the system include the refraction of laser beams during the transition from one atmospheric condition to another; therefore, the use of such systems in rain, fog, or other similar weather conditions is not recommended. The physical obstacles that arise in the way of the laser beam overlap the direct visibility of the laser plane builder, which prevents the search and determination of the position of the plane by photosensitive elements; this leads the system to a state of uncertainty at the time of overlapping the line of sight. Such obstacles can be construction objects and other construction equipment operating on the site. A significant disadvantage is the scattering of the laser beam at large distances; this is most evident when using laser devices with a planar beam. When working with high-power laser equipment, eye protection is required because even if a short-term laser level hit into the eyes, it blinds for some time, which prevents from the normal work of the operator of the road construction machine. Therefore, the use of protective optics is required when working with laser equipment of any power [7, 10, 11].

**GPS leveling systems.** This type of system, for implementation, requires GPS equipment, communication with a fixed point, and a road construction machine. The altitude position of WE is calculated by the method of triangulation.

The data from GPS satellites and a fixed point are used to determine the altitude position of the WE road construction machine. The leveling system calculates the altitude position of WE with sufficient accuracy by receiving and processing data from several satellites [12 - 14].

Despite the high cost of such systems, they have a number of advantages: high accuracy, ability to simultaneously control a large number of construction machines in large areas, and stability of the signal to perturbations from overlapping by surrounding equipment, trees, or small structures. The system of leveling based on GPS allows the streaming construction of wide sections of several roads and structures simultaneously. All earthmoving machines on a large area around the bench can work at a set altitude. When using a GPS leveling system, the presence of a surveyor is required only to adjust the elevation parameters of the site.

Despite the prospects of GPS leveling systems, their use requires the attendance of additional training courses for about a year. The surveyor needs to set the altitude level, and the operator to monitor the position of WE according to the monitor to work with the system. Also, the disadvantages include the inability to use systems in the absence of communication with the satellite and the need for line of sight with a fixed bench mark [12-14].

Leveling systems can also be divided into automated and non-automated. The automated leveling system itself analyzes the data on the WE position of the road construction machine in real time and sends a control action to change the position of WE. The system solves the functions assigned to it in a timely manner with the specified accuracy throughout the entire operation time. It is also possible to disable the automation system for manual control and input of adjustments. Such systems can significantly reduce the number of employees on the construction site working in the area; reduce the negative impact of the human factor; and the risk of errors in construction, financial. and time costs for profiling [5, 15, 16].

When using non-automated leveling systems, data on the position of WE are sent to the operator of the road construction machine, who adjusts the position of WE.

## 3. PROFILING USING LEVELING SYSTEM

The main problem at the profiling stage during construction is the sediment of the soil, which, during the construction of structures, affects the strength of the foundation and the durability of the structure. The weather conditions for the use of the roadway mainly influence durability in road construction. The main destructive effect on the roadway is the appearance of gaps in the layers of pavement, which are formed under the influence of water in the uneven laying of the roadway coat [15].

With uneven laying of the roadway coat, the sedimentary moisture, passing through the upper elastic layers, mines the lower sand layer, forming gaps, into which the crushed stone falls over time.

On the surface of the road, the hollows are formed, which, under the influence of dynamic loads, turn into pits [8, 15].

The leveling systems allow a more accurate layering of the roadway coat, which contributes to a more even distribution of the load on the roadway. The accuracy increasing of layer-by-layer surface profiling enhances the degree of resistance to moisture and promotes drainage. This is why the use of such systems is necessary in the construction of any complexity [6, 15].

The use of the leveling system makes it much easier to process the surface profiling. The application of the leveling system allows to reduce the number of passes of the road construction machine in the profiling mode from 10-15 to 2-3 times. Reducing the passes allows one to reduce the number of spent machine hours, contributes to fuel economy, and shortens construction time [5, 7, 10].

## 4. STRUCTURAL SCHEME OF THE AUTOMATED LEVELING SYSTEM

In this article, we will look at the developed leveling system, which consists of four subsystems (Fig. 1): construction of a laser plane, search and control of a laser plane, automation of control of the working elements of the construction machine, and visualization [12].

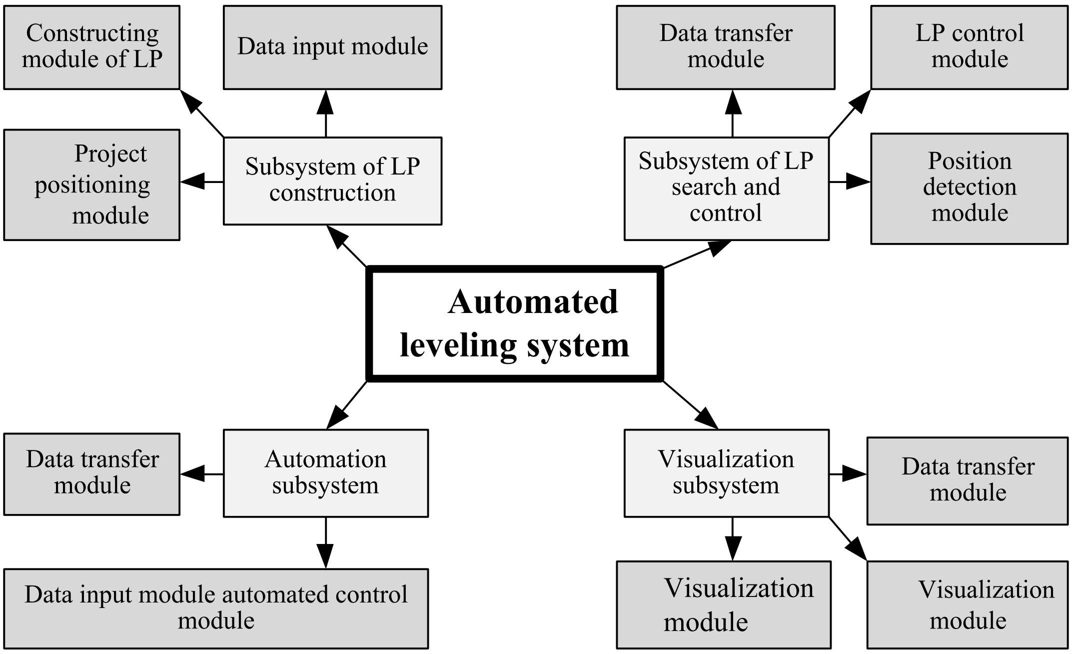


Fig. 1. Structural diagram of an automated leveling system for road construction equipment

**The subsystem for the laser plane (LP) construction** consists of a laser and sensors to determine the position in space. The LP constructing subsystem exposes the LP building module to the project position by automatically setting the required inclination angle. The elevation marks are entered by the surveyor through the data input module. The builder rotates the laser beam to create a plane that is parallel to the plane of the future roadway or foundation of the structure at an altitude measured from the bench mark. A laser no higher than 3A safety class is used to build a plane, which makes it possible to use the construction module in populated areas and cities without the use of additional protective equipment.

**LP search and control subsystem** performs an LP search by vertical movement on the mast installed on WE of the road construction equipment. It is used to determine the altitude position of project LP. The LP control module, which is part of this subsystem, consists of a telescopic mast equipped with an electric drive and performs a high-altitude search for LP by vertical displacement. The LP position detection module is a cylindrical receiver on which the laser plane is projected. Inside there are 4 high-resolution video cameras with a shooting frequency of more than 60 frames per second. The signal processing is performed by a unit based on Raspberry PI, which sends data over the wireless network to the monitor installed in the cab of the road-building machine, information on the position of the working element, and necessary adjustments, with manual operation of the system. In the automatic mode, the data from Raspberry PI are sent to the automation subsystem via a data transfer module that performs a control action on the hydraulic cylinder system. The data on the position of WE are duplicated on the display to the operator of road construction equipment [6, 11, 16, 17].

**The automation subsystem** of road construction equipment carries out automatic control over the executive mechanisms of the bulldozer and motor grader or excavator bucket. The control subsystem receives the position data from the LP position detection module and reacts to the smallest deviations of the working element from the project position. The automated control module consists of a control unit made using Raspberry PI and a module connected to the system of hydraulic cylinders of construction equipment.

The automation subsystem of the construction machine can be disabled for the manual control mode of WE. In the manual mode of operation, the operator of the construction equipment must himself make adjustments to the position of WE according to the data obtained from LP search and the control system on display in the cabin [11, 15, 17, 18].

**The visualization subsystem** includes a visualization module created on the basis of hardware in the form of a Nextion HMI touch screen, which allows displaying information on the position of LP and WE in a graphical form for the operator. Through the touch screen, the corrections to the altitude position of WE are made via the Input/Output module, which are processed by the data transfer module and entered into the project.

The leveling system developed is based on a modular construction principle and is a set of independent subsystems that permits to use them practically on all models of bulldozers, graders, and excavators presented in the world market, as well as to supplement already used leveling systems [5, 7, 11, 19].

## 5. SURFACE PROFILE ALGORITHM

We consider the basic stages of the process of profiling the surface using the automated leveling system. The process is formalized in the form of a diagram in IDEF0 notation (Fig. 2).

A0. Implementation of leveling system operation.

At the entrance to the block A0, the information is introduced about the project of the object, which is a set of data characterizing the required altitude marks.

The executive elements at this stage are the surveyor, the operator of the construction machine, software, and hardware. The surveyor inputs the data on the elevation marks required on the site. The operator monitors the profiling process and, if necessary, makes adjustments, the software analyzes the obtained data on the displacement of the working element of the road construction machinery relative to the projected laser plane, and calculates the thickness of the layer to be removed during profiling. Hardware in the automatic mode of operation of the system leads the working bodies to the project position without direct control of the operator of construction equipment.

The restrictive factors are the statements of work, safety rules, project parameters, and a terrain map. The technical specification limits the elevation marks during profiling. The safety rules limit the speed of road construction equipment and executive elements. The project parameters take into account the maximum and minimum possible WE displacement of each model of the road construction machine, as well as the load on WE optimal when working on this type of equipment. The terrain map is taken into account when creating a technical task by a surveyor [5, 7, 10, 19].

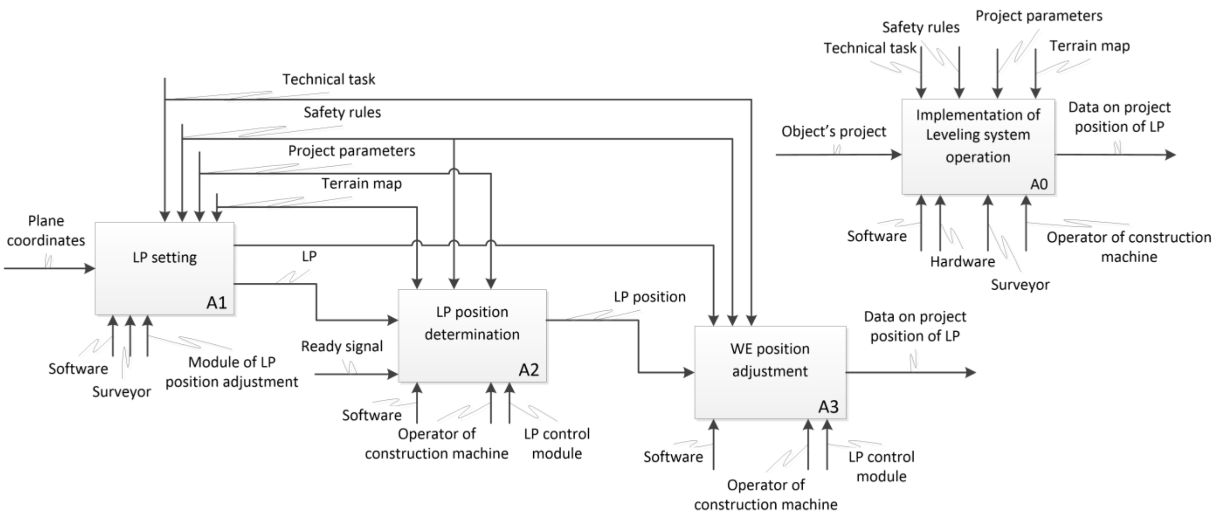


Fig. 2. The algorithm of the automated leveling system for surface profiling

A1. Laser plane setting.

At the next stage, the surveyor must install an LP builder in the project position. After installation in the projected elevation position, the surveyor includes a subsystem for constructing the laser plane, calculating manually the altitude mark relative to the reference point.

It is required to enter the angles of inclination of the future roadway to build the LP. After entering all the required information, the system automatically puts the LP builder in the specified position.

Input/output of data is carried out through a specially developed graphical interface with the help of a Nextion HMI touch screen. The interface is simple and intuitive, which saves time on learning the capabilities of the software part of the system.

The introduced to the subsystem information contains the data on the altitude at which the laser plane will be created, as well as the angle of inclination of the plane relative to the horizontal position, which must be obtained at the construction site. After entering information, the subsystem automatically determines its current position (angle of inclination, current altitude mark), then the calculations are made based on the relationships of the mathematical model for LP setting in the required position, and its construction is carried out.

A2. LP position determination.

The operator of the road construction equipment sets the moldboard blade to the vertical position, and then, using the display in the cabin, starts the LP search module, which is located on the mast installed on the working element (WE) of the machine. The module, by moving along the vertical axis, searches for the laser plane. When it is detected, a ready signal is sent to the operator's monitor and the position of WE of the machine is deflected from the project position.

A3. WE position adjustment.

The characteristic of the developed leveling system is the subsystem of automated control over the WE position of the construction machine. The control subsystem of WE of the construction equipment monitors and installs WE of the machine in the project position, and also allows the generation of the optimal route and the number of passes based on the load on WE. The control module receives data on the change in the position of WE from the controller and, without direct human influence, sets WE of the road construction machine in the project position. The change and displacement of WE are calculated by the system using the relationships of the mathematical model. The use of the automated position control subsystem of WE is possible after a small modernization of the motor grader control unit and allows us to reduce the time for the creation of high-altitude marks for profiling in the site, to reduce the negative impact of the human factor, significantly speeding up the leveling process and increasing the process safety, and also improving the quality of the roadway [7, 19].

Fig. 3 shows the decomposition of block A1. The initial stage in profiling is the installation of a tripod with a subsystem of LP construction, as well as the input of a high-altitude project of the object.

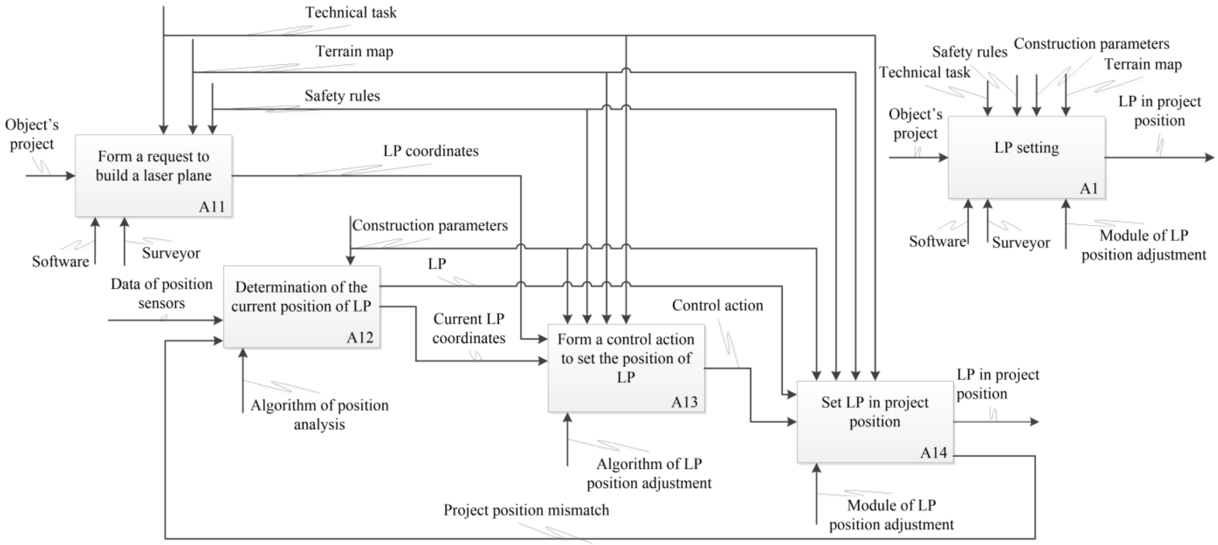


Fig. 3. Process of LP installing in project position

A11. Form a request to build a laser plane.

In this block, the surveyor fills in a special form on the screen of the LP builder, which shows the deviations from the horizontal position of the builder relative to the three axes, the elevation mark, for lifting the builder of LP over the surrounding obstacles (workers, construction sites, and other construction equipment). Thus, the matrix of the project position of the laser plane $MP_C$ is formed:

$$MP_P = (ax_p, ay_p, az_p, h_p), \tag{1}$$

where $ax_p, ay_p, az_p$ - the values of the angles of inclination of the laser plane along the axes OX, OY, OZ; $h_p$ - projected height of the laser plane.

The data input is carried out using a touch screen monitor Nextion HMI.

A12. Determination of the current position of LP.

For the determination of the current position of LP, the system processes data from position sensors: a magnetic compass, an accelerometer, and a gyroscope. The data are read and analyzed by the system automatically, and then entered into the matrix of the current position $MP_C$:

$$MP_C = (ax_c, ay_c, az_c, h_c), \tag{2}$$

where $ax_c, ay_c, az_c$ - the values of the angles of inclination of the laser plane along the axes OX, OY, OZ;

$h_c$ - current laser plane height

A13. Form a control action to set the position of LP.

At this stage, the software considers the difference between the data of the project location matrices and the current position, and then the control value for the LP position setting system $\Delta MP$:

$$\Delta MP = \left| MP_P - MP_C \right|. \tag{3}$$

Thus, by step by step changing the parameters of the matrix of the current position by means of the control action, we perform the transition of the laser plane to the required design position.

The height of the LP is adjusted in accordance with the difference with respect to the project value:

$$\Delta h_c = h_p - h_c,$$
$$h_c = \begin{cases} h_c + \Delta h, \Delta h_c > 0, \\ h_c - \Delta h, \Delta h_c < 0, \\ h_c, \Delta h_c = 0, \end{cases} \tag{4}$$

where $\Delta h$ - step of changing the height of LP.

After setting the required height, the inclination angles are adjusted:

$$\Delta ax_c = ax_p - ax_c, \Delta ay_c = ay_p - ay_c, \Delta az_c = az_p - az_c,$$
$$ax_c = \begin{cases} ax_c + \Delta ax, \Delta ax_c > 0, \\ ax_c - \Delta ax, \Delta ax_c < 0, \end{cases}$$
$$ay_c = \begin{cases} ay_c + \Delta ay, \Delta ay_c > 0, \\ ay_c - \Delta ay, \Delta ay_c < 0, \end{cases} \quad (5)$$
$$az_c = \begin{cases} az_c + \Delta az, \Delta az_c > 0, \\ az_c - \Delta az, \Delta az_c < 0, \end{cases}$$

where $\Delta ax_c, \Delta ay_c, \Delta az_c$ are the minimum step of changing the angles of inclination of the laser plane along the axes OX, OY, and OZ, determined by the accuracy of the positioning of the stepper motor.

The LP position setting system consists of three stepper motors installed at the base of the LP builder managed by the controller. This system allows one to change the inclination of the laser plane around three axes. The use of stepper motors is due to the possibility of minor displacements, which allows one to change the angle of inclination in step of several seconds. This facilitates the most accurate positioning of the LP builder.

A14. Set LP in project position.

The algorithm calculates the number of steps of the stepper motor and places the LP builder in the project position. After installation, the received data are checked and if they do not match, return to step A12. If differences between the matrices are not found (i.e. $\Delta MP = 0$), then LP is constructed in the project position. To determine the position of LP, the operator of the road construction machine needs to activate the LP search and position-monitoring system, which is installed on the working element of the road construction equipment.

The decomposition of block A2 is shown in Fig. 4 and includes the following steps.

A21. Generate a signal to turn on.

After activating the LP Builder, the surveyor signals to the road construction machine operator that LP is ready. When the signal is received, the operator activates the LP control module.

A22. Determine the position of the LP control module.

The algorithm from step A12 is used and the matrix of the current position of the monitoring module $MP_{MC}$ is formed to determine the position:

$$MP_{MC} = (ax_{mc}, ay_{mc}, h_{mc}), \quad (6)$$

where $ax_{mc}, ay_{mc}$ are the inclination angle values of the control module along the axis OX, OY and $h_{mc}$ is the current height of the control module.

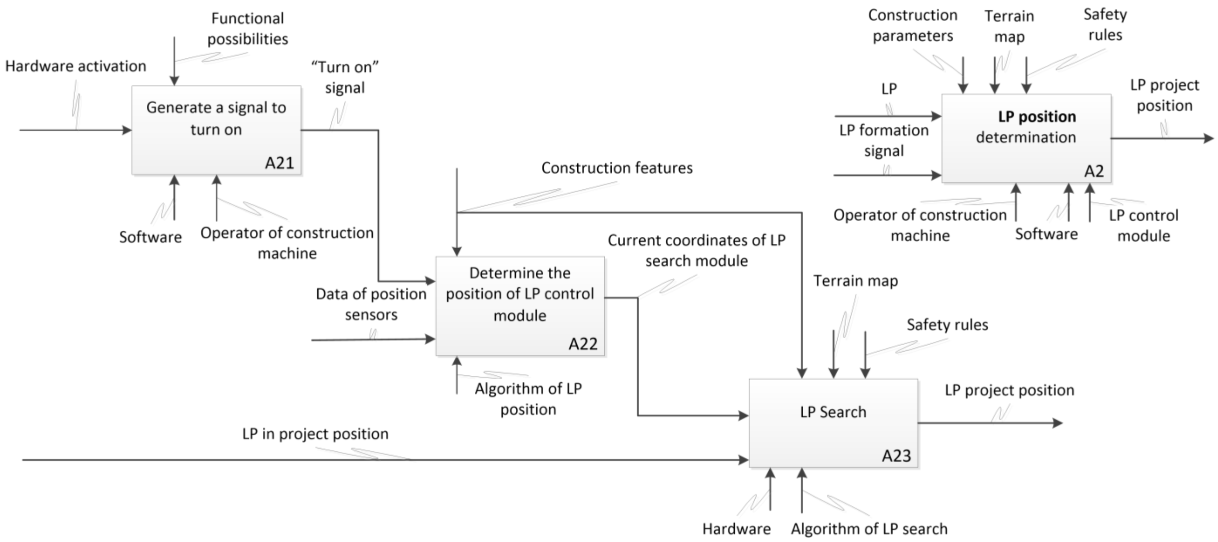


Fig. 4. The process of LP position determination

A23. LP Search.

After the matrix is formed, the data on the deviation of WE from zero position are sent to the monitor of the operator of the road construction machine. The system considers Zero position as the vertical position of the moldboard blade, at which the system displays the value «00.00» in all fields on the operator's screen.

When installing WE in the zero position, the LP control module starts searching for the constructed LP by translational vertical movement. When LP is detected by the reader of the LP monitoring module, the search and control system centers LP with respect to the center of the lens of the reader and transmits the current position and deviation data from the project WE position to the operator's monitor in the corresponding fields.

The height of the monitoring module is adjusted in accordance with its difference with respect to the position of the laser plane:

$$\Delta h_{mc} = h_c - h_{mc},$$
$$h_{mc} = \begin{cases} h_{mc} + \Delta h_2, \Delta h_{mc} > 0, \\ h_{mc} - \Delta h_2, \Delta h_{mc} < 0, \\ h_{mc}, \Delta h_{mc} = 0, \end{cases} \tag{7}$$

where $\Delta h_2$ is the step of changing the height of the control module.

After setting the required height at the time ($\Delta h_{mc} = 0$), the inclination angle adjustment begins in accordance with the following rules: an elliptical section is formed when crossing the laser plane with the cylindrical receiver of the monitoring module, and then, to determine the desired angles of inclination, it is necessary to vary them so that the cross-section takes the form of a circle and is situated at the center of the camera lens of the search and control module. In this case, it is necessary to take into account that the initial section has two axes: the larger is set as $d_2$ and the smaller as $d_1$. Then, the resulting circle's diameter must have a value equal to the smaller axis, i.e. $d_1$.

In the formalized form, we obtain:

$$\Delta ax_{mc} = ax_c - ax_{mc}, \Delta ay_{mc} = ay_c - ay_{mc},$$
$$ax_{mc} = \begin{cases} ax_{mc} + \Delta ax_2, \left|d_2^* - d_1^*\right| < \left|d_2 - d_1\right|, \\ ax_{mc} - \Delta ax_2, \left|d_2^* - d_1^*\right| > \left|d_2 - d_1\right|, \\ ax_{mc}, \left|d_2^* - d_1^*\right| = 0, \end{cases} \tag{8}$$
$$ay_{mc} = \begin{cases} ay_{mc} + \Delta ay_2, \left|d_2^* - d_1^*\right| < \left|d_2 - d_1\right|, \\ ay_{mc} - \Delta ay_2, \left|d_2^* - d_1^*\right| > \left|d_2 - d_1\right|, \\ ay_{mc}, \left|d_2^* - d_1^*\right| = 0, \end{cases}$$

where $\Delta ax_2$ and $\Delta ay_2$ are the steps to change the inclination angles of the control module along the axis OX, OY; $d_1^*, d_2^*$ are the values of the smaller and larger axis of the section ellipse after changing the slope of the control module.

After initialization, the system calculates the current position of WE and compares it with the position required for profiling. After the comparison of the data, the value of the control action is calculated to place WE of the road construction machine in the design position. The process of the correction in the automated mode is shown in Fig. 5.

A31. Determine the current position of WE.

At the stage of presetting the leveling system, the user is offered a list of models supporting the automation system when choosing the model of road construction equipment; the system takes into account the standard dimensions of WE and the capabilities of each machine.

When the leveling system is operated in an automated mode, the data from the LP monitoring module are sent to the control subsystem of WE of the construction machine and duplicated to the operator's monitor. The system analyzes the resulting matrices, and then calculates the position of the extreme WE points of road construction equipment based on the model of construction equipment chosen by the operator. These provisions are made in the form of a matrix of the current position of WE and sent to the automation unit:

$$MP_R = (ax_r, ay_r, az_r, h_r, p_r), \tag{9}$$

where $ax_r, ay_r, az_r$ are the values of inclination angles of WE along axes OX, OY, and OZ; $h_r$ is the WE height; and $p_r$ is the pressure on the surface of WE from the profiled surface.

A32. Set the WE trajectory.

After receiving and processing the matrices of the current position of WE and LP, the algorithm calculates on the basis of the mathematical model the optimal movement of WE based on the capabilities of the road construction equipment. WE trajectory and the optimal number of WE passes are calculated using the following correlation:

$$N = \frac{(|h_0 - h_p| \cdot l_0)}{hs_r \cdot l_r}, \tag{10}$$

where $h_0$ - ground level, $h_p$ - project level;

$l_0$ - working area width;

$l_r$ - WE width;

$hs_r$ - height, which can remove WE in one pass, determined by the density of the material and the characteristics of the working element (for the land grader, it varies from 0.5 to 10 cm).

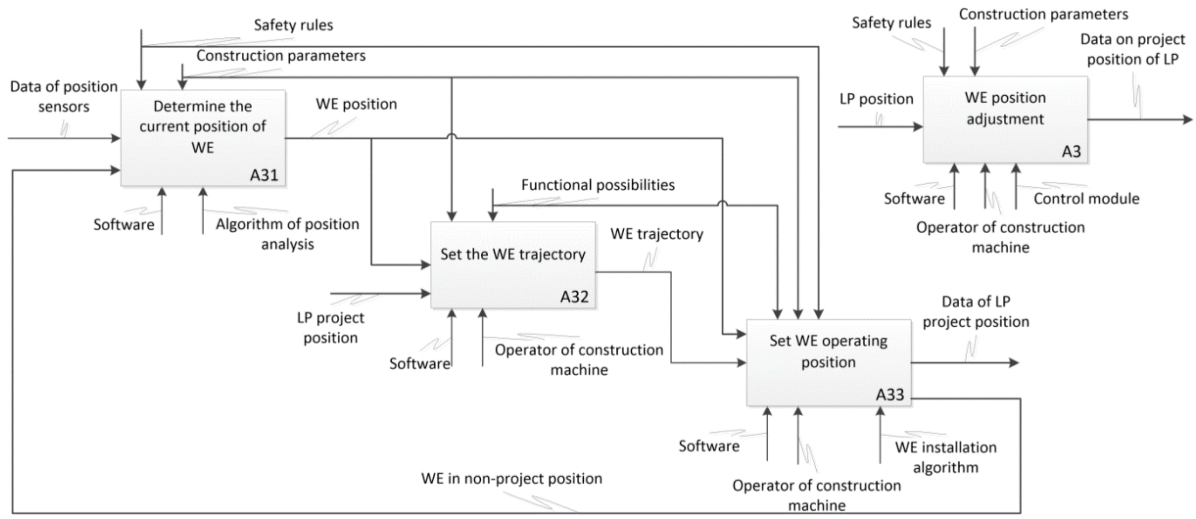


Fig. 5. The process of adjusting the position of WE of a road construction machine in automated mode

A33. Set WE operating position.

Based on the WE trajectory, a control action is created on the system of hydraulic cylinders of a road construction machine. After each change in the position of WE, the system returns to step A12; this approach allows WE of the construction machine to be stored in the project position throughout the entire surface profiling process.

Despite the fact that the road construction machine operates in an automated mode, the operator has the opportunity to stop the profiling process and make corrections. It should also be noted that the use of the automation system requires a change in the design of the hydraulic cylinder control unit.

## 6. USER INTERFACE OF THE LEVELING SYSTEM

For the interaction of the operator with the system according to the presented algorithm, a graphical interface of the software of the automated leveling system was developed. The user is asked to choose the company of the manufacturer of the road construction machine, and then the type of special equipment and its model. This will allow the system to determine the parameters required for its normal operation.

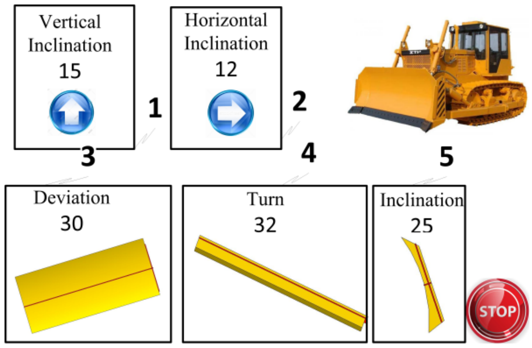


Fig. 6. Interface for managing the profiling process

On the start page of the program, one can find a list of companies, when clicked on which the system will offer construction equipment for their production; function buttons to go to the settings and security rules; and a button to stop the process of the system.

Fig. 6 shows the user interface. In the upper right corner, a model of road construction equipment, selected by the operator, is displayed. In the field indicated by number 1, the vertical deviation of WE of the road construction machine in millimeters relative to the project LP is shown. The arrow indicates the direction of the required WE. Number 2 indicates the field for displaying the movement along the horizontal axis. Fields 3-5 show the current position of WE. Number 3 shows the angle of inclination of WE relative to the horizontal position or the project LP depending on the selected operating mode. Number 4 shows the rotation of WE relative to the axis perpendicular to the direction of motion of the road construction machine. Number 5 shows the inclination of WE relative to the horizontal position or the project LP. A stop button is provided in the lower right corner to stop the profiling process.

Thus, the presented software implements the above algorithm of functioning of the automated leveling system.

## 7. PRACTICAL APPLICATION OF ALGORITHM IN THE IMPLEMENTATION OF THE PROTOTYPE OF THE LEVELING SYSTEM

The developed algorithmic and mathematical software was used in the implementation of the prototype of the automated leveling system. It includes prototypes of the LP builder and receiver, the principle of operation of which is based on the presented algorithm. Fig. 7 shows the prototype of the LP construction subsystem.

The subsystem for LP construction allows the creation of LP in an automated mode. The prototype is equipped with a 2.4” touch screen, 5 duplicate buttons, a power button, and a digital level. For rotation around a vertical axis, a stepping motor is applied, the shaft of which is fixed in a specially designed planetary gearbox, which allows the system to rotate with a minimum load on the motor axis. A rigid base design allows one to turn off the power from the engine after setting LP in the design position.

To search and control the position of the laser plane in space (according to the block diagram), a software–hardware complex is developed - a prototype of the LP search and control subsystem

(Fig. 8). The prototype is connected to the onboard network of the road construction equipment. The interface "receiver-user" is represented by an Android application that is installed on a tablet computer, which is located in the cab of a road construction machine operator.

Fig. 7. Prototypes of the LP subsystem construction

A series of tests were carried out to test the adequacy of the developed algorithms for LP construction, as well as the correctness of the selected structure of the subsystem for LP construction.

Fig. 8. Prototypes of LP search and control subsystem

The following constructive requirements for the developed prototype were stated:

- The module prototype should provide an uninterrupted operation within the temperature range from -10 to +35 degrees C.
- The module prototype must withstand a fall on compacted soil from a height of no more than 1 meter.
- The prototype of the module should provide an angle of inclination of the laser plane of at least 20 degrees.
- The applied engines must provide a rotational speed of at least 30 Hz.
- The software of the module prototype should provide the ability to upload data to mobile devices running Android OS.

The developed prototypes were tested under laboratory conditions and proved their efficiency. Using the subsystem of the LP construction in the room, a sufficient rotation speed was a speed of 30 rpm. At this speed, the prototype can be compared with the usual available on the market rotary separator, the average price segment. The radius of the laser plane reached 40 meters outside in clear, rainy weather. A 5 mW laser was applied. The laser point was visible without the use of special equipment. This result makes it possible to use the system for outdoor work.

The disadvantage of the developed system was the use of a mirror reflecting surface with an internal wall of reflection. On applying a mirror surface, a significant attenuation of the laser beam was noticed, caused by a strong dispersion when it hit the reflective surface. To eliminate this drawback, it was decided to use a special pentagonal lens, the pentaprism.

In the course of practical tests, it was concluded that for the normal operation of the subsystem of LP construction, together with the subsystem of the search and control of LP, the rotation speed of the laser beam needed to be increased to at least 200 rpm. At this speed, 2-3 laser points are projected onto the translucent receiver screen every second, and the position of LP is mathematically calculated.

Thus, the structural scheme and the profiling algorithm considered in this study were successfully tested in the practical implementation of the leveling system prototype.

## CONCLUSION

The article presents the algorithm of work and the structural diagram of the automated leveling system, which performs the control over the position of the working element of the road construction machine. The questions of creating leveling systems are considered, and the principles of operation of the most common systems and their use on construction sites are presented. A comparative analysis of the most common leveling systems was carried out, and their strengths and weaknesses were analyzed, which led to the conclusion that the use of such systems allows reducing the financial and time costs for road construction works, as well as to increase the durability of the roadway due to a more accurate altitude mark.

The article considered the structural scheme of an automated leveling system, which includes four main subsystems: laser plane construction, laser plane search and control, automation, and visualization. Each subsystem includes a set of interconnected modules that ensure the correct operation of the system as a whole.

For the implementation of the profiling process, an algorithm for the functioning of the leveling system is proposed. The algorithm allows one to formalize and organize the operation of the system through a detailed algorithmic and mathematical description of the processes of its functioning. The algorithm includes the following steps: LP setting, determining the position of LP, and WE position correcting.

The article also presents software developed on the basis of this algorithm and implements the basic operations of the profiling process control. Further research will be aimed at developing a mathematical model of the leveling system, optimizing it to increase the productivity and efficiency of the profiling process.

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