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DIGITAL LEVELING SYSTEM FOR ROAD CONSTRUCTION MACHINES

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Abstract. *Due to the acceleration of scientific and technological progress and the growth of labor productivity, road construction machinery is facing a complex task. This refers to the harmonious, integrated, and efficient operation of equipment without loss of quality. As a result, more and more complex mechanized and automated machinery is emerging. Among such machinery, earthmoving machines, i.e., motor graders, hold a significant share. A motor grader is a fairly wide-profile earthmoving and transport machine that has its place in construction. This equipment has a number of advantages that are fundamental in selecting a construction unit for excavation work at the site. The relevance of this work is primarily due to the need to improve this technique, which will increase its productivity and reduce the specific gravity of energy consumption. The modernization of existing motor graders will have a significant impact on the further development of construction machinery and will expand the scope of road surface preparation work for future construction.*

Annotatsiya. *Fan-texnika taraqqiyotining jadallashuvi va mehnat unumdorligining o‘sishi tufayli yo‘l-qurilish texnikasi oldida murakkab vazifa turibdi. Bunda asbob-uskunalarning sifatni yo‘qotmagan holda uyg‘un, yaxlit va samarali ishlashi nazarda tutiladi. Natijada tobora murakkab mexanizatsiyalashgan va avtomatlashtirilgan mashinalar paydo bo‘lmoqda. Bunday mashinalar orasida yer qazuvchi mashinalar, ya’ni avtogreyderlar salmoqli o‘rinni egallaydi. Avtogreyder ancha keng profilli yer qazish va transport mashinasi bo‘lib, qurilishda o‘z o‘rniga ega. Ushbu uskunalar bir qator afzalliklarga ega bo‘lib, ular obyektda qazish ishlarini bajarish uchun qurilish agregatini tanlashda asosiy hisoblanadi. Ushbu ishning dolzarbligi, birinchi navbatda, ushbu texnikani takomillashtirish zarurati bilan bog‘liq bo‘lib, bu uning unumdorligini oshiradi va energiya sarfining solishtirma og‘irligini kamaytiradi. Mavjud avtogreyderlarni modernizatsiya qilish qurilish mashinasozligining yanada rivojlanishiga sezilarli ta’sir ko‘rsatadi.*

Аннотация. *В связи с ускорением научно-технического прогресса и ростом производительности труда, перед дорожно-строительной техникой стоит сложная задача. Речь идет о гармоничной, интегрированной и эффективной работе оборудования без потери качества. В результате появляются все более сложные механизированные и автоматизированные машины. Среди таких машин значительную долю занимают землеройные машины, то есть автогрейдеры. Автогрейдер — это довольно широкопрофильная земляная и транспортная машина, имеющая свое место в строительстве. Данное оборудование имеет ряд преимуществ, которые являются фундаментальными при выборе строительного агрегата для проведения раскопок на объекте. Актуальность данной работы обусловлена, прежде всего, необходимостью совершенствования данной техники, что повысит ее производительность и снизит удельный вес энергопотребления. Модернизация существующих автогрейдеров окажет значительное влияние на дальнейшее развитие строительной техники и позволит расширить.*

Key words: *digital system, control, motor grader.*
Kalit so‘zlar: *raqamli tizim, boshqaruv, avtogreyder.*
Ключевые слова: *цифровая система, управление, автогрейдер.*

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Introduction. One of the most important processes in modern construction is preparing the construction site for future construction. It is precisely the quality of this stage's execution that imparts the required strength to the road surface, allowing for the achievement of maximum road serviceability in the future. The acceleration of the scientific and technical process and the increase in labor productivity necessitated the creation and mastery of efficient systems of various machines for the integrated mechanization of construction.

It should be noted that the creation of a modern automatic control system for the motor grader's working element for the soil leveling process is relevant, as the automation systems known in this field are typically devices that stabilize the tiller's height position and do not allow for a significant increase in the operational efficiency of earthmoving and transport machinery. The goal of automatic control regarding the layout process must be to achieve the maximum possible machine productivity for a given area of the machined surface. Regarding this stage, an important role here is played not by the actual process of adapting the dump onto the accurately obtained surface, but by the thoroughly conducted soil geodesy during the planned construction. This study significantly simplifies the operation of the motor grader, as all characteristics of the selected land plot can be taken into account in advance [2,4,7].

It should be noted that the purpose of this work is to increase the productivity of the motor grader by installing an automated system for adjusting the position of the embankment relative to the soil layer, as well as to implement a precise positioning of the motor grader on the construction site for the precise, step-by-step creation of a flattening on project landmarks controlled by aerial photography.

The performance of a motor grader primarily depends on the accuracy of the controlled parameters of the controlled system. In the operation of this construction machinery, 2 sensors operate: the cutting angle sensor and the grip angle sensor for removing the soil layer [1,3].

However, the number of sensors may vary depending on the system being assembled. It should also be noted that when creating the cutting plane with the actuator of a motor grader, it is necessary to create several models step-by-step, i.e., using sensors to create them. Thus, the construction of a model in a 3D leveling system can be carried out in various ways [1,6].

- Plane model;
- Slope model;
- Road model;
- Surface model;
- Linear reference model;

Figure 1 shows an example of an interface for selecting a model construction:

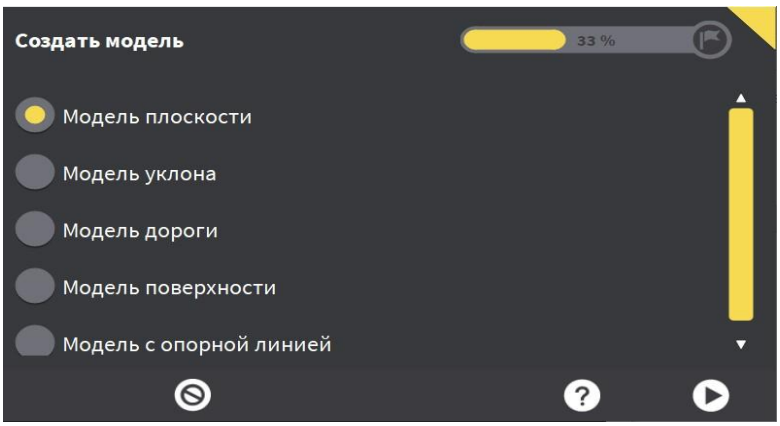

Figure 1. Create model

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The sensors installed on the motor grader allow for the real-time detection of the required relief changes to correct the cutting angle α (30-80 degrees) within the range of 3-5 degrees and the trapping angle λ (0-180 degrees). In the second and third figures, the cut and grip angles are shown to clearly demonstrate the parameters being adjusted.

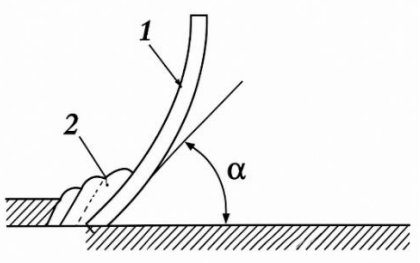

Figure 2. Angle of incision

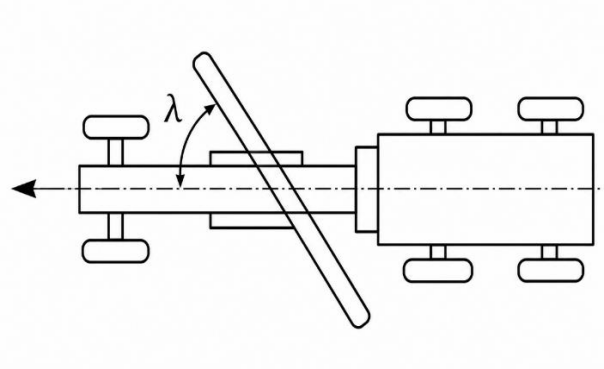

Figure 3. Capture angle

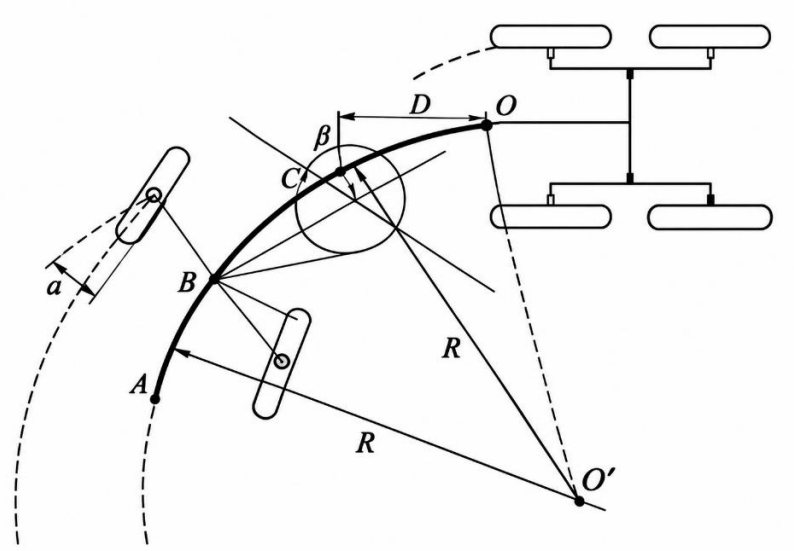

Figure 4. Determination of the turning radius of the motor grader

In addition to the capture and cutting angles, the system may also contain other sensors, and determining their desired position on the interface is shown in Figure 5.

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Figure 5. Providing specific information using an interface

The final appearance of the planned model by entering the necessary parameters is shown in Figure 6.

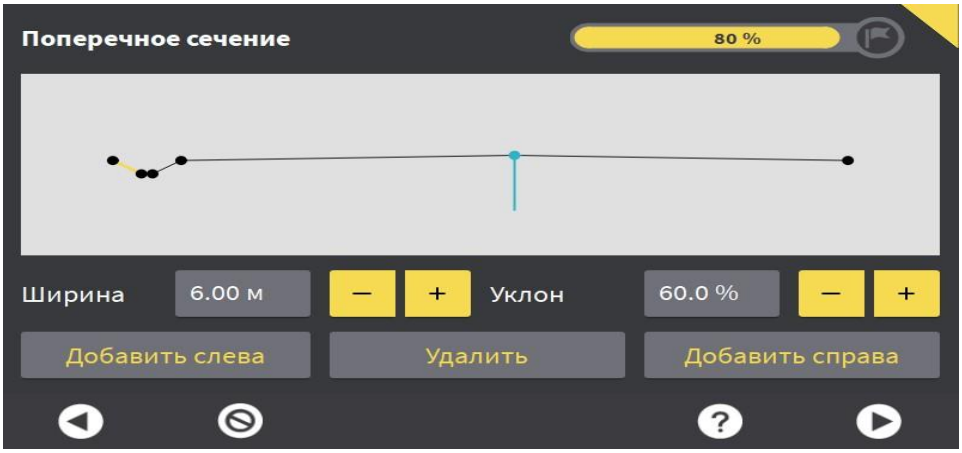

Figure 6. Cross section of the cross-sectional area model

Thus, since the motor grader is a multifunctional device, it should be noted that in its classic version, the motor grader is used for final surface preparation, "smoothing," as well as for leveling previously treated soil and any other pavement with less specialized machinery. The driver also plays an important role in the proper operation of the motor grader. Under all necessary conditions, the smooth positioning of the machine and the tiller guarantees a flawless surface.

The operating principle of the 3D leveling system. The 3D system ensures the implementation of design solutions based on three parameters, such as plan position, elevation marks, and transverse slopes. Figure 7 shows a bulldozer equipped with a 3D system with two satellite antennas rigidly connected to the bulldozer's working parts. Two antennas allow for spatial orientation and reliable provision of spatial data [7,8].

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Figure 7. Two-antenna 3D system

Figure 8 below shows a 3D system on a bulldozer with a single antenna and spatial position sensors: inclinometers and angular rotation sensors.



Figure 8. A 3D system based on GNSS and spatial orientation sensors

As we can see, the configuration of the automated leveling system varies. As previously noted, all of this is related to the goals set for a specific object and system.

Figure 9 below shows another real analog system developed by Siberian State University, which includes a similar GNSS-based automated control system (AVS) for motor graders.

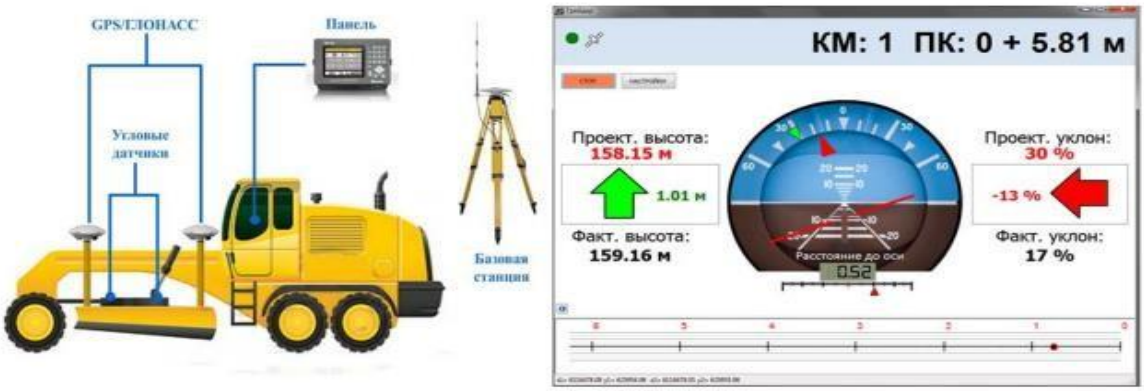

Figure 9. 3D system for motor grader (SGUPS development)

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It should be noted here that the main difference of this system is the possibility of working with a universal digital design created for various construction machines. This possibility of using a single digital project for all construction machinery allows for a significant reduction in the cost of creating a digital project. At the same time, such a system can be used both as an indicator-type system without being connected to a hydraulic or electric drive, and in automated mode. [7; 8].

It should be noted that the leveling system using GLONASS sensors includes a composition of closely interconnected elements and processes, as shown in Figure 10.

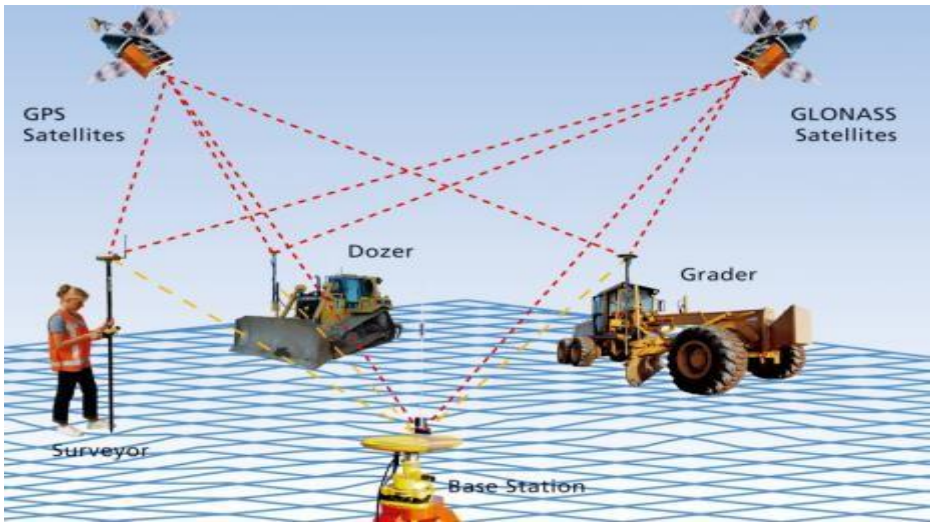

Figure 10. Operating diagram of the 3D leveling system

The main task of such a system is to automate the working part. It is automated by introducing a group of displacement sensors installed on the working element of the motor grader, the turn wheel, and directly on the frame. The information received from the sensors regarding the location of the motor grader and its working element is linked to the electronic plan of the pre-examined site, as well as the direct location of the grader, as shown in Fig. 10. It should also be noted that leveling systems not only increase the productivity of machinery but also allow for material savings in construction, which is achieved through high-precision surface treatment. Thanks to the system, it is also possible to save fuel and lubricants, as well as reduce the requirements for operator skills, which makes it easier to find workers for construction. [2; 6]

It should also be noted that the device provides a system for precise control over geometric parameters during the cutting of contaminated ballast for gravel cleaning machines, and the SAU-3D system was developed based on GNSS and hydrostatic leveling, as shown in Figure 10.

Aerial imaging system and its impact on modeling. Focusing on all possible variants of 3D leveling systems, we would like to note that the system proposed in the work allows for the consideration and utilization of all the aforementioned advantages of the 3D leveling system, as well as its application in conjunction with aerial photography and aerial laser scanning, which allows for achieving maximum accuracy and visualization of the constructed 3D model of the object when working on a construction site [7; 8].

This combination allows you to perform the following list of tasks:

- Creation of high-precision orthophotoplanes and 3D terrain models;
- Survey of the site and corridor for engineering surveys;
- Design and monitoring of infrastructure facilities;
- Aerial laser scanning of forest areas;
- Mapping at a scale of 1:10,000 – 1:500;

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- 3D models of cities

Figure 11 shows a 3D model of an object created using this system.

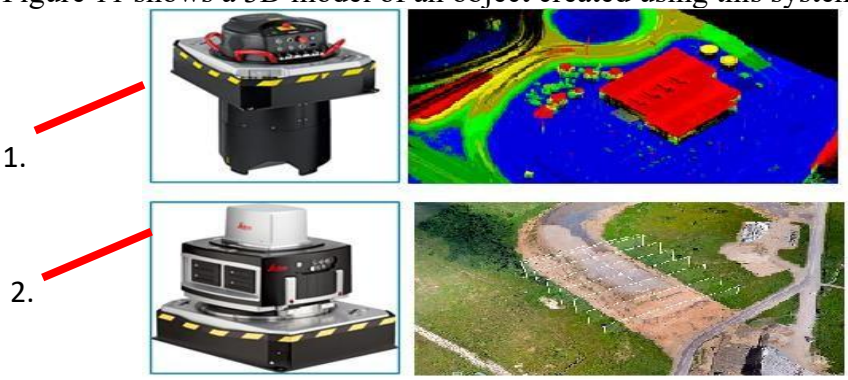

Fig. 11. 3D model created by aerial imaging system

As shown in Figure 11, the system precisely processes all the necessary details. Figure 1 shows a laser scanner operating in the infrared range as element 1. Its main task is to collect geodetic data about the object and build a 3D model. The second device does the same, but scans without using an infrared sensor. When constructing such a 3D system in road construction, all risks of unexpected road defects at the beginning of construction are minimized, which allows for expanding the information flow at the work site and clearly visualizing the location of the future road.

It should also be noted that, depending on the type of equipment used (marked with numbers 1 and 2 in Fig. 11), it is possible to obtain various images of any object and, ultimately, obtain a complete 3D model of the object. Thus, the aerial survey system complements the 3D leveling system, helping to expand information about the object and collect all the data necessary for high-quality road construction. The operation of the 3D data collection system based on sensors and 3D levelers is synthesized with UAV data using pre-installed equipment, as shown in Fig. 11, after which the final complete version of the system is obtained, suitable for analysis and planning of future construction [8].



Figure 12. UAV for geoscan

System Algorithm: Before describing and constructing the algorithm itself, it is necessary to define the stages of the work.

Figure 13 shows the main stages of constructing an algorithm

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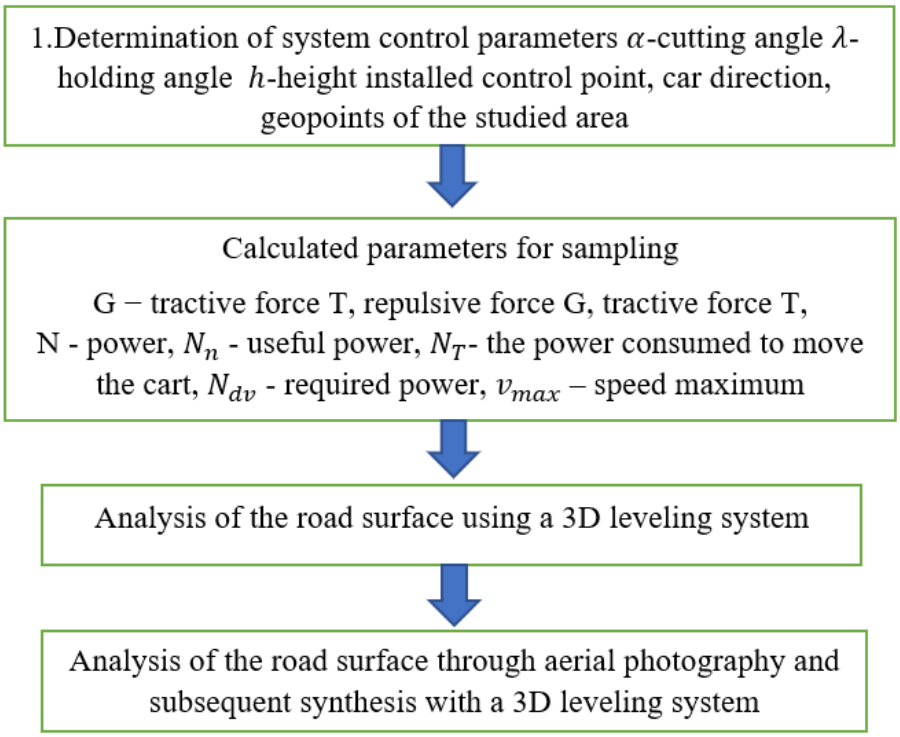

Figure 13. Main stages of constructing an algorithm

The general operating algorithm of the motor grader operates as follows: after starting the engine, the ability of the motor to operate in operating mode is verified by determining the engine speed. Then, the values of the cutting angle and the grip angle are assigned, and the installation of both angles is verified. In the correctly established state according to the algorithm, the value of the control height point is assigned, the value is verified, and then the value of the model direction is assigned according to the algorithm. After checking the specified direction of the model, the points for constructing the cutting plane are recorded according to the algorithm. Next, check that the points for constructing the cutting plane have been plotted, and only after all conditions are met will the motor grader begin its movement. If one of the conditions is checked and none of the processes is performed, the algorithm provides an alternative scenario according to which, if the check condition (rhombic condition) is answered negatively, the operation is repeated. [1; 5; 6].

Summary. The process of 3D leveling and aerial photography of a road construction object is an important and fundamental stage in modern road construction. The longevity and wear resistance of the coatings depend on the quality of this operation. The research conducted throughout the work allows us to conclude that the creation and improvement of automated equipment in modern technology is a trend in modern road construction. Due to the peak achieved in the equipment of construction machinery, automation is the driving element of any technical progress.

Examining the existing classification of motor graders and studying its strengths and disadvantages will help to fully approach the choice of this construction unit for the facility. The selection of 3D leveling equipment and aerial survey analysis, followed by synthesis with the leveling system, will enhance the accuracy and quality of the future road surface.

As a result of the conducted research, it was determined that improving the processes of construction site preparation, soil leveling, and surface formation in accordance with design features at modern road construction sites based on digital technologies is of great importance. In particular, the introduction of 3D leveling systems into the workflow of motor graders will increase

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the accuracy, productivity, and management efficiency of construction work. In this case, one of the main technological capabilities is real-time monitoring of the motor grader's working element and its connection to a pre-formulated digital project.

The study examined the operating principle of the 3D leveling system, demonstrating that it can be used to implement design solutions based on key parameters such as plan position, elevation mark, and transverse slope. The system allows for the control of parameters such as cutting angle, grip angle, elevation mark, machine direction, and the geodetic coordinates of the studied area. The real-time determination and control of these parameters serves to ensure the placement of the motor grader's working element in accordance with design requirements. The capability to generate digital models in the 3D leveling system, such as a plane model, a slope model, a road model, a surface model, and a reference line model, helps account for the specific characteristics of the construction site.

Based on these models, the direction of the motor grader's movement and the position of the working element are adjusted to the pre-determined design surface. As a result, manual adjustment work performed by the operator during the work process is reduced, and the stability of the surface formation process is increased. During the study, the possibilities of using GNSS/GLONASS satellite navigation systems, spatial position sensors, inclinometers, and angle sensors were also considered.

The integration of data obtained from these devices into a unified digital design allows for the determination of the spatial position of the motor grader and the monitoring of the working element's parameters. This approach forms the information base necessary for automating the operation of construction machinery in various operating modes.

Furthermore, the use of a 3D leveling system in conjunction with aerial photography and aerial laser scanning technologies allows for the more complete and accurate formation of a digital model of a construction project. As a result of synthesizing orthophotoplanes, geodetic data, and three-dimensional models obtained from aerial photography with data from the 3D leveling system, comprehensive information about the construction site is generated. This will serve to improve the processes of planning construction work, assessing the existing terrain, and forming the design area.

Another important feature of the system is the possibility of using a single digital project for various construction machines. This approach allows for reducing costs associated with digital project preparation, improving information exchange between construction machinery, and organizing technological processes based on a unified information environment. At the same time, the system can be used both in indicator control mode and in automated control mode.

According to the research results, the use of 3D leveling systems allows not only to increase the productivity of the motor grader but also to improve the efficiency of using construction materials. High-precision surface treatment can reduce the consumption of excess soil or other materials.

Furthermore, it is possible to save fuel and lubricants during operation, facilitate the operator's work, and reduce manual control operations. The automated control algorithm of the motor grader is also an important part of the research. This algorithm involves sequential operations such as determining controlled parameters before starting work, checking cutting and grip angles, setting the control height, determining the model direction, and forming the cutting plane. It is assumed that the motor grader will begin its operation only after all specified conditions have been met. This approach allows for the early detection and elimination of errors in the technological process. Overall, the integration of 3D leveling, GNSS/GLONASS navigation, space sensors, aerial photography, and aerial laser scanning technologies is one of the promising directions for the digitalization of road construction processes. The application of these technologies in conjunction with a motor grader creates the necessary conditions for forming a

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digital model of the construction site, monitoring project parameters in real time, and automatically controlling the condition of the working element.

Thus, the research results demonstrate the practical significance of using digital control systems in the processes of leveling construction sites and preparing the foundation for road surfaces based on a motor grader. By combining the 3D leveling system with aerial photography and geoscan data, it is possible to form a precise digital model of the construction site, monitor differences between the project and the actual surface, and control the movement of the working tool based on specified parameters. As a result, a technical basis will be created to increase the accuracy, technological stability, and resource efficiency of road construction work.

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