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Satbayev University

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ИЗВЕСТИЯ

НАЦИОНАЛЬНОЙ АКАДЕМИИ НАУК
РЕСПУБЛИКИ КАЗАХСТАН
Satbayev University

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ROBOTIC COMPLEX FOR THE RUNWAY LEVELING

Abstract. There is a global trend towards an increase in the weight and dimensions of the aircraft fleet. At the same time, the load on aerodrome pavements increases, which contributes to their faster wear, changes in the pavement profile, and the appearance of defects that threaten flight safety. Therefore, constant monitoring of the condition of airfield pavements is carried out, in particular, the determination of its profile.

A robotic complex has been developed for leveling the runway. The complex includes mobile leveling devices, mobile leveling rods, which are located on the runway during the performance of leveling, and a control device located at the central control station of technical systems of the airport.

The control device contains the following blocks: control with a monitor; processing and storage of information; an intelligent subsystem with a set of logistics programs; geographic information system with GPS receiver; signal coding; reception and transmission of radio signals.

Mobile levelers and mobile leveling rods are controlled from the central station and transmit coded information to the central station via radio communication channels.

The mobile leveling rod is similar in design to a mobile leveling device due to the absence of a rangefinder measurement unit, a turning unit and the optoelectronic device itself.

The movement of robotic mobile leveling devices and sighting targets with stops for measurements is carried out according to a pre-compiled program transmitted via coded radio communication channels. For the initial ones, the marks of the benchmarks are used, the horizontal plates of which are laid flush with the surface of the runway at its lateral ends, along which the steps of precise leveling are preliminarily laid.

The proposed robotic complex allows to quickly determine the marks of the runway in automatic mode with an adjustable scanning step and build longitudinal and transverse surface profiles.

Keywords: leveling, runway, GPS-leveling, robotic complex, mobile leveling works.

Relevance of the topic. In a relatively short period of time, the aviation fleet has significantly expanded both in Ukraine and abroad. There appeared heavy and super-heavy aircrafts (AV), and this tendency is continuing (table 1) [1],[2].

Table 1 – Weight characteristics of passenger aircrafts

Name of the AV	An-24	An-158	Tu-134	Tu-204	Boeing-737	Boeing-777
Weight, tons	21,8	43,7	47,0	107,9	52,8	242,6

The increase in the weight of the aircraft leads to an increase in the load on the aerodrome surfaces during taxiing, takeoff and landing. This in turn leads to faster wear of airfield surfaces and the appearance of their defects that threaten flight safety, change of the profile of the surface. Therefore, the condition of aerodrome surfaces is constantly monitored [3],[4].

Analysis of recent research and publications. An important indicator of the condition of the aerodrome surface is the profile of its surface, in other words – the unevenness of the surface. The value of the unevenness of the aerodrome surface is determined by several methods, which can be attributed to geodetic ones, because during their implementation, geodetic instruments and methods are used.

In the first case, a 3 m long rail and a wedge gauge are used [5],[6]. The clearance between the plane of the coating and the lower face of the rail is measured using a wedge gauge. The wedge gauge has divisions on the oblique face, which determine the distance from the plane of the rail to the surface of the coating. Moreover, the measurements are performed at several intervals of rail length. Measurements are made in sections of 300÷400 m, and the total length of the sections must be at least 10 % of the total length of the pavement. In this way, the short-period deviations of the coating surface from the plane are determined.

The unevenness of the aerodrome surface can be determined using a level and a rail [5]. The method is based on determining the deviation of the points of the coating surface on which the rail is installed, from the horizontal plane specified by the sighting beam of the level. The leveling step is 5 m along the pavement. The relative excesses (marks) of the coverage points are determined and the deviations δh_i of these points are calculated (except the first and last in the measurement area) relatively to the line passing through the previous (i – 1) and next (i + 1) points relatively to i point by the formula:

$$\delta h_i = \frac{h_{i-1} - h_{i+1}}{2} - h_i . \tag{1}$$

The length of the measurement area is 400 m. In this way, longer periodic values of unevenness are determined, in comparison with the previous method.

It is possible to process the results of leveling aerodrome surfaces in another way [7]. Thus, the starting point of the leveling is assigned a positive value of the mark, relative to which the calculation of excesses h_n is performed in the areas of leveling. Next, the values of the slopes i_a are calculated for the distances between adjacent points a = 5, 10, 20 m by the formula:

$$i_a = \frac{h_{i+1} - h_i}{a} . \tag{2}$$

According to the results of calculations, a longitudinal profile is built on the leveling areas. In this way the deviation of the points of the surface of the coating with periods of 5 m, 10 m, 20 m is determined, as well as the deviations of the surface at the same intervals.

The satellite leveling technique called GSP-leveling is widely used to determine the ellipsoidal (geodetic) heights of the Earth's surface relative to the reference surface (ellipsoid), in the creation and development of state geodetic networks [8], in determining the geoid surface, when the obtained GPS ellipsoidal heights are converted into orthometric ones using an exact geoid model [9] and when constructing or refining digital terrain models [10].

In [11], a study of the accuracy of height determination using GPS-leveling in real time has been performed, based on a comparison of the results of GPS-leveling and high-precision geometric leveling. The obtained results showed the accuracy of height determination using GPS-leveling with a mean square error of almost 15 mm at a stroke length of 933 m, which corresponds to the IV leveling class.

These methods and means of their implementation to determine the unevenness of the aerodrome surfaces, which have a large length, require significant time to perform field measurements and a large group of performers.

There is a mobile device for automated leveling of surfaces [12] figure 1, which will give the opportunity to obtain the value of the high point in the automatic mode of a given tape line with adjustable scanning.

The disadvantage of this device for automated leveling of surfaces is the presence of a significant amount of manual labor: the installation and movement of sighting marks for each level of alignment and marking the places of their installation. This in turn slows down the pace of surface leveling work. To perform the leveling of the runway, which is intensively used for the departure and reception of aircraft, the time factor is a priority.

Presentation of the main material. A robotic complex has been developed for leveling the runway (RCLR) [13]. The RCLR includes mobile levelers (ML), mobile leveling rails (MLR) located on the runway, and control devices located at the central control station of the airport's technical systems, which is located on the control tower.

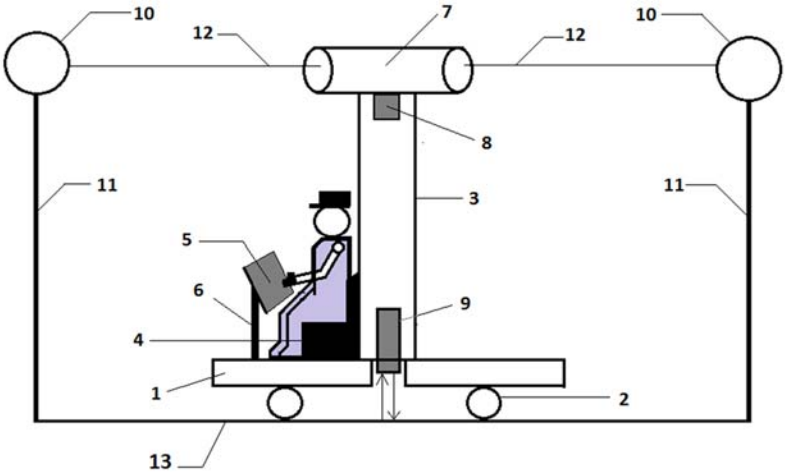

Figure 1 – Scheme of the device for automated leveling:
1 – mobile device; 2 – running gear; 3 – top rack; 4 – operator's seat; 5 – remote control; 6 – control panel rack;
7 – leveling optoelectronic device; 8 – the mechanism of rotation of the block 7; 9 – ultrasonic location unit;
10 – sighting marks; 11 – racks of sighting marks; 12 – sighting rays; 13 – the surface of the site

Figure 2 shows the interaction of mobile devices and units of the central control station of the technical systems of the airport. Blocks 1, 2, 3, 4, 5, 6 are located at the central control station of the airport's technical systems. ML 7 and MLR 8 are controlled from the central station and transmit information through the unit 6 to the central control station of the technical systems of the airport via radio channels.

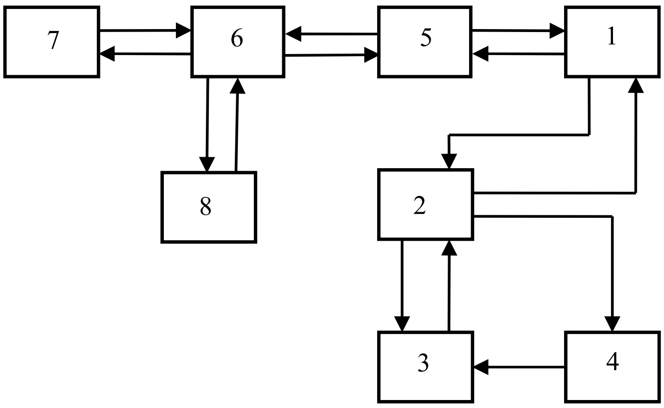

Figure 2 – Interaction of mobile devices and units of the central station of control over the airport's technical systems:
1 – control unit with a monitor; 2 – information processing and storage unit; 3 – intelligent subsystem unit with
a set of logistics programs; 4 – geographic information system unit with GPS receiver; 5 – signal coding unit;
6 – unit for receiving and transmitting radio signals; 7 – mobile leveler (ML); 8 – mobile leveling rail (MLR)

Signal coding units are required to eliminate unauthorized access to the operation of the RCLR.

Figure 3 shows the location of the mobile leveler and mobile leveling rails on the runway plane during leveling.

ML 7 has an optoelectronic device (OED) 9 with a double photodetector array and two lenses forming two optical tubes with sight axes in mutually opposite directions, below which there are two light-range units with the same directions of light probing rays. The plane of the sighting target of 11 ML is located parallel to the sighting beam 20 of the optoelectronic device 7. The sighting targets 11 of ML 7 and MLR 8 contain planes with a set of LED matrices, and in the lower part of the sighting target there is a reflector for long-range measurements. The benchmarks 19 are made in the form of metal plates with flat horizontal surfaces laid flush with the runway coating.

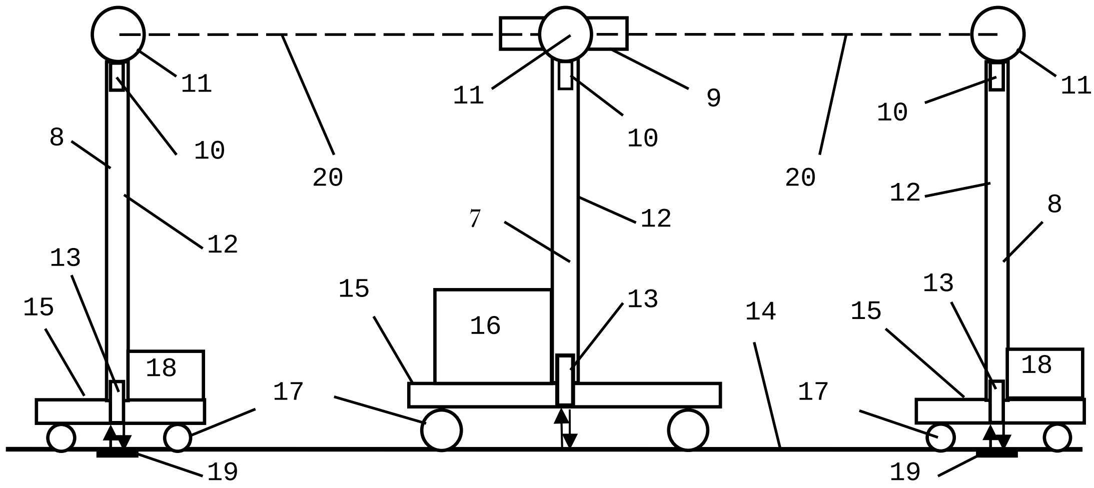

Figure 3 – Location of the mobile leveler and mobile leveling rails on the runway plane:
9 – optoelectronic device (OED) and light rangefinder units; 10 – the mechanism of rotation of OED 9 and the sighting target 11; 12 – vertical rack; 13 – ultrasonic sensor of the excess of the base over the surface 14, which is leveled; 15 – stand; 16 – boxing with a set of ML blocks; 17 – running gear of the cart; 18 – set of MLR blocks 8; 19 – high-altitude training benchmark; 20 – sighting beam

The operation of the light rangefinder unit is based on the principle that is described in [14].

Figure 4 shows the interaction of a set of blocks of a mobile leveler.

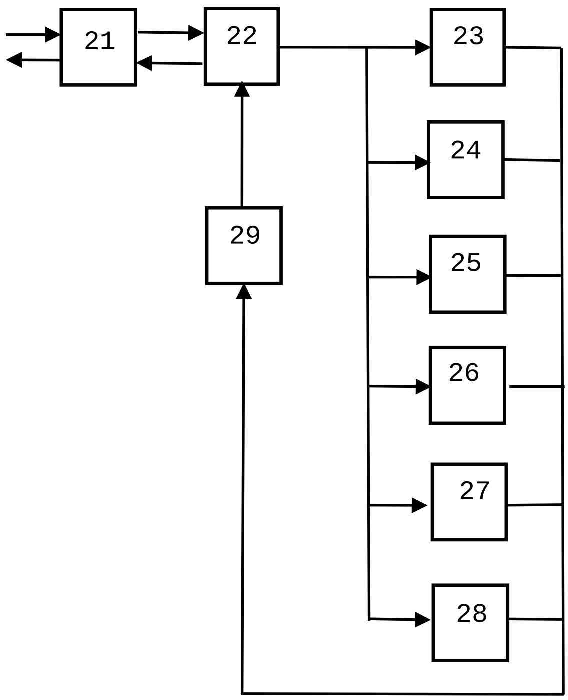

Figure 4 – The composition of the blocks of the mobile leveler:
21 – unit for receiving and transmitting radio signals; 22 – signal coding unit; 23 – electronic control unit for the running gear; 24 – block of light range measurements; 25 – ultrasonic location unit; 26 – GPS receiver; 27 – rotation unit of the OED, sighting target and light-range measuring unit; 28 – OED; 29 – signal generating unit

Figure 5 shows the interaction of a set of blocks of a mobile leveling rail.

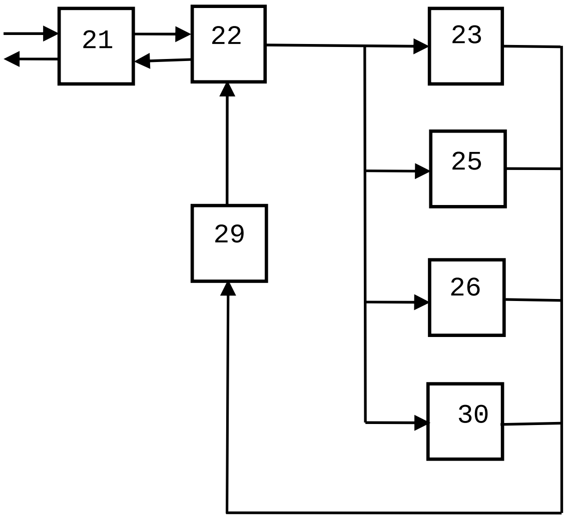

Figure 5 – Set of blocks of a mobile leveling rail:
21 – unit for receiving and transmitting radio signals; 22 – signal coding unit;
23 – electronic control unit for the running gear; 25 – ultrasonic location unit;
26 – GPS receiver; 30 – the unit of rotation of the sighting target

The operation of the RCLR is as follows. After turning on the power of the complex of units located at the central control station of the airport technical systems (see figure 2), from the control unit 1 through the information processing and storage unit 2 comes a command to the intelligent subsystem 3 to select a logistics program to solve specific tasks of the runway leveling. These programs provide the order of placement of ML and MLR on the runway plane and the routes of their movement in the areas of runway leveling. Also in block 3 there is a program for search and recognition of images - to identify sighting targets on their images obtained by OED of ML. At the request of block 3 from the block of geographic information system 4 there come the planned coordinates of the leveling points and benchmarks of altitude training 19 (see figure 3), the data of which are entered in advance in block 4. In addition, the marks of the height training benchmarks H_{R_i} are determined in advance by geometric leveling, the distances l_{N_i} on the vertical racks from the centers of sighting targets to the sensitive plane of ultrasonic sensors MLR 8 and l – the length of the vertical rack of ML from the transceiver plane of the ultrasonic sensor to the central point of the optoelectronic device, which are input to block 4. The GPS receiver of unit 4 operates in the base station mode and performs coordinate support of the ML and MLR with the required accuracy. The information from blocks 4 and 3 enters the information processing unit 2, where signal processing and creation of an information packet is performed, which through the control unit 1 enters the coding unit 5, in which the information packet signal is encoded and transmitted by the radio signal receiving and transmitting unit 6.

MLR 8 (see figure 3) receive radio signals from the central station in the block of reception and transmission of radio signals 21, which (see figure 5) are decoded in block 22 and undergo the procedure of selection of component signals from the information package in each of the respective blocks: 23, 25, 26, 29. According to the signal of the electronic control unit of the running gear 23 and the actual coordinates of the MLR from the GPS receiver unit 26, the MLR 8 is moved to the location of the high-altitude training benchmarks 19 (see figure 2), the coordinates of which came from the central station. After stopping the MLR 8 over the benchmarks of altitude training and the command from the central station, and selecting it from the information package in block 22 (see figure 8, figure 6), the ultrasonic location unit 25 measures the distances Δl_{N_1}, Δl_{N_2} from the runway surface 14 to the receiving and transmitting planes ultrasonic sensors 13 MLR №1 and MLR №2, respectively. According to the commands from the unit of rotation of the sighting target 30 and the operation of the mechanisms of rotation 10 sighting targets are set in the direction of leveling. Information from block 25 about the measured exceedance, from block 26 about the coordinates of the location of the MLR and the execution of commands to move the MLR from block 23 and from the unit of rotation of the sighting targets 30 enters the signal generating unit 29 transmitted by radio unit 21 to the central station. ML 7 receives radio signals from the central station in block 21, which are decoded (see figure 3, figure 4) in block 22, and the selection of components of signals from the information packet in each of the respective blocks is performed: 23-28. By command from the block 24 ML 7 performs maneuvering and by the actual coordinates from block 26 go to the leveling point, the coordinates of which came from the central station.

According to the commands from the OED unit 28 and the OED rotation unit 27, the sighting targets 11 of the MLR 8 are searched and the OED sighting axes are set to the sighting targets 11. According to the signals from block 28, the registration of readings a_1 and a_2 is carried out on the matrices of the OED. At the command of the light range measurement unit 24, the distances S_1 and S_2 are measured by the light range unit ML 7 to the reflectors of the sighting targets 11 MLR №1 and MLR №2, respectively. By the command from block 25 the distance Δl is measured from the surface of the runway 14 to the transceiver plane of the ultrasonic sensor 13 of ML 7. Data on measurements and execution of commands from blocks 23 - 28 are sent to the signal generating unit 29, are formed into an information packet, are coded in block 22 and are transmitted by block 21 to the central station.

At the central station (see figure 2) radio signals are received by block 6, decoded in block 5 and through block 1 come to block 2. Here the information packet is decomposed into appropriate component signals that come to the control unit - for operator intervention in the system (if necessary), to the intelligent subsystem - to compare the actual coordinates of MLR and ML with the planned ones and to produce corrective signals and transmit them back to MLR and ML. In addition, in block 3, the calculation of the marks of the runway plane 14 under the ultrasonic sensors of excesses 13 is performed according to the formula

$$H=\frac{1}{2}\left[H_{M_1}+H_{M_2}-\frac{(S_1-S_2)\left(H_{M_1}-H_{M_2}\right)}{S_1+S_2}\right]-\frac{1}{2f}(S_1a_1+S_2a_2)-l-\frac{1}{2}\left(\Delta l_{N_1}+\Delta l_{N_2}\right) \qquad (3)$$

where $\left.\begin{matrix} H_{M_1}=H_{R_1}+l+\Delta l_{N_1} \\ H_{M_2}=H_{R_2}+l+\Delta l_{N_2} \end{matrix}\right\}$ - marks of heights of the centers of sighting targets of MLR №1 and MLR №2; H_{R_1} and H_{R_2} – marks of reference benchmarks R_1 and R_2; l – the length of the vertical rack of ML from the receiving and transmitting plane of the ultrasonic sensor to the central point of the optoelectronic device; Δl_{N_1}, Δl_{N_2} – the distance from the runway surface to the receiving and transmitting planes of the ultrasonic sensor of MLR №1 and MLR №2; f – focal lengths of digital cameras of optoelectronic device; S_1 and S_2 – horizontal distances measured from the optoelectronic device to the centers of sighting targets of MLR №1 and MLR №2; a_1 and a_2 – readings in pixel fractions on the sensitive elements of the double matrix of the optoelectronic device.

The value of the calculated mark from block 3 is sent for storage to the unit for processing and storage of information 2 and on request from block 1 - on the monitor screen.

Figure 6 shows the location of ML and MLR on the first section of alignment.

Figure 7 shows the location of ML and MLR on the following sections of leveling. Leveling of the last section of sight is performed by placing the ML and MLR as on the first section.

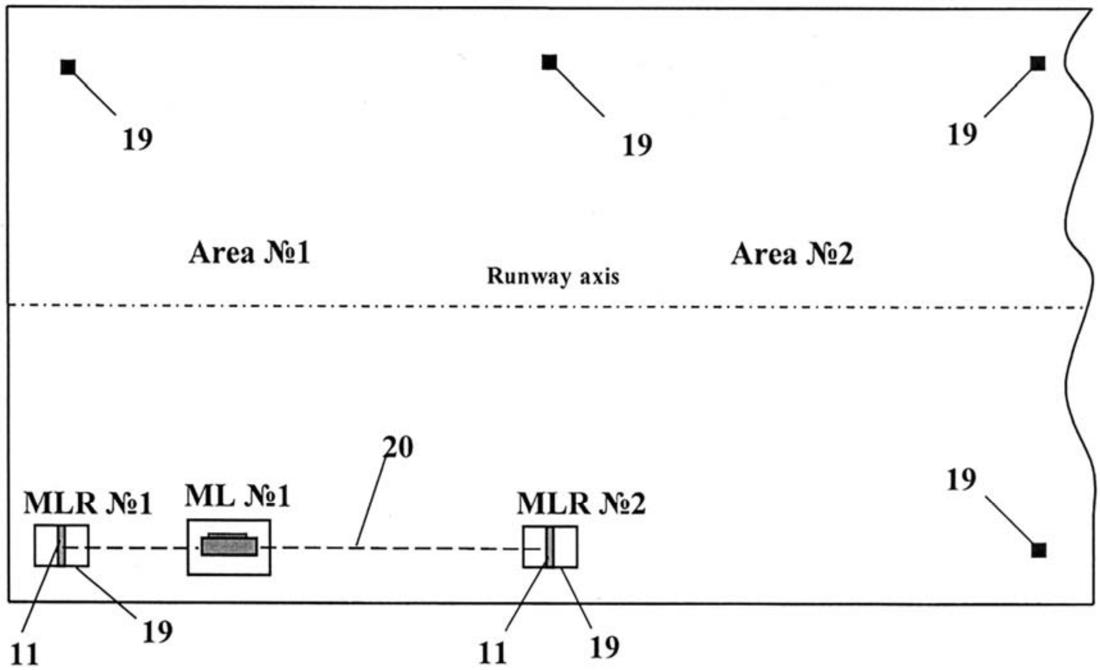

Figure 6 – Location of ML and MLR on the first section of leveling

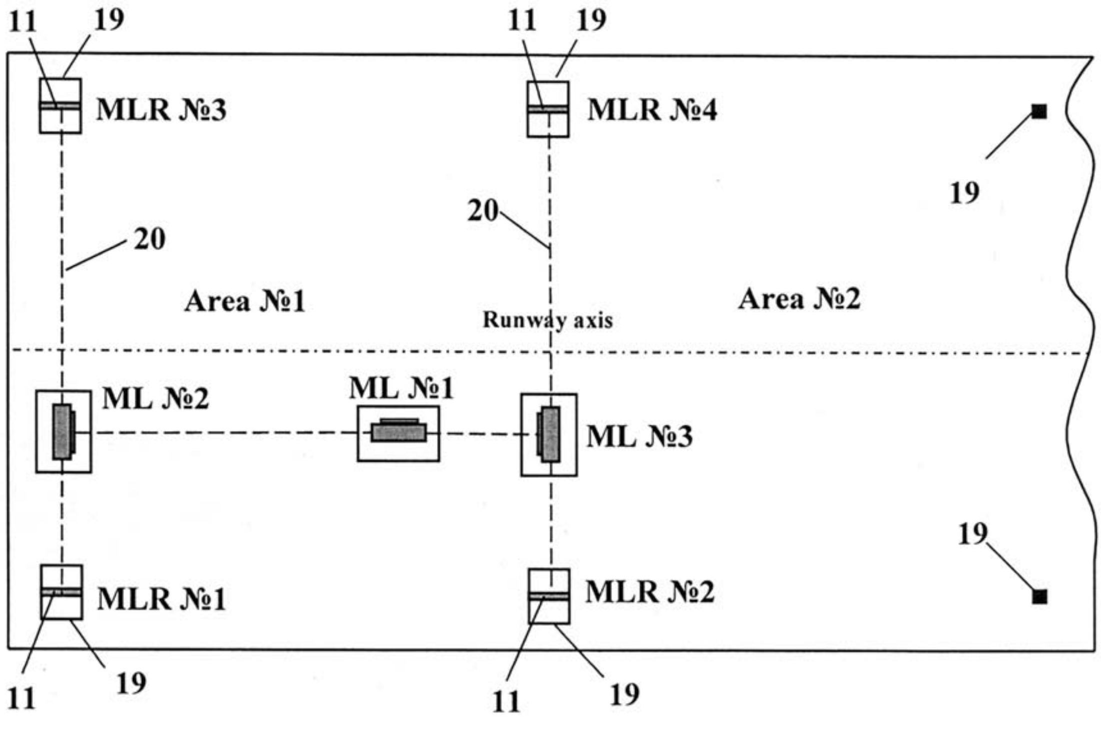

Figure 7 – Location of MLR and ML on the following sections of leveling

Runway surface profiles are built based on the leveling results.

Conclusions. The proposed robotic complex allows to quickly determine the marks of the runway in the mode of remote GIS / GPS control of the complex of mobile leveling robots in automatic mode with adjustable scanning step and to build longitudinal and transverse profiles of the surface.

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ҰШЫП-ҚОНУ ЖОЛАҒЫН НИВЕЛИРЛЕУГЕ АРНАЛҒАН РОБОТТАНДЫРЫЛҒАН КЕШЕН

Аннотация. Әуе кемелері паркінің салмағы мен ауқымының ұлғаюына қатысты әлемдік тенденция байқалады. Бұл ретте әуеайлақ жабындыларына жүктеме артады әрі бұл олардың неғұрлым жылдам тозуына, жабын бейінінің өзгеруіне, ұшу қауіпсіздігіне қатер төндіретін ақаудың пайда болуына ықпал етеді. Сондықтан әуеайлақ жабындарының ахуалына, атап айтқанда, бейінін анықтау үшін тұрақты мониторинг жүргізіледі.

Ұшып-қону жолағын нивелирлеуге арналған роботтандырылған кешен әзірленді. Кешен құрамына: нивелирлеу өндірісі барысында ұшып-қону жолағында орналасқан бейімделгіш нивелирлеушілер, мобильді нивелирлік төрткілдеш (рейка) және әуежайдың техникалық жүйесін басқарудың орталық станциясында орналасқан басқару құрылғысы кіреді.

Басқару құрылғысы келесі блоктардан тұрады: монитормен басқару; ақпаратты өңдеу және сақтау; логистикалық бағдарламалар жиынтығы бар интеллектуалды ішкі жүйе; GPS қабылдағышы бар геоақпараттық жүйе; сигналдарды кодтау; радиосигналдарды қабылдау және беру. Мобильді нивелирлеушілер мен мобильді нивелирлі төрткілдештер (рейка) орталық стансадан басқарылады және радиобайланыс арналары арқылы орталық станцияға кодталған ақпарат жібереді. Мобильді нивелирлік төрткілдеш (рейка) құрылымы бойынша жарықты алыстан өлшегіш блоктың, бұрылу блогының және оптикалық-электрондық аспаптың болмауы себепті мобильді нивелирлеушіге ұқсас келеді.

Роботтандырылған бейімделгіш нивелирлеушілер мен өлшеуге арналған аялдамалары бар нысаналық мақсаттарды ауыстыру кодталған радиобайланыс арналары арқылы берілетін алдын ала жасалған бағдарлама бойынша жүзеге асырылады. Бастапқы ретінде репер белгілері пайдаланылады, олардың көлденең пластиналары ұшып-қону жолағының бетімен оның бүйірлік ұшында орналасқан, олар арқылы дәл нивелирлеу жолдары алдын ала белгіленген.

Ұсынылған роботтандырылған кешен реттелетін сканерлеу қадамымен автоматты режимде ұшып-қону жолағының белгілерін жылдам анықтауға және беттің бойлық және көлденең бейіндерін құруға мүмкіндік береді.

Түйін сөздер: нивелирлеу, ұшып-қону жолағы, GPS-нивелирлеу, робототехника кешені, мобильді нивелирлік жұмыстар.

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РОБОТИЗИРОВАННЫЙ КОМПЛЕКС ДЛЯ НИВЕЛИРОВАНИЯ ВЗЛЁТНО-ПОСАДОЧНОЙ ПОЛОСЫ

Аннотация. Наблюдается мировая тенденция увеличения веса и габаритов парка воздушных суден. При этом возрастает нагрузка на аэродромные покрытия, что способствует их более быстрому износу, изменению профиля покрытия, появлению дефектов, угрожающих безопасности полетов. Поэтому проводится постоянный мониторинг за состоянием аэродромных покрытий, в частности – определение их профиля.

Разработан роботизированный комплекс для нивелирования взлетно-посадочной полосы. В состав комплекса входят: мобильные нивелировщики, мобильные нивелирные рейки, которые при производстве нивелирования располагаются на взлетно-посадочной полосе, и управляющее устройство, находящееся на центральной станции управления техническими системами аэропорта.

Управляющее устройство содержит следующие блоки: управления с монитором; обработки и хранения информации; интеллектуальной подсистемы с комплектом логистических программ; геоинформационной системы с приемником GPS; кодирования сигналов; приема и передачи радиосигналов.

Мобильные нивелировщики и мобильные нивелирные рейки управляются с центральной станции и передают кодированную информацию на центральную станцию по каналам радиосвязи. Мобильная нивелирная рейка аналогична по конструкции мобильному нивелировщику за отсутствием блока светодальномерных

измерений, блока поворота и самого оптико-электронного прибора. Перемещение роботизированных мобильных нивелировщиков и визирных целей с остановками для измерений осуществляется по предварительно составленной программе, передаваемой по кодированным каналам радиосвязи. В качестве исходных используются отметки реперов, горизонтальные пластины которых заложены заподлицо с поверхностью взлетно-посадочной полосы на боковых ее торцах, по которым предварительно проложены ходы точного нивелирования.

Предложенный роботизированный комплекс позволяет быстро определить отметки взлетно-посадочной полосы в автоматическом режиме с регулируемым шагом сканирования и строить продольные и поперечные профили поверхности.

Ключевые слова: нивелирование, взлётно-посадочная полоса, GPS-нивелирование, робототехнический комплекс, мобильные нивелирные работы.

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