Digital technologies for remote control and monitoring in road construction

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Abstract. The use of UAVs is becoming more pressing than ever with the ever-increasing need for computerization and digitalization in the construction industry. The article discusses the issues of effective use of unmanned aerial vehicles in the process of road construction and subsequent operation of linear capital construction projects. The study is devoted to identifying the practical capabilities of UAV technologies for their effective use in the realities of a construction site. The process of studying scientific publications is based on the descriptive method of scientific research, analysis of specialized literature in the field of construction production and the study of world experience in the practical use of UAV technologies. The article identifies the possibilities of unmanned technology for monitoring, controlling material and financial costs, reducing the level of injuries, solving environmental problems that arise during the period of road construction and during the operation of linear objects, as well as their repair or reconstruction. The authors identified some limitations and forty-one additional capabilities of unmanned aerial technologies. Eight criteria require improvement of the technological equipment used in the process of comprehensive monitoring of the quality of the construction process by unmanned aerial vehicles.

1 Introduction

Today it has become obvious that in the current situation it is necessary to use digital technologies for remote control and monitoring in combination with new scientific developments for the development of capital construction in Russia.

The subject of this study is the problem of remote control of capital construction projects using unmanned piloting technologies during the construction and operation of linear objects, bridges and overpasses. An attempt was made to trace the conditions for the effective use of UAVs in the construction industry for the period 2016-2023. The stated topic brings out two aspects of the problem - first: the possibilities of digital technologies for remote control and monitoring during construction work; second: monitoring of linear capital construction objects, bridges and overpasses using UAVs. Let us briefly look at the existing developments for each of them.

In scientific and special publications various aspects of the problem of digital technologies in construction are actively discussed: key technologies used in the development

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of digital twins in construction [1]; factors affecting the introduction of digital technologies in large projects [2]; the use of a limited number of sensors in civil engineering [3]; a digital twin-based decision support tool to assist road operators in road inspection, maintenance and upgrading [4]. The study analyzed the capabilities of digital technologies for the wider use of UAVs in road construction during the period of renovation of the construction industry.

Let us move on to the problem of monitoring the construction of linear objects, bridges and overpasses using UAVs. Publications since 2016 have presented the main ways of using unmanned aerial vehicles in the construction industry and discussed the prospects for expanding their functionality. Papers published in 2016 and 2023 present an innovative integrated system based on material, machine and human decision information for adaptive quality control using intelligent compaction (IC) technology; conceptualizing the idea of a lightweight digital twin for non-high-tech industries. The reasons for the decrease in the efficiency of road construction machines with existing operating strategies have been identified. And, if scientific publications periodically discuss the MCDM-GIS method for digitizing and analyzing various sustainability factors for road alignment planning; integrated BIM (Building Information Model) - IoT (Internet of Things) and IC (Intelligent Condensation) framework providing a fundamental platform for advanced monitoring and quality management; SfM (Structure from Motion) algorithm as a computer vision algorithm; digitalization of transport technologies that form the industrial and social infrastructure of the regions, then not enough attention is paid to research combining the control of linear capital construction objects, bridges, overpasses and the use of UAVs. Within the framework of the capabilities of UAVs, architectural and structural design and the progress of construction and installation works themselves, the problem of synthesizing the use of UAVs and parameters for monitoring the implementation of construction plans, for which appropriate financial resources are allocated, have been studied [5-11].

The aim of this paper is to study the conditions for ensuring control over the construction of roads, bridges, overpasses and the process of their operation. To achieve this goal, the following tasks were set:

1. to identify the possibilities of remote control technologies during construction and installation work;
2. to formulate parameters for assessing quality control of the construction of linear capital construction projects;
3. to determine the capabilities of unmanned piloting when performing control tasks in the process of monitoring road construction sites.

2 Materials and methods

The article was prepared based on the results of an analysis of modern research covering issues of the construction industry through the specifics of digitalization of capital construction (Qingu Xu, George K. Chang, Tony Greif, Nikolai Stein, Christoph M. Flath, Stanislav Grushetsky, Sergey Evtyukov, Yaroslav Raichik, Feng Jiang, Lin Ma, Yang Pei, Tao Han, Tao Ma, Chengjia Han, N. Kiriyak, D.V. Andreev, M. Makarova). The methodology of this study required taking into account a pragmatic approach to modern construction technologies. Solving these problems also affected the problems of information modeling in the road construction industry (Valerian Vanessa Thues, Joseph Handibry Mbatu Tah, Fonbein Henry Abanda, Jingxiao Zhang, Meirong Zhang, Simon P. Philbin, Faisal Siddiqui, Paul Sargent, Gary Montague, Alice Consilvio, Jose Solis Hernandez, Mara van Wely).

A study of the publications of the above authors allows us to conclude that the issue of using UAV technology to ensure the implementation of material and financial control tasks during the construction of linear capital construction projects, bridges and overpasses has been little studied. This preliminary conclusion is a prerequisite, the basis of the presented research and indicates the insufficient degree of development of this problem, revealing the relevance of the research topic. In accordance with the objectives, the study was carried out in three stages.

2.1 First stage: possibilities for the practical application of digital technologies for remote control and monitoring in the production of general construction works and during the operation of buildings

Since 2000 the Russian construction industry has seen a steady aging of production assets, and the pandemic has slowed down the pace of modernization of production, which has led to an increase in industrial injuries. According to statistics about 131 thousand Construction and Installation Departments and repair organizations, enterprises producing products for the construction complex are registered in the country; means of mechanization; carrying out freight and passenger transportation; design and research institutes. Figure 1 shows the statistics of fatal accidents in various sectors of the economy.

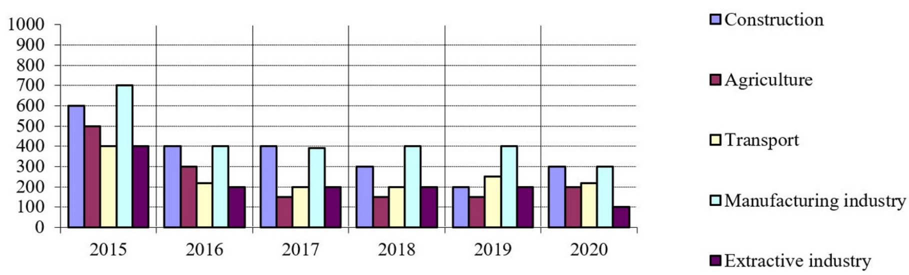

Fig. 1. Fatal accidents in various sectors of the economy in Russia.

In terms of the number of specialists employed in construction, the industry is in fourth place behind trade, services and agriculture. In the construction sector, work-related injuries are even higher than in the mining industry.

The study revealed facts of a direct relationship between worker life safety, labor protection and digital technologies for remote control and control of the production of general construction works. These possibilities are as follows:

- freeing people from hard physical labor;
- performing dangerous, tedious and unskilled work;
- reducing the risk of injury;
- effective use of human resources;
- exemption from work at height;
- acceleration of commissioning of a facility under construction;
- reduction of construction time;
- improving the quality of work.

Work in difficult climatic conditions leads to human errors, namely: soil collapse during development; loss of balance of construction equipment when developing dumps and working in quarries; breakdown of equipment during demolition work; "failure" of equipment during transportation; failure of various systems that ensure the operation of construction machines.

Thanks to artificial intelligence with the skill of self-learning, while flying over a construction site, a signal is sent to the person in charge if facts of violation have been identified, for example: a worker does not have a helmet or scaffolding without fences.

The result of effective automation and robotization of construction are the following:

- improving working conditions and worker safety;
- reduction of labor costs;
- reduction in the number of workers;
- increasing the productivity of machinery and equipment;
- reduction of equipment downtime;
- monitoring its technical condition;
- automation of control of general construction processes;
- increasing the service life of construction equipment;
- reducing the number of repair cycles of machinery and equipment;
- reduction of energy consumption;
- control of consumption of building materials;
- improving the quality of construction and installation work;
- compliance with the required operating procedures.

Next we will dwell on the issue of monitoring the technical condition of building structures. Monitoring the operational and technical condition of capital construction projects and assessing this condition is based on a regulatory and legislative framework that determines the type and composition of work to inspect and assess the technical condition of buildings during the period of its operation. It is possible to complete the assigned tasks as quickly as possible using digital technologies of automated systems for monitoring the technical condition of building structures using domestic software, which is relevant in the current economic situation of the country. The use of these technologies allows:

- to receive "online" information about the condition of load-bearing and enclosing structures;
- to fill out the operation log of a capital construction project;
- to solve design and construction problems arising during operation promptly;
- to plan optimal repair and restoration work in a timely manner;
- to reduce material and financial costs for the process of monitoring main structures;
- to reduce material investments to ensure the operability of load-bearing and enclosing structures of buildings during operation;
- to exclude the situation of structures falling into an emergency state.

For example, the Korean Atomic Energy Research Institute proposed using a robotic snake of its own production. A drone picks it up and delivers it to the suspected location of damage, which becomes known thanks to special cable sensors. The robotic snake is equipped with a camera, controlled remotely, and is capable of moving longitudinally and transversely, as well as vertically, by grasping a pipe. A bunch of these devices can be used, for example, in industrial structures where there are intertwined pipes. The sensor signals the area of the leak, the drone delivers the robotic snake, the robotic snake will penetrate into a hard-to-reach place and detect the leak faster than a person, which in turn will speed up the repair process and reduce the financial costs caused by the leak.

Thus, the study revealed the main results of the use of digital technologies for remote control and monitoring in the construction industry.

2.2 Second stage: parameters for assessing the quality of road construction

First let us dwell on the concept of a linear object. The concept of a linear object is a structure, a continuum of a piece of land and spatial and structural components. Among the many systems, we will single out a road, a bridge, an overpass. They are designed for the movement of ground vehicles with certain dimensions, loads and speeds, carrying passengers and goods.

According to statistics from the Scientific Center for Road Safety of the Ministry of Internal Affairs of Russia 67,800 accidents were registered due to “bad roads” in 2021. The main reasons are as follows:

- absence or poor visibility of markings on the roadway (55.7%);
- lack of road signs in necessary places (23.6%);
- problems with cleaning roads in the autumn-winter period (16.7%);
- vehicles leaving the roadway;
- inadequate quality of road restraint barriers, the quality of which makes them useless for stopping buses and large-tonnage trucks;
- operational condition and arrangement.

The dynamics of accident rates associated with the presence of deficiencies in the operational condition and arrangement of the road network and railway crossings is shown in Figure 2.

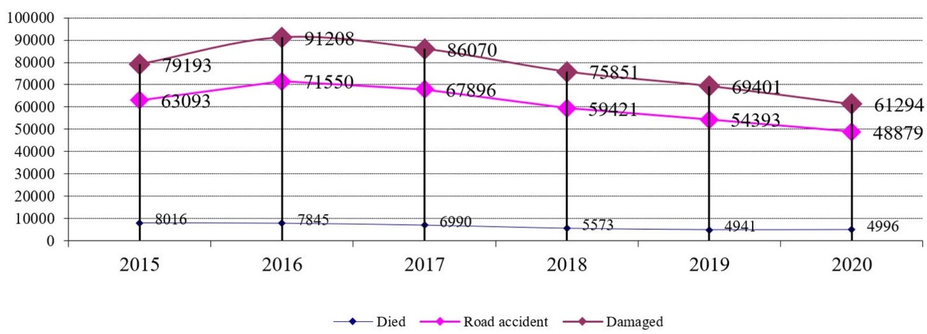

Fig 2. Dynamics of accident rates associated with the presence of deficiencies in the operational condition and arrangement of the road network and railway crossings.

As a result of the above, it is advisable to focus on the quality standards observed when commissioning after construction, reconstruction or major repairs of linear facilities [12,13].

The effectiveness of quality control is determined by its timeliness and compliance with the requirements of regulatory, design and working documentation. The use of modern digital monitoring technologies, considering the achievements of scientific and technological development in road construction, will help reduce dependence on highly qualified personnel when conducting an objective assessment of the results obtained. For example, using a UAV to perform an orthophotomap of a road surface with an area of 40 km2 on a scale of 1:500, a team of 2 people will need 24 hours to complete this task. Using classical geodetic survey methods for the same task will require several man-months.

During the study, design control parameters during the construction of asphalt concrete pavement were determined as the following:

- evenness and density of treatment of the soil base with a binder;
- composition and consistency of the thickness of the “pie” of the road surface;
- compaction mode;
- compliance of the installation of side stones, gratings and manhole covers for underground utility networks with the design position;

- the quality of the conjugation of asphalt concrete pavement strips, the width and transverse profile of the coatings are checked after 100 linear meters;
- compliance of the transverse and longitudinal slopes with the design, the evenness of the coating in the longitudinal and transverse direction is checked after 30-50 m.

All structural elements of artificial structures, subgrades, bases and coatings of road pavements, drainage and fortification structures are also subject to a comprehensive quality assessment.

Next, the consumer properties of roads for which transport and operational indicators are responsible were determined. It is important to note that the assessment of consumer properties must be carried out in the autumn-spring period of the year, when all defects appear most clearly and objectively [14]. The results of a comprehensive assessment include the following actual parameters:

- space-planning indicators (execution of longitudinal and transverse profiles according to the design solution);
- transport and operational condition of roads and road structures;
- compliance of existing consumer properties with the required ones;
- reliability, stability, longitudinal evenness, roughness, adhesion qualities of the road surface;
- level of engineering equipment and landscaping;

A comprehensive assessment and diagnostics of consumer properties makes it possible to identify sections of roads with unmet requirements, the reasons for the decline in transport and operational indicators and outline measures to improve them. Types of comprehensive assessment of the quality of highways and the results obtained after its implementation are presented in Table 1.

Table 1. Types and results of a comprehensive assessment of the quality of highways.

Evaluation type	Result
Audit	Determination of the actual technical and operational condition of the highway
Certification	Commissioning of the highway
Depreciation	Determining the operational condition of the road
Local	"local"

Table 2 shows diagnostic methods.

Table 2. Diagnostic methods.

Method	Source
Project	Working, design and estimate documentation, technical passports
Full-scale	Field work

The analysis made it possible to identify the design parameters and consumer properties of public roads, to formulate the types and methods of conducting a comprehensive assessment and diagnostics in the process of monitoring road construction.

2.3 Third stage: application of UAV technology when performing monitoring tasks during the construction and operation of linear facilities

Continuing our research, let us dwell on the concept of unmanned piloting. An unmanned aerial vehicle, or copter, the drone is equipped with an electric motor. A distinctive feature of the UAV is its ability to move in the air, which does not require direct piloting. The device is controlled using a remote control or on-board computer, and some UAV models can be programmed to operate completely independently. The UAV takes off from a special launch and parking pad where it is charged. They will fly over a route preset in their own neural network, performing a specific function. The UAV classification consists of many parameters: flight range, weight, payload weight, basic mechanism. There are two types of UAVs, which differ radically in their flight principles: airplane and helicopter. Aircraft models are based on load-bearing planes-wings, which provide the UAV with high, long flight of a large radius. Helicopter-type "drones" are equipped with propellers; their main advantage is smooth and stable flight, and the ability to "hover" in the air.

There are programs and services for a fully automated system of intelligent construction and reporting, creation of 3D models of real estate, methods of continuous automated monitoring and processing of geodetic data to build an information model [15-18].

The study also identified problems in the use of UAVs associated with a number of limitations. 80% of all crashes of unmanned aerial vehicles occur due to the absence or low qualifications of operators operating aircraft. Thus, federal rules of Russian airspace prohibit:

- the use of UAVs for commercial purposes;
- acquisition of the right (license) to work;
- to carry out unmanned piloting remotely, out of direct visibility of the device operator;
- commercial flight insurance.

The need for a cameraman to be present in the shooting area complicates logistics and increases transportation costs. Climatic conditions depending on the geographical location, meteorological weather characteristics, wind, dust, snow, have an adverse effect on the operation of the UAV and, ultimately, on the objectivity of the information received.

In November 2021 a meeting of the SCRF (State Commission on Radio Frequencies) was held, at which the issue of official use of the radio frequency band 5850-6425 MHz by radio-electronic means for organizing communications with unmanned aerial vehicles was considered.

Thus, there is still a high interest of states in implementing the concept of digital technologies in construction and the need to support domestic construction organizations in the process of transition to digital technologies [19-21].

3 Results and discussion

Previous sections of the paper described 28 results of the use of digital technologies for remote control and monitoring in the construction industry. The analysis also made it possible to formulate 6 design parameters and 9 consumer properties of public roads, to determine 4 types and 2 methods of conducting a comprehensive assessment and diagnostics in the process of monitoring road construction.

At this stage of the study it was determined that one of the main values of modern society, in our opinion, are: the formation of a unified information space; culture; Orthodoxy; improving living standards; National security; ecological problems.

Many studies have been devoted to the principles of piloting, collecting and transmitting information. One of the principles of processing the results is based on photogrammetry. To determine the coordinates of points in the study area, it is necessary to take two or more photographs from different angles and positions; the more photographs, the more accurate the measurements will be. Then the distance from the camera on the drone is determined to each point in the image and a point cloud is built. Since the distance to the same point in different images is known, the intersection of these segments determines its spatial coordinate.

Using drones and appropriate software, when inspecting roads for land transport, it is possible to determine the parameters of longitudinal slopes, type of road surface, radii of curves in plan, and width of the roadway. Nevertheless, there are some indicators whose accuracy in determining compared to traditional ground-based instruments is not yet possible, namely:

- visibility of the road surface in profile;
- composition of layers of road pavement and subgrade;
- longitudinal evenness of the coating;
- adhesion properties of the coating;
- strength of road pavement;
- formation of winter slipperiness;
- quantity and composition of traffic flow.

Using the collected data on rut depth, longitudinal and transverse evenness, it is possible to assess the presence of damage, its area and size, and the presence of ruts. As a result, perform a complete calculation of the transport and operational state of the highway using a UAV.

Additional resources for the use of UAV technology have also been identified. We analyzed the connection between unmanned piloting technologies and material and financial quality control, accident reduction, and environmental conservation when monitoring linear facilities during construction and reconstruction, major repairs and operation [22-29]. The results obtained are presented in the form of a tracing matrix (Table 3).

Table 3. Material and financial quality control of linear facilities using UAV technology.

Quality control		**Possibility of using UAVs**	**Type and method of conduct**	**Examination result**			
Total information							
1	Road category	-	C; П	D	-	-	
2	Climate zone	-	C	D	-	-	
3	Service organization	-	C	D	-	-	
4	Length of road	+	C; A; H	D	-	-	
5.	Location of kilometer pillars	+	P; H	D	-	-	
Geometric parameters							
6.	Location of the road axis on the ground	+	P; C; A; H	-	F	B	-
7.	Width of the roadway and widenings	+	P; H	-	F	B	-
8.	Number of traffic lanes, transitional express lanes	+	P; C; A; H	-	F	B	-
9.	Width of the roadway and shoulders	+	P; H	-	F	B	-
10.	The slope of the "cross" of the road, the turn of the trace	+	P; H	-	F	B	-
11.	Embankment elevation, depth and profile of soil cutting	+	P; H	-	F	B	-
12.	Visibility of the road surface in plan and profile	-	C; H	G	F	B	-
Condition of road pavement and subgrade							
14.	Composition of layers of road pavement and subgrade	-; (+)	A; H	G	F	B	-

15.	Coverage type	+	A; H	G	F	B	-
16.	Presence, type, location and characteristics of defects	+	A; H	G	F	-	-
17.	Longitudinal evenness of the coating	-; (+)	A; H	G	F	-	-
18.	Rutting	+	A; H	G	F	-	-
19.	Coating adhesion properties	-	A; H	G	F	-	-
20.	Durability of pavement	-	A; H	G	F	-	-
Artificial road structures							
21.	Location of bridges, overpasses, overpasses, tunnels, their type, length and dimensions	+; (+)	A; H	G	F	B	W
22.	Load capacity of bridges, overpasses and overpasses	-	P; C; A; H	G	F	B	W
23.	Presence and height of curbs	+	A; H	G	F		W
24.	Type and condition of the bridge deck	-; (+)	P; C; A; H	G	F	B	W
25.	Location, material, type and dimensions of existing pipes	+	P; C; A; H	G	F	B	W
26.	Location and dimensions of underground and overground pedestrian crossings	+	A; H	G	F	B	W
27.	Location of open and closed spillways, edge trays, slope trays, dampers	+	A; H	G	F	B	W
Construction of highways							
28.	Location, type and technical parameters of lighting objects	+; (+)	A; H	G	-	-	-
29.	Location of signal posts	+	A; H	G	-	-	-
30.	Location of road signs	+	A; H	G	-	-	-
31.	Location of road markings	+	A; H	G	-	-	-
32.	Location of road barriers, their design and dimensions	+; (+)	A; H	G	-	-	-
33.	Location of junctions, intersections and exits, their type and geometric parameters	+	A; H	G	-	-	-
34.	Location of railway crossings	+	C; A; H	G	-	-	-

35.	Location of public transport stops, recreation areas, vehicle stops and parking, landscaping elements	+	C; A; H	G	-	-	W
	Fencing structures						
36.	Location of protective plantings	+	P; H	G	-	-	W
37.	Location of enclosing structures for protection against snow drifts and movement of surface soil layers	+	P; H	G	-	-	W
38.	Location of noise and wind protection devices	+	P; H	G	-	-	W
	Roadside service facilities						
39.	Location of gas stations, service stations, motels, campsites, hotels	+	C; L; H	-	-	-	W
40.	Localization of emergency situations centers	+	L; H	G	-	-	W
41.	Location of stationary and mobile traffic police posts	+	L; H	G	-	-	W
42.	Location of drinking water sources	+	L; H	-	-	-	W
43.	Location of truck wash stations	+	L; H	-	-	-	W
	Road service facilities						
44.	Prevention of winter slipperiness	-; (+)	L; H	G	-	-	-
45.	Location of road construction equipment	+	L; H	-	-	B	-
	Driving performance						
46.	Number of vehicles per unit of time and composition of traffic flow	+; (+)	L; H	G	-	-	-
47.	Location of the accident	+	L; H	G	-	-	-
48.	Video surveillance in both directions	+	L; H	G	-	-	-

Note:
- impossible using a UAV;
+ possible using a UAV;
(+) development of technologies for using UAVs equipped with the necessary equipment.
Type of assessment:
"R" - Audit; "C" - Certification; "A" - Depreciation; "L" - Local.
Method:
"P" - Design; "N" - Natural.
Examination result:

accident reduction - "G"; reduction of material and financial costs - "F"; reduction of deadlines construction - "B"; environmental protection - "W"; compliance with project documentation - "D".

4 Conclusions

Thus, as a result of the study, the conditions for the effective use of UAV technologies were identified. They described certain limitations of the use of UAVs, but focused on the real possibilities of using unmanned piloting technologies in a comprehensive assessment of the quality of road construction. We identified 33 additional criteria for the use of UAVs in the construction of linear facilities and 8 ones that require the development of the necessary equipment to equip an unmanned piloting device.

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