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Perspectives of construction robots

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M A Stepanov[1],A M Gridchin[2]

[1] Moscow State University of Civil Engineering, Yaroslavskoe Shosse, 26, Moscow, 129337, Russia
[2] Belgorod state technological university named after V. G. Shukhov, Kostyukova St., 46, Belgorod, 308012, Russia

E-mail: masmias@mail.ru

Abstract. This article is an overview of construction robots features, based on formulating the list of requirements for different types of construction robots in relation to different types of construction works.. It describes a variety of construction works and ways to construct new or to adapt existing robot designs for a construction process. Also, it shows the prospects of AI-controlled machines, implementation of automated control systems and networks on construction sites. In the end, different ways to develop and improve, including ecological aspect, the construction process through the wide robotization, creating of data communication networks and, in perspective, establishing of fully AI-controlled construction complex are formulated.

1. Introduction

Modern construction industry is highly mechanized industry. However, it still has a high percentage of manual labor due to the limited possibilities for the further mechanization of many kinds of construction work.

And so, the greatest prospects of increasing the speed of construction and raising the quality of work are lying in the field of automatization and robotization of construction. Such trends can be seen for a while now [1]. Significant progress has been made in recent years in computing, electric drives, control systems, batteries and other, important for robotics, fields of science and technology. This opened up broad prospects for the usage of robots and robotic systems.

Reducing the costs and expansion of the possibilities of robotic systems allows one to consider the possibility of their application and implementation in the construction at the practical level. In addition to improving the speed and quality of work, which is a direct challenge for robots, it is worth noting other positive effects of their implementation, related primarily to the increasing of safety of human labor. Replacing human with machines in hazardous jobs, the usage of robots in difficult climatic and natural conditions - and increasing of the overall level of robotization of construction, which will reduce the share of human labor on the construction site, which in itself is the object of increased danger. Also, robotization can bring a higher degree of ecological safety to the construction process through better optimization of work and lower emission levels.

At the same time, it is clear that the use of automated construction machines has some features associated with specific requirements for robots.

2. Features of the construction robots

First of all, there are several general features essential for construction robots. These features are clearly seen from analysis of working processes and construction site conditions [2]:

- Positioning system for manipulator arm or other working device. This system is closely intertwined with drive units and transmission types, and relies heavily on sensors and feedback.
- The drive unit and the transmission system, able to make necessary positioning, safe and energy-effective.

- Safety systems, which will provide safety-working conditions for humans on the site, and lower the risks of emergencies.
- Kinematic scheme, which must be simultaneously as simple as possible, but effective and able to provide requested working area shape and volume.

6 degrees of freedom of the mechanism. This condition can be written mathematically as:

$$W = 6n - p_1 - 2p_2 - 3p_3 - 4p_4 - 5p_5 = 6, \quad (1)$$

where W – amount of degrees of freedom; n – amount of links of the mechanism, pi – amount of kinematical connections with i degrees of freedom.

A cycle of construction works can be divided into three groups according to the terms of robotization and specialized requirements for robots [3]:

2.1. Ground works
They are the most highly mechanized and simple to robotize. The creation of special designs of robots is not required, as modernization of existing machines and their designs to move to an automated management system that does not require human intervention will be sufficient. It, in fact, means that the requirements for robots in the area are for the most part are the same as the requirements for a modern excavation machines.

2.2. Construction and installation works
The two types of works can be distinguished as parts of this field - lifting and concreting with some specific requirements. In general, this area of the construction process has great potential and the need for robotization, which will greatly reduce the cost of manual labor for the construction of buildings and structures.

Requirements for lifting manipulators are:
- High load capacity
- The large volume of the working area.
- Higher speed than that of modern crane equipment, using a rigid hand-capture instead of the cable suspension.
- The relatively high positioning accuracy, providing a very high quality of the geometry of structure being built, bringing the basic geometry errors to the errors of the materials used.

Increased demands on the reliability and safety, the use of robotic manipulators, while reducing manual labor within the construction process, do not exclude it entirely.

Concreting robots (Figura 1) have a number of distinctive requirements, in addition to the ones mentioned:

Increased mobility within the work area, these robots work among the already erected structures and their mobility, should be high enough to provide easy access to any part of the building.

The ability to control the amount and quality of feed mixture.

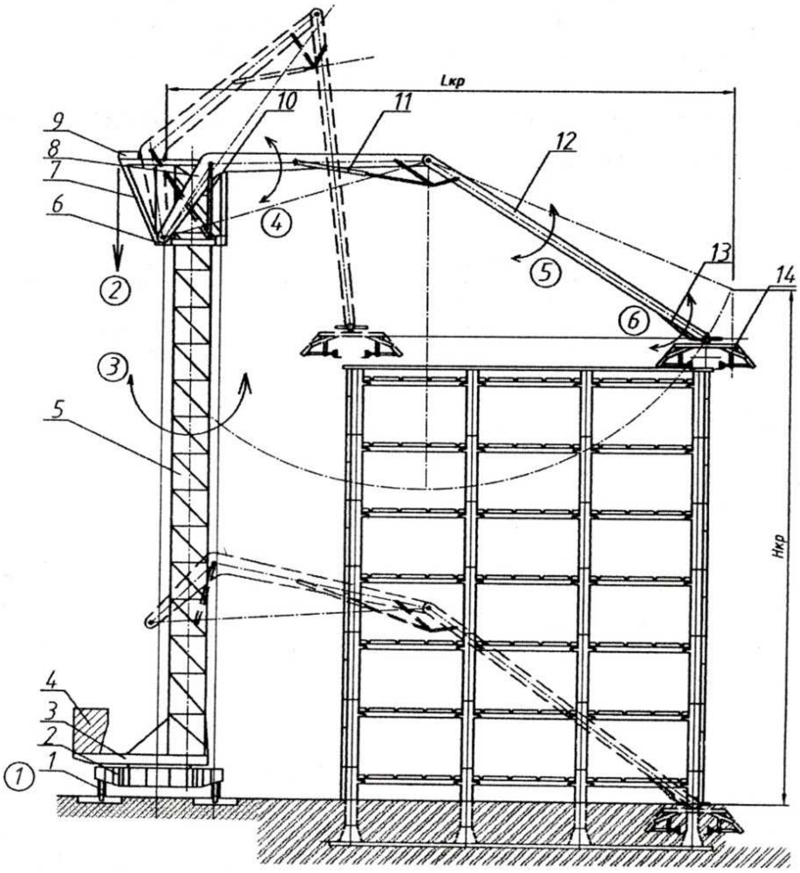

Figure 1. Crane-manipulator, MSUCE;1 – mechanism of movement; 2 – support-rotating device; 3 – rotating platform; 4 – counterweight; 5 – tower; 6 – lifting column mechanism; 7 – lifting column; 8 – hydraulic drive of crane; 9 – counterweight; 10 –boom; 11 –hydraulic cylinder of the boom; 12 –handle; 13 –hydraulic cylinder of the handle; 14 – gripper.

2.3. Finishing and auxiliary works

For this type of work, some robots are already designed, but have not found wide application. These include various kinds of work areas - from plastering walls to window cleaning, as well as the sealing of joints and seams of the building structure. The amount of manual labor is very high, and wide robotization can bring very significant economic effect.

Requirements for robots (Figura 2) intended for work in this class are:

- High positioning accuracy for high-quality finish work.
- High speed.
- Autonomy, which means that the robot should be able to handle the work area without frequent replenishment of the working material.
- Low capacity, because of the small mass of manipulated objects.
- Safety of operations - when working indoors, especially with the presence of dust, flammable and toxic materials, robots must ensure the safety of both peopleinteracting with them, and general - in particular fire - safety of works. In this case, this is important requirement for outline, as this type of robots is working very close to people.
- Compactness - when working indoors, the robot should be able to move freely, which means that its dimensions are limited.

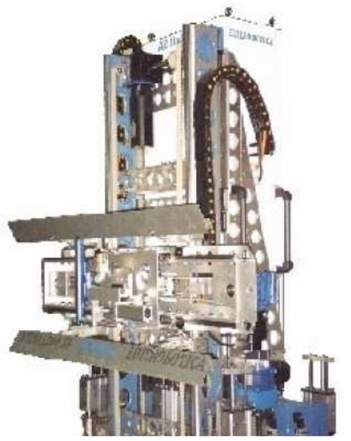

Figure 2. INTOMAX plasterization robot.

On the basis of these requirements, it can be seen that this type of robots in many aspects is similar to the existing general industrial robots. This opens up a wide range of possibilities for adaptation of individual design solutions and existing robots for construction needs.

All the requirements listed above determine the structural and kinematical scheme of the robot, which allows finding optimal robotic constructions. To evaluate the kinematical scheme of construction, a Lee-Young theorem can be used [4]. This theorem states [5]:

$$K = \frac{V}{\left(\sum_{i=1}^{m} L_i\right)^3}, \qquad (2)$$

where K – the kinematic quality of construction, bigger number means that the construction is better optimized; V – the volume of the working area of the robot; Li – the length of i-th link of the robot; m – the amount of links.

After the kinematical scheme is determined, the dynamical analysis takes place. It calculates movements, forces and speeds of the mechanisms links, determining the positioning precision and working speeds. During this kind of analysis, the drive units, link shapes and dimensions, actuator types and many more important details are taken into account, and, therefore, are being determined iterationally, until the desired speed and precision are reached [6].

It should be noted that the first phase of robotization makes it possible and appropriate to use remote-controlled semi-autonomous manipulators. This allows achieving a significant improvement in the conditions and quality of construction and installation work. However, the ultimate goal is still a full automatization, which leads to the additional, perspective requirement - the automatic control system.

ACS of construction robots has a number of unique features. Firstly, it has rather low requirements for independence because of the large number of characteristic objects that are suitable for use as markers to help orient the robot. Secondly, the ACS should provide highly accurate and fast control of the robot drive. Third, because of the large dimensions of the building elements, ACS must be able to quickly and accurately calculate the overall dimensions, mounting dimensions and location of the mounting fixture on the building structure itself.

In addition, widespread usage of ACS opens the possibility of creating a full-fledged information network within the construction site. This network will allow improving the interaction between machines and workers, and the level of control over the safety measures and quality of work done.

3. The usage of AI in construction Robotics

However, ACS - only the first step towards a full robotization of the construction process. In perspective, the creation of a highly specialized form of artificial intelligence for the control of machines on a construction site seems most likely.

The main difficulty of creating classic automated control systems for different machines and mechanisms at the site lies in the fact that, unlike the laboratory and even the factory floor, construction site, is the environment with unpredictably changing conditions. Here is the human factor, and weather conditions and constantly changing work places and diversity of types of work. Standard ACS cannot bear such complex tasks, or do so very badly.

But robots equipped with AI are capable of more. Picture and sound recognizers, the ability to orient in an ever-changing space will allow the robots to work without danger for themselves and others working at the construction site. AI can operate with non-specialized instruments with universal grips; it can calculate how to properly and securely use them in the absence of hard-coded application program. AI can safely and efficiently interact with humans directly, which is very important in the conditions of the construction site. Creating the self-learning program module for such agent would be much easier than writing a rigidly programmed ACS.

Also, robots with artificial intelligence are capable to replace the human at work involving a high risk to life and health. When parsing the rubble, eliminating the consequences of technological disasters, in particular accidents at nuclear power facilities or chemical plants - the conditions are extremely dangerous for people and the work of remote-controlled robots is ineffective. Adapting to difficult environmental conditions robots with full or even "weak" AI will be able to save the people and perform a task on the same level as humans. Another field of application of robots with AI are construction works carried out in difficult conditions - high mountains, the far north and the Arctic, under water (up to a sufficiently great depths) - the places where work of humans is difficult and rapidly changing environmental conditions make efficient use of conventional robots impossible.

Over time, the AI self-learning module, in theory, will allow robots to perform their work more and more efficiently with the accumulation of information and education. Creation of the network between agents will allow them to co-educate, speeding up the process of self-improving. This self-learning can lead to the appearance of heuristic properties of the AI, which will allow him to look for new, non-trivial solutions of tasks [7, 8].

4. Conclusion.

There are several promising areas, which together lead to a robotization of construction works simultaneously from several different sides.

First, the development and implementation of ACS and remote control systems, which will improve the operation of the existing building machines with minimal costs. It is closest to the practical implementation, even though it cannot be called full robotization as participation of the human operator is still needed. However, it is important that all necessary technology already exists, and is sufficiently developed, which significantly simplifies and reduces the cost of implementing of such systems. In addition, the new control system can be installed on existing equipment without radical design changes.

Second, creating of small building robots for automated finishing works to reduce an amount of manual labor in the construction process. Some robots for these problems already exist - window cleaners, automatic plasterers and others. The creation of new models does not present any particular technical difficulty since it may structurally be based on the existing well-established industrial robots. The widespread use of such small robots, or at least similar semi-automatic machines, is currently quite expensive, but could provide a very high quality finishing and other works of the final cycle.

Third, formulating network communication between machines on a construction site that will allow us to keep track of everything that happens on the site and adjust the construction process. The rapid development of network technology and so-called "Internet of Things" in the near future will dramatically increase the level of coordination between the workers and reduce the risks due to the constant monitoring of the situation in an automatic or semi-automatic mode, with the exchange of data between individual workstations and machines. This will also be a complex step towards ecological safety through optimization and organization of the nature-safe working process and calculation of emission levels

Finally, fourth, the creation of a specialized AI will bring together all of the above-mentioned achievements and virtually eliminate human participation in the construction process itself, leaving him only the role of controller and observer. Although the current prospects for the creation of the AI is very distant, in fact it is the way to achieve the fullest possible integration of individual machines and robotic systems at the construction site in a single integrated system, with a minimum part of human labor, and flexible adjustment of working processes under conditions of a particular construction project.

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