Rethinking of Construction Robot in the Whole Project Life Cycle

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Abstract: Assistive technology and evaluation system are expected to effectively solve the challenges of using robots in construction activities and improve the efficiency and building performance. Still, challenges are still need to be addressed before using robots for construction on a large scale. This Studies were corresponded to the identified areas for further critical review, and the development of research and application in each area was systematically analyzed to identify future directions for both the academia and the industry. More specifically, this review focus on determining the requirement of technology and application profile for robots, and based on the above analysis, a complete set of construction framework for robot was proposed, which integrates robots and activities with the various modular systems and digital technology to get global optimum solution.

Keywords: Assistive technology; Evaluation system; Artificial intelligence

1 Introduction

1.1 Computer vision system

Important precondition of the practical application of robot is to have the technology of perceiving the external environment. With the approaches like machine learning(MI) (Lawaniya 2020), artificial intelligence(AI), approximate nearest neighbors (ANN) (Wahrmann 2019), pre-assumption, computer vision system could assist robot to achieve navigation (Feng 2019), identification and modeling in completely unknown environments. Yet, there are some challenges such as object recognition. Until now, only a few of object which have a proper scale could be well recognized, other objects may have the following identification errors such as low-accuracy (i.e., deformation, fuzziness etc.) and drifting effects (i.e., scale variation, warp etc.), which will reduce the efficiency of recognition in robot vision.

1.2 Communication technology

The timeliness, nondestructive and efficiency of information flow exchange in human-robot interaction and it play an important role in the development of robot technology, and significance are continuously deepened. However, the current communication signal on the site attenuates seriously in the process of transmission, so the communication speed is slow and the cost is high. For the complexity, variability, and abundance of information at the scene, thus it is critical to create communication network between the site work status and the project network and establish information integration management standards, so as to solve interoperability and cloud computing problems to ensure the seamless exchange of information flows.

1.3 Intelligent system

With robots failing to comprehend actual situation on expectations, the use of construction robots has been planned at three different levels of abstraction. At the bottom signal, the data and corresponding actions are mapped at physical level; the middle layer and language layer reflect the robot's reading of external information in the form of symbols. The automation system developed to realize above function based

on the development of intelligent system. One key advance in this domain process sensor data and drive robot hardware, allowing system interfaces to access various databases and hardware control systems (Zekavat 2014; Kangari 1988)

1.4 Control technology

Vigorous development of control technology enable the robot to complete the scheduled task in contexts that either structured/unstructured environment. For example, remote control technology further illuminate not only the capability to construction robots or mechanical equipment to reach extreme environments that are difficult to reach or unsuitable for human beings, but also the construction costs were effectively reduced and efficiency were improved (Hainsworth 1993.). Research crux in this domain highlights not only restricted to provide the robot with tools to sense the dynamic environment and make corresponding decisions and instructions, and arguably deserves more attention, how to achieve reliable environmental identification, effective motion control and real-time acquisition of location sensor data (Fong and Thorpe 2001). The author's table reports the existing control system has certain limitations which make robot having a higher error rate when completing tasks required high accuracy.

1.5 Simulation technology

Management could be uniform and effective, with the integrated modeling and simulation environment, for various resources involved in the simulation. Going beyond above content, the simulation of robot in different scenarios can provide empirical evidence and quantitative analysis for production activities, identifying the optimal resource allocation level and operation mode, the integration of economic indicators into the simulation operation can also reduce the cost budget to a certain extent. Yet, the technology has little considered in the actual production environment of prefabricated and modular structural design, with only around 13% (Abbasian-Hosseini, Nikakhtar, and Ghoddousi 2014) of the studies combining the actual production with robot simulation.

1.6 Positioning technology

In addition to the technologies mentioned above, improving the positioning accuracy of robot is also a key issue in robot research (Yu 2019). The use of multi-sensor fusion has become a spotlight in recent years. Besides, interactive execution demonstration based on model and visual simulation in advance, and the attitude control of the robot was integrated with the external environment to ensure robot operation accurately also become a trend. The strategies pose a significant challenge to robot application, because even with the most advanced localization technology or sensory, the needed accuracy is still difficult to achieve at a large environment.

2 Description of problems in construction whole-life cycle management

2.1 Planning and Design Phrase

2.1.1 Adaptive design

With building system and economy level became more complex and higher, a novel challenge in automatic construction research was emerged. How to ensure the success and smoothness of the construction process while various factors existed which affecting the construction quality and machine performance (Goessens, Mueller, and Latteur 2018) has important practical significance in the new era. Although variety of auto-adapted design approaches were applied during Planning and design phase, there still face many challenges. For example, it is difficult to form a complete design and construction mechanism.

2.1.2 Structural architecture

The components involved in the construction process were defined as the specific products from combinations of common elements, could be distinguished as multi-unit or single-unit modules. Traditional construction methods cannot flexibly combine components according to the functional requirements of the building, blind use will only increase construction costs, leading to a reduction in economic benefits. At present, intelligent and distributed control strategies are adopted to co-design construction structures, materials and robots, based on a variety of existing tools, such as Rhinoceros 3D, Grasshopper and Robot structure Analysis, can maximize the flexibility of the construction component to some extent. Yet, those methods always apply only to the design phase and does not take into account the uncertainties associated with subsequent related operations.

2.1.3 Robot oriented design

The selection and scheduling of construction equipment is also a task to be considered in the design and planning phase. Due to, existing machine or robot usually unable to meet the needs of construction automation, thus, how to combine the architecture design, construction process and mechanisms to design the construction robot mechanism and volume, as to achieve robustness and adaptability of robot in construction site, which became an urgent problem in application.

2.2 Construction Phrase

2.2.1 Industrial flow operation

Construction systems can be classified according to the types of equipment involved, building materials or operating environments, etc. Currently, most construction operations use distributed robot group cooperation to operate the pre-processed building components respectively. The more common way of definition is to define the streamline construction in the construction process from the aspects of numerical control program and path attitude. Although the former method clearly demonstrates the arrangement and design of the robot in accordance with the construction process, it does not consider the robot's adaptability to the inherent irregular terrain and environment of the site.

2.2.2 Construction man-machine management

Effective man-machine management can help the managers to gain more effective control over the flow of work at the operational level when the production blocks are issued to the unit of work according to the construction plan. At present, new information and communication technologies are widely used in on-site management of construction, effectively helping managers save materials, improve productivity and speed of information dissemination, but it cannot simplify the flow of information. The man-machine cooperation mode of construction site also brings new challenges and dangers to site management. To mitigate these hazards, operators need to have a rich understanding of the building and robot operation characteristics.

2.3 Maintenance Phrase

2.3.1 Evaluation and monitoring stage

Quality assessment and testing is an indispensable process in the whole construction activity, and continuous testing of building performance after construction is completed is necessary (Ghaffarianhoseini et al. 2017). Accordingly, the researchers designed and developed various mechanical equipment capable of quality inspection, evaluation and monitoring, and equipped the equipment with multiple sensors related to the developed fusion algorithm. Yet, for the existing equipment, the error of position estimation is large, and the efficiency, availability and repetition are also unsatisfactory, which means higher requirements for perceptive hardware system.

3 Research related to construction robot

3.1 Planning and design phase

As a new construction element, the robot has a certain impact on the original construction method. Based on the demands of all parties, the robot-oriented construction method leads to more complex construction systems due to its multi-faceted products, life cycle with complicated and long-lasting characteristics, multiple and critical dimensions, as well as the fixed construction site. Hence it is absolutely vital to use a comprehensive modular construction design method (Bock and Thomas 2015) to add the robot as a new element to the original building system while meeting the functional requirements and construction specifications. How to reduce the factors affecting construction quality and the performance of robot by appropriate combinations while ensuring the proper construction of the robot has important practical significance in the new era (Goessens, Mueller, and Latteur 2018) , have important realistic significance in the new period.

In order to better adapt to the characteristics of construction activities, the modular design of the robot itself is also a major focus of research. The process can be generated through the use of Automated Construction System and Integrated Information Management System, but the implementation of the process confronts various challenges which depends largely on how the operator transforms a particular building form (Mammen, Jacob, and Kokai 2005; Werfel, Petersen, and Nagpal 2014) into a construction activity performed by robots. High-efficient auto-control system and perception also needs to be added in robot itself , tightly integrated structuring , construction, mechanism and control

to achieve scalability and adaptability (Petersen et al. 2019) for a particular job or top-down bottom-up collaborative integrated hardware and software systems, adjusting traditional construction processes and improve the role of the construction party, eventually generate the viewpoint of technological innovation in the building environment guided by the whole life cycle (Bock and Thomas 2015).

What's more, single robot always inability to meet the demands of actual application during construction process. Therefore, multi-robot system is often be considered to systematically accomplish the tasks of automatic acquisition, transmission and accurate matching of components in construction tasks. The strategy gets closer to real scene of construction of the object, so that the robot can reach to more coverage and more powerful work and adaptive capacity.

3.2 Construction phase

The more common robot strategy at this stage is to define the application of the construction robot from the NC program and the attitude path, employing computer-control system to realize the autonomous construction of different types of robots on the physical plane based on the mathematical model and coordination algorithm. Although the above clearly illustrates the mechanism of the robot for the construction process, few considerations have been given to the robot's adaptive capacity for the inherent irregular terrain and construction environment of the site. To make up for the above-mentioned shortcomings, distributed multi-robot architectures and visualization began to be considered by researchers in construction site.

Distributed multi-robot architectures are often used in irregular terrain to complete tasks such as component identification, transportation, and exact matches between different locations by heterogeneous robot groups (Parker 1994; Rus D 1995; Wawerla, Sukhatme, and Mataric 2002). During construction while avoiding collision or interference ensure better efficiency collective robot construction, with a visual or communication technology (Balch and Arkin 1998; Carpin and Parker 2002; Desai, Kumar, and Ostrowski 2002) precise positioning is necessary. However, the application of the collective robot is limited to the height of the feature processing rules in a structured environment for construction work at present. It is necessary to develop the ability of

collective robot to recognize the structures with obstacles and mobilization of mechanical resources on the scene can be improved by extending the model and algorithm, while the robot is not constrained by irregular terrain.

Visualization is one of the basic elements of a robot construction-management system. Robots at the construction site must move through an unstructured environment to perform tasks (Liang et al. 2019), and the robot and operator also need to maintain real-time perceptual interactions. With the sensors and vision systems we may monitor the attitude in real time and strengthen the locale information by Augmented Reality, providing real-time information necessary for the workers and the operator (Lundeen et al. 2016; Azar and Mccabe 2012; Soltani, Zhu, and Hammad 2018; Vahdatikhaki, Hammad, and Siddiqui 2015).

3.3 Detection and recovery phase

Quality assessment and inspection act as an indispensable process in the event overall, with the emphasis on the continuous inspection of building performance after construction (Ghaffarianhoseini et al. 2017). Accordingly, researchers devised the robot with quality inspection, evaluation and inspection capabilities, and equipped the robots with multiple sensors related to the fusion algorithm, making robots perform non-contact detection in certain areas to improve efficiency. The real trick is to establish a larger computer vision database identifying more types of nonconforming components in conditions, providing information for quality control and updating architectural models.

The combination of computer vision technology and full coverage path planning algorithm to complete the recycling of construction waste can effectively solve the inefficiency and high cost of traditional methods. The second way is to use neural network technology to attract the robot to the unscanned area and produce the effect of repelling the robot's obstacles (Batsaikhan, Janchiv, and Lee 2013; Khan et al. 2017; Caihong et al. 2015; Freeman and Shapira 1975), typical algorithms including full coverage path planning algorithms.

4 Shortcomings and Challenges of robot in construction

The robot in construction is often regarded to be non-obvious in improving Construction benefits due to

the challenges in Section 4. As diverse innovative technologies and application range continue to develop, researchers and engineers are increasingly aware that innovative technologies and application can be an effective solution to inefficiency of robots. In the period of rapid development of automation and information, a large body of research have just tried to apply robots to particular construction activities without determine: (1) Adaptability to the dynamically changing built environment; (2) Whether the accuracy required by the building can be reached; (3) The contribution of robots on construction. Then, we will discuss the challenges of applying robots to construction application and technical challenges. The details are as follows.

4.1 Technical challenges

Having a complete system of robotics of multiple categories to enhance the applicability of robotics to single or multiple construction tasks is the critical factor to future research. simplifying and controlling the construction site or process by determining the duplicated degrees and regularity of structural configuration and material repetition, while increasing the complexity of operation and production to develop new technologies of high effectiveness. However, the construction operations involve many characteristics like complexity, long life cycle, dimensional diversity and physicality, and the unique nature of fixed location (Diaz, Doostan, and Hampton 2017) that stymies the use of technology for construction of robots.

To make the feasibility of robots at the activity level, the gap between product design and mechanical devices must be narrowed (Gambao, Balaguer, and Gebhart 2000), the crux of research is the evolution of CAD that we can give the robot the ability to design and control which are beneficial to make up of the interaction and interconnection. Thus, there is a new system for collecting, processing, analyzing, exchanging and implementing construction information to integrate the design of Processes and products and manufacture on the premise of improving communication technology. The establishment of some kind of self-positioning access implementation "sense-act" (Linner and Thomas 2013) Operation, combining the robot's position and posture more accurately, and finally forming an optimal path.

Due to the drastically different between simulation modeling examples and the actual robot construction process, researches have had to spend so much time and energy undertaking their experimental works to ascertainment error. The key to the problem is to re-analyze and plan the nature and implementation of the construction operation, an effective method is to explore the potential use of mechanized or automated methods to change the design or equipment. To increase the degree of mechanization and automation of construction under the inherently rigorous and chaotic background, the priority is to develop hardware equipment with high universality and accuracy to cover the single type device to improve the automation of machinery to meet the requirement of precision and efficiency of robot programming control in remote or off-line state.

While simulation software is capable of Predicting the effect, it is essential to recognize that large deviations between the path or attitude of the robot construction and the theoretical design model due to environmental factors or the robot itself. Thus, we should analyze the intelligence control research (Ma and Liu 2018) to make intelligent robots constantly report site geography, project progress and location information to central computer and so on (Omar and Nehdi 2016).

4.2 Deficiencies of the application

As mentioned above, there has been a guarantee for robot activities to ensure its maturity and usability to rely on the complete standard system with sufficient operating efficiency and comparatively high operational suitability of robot. By means of different standards for various construction activities are classified in terms of the basis of the sufficient research about materials, categories of robotics, construction procedure, etc. and in combination with robot standard operating system, evaluation method of digital technology and sustainability performance evaluation index building a robot construction standards to determine the relationship between the different factors of production in new construction mode.

Relatively little economic data has been produced on robots due to the lack of experience of robots in the construction industry. Thus need to build a comprehensive evaluation index system to describe the robot activity and form a model of it and the

common steps and economic evaluation system of the robot on the civil engineering, which can forecast a wide range of common economic activities and allocate resources timely(Moselhi and Hason 1989).

5 Solution and further research

5.1 Combining robotics & basic technologies in key research area

Compared with actual requirements, the production efficiency for robotics was lower. Current robotics technology will inability to complete a series of activities smoothly with the increasing complexity of the construction and the closer links with multi-modules. The technology will not be of utility value if it cannot be improved to adapt to changing construction specifications and provide real-time feedback on a dynamic environment.

5.2 Ensuring the man-machine interoperability & exchange of information flows

Research on construction robots is a multidisciplinary field (Cai et al. 2019), the improvement of robot level relies on the robot positioning accuracy. We suggest that robot should use the computer-based image processing for architectural design visualization and simulation models interact to perform demonstration. The robot posture control with the external environment is integrated that shows states, sequence, and information stream between them to improve the robot level of the building will be an important topic. With this in mind, the integration of BIM and IOT should be developed that addresses two issues: (1) ensure unhindered man-machine interoperability; (2) extend data manipulation capabilities with minimal cost and speed by cloud computing; (3) the real-time exchange of information stream.

5.3 Auto-create robotic "sense-act" framework

The automated system developed for the autonomous construction of robots relies greatly on the Artificial Intelligence, transfers design information to databases supported by robots. Thus, we attach that there is a critical point to develop an intelligent control system for processing the sensor data on the control signal and the driving of the robot hardware. In doing this, this system would able to allow system interfaces to access various databases and hardware control systems (Zekavat 2014; Kangari 1988), thus

controlling the robot to reach extreme environments (Hainsworth 1993.). Thus, 'perceived data - response' data can be stored in the system internally, which can be trained and iterated continuously in real-time. By this means, new-type of correspondence will be able to be forecasted, with poor feedback or handling being able to be improved(Fong and Thorpe 2001).

5.4 Virtualization with simulation platform, mode-lling software and BIM

Virtual simulation technology has been frequently applied while Implement the construction activities, quantitatively analyzed and improved the robot situ-model involved with various resources. Through using this technique, it is sufficiently feasible to establish systems that can develop, design and plan in order to:

•Visual architectural management during the design and construction process.

•Identify optimal resource allocation levels and practices.

•Obtain real-time model information that represent the entire implementation.

The advantages of using BIM over the whole life cycle (Davtalab and Omid 2017; Becerikgerber and Rice 2012) are explicit that beyond the reach of the degree of participation and implementation details in various stages of robot. The lack of data interoperability between the BIM platform and robot system currently makes it impractical to use algorithmic approach to automatically generate a database of automated operating locations. There is a need to customize and expand the BIM platform by inheriting the virtual reality interface, and attach information related to automation to fully take advantage of the new opportunities provided by robotic systems (Davtalab, Kazemian, and Khoshnevis 2018).

5.5 Applying robots in practice

5.5.1 Establish comprehensive system of technical standards

Robot has generally been applied in construction within an explicit benefit goal where the high adaptability application condition is defined, so it is necessary to establish a complete set of technical standards system to evaluate research conducted by independent research institutions, using various indicators to detect the efficiency of construction

of robots as well its operational reliability and running efficiency. Classify various construction activities by different criteria, combining with the standard system for robot operations, evaluation method of digital construction technology and sustainability performance evaluation index based on the sufficiently study of mechanical equipment, the categories of technologies, scope of application, conditions on the spot, resource allocation, economic benefits and energy consumption, etc. building a standard system and eventually confirming the new fabrication approach of the relationships between various factors of production.

Simultaneous, factor of influencing the performance of technology in context to sustainable development including robustness, adaptability, and accessibility should also be evaluated:

•Detailed techniques need to be evaluated according to its popularity, and reliability at operation process would be considered synchronously during runtime.

• Robot should be able to complete construction activities in the uncharted and highly dynamic changing environment, and maintain higher adaptability.

• The accessibility of technology would be evaluated by the technology provider and machine component performance.

5.5.2 Define the evaluation system between economic benefit and social performance

It is predictable that robots can directly use, supplement or substitute human activities to brings the direct benefit of decreased cost of production and elevated productivity. Here, the social benefits evaluation research has three approaches:

Adopt the thought of systems engineering to establish a project-oriented evaluation system which including five major indicators: 1) construction site; 2) mission objectives; 3) related agency; 4) resource allocation; 5) other. Evaluation system integrate five indicators aim to overcome the drawback of incompleteness of individual ones.

The improvement of building quality by robots, the government's encouragement of innovative technologies and the new impact of applying robot to the construction environment are taken into account in terms of economic benefits, and the effect of increase and decrease of related benefits by automation to varying degrees are considered.

With the growth of robotics, the corresponding social benefit evaluation research will achieve rapid development, such as carbon emission statistics, analysis of resource and energy consumption, cost estimation, etc, forming a virtuous circle related to the development of robotics, which in turn will promote the iteration of the technology itself. Ultimately, it helps us assess the potential benefits of each level of complexity in the robot construction process.

6 Conclusions

Assistive technology and evaluation system are expected to effectively solve the challenges of using robots in construction activities and improve the efficiency and building performance. Still, challenges are still need to be addressed before using robots for construction on a large scale. This Studies were corresponded to the identified areas for further critical review, and the development of research and application in each area was systematically analyzed to identify future directions for both the academia and the industry. More specifically, this review focus on determining the requirement of technology and application profile for robots, and based on the above analysis, a complete set of construction framework for robot was proposed, which integrates robots and activities with the various modular systems and digital technology to get global optimum solution. As the improvement of information and automation technology, modular design and digital technology will be gradually introduced into the construction site, robot framework proposed by this review will act as a powerful tool to improve the efficiency of robot construction and lay the foundation for the industrialization of construction.

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