AUTOMATION AND ROBOTICS IN CONSTRUCTION: OPPORTUNITIES AND CHALLENGES

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(Received March 2008 and accepted August 2008)

Building and construction is one of the major industries around the world. Construction industry is labor-intensive and is conducted in dangerous situations; therefore the importance of construction robotics has grown rapidly. Applications and activities of robotics and automation in this industry started in the early 90s aiming to optimize equipment operations, improve safety, enhance perception of workspace and furthermore, ensure quality environment for building occupants[1]. The main goal of this paper is to convince building designers and managers to incorporate robotic systems when managing modern buildings. This paper studies recent applications for robots and automation in the construction industry and sets opportunities and challenges through a new framework for better planning and control of construction equipment operation.

Keywords: Building automation; Robotics; Construction; Management; safety; Performance; Maintenance; Opportunities and challenges.

1. INTRODUCTION

Construction industry in most countries amounts to 10–20% of the GNP, making it the largest economic employing sector. Construction work is labor-intensive and is conducted in dangerous situations, also the work content and materials change frequently. Robots are used widely to help human workers in construction sites. This approach demonstrates a decentralized, autonomous, flexible, simple, and adaptive approach to construction. Therefore, construction robotics has been a very hot research area in the construction industry[2].

The main goal of this paper is to convince building designers and managers to incorporate robotic systems when managing modern buildings to save manpower and improve efficiency. The objectives of this paper include, among others: 1) Studying recent applications and projects for using robots and automation in the construction industry, 2) Setting opportunities and challenges facing the use of robots in the construction industry, 3) Predicting changes in construction industry resulting from robot usage, and 4) Setting framework for better planning and control of construction operations.

The need for automating is justified first and the existing techniques, technologies and applications for robotics in construction industry are identified. Tools for selecting/assembling optimal automated and robotics system according to required tasks in construction works are then identified.

2. FUTURE OF BUILDING INDUSTRY

Changes in building production are essential and necessary because the next few decades will see an enormous migration to cities. Forecasts indicate that in 2015, 55% of the world's population will live in the urban areas (Table 1)[3]. The role of computer technology applications in construction changes
rapidly. Artificial intelligence (AI) provides a new tool for addressing large-scale and complicated field problems.

Building production is ultimately designed to improve performance and satisfy clients. It is always difficult to keep sight on the overall picture and the final goal. Developments of construction process result of changing circumstances and conditions that lead to improved performance for the client. Figure 1 shows the relationship between management, engineering and performance.

Table 1. Ratio of urban population

<table>
<thead>
<tr>
<th></th>
<th>1995</th>
<th>2015</th>
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<tr>
<td>Global and total</td>
<td>45%</td>
<td>55%</td>
</tr>
<tr>
<td>Developing countries</td>
<td>39%</td>
<td>50%</td>
</tr>
<tr>
<td>Industrial countries</td>
<td>75%</td>
<td>80%</td>
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Figure 1. Relationship between management, engineering and performance

3. AUTOMATION IN CONSTRUCTION

The project success from the project management's viewpoint is achieved when the project is completed with the lowest possible cost, the highest quality, no accidents, etc. In other words, success means bringing each of the project performance indicators (PPI)- such as cost, schedule, quality, safety, labor productivity, materials consumption or waste, etc. to an optimum value.

Applying automation and robotics in construction is addressed from the perspective of raising building projects performance to serve the client and the environment. Robotics and automation systems in construction industry can achieve the following advantages:

- Higher safety for both workers and the public through developing and deploying machines for dangerous jobs.
- Uniform quality with higher accuracy than that provided by skilled worker.
- Improving work environment as conventional manual work is reduced to a minimum, so the workers are relieved from uncomfortable work positions.
- Eliminating complains about noise and dust concerning works such as removal, cleaning or preparation of surfaces.
- Increasing productivity and work efficiency with reduced costs.

The past two decades have witnessed an intense/active search among researchers for suitable ways to introduce robotics into the construction field. In Japan, robotic manipulators were used as assistants to human construction workers. This approach allows the robot to be less autonomous and technically simpler, needing only limited sensing abilities. According to this approach, the human performs the vital parts of the task, and the robot is used to expand the human physical limits. Such systems, of less autonomous performance, can be more easily adapted for assistance in a variety of building tasks[5].

As improvement of the construction process will be the task of the future, new developments cover design strategies, human machine technologies, employee safety, progress monitoring, and distributed production information. Various approaches of integrating the work of humans and robots in construction fields are introduced hereafter.

3.1. Concrete Works

Applications for automation in concrete works cover concrete laying to post-laying leveling, removal of surface water, and final floor finishing[6], Figures 2 and 3.

In addition, efforts were made to design a robot for concrete surface processing which receives the floor plan as an input, and after some calculations of its movement, presents it to the operator for improvement before acting[7]. The previous applications will probably change the overall system for concrete work as shown in Figure 4.

3.2. Construction of Roads

Road paving robots show high level of automation through providing the followings[8],
- automated reception of asphalt
- automatic control of asphalt conveyance
- automatic control of asphalt spreading
- automatic steering control with mechanical sensor and automatic control of paving speed
- automatically controlled start/stop of all paving functions

In addition, tasks can be performed automatically based on an artificial vision and a laser range sensor. Hence, graphical remote control system let human operator control more the fixing process, while reducing the need for range sensors[9].
Similarly, Longitudinal Crack Sealing Machines can fill and seal cracks running along the road, for example between lanes and the shoulder. The process is remote-controlled by the driver, and the machine can fill cracks at up to five miles per hour. In comparison a manual sealing operation would take a large crew all day to complete two miles. Robots are also helping to remove roadside litter and debris, another hazardous, labor-intensive operation[10].

3.3. Finishing Works

The following tasks related to finishing works can be achieved.

- Development of a robotic system for indoor plastering while human operator completes final delicate parts of the task[11].
- A masonry robot that pre-plans its tasks in detail. Within that project, adding a global positioning sensor corrects deviations of the robot's Tool Center Point (TCP) due to static deflection of the manipulator structure[12].
- Window glass mounting or panel fixing using a hybrid-type robot with pneumatic actuator and servo motor. The hybrid-type robot mechanism has a wide range of workspace and precision, and it consists of a serial and parallel part[13].
- Welding as the robot identifies the seam to be welded and tracks the seam while welding it[14].
- Surface finishing in tunneling, leveling and compacting concrete, tile-setting, interior-finishing such as painting, plastering, tiling, etc.
- Pre-fabrication of GRC parts manufacturing such as robotic spraying of panels, also optimization and rationalization including panels’ transportation and storage[15].
- Simple, identical, autonomous robots assemble two-dimensional structures using prefabricated modules as building blocks. Modules are capable of some information processing, enabling them to share long range structural information and communicate it to robots. This communication allows arbitrary solid structures to be rapidly built using a few fixed, local robot behaviors[16].
- Attaching heavy ceramic tile on walls using a designed robot which lifts or manipulates the tile, while a human worker attaches it on wall. In experiment, the proposed construction robot lifts the tile (5 kg) and moves it through the circle path. The designed sliding controller is adequate for a pneumatic cylinder control [17].
- Renewal of facades using a proposed System consisting of three components: tool head, a telescoping manned platform or another lifting unit, and a vacuum cleaner. The principal application is the removal of roughcast or other old coating by means of a brush. The vacuum "swallows" the particles loosened from the treated surface, passing them through its hoses to a receptacle. The air is then filtered, and the remaining refuse divided among designated
containers. The system is a robot with an operator for the demand of an outstanding security level on public\textsuperscript{[18]}.  

3.4. Building Management and Security Systems

Surveillance for security purposes after the commissioning of buildings or large estate is required to ensure quality environment for the occupants. If the surveillance job can be done by robots, the efficiency can be enhanced, resulting in great savings of manpower and improved safety of the management staff. Furthermore, if the robot can retrieve commands from the building management system via a local area network (LAN), further savings in manpower can be achieved in terms of first-line fault attendance by human management staff\textsuperscript{[19]}.  

The development of a particular security system where the compulsory safety helmet required for all workers in construction sites is used as the base to accommodate miniature positioning and communication instruments. The position and ID of each worker is sampled periodically and sent via radio to a monitoring station, where the information is compared to a database containing the tasks and processes being performed in the site. According to this, workers and machines' positions are known in each instant and risk situations may be recognized immediately and therefore damage can be prevented\textsuperscript{[20]}.  

4. CHALLENGES FACING AUTOMATION AND ROBOTICS IN CONSTRUCTION

The primary contribution of automation in construction is the development of a comprehensive, multidimensional analysis of costs and benefits associated with a specific robotic application. It is quite important to analyze success through the technical and economic feasibility. The technical feasibility is determined by an ergonomic evaluation of individual steps taken to accomplish the given work task, and by analysis of the requirements for robot control and process monitoring. The economic feasibility, which is perceived to be the decisive factor in the market success of the proposed robotic systems, is determined by the analysis of the costs and benefits associated with their development and field implementation. Specific technologically challenging process and characteristic of robot construction applications include\textsuperscript{[21]}:

- Performance in a harsh work site environment, or undefined and sometimes hostile conditions such as:
  - Difficult climatic conditions
  - Exposure to dust
  - Calibration in relation to environment
  - Adjustment to changing surface conditions
  - Complexity of the working environment

- Some changes in the nature of the robotized work process versus the traditional, human-performed work process.
- Real-time “Sense-and-Act” operation for mobile construction robots to perform accurate and/or delicate tasks
- Identification of various types of objects in natural environment conditions
- Interactivity between sensors and end-tools

In contrast, a robotic system that would operate with no need for detailed pre-planning would be less technologically demanding and may, therefore, be easily developed during early stages of robotics integration into the construction field. The “Sense-and-Act” process can probably eliminate the need for high accuracy when positioning the robot at its workstation, a fact that saves time and leads to greater economic feasibility of the system. Some researchers attempted to increase the autonomy level of robots by enabling them to map their environments and independently navigate through them. Although construction sites are characterized by inaccurate geometries, numerous obstacles, etc. the mapping and navigation methods may be adapted to it. Such navigation methods are expected to deal with these difficulties and succeed in achieving accurate enough results. Researchers and developers of autonomous robots have attempted to solve the problem of adjusting the robot to its environment by developing automatic mapping and self-positioning methods. The robot then autonomously navigates from one workstation to another\textsuperscript{[22]}.  

Forsberg et al. suggested a plastering robot that uses a rotational laser beam to measure and map its surroundings (walls and openings). The mapping data was to be translated into a working plan, which would be presented to the operator for improvements. The suggested system depended on accurate navigation methods, and was supposed to bring the robot to within ±1 cm of its workstation\textsuperscript{[23]}.  

Beliveau described an orientation system for indoor automated guided vehicles (AGVs), using three laser transmitters accurately positioned on the floor at known points. Experiments with this system revealed that the deviation of the measured path from the desired path was ±10 cm\textsuperscript{[24]}.  

Shohet and Rosenfeld examined the accuracy achievable by automatic mapping of indoor construction environments. It was found that when robot positioning was precise (orientation and location errors of 0.2° and 3 cm, respectively), the achievable accuracy of indoor environment mapping was 3–5 cm. This degree of accuracy is sufficient for tasks that do not require contact with the treated element (e.g. spraying). However, tasks that involve precise placing of elements (e.g. block laying and tiling) require a mapping accuracy of 2–3 mm, as well as the utilization of well-controlled end-tools\textsuperscript{[25]}.  

Yet, it is clear that these methods are not likely to conform to the accuracy requirements of many construction tasks. Moreover, even when correct positioning of the robot is assumed, accuracy of the robot's arm, or even that of the interpretation of its environment, is not sufficiently reliable. The accuracy of the manipulator’s moves may vary from cycle to cycle due to variations in the load at the arm's end and in the arm configuration. Creating a more robust arm, one that would be less sensitive to the varied loads would lead to heavier and more expensive robotic systems with lower economic feasibility.

5. EVALUATION FOR USING ROBOTS AND AUTOMATION

Initially, robots were developed for the manufacturing industry and were intended to perform routine task in a very familiar environment. Unlike such robots, those designated for work on construction sites must be mobile, maneuver in changing environments, and perform a different task at almost every step. Construction engineering is changed by the application of more industrial production, sustainable production, mass individualization, and intelligent building to improve constructability. Therefore, recent research indicates that robot technologies can; in fact; significantly improve quality and equipment control in several construction automation applications. The ability to automate construction would be useful particularly in settings where human presence is dangerous or problematic; for instance, robots could be initially sent to underwater or extraterrestrial environments, to create habitats to await later human travelers. Actually, there is plenty of room for improvement in all process elements concerning robotics and automation.

6. CONCLUSIONS

The following conclusions are made:
- Robots are increasingly involved in construction operations to maintain highly accurate actions and to reduce hazardous risks achieving improved control and safety.
- Automated construction can be further developed to include: design, engineering, maintenance of existing and planned structures.
- Many research works suggest highly autonomous robotic system for the construction performance. The “Sense-and-Act” may indeed become a reality in the development of more advanced robotic systems for construction applications.
- Real-time planning is commonly employed in tasks that require the robot to contend with uncertainties and undefined environments.
- Efforts should be paid to convince professionals in building management to look into the possibility of integrating robotics and building automation together to improve the quality of services for modern intelligent buildings.
- All new ideas for Automation or robotizing on the building site have to be generated by a combination of new designs, new forms and new materials that meet the requirements for building in a metropolis. However, many problems in construction engineering cannot be fully addressed through optimization and computation.
- With intelligence activities such as generalization, analysis and decision-making for multi-objectives, there can be a better understanding of the construction engineering problem.

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