"How New, Innovative Technology and Project Execution Tools and Techniques Can Be Used to Improve the Construction Process (Including Safety and Efficiency)."

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Abstract

Humanity has often sought to utilize tools and technology to make working faster, more efficient, more comfortable, and more accurate. While humans may have started with stone tools, we have since developed complex and sophisticated mechanical and digital technologies. The construction industry has been utilizing construction technology and equipment for these same reasons for generations. While other industries have embraced the use of smart, autonomous technology and robotics, the construction industry has steadily fallen behind in this effort. In this paper, I will discuss current work using these tools and possible applications for future development.

1. Improving the construction process

1.1 Using innovative technologies

Ever since the experiments and work of Charles Babbage, the father of the computer, mankind has been using mechanical and digital computation tools to help create efficiency in all walks of life. In construction, robotics and technology have been primarily limited to office work programs. However, many robotic devices could improve the construction process and make up for the deficiency of a low-skilled labor force in the construction industry (AGC's Construction Hiring and Business Outlook Reports).

There are opportunities for machines that could create a much more efficient and well-documented construction process. One application would be a material-moving system on job sites that utilizes robots. These robots could be programmed to automate deliveries between pre-set drop-off zones within a construction site. This process creates efficiency by allowing skilled construction workers to concentrate on more profitable and complex work. Construction also requires documentation, so another application could be the automation of progress photography and scanning. The material-moving robot could document project progress while recording the last known location of materials using photography and other sensors.

1.1.1 Construction robots

Skibniewski noted in "*Robotic materials handling for automated building construction technology*" that "the robot serves as a [middle-man] between the arrival of individual components and materials and the [worker] requiring them. This handling robot receives material at a pickup point and automatically identifies and inspects it. The robot then stores the material in an appropriate location according to its type or transfers it to a delivery point for immediate transfer to the [worker] or transfers it to a delivery point for the return to the manufacturing facility." (Skibniewski, 12). Robots can take a lot of labor demands off the backs of construction workers. As noted above by Skibniewski, these kinds of robots could help lower the amount of intense labor-related injuries caused by material moving. Making the construction workplace safer helps companies retain employees longer and can also increase the quality of life for laborers in the field. This kind of system also creates all sorts of opportunities to make the job site more efficient.

Robots need many sensors to help them navigate and interact with the world around them. By using these sensors, a robotic material mover could help human workers with tasks that do not require their direct attention. Examples of using such sensors might be using high-resolution video recording and streaming equipment for QR code reading, remote control, and tracking the robot's actions on the job site. Infrared electronic distance measurement sensors could be utilized for collision avoidance and response protocols, as well as drift correction. All of these sensors and devices could also be used to document work.

1.1.2 Automated construction progress documentation

A smaller robotic device could also be used for both virtual job site tours and automated progress photos. Using systems similar to the robotic material mover discussed above, a camera robot could be programmed to follow specified routes for progress photos, laser scans, or taking a client on a pre-routed job site tour. The camera robot could also be programmed to follow a specified individual, by using a QR code printed on a safety vest for job site tours, or could be remote-controlled by the client (with collision avoidance protocols in place to protect the job site and the robot).

At the end of each workday, a robot could be programmed to run a route with a laser scanner attached. This would allow the General Contractor, Architect, and Owner to have a precise reading and images of the daily work. This kind of transparency and accuracy, when automated, would help the entire project run smoothly and keeps all the contracted parties informed about the project's progress. Errors can be immediately seen by all parties and dealt with swiftly to avoid delays to the schedule.

At the end of the project, the images (or a select few of them, given that point cloud models are large) can be layered to give a 3D model as-built with cut through sections to show every stage of the project's structure. Not only does this assist with future maintenance, repair, and renovations to existing structures, but researchers could use that information almost like a snapshot in time to show how the structural elements shift as the building ages. This could help engineers better understand what methods and materials last longer than others.

2. Undergraduate research – personal experience with robotics for construction

2.1 Undergraduate research topic description

As an undergraduate research student, I have been using a small consumer-level AI (Artificial Intelligence) robot to test a proof of concept for a material-moving robot on small scale construction job site layouts. The robot chosen for these experiments is called the Robomaster EP Core. The EP core and its dimensions can be seen in Figure 1.0 below.

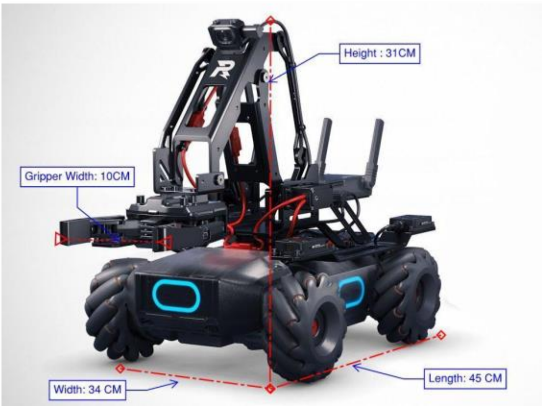

Figure 1.0

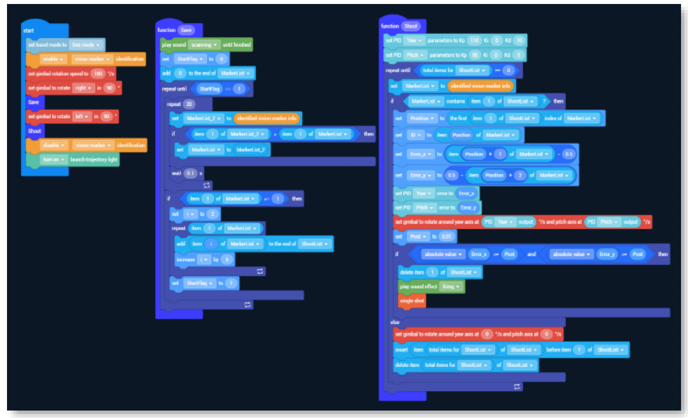

Figure 2.0

In Figure 1.0, general robot dimensions can be found for the length, width, and height of the robot, as well as the gripper width. This robot uses a specialized wheel system that not only allows it to move and turn like any other vehicle, but also enables it to move in specialized directions/ways. The wheels' motors operate independently of one another, which allows the robot to move directly left or right, like a drone, without rotating. The robot can also rotate itself without moving in any direction. The robotic arm on the robot is fixed in place at the front of the chassis. The robotic arm utilizes two servos which allow it to move up/down and forward/back to position the gripper in the proper location.

I set my experiments up at a 1:10 scale to make the gripper large enough to lift a 3'x 3' pallet—adding to the realism factor of my tests. Another reason the 1:10 scale is best for this research is that it makes a one-lane road about 0.5 meters wide at a smaller scale. At this scale, the robot is similar in size to a commercial truck or a small 100 HP excavator. The Robomaster EP Core is programmed using Scratch 2.0, a graphical coding program. An image of this programming language can be seen above in Figure 2.0.

2.2 Latest experimentation update

Using this programming language, I successfully programmed the robot to move from one point to another while delivering materials. In this experiment, the robotic material-mover robot was manually set up and calibrated, then set out to automatically move material from a drop-off zone to a laydown yard, and then navigate back home.

This first attempt was not a proof of concept. I expect to create and utilize a navigational system that uses multiple sensors and sources of information. This includes QR codes, tape lines, IR (infrared) distance sensors, and clap/gesture commands to teach the robot how to go to a point from anywhere on the job site and complete a material-moving tasks in one coding script. This experiment will include functions like collision avoidance and reaction protocols, drift correction, smart object locating and sorting, and other programs to help keep the robotic material mover as intelligent and reactive/interactive as possible.

3. How the construction industry is addressing the use of robotics and the advantages and disadvantages

3.1 Automation in Japan

There is a great deal of automated robot construction in Japan. In fact, "Several leading Japanese construction firms are developing fully automated, self-rising platforms for the construction of high-rise buildings. These automated building construction systems provide an integrated building construction environment for robotized cranes, finishing robots, computer work stations, and other automated construction equipment." (Skibniewski, 1). This emphasis on automated construction has propelled Japan's construction industry to develop some very useful automated construction systems. One area that seems to be lacking in development is an automatic, mobile semi-autonomous material handling system. In this automated building construction system, "components are … trucked to fully automated storage facilities at the building site, where they are stored or transported to the assembly platform by an automated material handling system. The material handling system consists of automated lifts, conveyors, and elevators. When components arrive at the assembly platform, they are carried by an overhead gantry crane, which positions them at their proper location for erection." (Skibniewski, 2).

3.2 Advantages and disadvantages

3.2.1 System speed

While the system described above works well for a fully-automated construction process, what about those projects that are being built and managed by people? It could be feasible to have a mobile robotic material-handling system to assist in the construction process and cut down on labor costs for material moving. There can be some drawbacks to an approach like this. For example, "Compared with hard automation, [a multi-purpose robot] is slower in throughput; however, the flexibility offered by [a multi-purpose robot] allows easier integration within the dynamic ABC construction environment. Also, fixed automation may become obsolete when removed from a production site" (Skibniewski 15). The mobile system may also be slower than a human counterpart, but being able to use human assets for complex tasks that a robot is not capable of is another factor of productivity that is important to remember.

3.2.2 Health and safety

Tasks like material moving can cause some severe health problems for an increasingly-aging workforce. Because "robots are primarily developed for the sectors in which poor labor conditions prevail and in which a reduction of the load is possible," it seems fitting that these automated systems could be used to help lighten the load on construction workers (Bock, 14). "The comparatively high frequency of accidents as well as the high statistics of labor-related sickness and premature retirement in the building industry are an indication of the special requirements." (Bock, 14). Also, "A positive relationship has been established between physical workload and level of exhaustion." (Lee 3.) Seeing as it could help decrease injury rates in construction, a mobile semi-autonomous material-moving system could be vital in creating a better work environment for laborers.

3.2.3 Profits and labor costs

Profit margins and costs are always necessary to consider, but it has been stated that "By automation, increased productivity could reduce high labor cost share of 40 or more percent." (Bock, 1). This large cost saving is the result of several factors. Robots do not require payment or health insurance. They can work all day or all night. If programmed creatively, the robot could aid human workers with set up and close down each day.

4. Addressing challenges

4.1 Current technology

To address the challenges expressed above, I propose to devote more time, energy, and other resources to utilize technology to make up for the deficiency of low skill laborers in the workforce. Creating robots that can perform various tasks or one complex task can pay for itself over time by reducing labor costs – one of the construction industry's largest cost sectors. Looking back on the undergraduate research section above, I see an opportunity to develop an advanced, full-scale AI material-moving robot. With some added accuracy and innovative software design, such a machine could go beyond the applications studied in my research. A more accurate and intelligent robot could be used for operations like modular building construction by placing the prefabricated elements into their proper position. Smaller versions could also be created as an automated tool cart to help organize and distribute tools to the laborers as they work.

4.2 Health and safety

A robot does not have to go home at the end of the day or need to breathe or use light to navigate in the dark, etc. A robot does not have a mandated carry limit like OSHA requires for human workers. "To prevent workers from taking on excessive workloads in material handling jobs, safety professionals' guidelines limit the weight of materials that workers need to install and carry. In terms of ergonomics, it is better to manage the demands of all tasks through the control of tools, equipment, and the work environment." (Lee, 10). This benefit to vital in the robot's success as a real-world option. The robot's lack of human limitations can be used to maximize its efficiency.

5. How an organization such as the AGC might play an important role in addressing issues related to this topic

AGC could start addressing the lack of technology in construction by initiating the conversation on construction robotics with students to spur creativity in the academic community. The academic community would advance and find new applications for current technologies, which could then be made feasible and cost-effective by industry professionals.

From a research and development perspective, the goal should be to integrate existing technology into smarter, more automated systems. I see opportunities for fully automated material-moving assistants, as-built laser scan robots, virtual replacements for job site tours, and many more applications that utilize and integrate existing technologies. These efforts toward the application of AI robotics on a more routine basis will surely help to advance smart construction technology on the construction job site.

6. Summary

Throughout history, mankind has sought to invent new tools and techniques. This overarching goal of our species has taken us from stone tools to advanced autonomous and self-learning AI technology. While advanced technology is being used in the construction industry, for the most part, construction is behind other industries as far as the application and implementation of on-the-job robotics. However, both the academic and business communities are steadily working to close that gap.

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