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Autor: Halpin, Daniel W.

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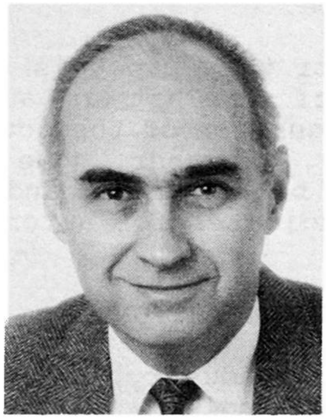
Automated Construction Technology: Background and Barriers

Méthodes de construction automatisées: principes de base et difficultés

Die Automatisierung von Bauverfahren: Grundlagen und Hindernisse

Daniel W. HALPIN
Professor
Purdue University
West Lafayette, IN, USA



Daniel W. Halpin, born in 1938, received Civil Engineering degrees from the Univ. of Illinois. He has been Director of Construction Management programs at Georgia Institute of Technology, the Univ. of Maryland and Purdue University.

SUMMARY

This paper examines basic issues which impact the application of automation and robotics to construction of facilities. Certain problems which must be overcome to allow widespread implementation of automation in construction are addressed.

RÉSUMÉ

Cet article examine les questions fondamentales ayant une influence sur l'application des techniques d'automatisation et de la robotique dans la construction. L'auteur mentionne certains problèmes qui doivent être résolus avant qu'une généralisation de l'automatisation ne puisse être réalisée.

ZUSAMMENFASSUNG

Der Beitrag untersucht die Grundfragen der Automatisierung und des Robotereinsatzes in der Bauausführung. Er spricht Probleme an, die der allgemeinen Einführung automatisierter Bauverfahren noch im Weg stehen.

1. INTRODUCTION

There has been a great deal of discussion about the increased use of automation in the construction industry. In fact, the 7th International Symposium on Automation and Robotics in Construction was held recently (6-8 June 1990) in Bristol, England. As evidenced by the papers in this meeting, there is clearly a great deal of research which is being conducted in construction automation. In addition, a wide array of automated systems are being used on field operations particularly in Japan and to a lesser extent in subsurface applications in Europe.

The objective of this paper is to present a brief overview of the existing state of the art in automation in construction and stimulate further discussion of the potentials for application in the construction industry. Further, some of the barriers to automation in construction will be discussed and some application areas which appear to be good candidates for automation will be presented.

2. EVOLUTION VERSUS REVOLUTION

The construction industry, in general, has been traditionally conservative in accepting new approaches to the management and placement of construction. Construction of facilities is based on both qualitative and quantitative procedures. Some of the procedures are based on quantitative considerations which can be worked out with mathematical precision. For instance, the design of formwork to support a certain concrete pour in the construction of a large building can be developed with a relatively exact degree of mathematical precision. On the other hand, many aspects of construction require engineering judgment and expertise which are not quantitative but rather acquired by experience in the field. Questions relating to earthwork construction such as the proper number of passes with a rubber tired roller to achieve acceptable compaction or the proper mix of betonite to insure impermeability in the construction of a cut-off wall are examples. Although calculations can be carried out to estimate these factors, the actual number of passes or the actual mix requires the integration of many qualitative considerations. Just as a chef learns to make an excellent souffle or a surgeon knows by "feel" how to deal with certain aspects of an operation, the construction manager is continuously confronted with situations where judgment is of paramount importance.

Decision making in the construction industry is based on a blend of qualitative and quantitative factors. For this and other reasons, progress has occurred in an evolutionary rather than a revolutionary mode. That is, the industry traditionally modifies existing and proven practice to achieve improvement rather than trying altogether new methods. Again, the qualitative aspects of totally new technologies are not easily evaluated, and the tendency to "not fix it if it's not broken" is prevalent among construction professionals. International competition in the construction market is interjecting a new variable into the equation, and the application of high technology to construction by non-US contractors has begun to have some impact on the resistance to change characteristic of the industry in the U.S.

This notwithstanding, it appears that the rule of evolutionary, rather than revolutionary, change will continue to hold, and that acceptance of robotization will necessarily be proceeded by an automation phase. That is, technology leading to a higher degree of machine and equipment automation will have to yield productivity improvement before full robotization will be accepted in practice.

Certain characteristics of construction processes are unique and complicate the implementation of robotization in construction (in contrast to the utilization of robots in manufacturing or other industrial applications). The following sections discuss some of these characteristics of the construction environment which make the use of robotics a more challenging proposition.

3. OPEN LOOP AND CLOSED LOOP SYSTEMS

In an article prepared for presentation at the "Symposium on Innovation in Computer Technology for the Building Industry" held in October of 1986, Kenneth Reinschmidt of Stone and Webster Engineering Corporation in Boston discussed several aspects of the construction environment which represent important constraints to the implementation of automation. The first of these characteristics addresses the open versus the closed loop nature of automation. In an open loop system, the loop is closed by the actions of a human controller who intervenes to provide input and decision making. In a closed loop system, the machine is fully automated and no human intervention is required.

Reinschmidt makes the following observation:

"Of critical significance in the field is the stack-up of deviations, each of which is individually within construction tolerances. This build-up of tolerances may be enough to defeat automated equipment. The feedback of as built dimensions can eliminate this problem...With feedback, succeeding elements can be adjusted to fit." (Rein 86)

This "problem of shimming" requires a high level of sensing sophistication. Although, the tolerances in construction are typically more generous than in manufacturing or the aerospace industry, the actual installation of items in construction will require very accurate metrology to establish the precise location of the interfacing elements.

This type of sensing is impacted by the dusty and unstructured nature of the construction site. Sensors on construction robots must be rugged and capable of resolving complex situations if they are to operate in a closed loop mode. Even teleoperated equipment using video cameras and similar version equipment have encountered difficulties in the construction environment (e.g. Three Mile Island repair work).

The shimming question and the complexity of sensing requirements is also indicative of the qualitative aspects of construction which are typically reconciled on the job site within the "skill" capability of the human worker. A good example of this qualitative skill aspect of construction work is the shotcreting of underground tunnels. The construction of tunnel liners in fragmented rock to stabilize the fracture zone is accomplished using shotcrete.

The material is sprayed onto the tunnel wall in order to achieve a layered build-up until the required thickness is reached. A number of qualitative (artificial intelligence related) aspects to this operation require very sophisticated sensing.

Among these qualitative considerations are:

(1) The "reading of the application surface to insure proper bonding of the shotcrete to the base material (i.e. the rock wall) is occurring.

(2) Evaluation of the layering and "set up" of the shotcrete to insure that the inter-layer bonding provides sufficient support so that the applied material will not fail and fall due to an exceeding of the bond strength of previous layers.

(3) Determination of the liner thickness which is required to control the fracture zone (Note: This is normally done intuitively by the equipment operator).

These are just a few of the qualitative considerations which the human operator is continuously sensing and integrating into his decision pattern regarding the application of the shotcrete.

Although the Japanese have developed a shotcreting "robot," it is not clear how successful this machine has been at overcoming the types of "skill" related actions referred to above. The robot does require the intervention of an operator and functions as an open rather than a closed loop system.

4. WORK FLOW CONSIDERATIONS

Reinschmidt again notes that:

"Without a steady, reliable source of supply, a robot will experience excessive idle time, and excessive idle time will nullify the economic advantages of any capital-intensive machine...Work-sampling measurements on large construction sites show that 30% to 40% of a worker's time is spent waiting for instructions, materials, tools, cranes, drawings, inspectors, and other equipment or information. If robots were installed that worked twice as fast as men, they would spend even more of their time waiting, unless the logistics system were improved. Therefore, substantial improvement in the material control and supply system is a prerequisite to the effective use of robots in construction." (Rein 86)

It is clear that unless material can be fed to the robotic device with sufficient speed, the economics of automation will be determined. Unless off-setting considerations such as worker safety and health justify a high level of machine idle time, the capital cost of an automated machine will not be justified.

Certain types of construction operations, on the other hand, are not constrained by material flow considerations. Operations which involve surface treatment (e.g. painting, bush-hammering, etc.) are not material feed constrained since the robotic device passes across the "material" to be processed. This would indicate that surface processing operations in construction would be good candidates for the application of automation and robotics. This is born out, to some degree when one considers the operations chosen by the Japanese for robotization. The shotcreting operation has been mentioned. The Japanese also have a robot which cuts rock in underground construction using a water jetting device. The most highly publicized Japanese robot is used to apply fire proofing material on steel members (e.g. girders) in high rise buildings. Another Japanese robot is used to inspect tiles on vertical walls to determine that a proper bonding has occurred. Proposals for robots to sand blast metal elements and clean forms have been made by Skibniewski (Skib 86).

The application of robots to earthwork operations recognizes that the "material" to be processed normally is available in large quantities. This means that the "feed" problem is normally not a major constraint. Automation of such operations as grading and entrenching have been reported (Paul 85). Protypical excavation robots designed to seek subsurface pipeline leaks and repair them are under development at Carnegie-Mellon's Robotics Institute (WhMo 86).

The material feed problem may also be tractable if the applied material is fluid or semi-fluid and sufficient area or work space is available.

5. METROLOGY CONSIDERATIONS IN CONSTRUCTION

As noted above in discussing the "problem of shims," metrology or the science of measurement will be critical to the implementation of robots in the construction environment. Since the assembly process in construction takes place in the unique and unstructured arena of the project site, navigation of mobile machines and precise definition of location both in the macro (machine) sense and in the micro (e.g. effector arm, work position) sense present formidable problems to the use of automation and robotics. Human intervention within the context of open loop systems is presently required to reconcile many of the positional and locational problems.

"The...solution to the shim and trim issue...is computer aided determination of the amount to shim and trim, coupled with an instantaneous permanent record of the correction. Automated machinery becomes feasible because the robot knows, through the data base, exactly where everything really is, even if it is not exactly where the drawings say it should be..."

"...Technologies such as stereophotogrammetry, monoscopic/convergent photogrammetry, laser ranging, radio transponders, and geodetic positioning can be used to locate permanent construction, items in lay-down areas, and moving vehicles with any desired degree of precision." (Rein 86)

The equipment to establish precise metrology on the construction site exists, although field testing of such equipment to evaluate performance on actual projects has been limited.

The problem of the data transmission and data base support required to make site metrology available for navigational purposes and work face definition is formidable. This appears to be the major area in which research is required. Although acquisition of metrological data is presently feasible, the organization of the required data structure needed to support robotics devices and the routing or transmission of the data to the machines will require development of compatible data protocols. In the manufacturing area, General Motors has begun to address this problem within the context of the system called Manufacturing Automation Protocol (MAP).

"The primary impediments to the implementation of integrated data bases on construction projects are the lack of common data dictionaries, to define how data should be organized, structured, and stored, and the lack of standard formats for the interchange of data between the many participants in the project. Standards, either consensus or de facto, are needed because individual clients cannot afford to define these conditions for every project." (Rein 86)

In addition, a great deal of research into the construction processes themselves is required in order to establish what kinds of data must be acquired, structured, and transmitted in order to establish machine control.

6. CHARACTERISTICS OF TECHNOLOGICAL FEASIBILITY

A study conducted by the author (Halpin 1987) identified certain characteristics of the processes which rank as highly feasible from a technological point. Such processes are ones which are related to the processing of surface areas (e.g. sandblasting, bushhammering, concrete finishing). They either require no material application (e.g. concrete finishing, bushhammering) or have to do with the application of a fluid or semi-fluid material (e.g. sandblasting, shotcreting). On the other hand, those processes which rank low in technological feasibility require complex operations involving the movement, attachment, etc. of solid components or objects to a fairly high level of precision (e.g. plumbing, structural precast).

Although automation to increase worker productivity is possible in such processes as forming or plumbing, the level of technology in sensors, artificial intelligence, and allied areas is not presently available to support closed loop automation of such activities. Notwithstanding the fact that Japanese firms such as Kajima report the development of reinforcing steel placement "robots," these are devices with local end-of-arm tooling automation requiring continuous human monitoring. They are not true robots in the sense of the closed loop definition of a robot (i.e. no human intervention required). The problems of "shimming" and feed of applied or processed material still present formidable problems to true robotization of processes involving the manipulation and installation of solid components in the dynamic environment of the job site.

7. THE PROBLEM OF MOBILITY

Mobility in the disorganized, sometimes chaotic, environment of the job site also presents a major problem to the development of robots for construction. Certain efforts to transfer fixed position or non-mobile robotics concepts from the manufacturing area to fixed plant operations in construction such as precasting, stone cutting, wooden truss and stud wall manufacture, etc. are being studied. The PALC ceramic prefabrication system for home building developed by the Japanese is an example of this approach.

The technology to support a truly mobile robot device able to act and react on the job site with no human intervention is, at best, only in the developmental stage at this time. It would appear that the way in which construction is presently done (ie. the methodologies of construction) will have to be modified to support the application of robotic devices. The structure of the job site and area in which a particular work process is to be achieved will have to be preconfigured to accommodate the needs of the robot. This is, in fact, being done in the prototypes which have been widely reported and discussed such as Shimizu's SSR-2 and SSR-3 fireproofing "robots." In the case of this and similar machines, position is developed by tracking sensors which move along tapes or wires prepositioned by human workers to act as guidelines for the mobile machine platforms carrying the processors (e.g. manipulator arms with end-of-arm tooling). The study of work processes to determine how they might be reconfigured to enhance and simplify the demands placed on a mobile robot is a major area of potential research relating to the implementation of robotics in construction.

8. SUMMARY

Several points appear to be central to the development of robots for the construction industry based on the research to date.

(1) Tasks which require assembly and installation of objects (particularly heavy prismatic solids) are not feasible using the present robotics technology.

(2) Tasks which involve the application of fluids or fluid like materials are better adapted to the material handling capabilities of existing robotics technology.

(3) Construction activities related to the preparation or processing of large surfaces are well adapted to construction automation. Particularly, when no material must be applied to the surface to be processed (e.g. bush hammering, concrete finishing), robotics can be applied.

(4) Inspection tasks appear to be well adapted to automation and robotization.

(5) Operations in unsafe environments offer excellent opportunities to apply robotics or teleoperation. Economics and worker safety considerations support significant developmental investment to robotize unsafe and dangerous work processes.

(6) The application of robotics to processes with significant economic potential (e.g. piping in industrial construction) may be justified if the synthesis of existing technologies support a high probability of successful development.

(7) Although processes involving the processing and assembly of solid objects are poorly suited to "closed loop" robotization, certain tasks within such processes may be candidates for automation with human support. For instance, although plumbing piping is a poor candidate for robotization, automation of the connection of piping using automated techniques (i.e. automated sleeving) and worker operated devices are good candidates for new technology application.

(8) Production of certain processes can be enhanced by using semi- or partial automation to reduce the skill level required of the human worker or operator.

Based on a study of construction technologies conducted by the author, the following processes would provide the best opportunities for development:

(1) Steel Fabrication
(2) Painting
(3) Wall Finishing
(4) Bush Hammering
(5) Tunneling (All Categories)
(6) Sandblasting
(7) Concrete Placement
(8) Fireproof Spraying

Steel fabrication is basically a fixed plant operation. Painting, sandblasting, spraying fireproofing material and concrete operations deal with a fluid or semi-fluid material. Bush hammering and wall finishing are surface treatment activities. Tunneling is repetitive and in the case of soft ground tunneling deals with a somewhat fluid material (particularly if slurries are used as a transport mechanism).

Investigation of how these processes can be reconfigured to facilitate robotization should be a central focus in further research into the application of robotics in construction. As noted by Whittaker:

> "It is common to mistake or overestimate chaos in a task environment simply because form and understanding are not apparent. There is a great prospect for structuring the apparently unstructured either by discovering structure or by imposing it." (Whit 85)

This ability to recognize structure or impose it represents the key element in achieving greater automation/robotization in the construction industry. This will require rethinking of how things are done and a serious consideration of how new technologies can aid in structuring construction processes.

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