Automation and Robotics in Construction: The Search for Potentials

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KEYWORDS

Evolution in Construction Technology, Process Modeling, Computer Simulation, Robot Control

ABSTRACT

Due to the prototype-oriented and still unstructured way of construction, self optimizing and self organizing systems, e.g. robots, will require organizational adjustments on the construction site as well as in the planning phase. But issues like safety, job enrichment, high quality, vanishing craftsmanship, optimal usage of resources and preventive maintenance are basic incentives to study construction operations applying both system theory and cybernetics. Furthermore, the high degree of repetition on the operational level makes certain construction processes good candidates for automation and robotization.

Automatisation et Robotique
dans la Construction:
Recherche de Nouvelles Applications

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MOTS-CLÉS

Evolution de la Technologie de Construction, Modelisation et Simulation de Control Robot

SOMMAIRE

Du fait de l'orentation prototype et encore instructuré du mode de construction, les systems optimisateurs et organizateurs, comme les robots, demanderont des modifications d'organization sur le site de construction et dans les phases préparatoires. Toutefois des problemes comme la securité., l'aspét enrichisant du travail. la haute qualité, l'usage optimale des ressources et la maintenance préventive, stimulent la recherche d'opération de construction appliquant ā la fois la thēorie de system et la cybernētique. En outre, le haut degrē de rēpētition au niveau operationel fait de certains procedēs de construction de bons canditats pour l'automatisation et la robotisation.

INTRODUCTION

Automation and robotics promise to become essential for increasing safety, productivity and quality in construction. Albus stated [7]:"From the standpoint of creating wealth and increasing the standard of living, the introduction of robotics into the construction industry is extremely important."

There is, however, a major concern related to the fear that robots may take away jobs from people. Albus refutes [7]:"The amount of work is not limited. In fact it´s probably infinite. The production of real wealth is what supports the ability to meet a payroll, and that makes possible to hire people to do things we can´t afford to do now. The idea that putting robots to work doing something that people are doing today somehow decreases the total amount of work is, I think, one of the most pernicious notions ever perpetrated."

Based on this premise, researchers worldwide started to systematically analyze construction areas, disciplines, processes and work tasks for potential applications. Several questions are being raised. How could the interested parties (e.g. equipment manufacturers, construction companies, etc.) combine their efforts to ensure a most optimal introduction of the new technology into the construction industry? How could existing construction methods be modified to allow for an efficient utilization of intelligent machines?

This paper tries to address some of these questions, discusses an approach to identify potentials and presents tools for a detailed analysis of such construction tasks.

HIERARCHY LEVELS IN CONSTRUCTION

There is a general understanding that production operations in construction show numerous unique features, (e.g. construction is a prototype-oriented industry which basically does not use assembly lines). The manufacturing industry was very successful in implementing the concept of repetition and standardization which led to automation and massproduction in the last century. Construction on the other hand, wasn´t able to reevaluate the idea of uniqueness which prohibits repetitive processes.

Halpin/Woodhead [5] developed six hierarchy levels in construction management:Organization, project, activity, operation, process and work task. The first three levels can be considered as static, basically unique and non-repetitive. Operation, process and work task, however, represent dynamic systems. The character of these last three levels is very often related to the cyclic sequence of related tasks. For example, an earthmoving process is nothing more than a sequence of the work tasks: loading, hauling, dumping and travel back. Work tasks themselves are a series of micro tasks (e.g. grab, put, push, turn, etc.) Figure 1 presents a modified hierarchical structure, and demonstrates the characteristics of each level in terms of its repetitive nature.

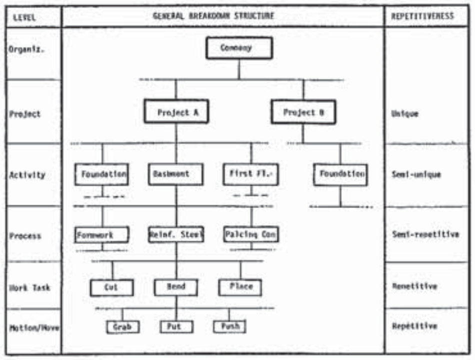


Figure 1. Example of a Functional Break Down Structure

The above tree structure highlights that uniqueness is generally limited to the company and its projects. The examples used for the activity level indicate that the same activity can be found in different projects (e.g. foundation). Albus [1] broke the motion/move level further down in order to model control systems which create a logical link with automation and robotics concepts.

It can be concluded that repetitiveness can be found in abundance on the three lowest levels, thus providing the backbone for economical applications robotics and automation.

SELECTION CRITERIA TO IDENTIFY POTENTIALS

The industrial revolution brought power-driven machines to the construction sites. Besides bigger machines and the introduction of some new equipment, (e.g. scrapers), nothing really revolutionary has happened since.

The introduction of automation and robotization in construction offers an excellent opportunity to reeavaluate traditional approaches. The search for potentials could be guided by six factors: safety, repetitiveness, quality, mobility, productivity and vanishing skill.

Safety

Some construction operations are characterized by their risk to the human body due to the exposure of the laborer to unhealthy conditions such as heat, dust, radiation, excessive noise, air and water pressure, gases and fumes. Monotony and carelessness are examples of other factors which contribute to hazardous work conditions.

Repetitiveness

Repetition has proven itself as the crucial factor for the optimal use of resources. A variety of projects, (e.g. Saudi Arabia-Bahrain bridge), demonstrated how repetitive design leads to efficient construction with a significant economical edge over traditional approaches.

The utilization of automation is significantly restricted by the lack of flexibility. Robots overcame this limitation, being by definition multifunctional and reprogrammable. Intelligence and flexibility, two very powerful elements, also make robots excellent candidates on the process level.

Quality

"Because robots perform their jobs the same way every time, they produce consistent quality in their goods, which provides the manufacturer with definite advantages.", write Hall/Hall [3]. Beyond the consistency, intelligent machines provide quality which encompasses standards reachable by humans. Good examples are processes which require accuracy in spraying, leveling, etc., (e.g. robotized shotcrete sprayer).

Mobility

Most robots at work today are fixed robots with mobile arms. Until efficient sensing systems and moving mechanisms for their utilization in the construction environment are found, stationary processes and work tasks have higher potential to be automated or robotized. On the other hand, the redesign of production processes traditionally requiring mobility, could lay the ground work for the implementation of semi-fixed fabrication methods.

The SSR-2, Shimizu´s fireproofing robot, shows that mobility can be achieved; but, it is doubtful that this test application will actually become economical in the present configuration.

Critical for Improving Productivity

The output rate of a system is usually controlled by a specific work task within the system. This work task is usually related to the applied technology and sets the pace for the production. Automates or robots may help to increase the production of such a "bottleneck" work task and, therefore, speed up the whole process.

Vanishing Craftsmanship and Skills

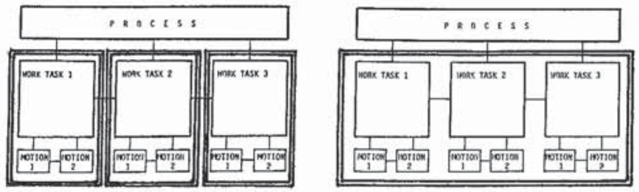
Unpopularity of certain jobs, the rising labor cost, etc. resulted in the disappearance of certain construction crafts, (e.g. stone cutter for cobbled pavements). It seems possible that a reevaluation of vanished crafts may lead to an economical renewal of these crafts, utilizing robotics and expert systems.

In addition, semi-automation is able to assist less skilled laborers, making them as efficient as trained laborers.

HIGH-TECH EVOLUTION, DOING SIMPLE THINGS FIRST

Construction technology improved in an evolutionary fashion. The mechanisms for technological innovation in construction are presently studied by Tatum [8]. Although it can be expected that robotization in construction will have breakthroughs in specific areas, the basic evolutionary progress has to focus on automizing and/or robotizing those parts of a process sequence which can be engineered easily. The introduction of high-technology will basically develop along two separate routes: (1) Integration into existing processes and (2) Total redesign of traditional methods.

Integration into Traditional Processes



(b) (c)

Figure 2. Technological Evolution through Integration

Figure 2 is based on the tree structure in figure 1. Considering the three lowest levels, "smart" equipment and tools could be introduced to:

(a) support a unit in a level element(e.g. motion)
(b) perform a specific work task
(c) accomplish a whole process.

With some exceptions, the general evolutionary thrust will naturally come from the motion/move level, slowly

integrating vertically and horizontally. Ergonomics demonstrates how moves or sequences of moves can be optimized on the bases of least energy consumption. At the same time, safety aspects can be included. The same holds true for the operation of machines. For example, there exists an optimal path for a loader to bite into dirt and bring the bucket to a vertical position. In addition, the engine has to produce a variable amount of power during this process. In order to minimize energy consumption, such a sequence of moves and related minimal engine thrust could be constantly optimized using computer controlled systems. The operator would start the sequence , observe, intervene if necessary and take over after successful completion.

Simple electronic devices can be used to monitor the moves of operators for safety reasons. For example, such a mechanism could calculate the moment of a crane´s hooked load and override the commands of the operator if it falls outside an accepted range, thus preventing fatal accidents.

Redesign of Traditional Methods

Based on a conceptually wrong approach to automate and robotize, operators end up "in a baby-sitting position while the computer drives faultlessly through its sequence. In such cases boredom and disillusionment often set in and this can cause unacceptable levels of stress...." says Gordon Tuff [9].

By simply replacing humans with machines, a great opportunity for innovative changes could be missed. Today´s techniques and products developed through history, accepted by the industry and society. Brick sizes, window structures and dimensions represent standards not based on scientific approaches but on traditions which grew out of labor intensive production process. It may well be that other methods or standards are more appropriate for automation and robotization.

By studying the basic structure of a work task, modeled as an Input/Output system, three areas for innovative modifications can be identified.

1. New input factors, e.g. intelligent machines, plastic material
2. New methods, e.g. fusion welding
3. New products, e.g. modular elements

A change in one area may result in a chain effect, requiring the two other areas to change which may develop a synergic effect. An invention in one area may also open new horizons for products, (e.g. new construction materials may foster a innovative building methods but also help to develop new building elements.)

EXPERIMENTING WITH POTENTIAL PROCESSES

Numerous modeling and simulation techniques are used today in engineering and other sciences. Modeling, which requires a thorough understanding of the system being modeled, leads naturally to the simulation approach in order to test "what if" questions. The following figure presents the principle elements of a self organizing system, an expansion of the simple Input/Output system.

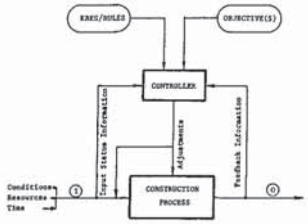


Figure 3. The Selforganizing System

The "brain" of the above system is the controller. It bases its controlling functions upon objectives and rules. Sensors, which provide data through a forward and a feedback loop, provide information necessary to monitor the process and to make decisions for adjustments, if necessary.

Selforganizing systems can be found in all hierarchical levels of construction. Inputs at the motion level, for example, consist of information about the following move necessary power to perform. The main focus of computer simulation, however, is the process level, where work tasks are linked in a repetitive fashion. Halpin [4] developed a simulation method, CYCLONE (CYCLic Operations Network), which can be expanded to handle the features necessary to simulate an intelligent machine.

Modeling the Robot Control

Halpin [4] calls work tasks which require more than one input factor, COMBI´s. Modeling an intelligent machine related to a specific work task, always a COMBI, requires the introduction of a control element, where conditions are constantly monitored and necessary decisions made.

Again, a modeler is forced to understand the system before he is able to model it with sufficient conformance between original and model. This is particularly important when modeling a control element. As indicated in figure 3, the intelligent control is based on rules or task specific

knowledge which makes it capable of handling an unstructured environment. This requirement suggests that it is necessary to combine simulation with an expert system, to integrate a rule based data base. O´Keefe [6] states:"Perhaps the most obvious way in which the two can be combined is by embedding an expert system within a simulation model."

Experimenting with the Model

Eventually, the expected productivity of the process under various conditions must be investigated. The experimenting procedure will also assist in the development of a catalogue of requirements for the actual robot control system as well as in testing physical options and designs. Through the combination of a knowledge base with a simulation system, the validity of the rules can be tested and enhanced before the actual system is built.

The goal of such a technique is to design a system which is balanced out at a high productivity level. Productivity transients which are created by interruptions provide indications of an inefficient system. The following set of cumulative productivity curves presents the result of several experimental runs.

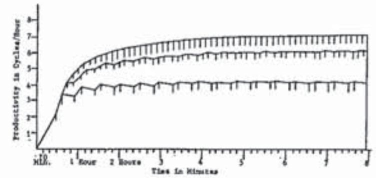


Figure 4. Productivity Curves of a Set of Experiments

The above figure shows that only one simulation run creates a transient free productivity curve with the highest final production rate. A detailed analysis of the different run results will furnish the cause(s) of these transients. Since this example shall only demonstrate the concept, the interested reader must be referred to other sources [2].

CONCLUSIONS

Three aspects concerning the future of automation and robotics in construction were addressed. First, a list of important criterions which could be used as guidelines for a basic search are discussed.

The second central topic introduced two approaches for the implementation of high-tech concepts on the construction sites, (1) integration into existing processes and (2) total redesign of traditional operations.

Thirdly, a method for the experimentation and analysis of restructured methods which bases on the simulation technique is presented.

The present development in introducing high-technology machines in all fields of construction is undoubtedly led by Japanese construction companies. U.S. research institutions interested in construction should use the opportunity to apply basic research techniques to reshape traditional construction, yielding to higher safety, productivity and quality.

ACKNOWLEDGMENTS

This work is supported by a grant from the National Science Foundation. The paper itself is based on ongoing research efforts.

REFERENCES

1. J. A. Albus, Brains, Behavior, and Robotics, BYTE Books, McGraw-Hill (Peterborough, 1981), Chap. 9, p. 268

2. L. E. Bernold, "Productivity Transients in Construction Processes," Thesis presented at Georgia Institute of Technology in partial fulfillment of the requirements for the degree of Doctor of Philosophy, (August 1985).

3. E. L. Hall, B. C. Hall, Robotics A Userfriendly Introduction, CBS College Publishing (New York, 1985), Chap. 1, p. 4.

4. D. W. Halpin, "CYCLONE: Method for Modeling of Job Site Processes," Journal of the Construction Division, ASCE, 103, (September), pp. 489-499 (1977).

5. D. W. Halpin, R. W. Woodhead, Design of Construction and Process Operation, John Wiley and Sons (New York, 1976), Chap. 1, p. 8.

6. R. O'Keefe, "Simulation and Expert Systems - A taxonomy and some examples," Simulation, 46, (January), pp. 10-16 (1986).

7. Panel Discussion, "Research in Robotics: Some Critical Issues," Robotics Today, (August), pp.66-71 (1984).

8. C. B. Tatum, "Exploratory Study of Fundamental Mechanisms for Technological Innovation in Construction", NSF Research Grant for Stanford University, (1985).

9. G. Tuff, "Plant Floor Interfaces for Batch Processes", Control and Instrumentation, (March), pp. 43-45 (1985).

Socio-Economic Aspects of Robotization

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KEYWORDS

Automation, Construction Industry, Feasibility Analysis, Robotics.

ABSTRACT

Most major industries have passed through a period of intense industrialization. Some have reached a period of extensive automation to include the use of robots. In particular, the automotive industry has successfully used robots to enhance both production and improve quality control. Recent advancements in robotic technology, control systems, and computers have vastly broadened the applicability of robots. In the construction industry, robotics principles have been applied to certain construction machines. Such equipment as tunnel-boring machines, automated paving machines, and scrapers with computerized transmission controls have sensors and processing abilities that bring them within the realm of robotics. However, unlike the manufacturing sector, greater intelligence, load, and force range is needed for a construction robot. It is generally agreed that the major justification for using robots in construction operations is related to: 1) Improvement of worker safety and elimination of dangerous construction operations; 2) Increasing productivity; 3) Improvement of final quality. The objective of this paper is to explore the socio-economic aspects of the robotics feasibility in construction industry, and establish a basic foundation for the future research. In general, the following questions will be addressed. What are the economic benefits of robots? What are the impacts on labor? How can construction operations with high potentials for robotization be identified?