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.

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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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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?

Les aspects socio-économiques de la robotisation

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MOTS CLEFS:

Automatisation, Industrie de construction, Analyse de faisabilité, Robotique.

Sommaire:

La plupart des grandes industries ont traversé une période d'industrialisation intense. Certaines ont atteint un stade d'automatisation importante qui inclut l'utilisation de robots. L'industrie automobile, notamment, a utilisé des robots avec succès dans le but d'améliorer la production et le contrôle de la qualité. De récents progrès accomplis dans le domaine de la robotique, dans les systèmes de commande et dans l'informatique ont élargi le champs d'application des robots de façon considérable. Dans l'industrie de la construction, les principes de la robotique ont été appliqués à certains engins de construction. Des machines telles que les perceuses de tunnel, les répandeurs de revêtement automatisés et les aplanisseuses à commandes de transmission informatisées sont équipés de détecteurs, et ont des capacités de traitement telles, qu'il est possible de les considérer comme faisant partie de la famille des robots. Toutefois, dans le cas des robots de construction, les besoins en intelligence artificielle, en plage de charge et en plage de force sont plus importants que ceux rencontrés dans la fabrication. On s'accorde pour dire que les raisons suivantes justifient l'emploi de robots dans la construction: (1) l'amélioration de la sécurité des ouvriers et l'élimination des manoeuvres dangereuses inhérentes à la construction; (2) l'augmentation de la productivité; (3) l'amélioration de la qualité du produit fini. L'objectif de l'exposé ci-joint est d'explorer les divers aspects socio-économiques de la robotisation dans l'industrie de la construction et d'établir un fondement sur lequel se baseront les recherches futures. D'une façon générale, les questions suivantes seront traitées: Quels sont les avantages économiques des robots? Quel est leur impact sur la main d'oeuvre? Comment les opérations de construction étant le plus susceptible d'être robotisées peuvent-elles être identifiées?

INTRODUCTION

Unlike the manufacturing industry, a construction site is a dynamic and random environment, therefore, a fully automated process requires a very intelligent control system, sophisticated sensors for feedback, an efficient material-handling system, and an advance mobility system. Under these conditions, it has become useful to explore at least those problems in the range of preliminary steps for the robotics feasibility in the construction industry.

Robots are used extensively by the manufacturing industry. However, the construction industry has unique characteristics which makes the robotization in most cases not a feasible alternative at the present time. It is not expected that robots will enter the construction trades before the end of next decade. The construction site is a random environment requiring a robot of highly sophisticated intelligence combined with a large load range and need for mobility. It seems that in the early days of robotics application in construction industry, the awareness of construction site hazards will provide the prime motivation to design and use a robot that would perform the tedious, repetitive, boring, dangerous and unpleasant construction jobs (Ref. 1).

Robot technology is not new, but many industries as construction are only just beginning to realize the impact that full automation could have in their production. Today, construction robots are still on the stage of research, and there are only few practical construction robots developed in the U.S., Japan, and some other countries. However, among all these robots only one or two may be called real construction robots, and the rest are partially automated construction equipment (Ref. 2).

Although today there is differences of opinion about exactly what a construction robot is, but in general may be defined as a fully automated mechanical device that can be programmed to perform construction tasks. In other words, robots are the machines which are controlled by computers.

A further essential question is the determination of an economical and practical level of automation for construction processes. There should be an optimum level of automation for each type of construction operation since excessive application of automation to a given process may not be economical. In certain cases, partial automation or robotization may even lead to an increase in the unit price. One approach to this question is to develop sequential stages in automation and perform a feasibility analysis for each stage.

SEQUENTIAL STAGES IN AUTOMATION:

To define an optimum level of automation for a given construction operation, the following five basic classifications are developed: 1) Pure manual labor construction operation which involves no tools, e.g., material handling by hand, or packing; 2) Manual labor construction operation with tools, e.g., manual excavation with a shovel; 3) Conventional construction equipment, or man-machine operation. These are the construction machines which are controlled by human, e.g., drilling rock by a conventional drill, or excavation by a conventional loader. Most of the construction equipment at the present time are under this classification; 4) Partially automated construction equipment, or man-machine-computer operation. This stage of automation improves the conventional construction equipment by adding a partially automated control system to the actuators, e.g., laser leveling grader, automatic gear shifting scrapers, hydraulic excavator with bucket tilt control, or remote control construction equipment for the construction work in dangerous places; 5) Fully automated construction equipment (robot), or machine-computer operation, e.g., SSR-2 spray robot for fireproof spraying on steel structures (Ref. 3), developed by the Research Institute and Construction Machinery Division of Shimizue Construction Co. in Japan. In the U.S., the Civil Engineering and Construction Robotics Laboratory at Carnegie-Mellon University is heavily involved in research and development of the construction robots to perform tasks in environment that are unsafe for human. These robots require occasional human involvement.

How does a robot operate? Essentially the computer of robot is provided with information representing a model of the robot, with details of the environment, data relating to the tasks to be performed and with a number of planning algorithms. When in operation it continually receives information concerning the robot with internally sensed information, and the environment with externally sensed information. By using this information in conjunction with planning algorithms, which can refer back to past experience, the computer develops control over the robot, causing it to move towards the correct execution of the task assigned to it.

The main difference between a construction robot and a conventional construction equipment is that the robot is able to react with its environment without a human intervention. However, the publicity surrounding the introduction of robots into the construction field exaggerates the true state of the theoretical and practical knowledge of robotics. The technical challenge is considerable because, at present, the characteristics of robot are far from attaining the performance required in an unstructured and dynamic construction field.

Large construction companies with an interest on equipment automation have not given a great deal of attention to research in robotics. There are only a few international contractors who have introduced robotics into their field, however, these robots are not capable of detecting the complex information directed to them from the environment.

If the number of repetitive operations are very large and the output product is fixed, then it might be economical to implement a fixed automation plant. For example, if a prefabricated plant is planning to build a large (infinite) number of fixed construction products (e.g., prestressed concrete beams) which does not require any change in size or type of material, then a fixed automation may reach a lower unit price than a flexible automated plant. This is due to the large volume of production and a lower variable cost.

Considering these sequential stages, the objective of this paper is to describe the feasibility of the last stage (robotization) in relation with the other stages. In other words, what construction operations should be robotized.

FEASIBILITY ANALYSIS

A modeling procedure is needed to evaluate the feasibility of robotics and justifying the implementation of robots in certain construction operations. In reality, robotics feasibility and justification is inter-disciplinary since it involves the input of several professional groups, therefore, this paper can only provide a guide for evaluation and discuss general considerations.

The following seven major variables affecting on the feasibility of the robotics are considered: 1) Cost Effectiveness and Economical Analysis; 2) Hazard Level; 3) Productivity; 4) Quality Improvement; 5) Standardization of Design and Level of Repetitiveness; 6) Union Resistance; 7) Technological Feasibility.

Any construction operation, if desired to be robotized, should satisfy a certain level of these variables. Since each construction operation is unique in nature, each operation will have different weight factors to the above variables depending on their level of importance in the operation. For example, in a welding operation inside a nuclear power plant with a high level of radiation, variables 2 and 7 will have higher weights than variable 5.

These variables must be analyzed in order to determine whether a particular operation should or should not be robotized. Next sections will describe briefly each of these variables.

Cost Effectiveness and Economic Analysis:

Applying robotics to a particular construction operation will most likely involve a large initial capital investment. Capital investments are based on the evaluation of the spending requirements and the returns generated over the lifetime of the equipment. Sometimes a particular construction operation is technologically feasible but not financially. To determine whether a robot is economically feasible, costs and benefits should carefully be studied.

In general, a determination of the total investment required is necessary, then the effect of the investment on operation's expenses and profitability should be analyzed. Items to be considered as cash out-flows are: 1) Total robot cost (e.g., Robot, Accessories, Options, and Installation); 2) Maintenance cost (e.g., Spare Parts, and Maintenance); 3) Downtime cost; and 4) Increase in energy cost. Items to be considered as cash in-flows are: 1) Savings on labor costs; 2) Productivity and quality improvement; 3) Depreciation saving through tax; and 4) Salvage value. Current industrial robots have payback periods of 2-3 years when compared against direct labor.

Hazard Level

Hazardous construction operations are very suitable for the robotization. The distinction between unsafe operations and hazardous operations should be made. Unsafe operations are assumed those in which there is a high occurrence of worker accidents. Accidents are considered to be the fault of the worker, either through carelessness or by the misuse of equipment. Hazardous operations are assumed those operations which expose the worker to an unhealthy environment (e.g., dust, radiation, heat, etc.). The worker is not considered responsible for the conditions but due to the nature of the operation, unhealthy human exposure is required. Historical data generally indicates the frequency of job related accidents, while standards relating to hazardous operations are provided by OSHA.

Some construction operations are hazardous, therefore, governmental and private agencies have dedicated special attention to this kind of operations. Several studies have been conducted in which permissible exposure limits for a variety of noxious elements commonly found in construction operations have been set. In determining if a particular operation is hazardous, the following areas should be investigated: 1) Concentration of dust; 2) Temperature levels; 3) Air and water pressures; 4) Noise; 5) Radiation, etc.

Productivity

Productivity levels in a particular operation are indicators of the effectiveness of the different resources involved in the operation.

In order to determine if a particular operation is suitable for robotization from the point of view of productivity, it is necessary to set a desired or expected productivity level. After having conducted a detailed and precise study of the productivity variation according to the type of machine being utilized and according to the expected robot productivity variation, the decision-maker should be in the position to decide if the operation is suitable for robotization or not.

Generally, productivity of an operation is measured by dividing the total number of units produced by the total amount of resources utilized in a determined period of time.

Productivity can simply be defined as the ratio of output to input, typically given as units produced per man-hours required. A comparison between productivities of the current system and the proposed robotic system should be made. If historical data on productivity is not available then a study to determine these values must be made. Simulation of the operation's tasks and sub-tasks for both systems may be used to determine the value of productivity. Several assumptions may be needed to model the robotic system, especially if it is a new or unique application. The most desirable results would indicate that the robotic system provides greater productivity in the comparison (Ref. 4).

If a construction operation is automated or robotized, it is expected to have a sharp increase in the productivity. The increased productivity, supposedly, gradually absorbs the cost incurred in the robot or automated equipment implementation. Obviously, productivity is not the only factor that pays for the robot. In some situations, the productivity achieved by a robotized operation remains the same, but substantial savings are expected to occur in other cost categories such as labor, overhead, etc., or even cost savings achieved by a better quality of the work.

A robot might have other uses in future projects. Therefore, the analysis must consider these possibilities, not just a study of whether or not the robot cost is justified by the better productivity achieved.

One must remember that certain construction operations involve considerable risk. In this situation, productivity plays a secondary role, because the main objective is to avoid detrimental and hazardous conditions. For these reasons, the project planner must weigh every factor accordingly to the desired goals.

Quality Improvement

One major reason for the implementation of robot is to produce a better quality compared to traditional systems. The results of quality analysis of the SSR-2 spray robot for fireproof cover work shows that the dispersion of the sprayed thickness decreased. Quality of a construction product can be measured by a numerical model which considers such characteristics as strength, dimension, color, etc. Only the relevant characteristics of an operation product should be considered. There is a direct correlation between cost and the level of quality improved.

Standardization of Design and Level of Repetitiveness

The cyclic and repetitive operations are the most suitable operations to be robotized or automated. A repetitive routine operation is a desirable operation characteristic for the robotization. A construction operation should be broken down into individual processes, tasks, and subtasks. The amount and type of repetition in each of these work divisions should be analyzed. The decision-maker determines the number of cyclic motions required in the production of one unit (Refs. 5 and 6).

Standardization of design also involves repetition but on a larger scale. Here, repetition is studied on the project or activity level. Basically, this parameter evaluates the number of production units required for successful robot implementation. Justification depends upon whether the number of production units fall within an optimum range. If not, perhaps some other man/machine system is more appropriate.

There are several means by which the number of production units in a project may be modified to fall within the optimum range for robotization. In the project planning phases it is advantageous to orient various building components (i.e. steel framing, doors, windows, rooms, etc.) in a regular and predictable manner increasing the feasibility of robotization by increasing the quantity of repetitious work cycles. Standard dimensions, regular geometric shapes and standard size fixtures would simplify implementation. Simplifying the construction design would in turn simplify the robot's job, reduce the necessary 'learning period' (teaching and reprogramming) and thereby increase robot effectiveness.

Standard design and repetitive operation are two factors that are required for robotization or automation of any construction operation.

Union Resistance:

Labor unions currently have few standard policies concerning the automation or robotization of construction operations, therefore, the reaction from organized labor can only be estimated. Unions have traditionally viewed automation as providing improvements to working conditions and in most cases respond in a positive manner.

Union resistance is considered to be somewhat dependent upon the following: 1) number of workers being displaced; 2) union strength in the area; 3) policies of management (advance notice to union officials, placement programs for displaced workers, etc.). These parameters are more difficult to model because no definite measurement scale of union resistance exists.

Technological Feasibility

In spite of the technological advances achieved in the last few years, technology does not always provide the necessary elements to develop machines for certain kind of industrial operations. For this reason, it is important that this factor be analyzed in the first stages of the study in order to determine if technology provides the tools to develop the appropriate machine for the operation in question. If the study reveals that development of a robot is not technologically feasible, further study of the other factors are not necessary, since the whole operation cannot be achieved.

It is expected that mobile robots will find increased popularity in construction industry. A fixed robot has a limited sphere of operation and is not appropriate for the construction sites.

A construction wheeled vehicle robot, such as a motor car, with firmly inflated tires represents an ideal system with minimum eneregy to operate on smooth surfaces which have sufficient friction to the wheels to propel and steer the robot without slipping. Wheeled systems can only operate over relatively smooth surfaces. The track systems are the known alternatives to wheels for rough ground mobility.

SUMMARY AND CONCLUSIONS

Seven major variables affecting on the feasibility of the robotics in construction industry were identified as: 1) cost effectiveness; 2) hazard level; 3) productivity; 4) quality improvement; 5) standardization of design and level of repetitiveness; 6) union reistance; and 7) technologically feasible. It was concluded that hazardous construction operations are the prime motivation in the U.S. to implement robotics in the construction domain. However, the problem of lower productivity in construction industry is expected to be an incentive for future use of robotics. Developing new design techniques based on standard elements and repetitive operations must be further investigated. This can result in developing entirely new techniques of construction, feasible for the robotization.

REFERENCES

1. D.A. Sangrey, Constraints on the Development of Robots for Construction, Civil Engineering Department, Carnegie-Mellon University, 1984.

2. Boyd C. Paulson, Automation and Robotics for Construction, Journal of Construction Engineering and Management, ASCE, Vol. III, No. 3, pp. 190-207, Sept., 1985.

3. Takatoshi Vend, Robotization of Spraying Work for Fire Proofing Steel Structure, Robot, pp. 53-61, March, 1983.

4. Daniel W. Halpin, CYCLONE: Methods for Modeling of Job Site Processes, Journal of the Construction Division, ASCE, Vol. 101, pp. 489-499, September, 1977.

5. Robert Carr, Simulation of Construction Project Duration, Journal of the Construction Division, ASCE, Vol. 105, pp. 117-128, June, 1979.

6. A. Warszawski, Application of Robotics to Building Construction, Paper presented at the Workshop Conference on Robotics in Construction, Carnegie-Mellon University, Pittsburgh, PA, June, 1984.