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


Les aspects socio-économiques de la robotisation

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MOTS CLEFS:
Automatisation, Industrie de construction, Analyse de faisabilité, Robotique.

Sommaire:
Le 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 champ d'application des robots de façon considérable. Dans l'industrie de la construction, les principes de la robotique ont été appliqués à certains types de construction. Des machines telles que les pelleuses de caisson, les répandautes de revêtement automatisées et les aplanisseuses à commandes de transmission informatisées sont équipées de détecteurs, et ont des capacités de traitement telles qu'elles sont possibles 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 manœuvres 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'œuvre? Comment les opérations de construction étant le plus susceptible d'être robotisées peuvent-elles être identifiées?
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; 8) 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 solution, e.g., inner leveling grade, automatic gear shifting scrapers, hydraulic excavator with bucket tilt control, or remote control construction equipment for the construction work in dangerous places; 9) 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 Shimizu 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 robots are far from attaining the performance required in an unstructured and dynamic construction field.

Large construction companies with an interest in 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 beam) which does not require any change in size or type in dangerous, then a fixed automation plant 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 the feasibility of the robotics are considered: 1) Cost Effectiveness and Economic 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 per 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 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 SEM-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 quality 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 repurposing) and thereby increase robot effectiveness.

Union resistance 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 an improvement 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) politics 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 energy 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 on 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 resistance; 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


