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A CRITICAL APPRAISAL INTO CRITERIA CONCERNING THE APPLICATION OF AUTOMATION AND ROBOTICS IN CONSTRUCTION

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ABSTRACT

Before arriving at any decision regarding the use of automated devices to perform specific tasks, it is necessary to consider a variety of factors including, health and safety, the building design, quality standard, labour cost, productivity, the project environment, mobility, available sensors and the like. In short there are three feasibility criteria that can accommodate the above factors and subsequently can shape the viability of applying automation and robotics in construction. These criteria are: Technology, Need and Economic feasibility.

This paper summarises the approach of innovation to automation and robotics (A&R) as well as the constraints imposed upon implementing this advanced technology. It then analyses the result of a survey into criteria concerning the application of automated devices in construction.

1. INTRODUCTION

The development of construction automation and robotics (A&R) have now reached the point where various modules have been presented for the economic justification of different computerised applications [1]. One of the premises of the evaluation of construction processes is that the driving force supporting robotisation of a production process is the need and economic feasibility of the robotisation. Counterbalancing this need, however, is the technological state of the art, which can either support or present formidable barriers to the automation.

The construction industry, in general, has been traditionally conservative in accepting new approaches. It appears that the rule of evolutionary, rather than revolutionary, change will continue to hold, and that acceptance of robotisation will necessary be proceeded by an automation phase. As with any process innovation, the philosophy of new robotic technology and on-site automation provide opportunities to increase output using the same size of labour force or to produce the same output using fewer inputs, especially at a time when material prices are rising .

The construction site can be regarded as dangerous and operating under difficult environmental conditions. In this respect, safety on site is now becoming of great concern to those involved in it as a result of a continuous rise in accidents over the past years. Safety statistics [2] show that maintenance activity accounted for between 34% and 50% of the total number of fatal accidents in construction. Accidents should be due to operatives' fault, either through carelessness or by the misuse of equipment, as well as mismanagement. In other cases there are some construction operations that expose the operatives to a hazardous environment such as radiation, temperature and noise. Therefore it has been suggested that the robot is able, if feasible and practical, to react safely with its environment without human intervention.

The employment of robotic devices for manipulating components designed for automation would lead to a higher level of speed and substantially reduce the construction time due to mitigating a number of outside factors such as working hours and weather conditions. Of course, full advantage of the new technology can only be achieved if management is in a position to fully utilise the shorter period of erection time. In manufacturing, great gains in performance have been realised by a new production philosophy, which leads to "lean production". This new production philosophy is a generalization of such partial approaches as 'Just in time' and TQM, time-based competition and concurrent engineering [3].

There is a direct correlation between the cost of robotised operation and the level of quality achieved. Quality in this context refers to a finished building meeting its technical specification of the client and professionals involved. Quality of a construction product can be measured according to the initial performance and appearance of the building. However the definitive test of quality will manifest itself according to time. Consequently, conformance and dimensional tolerance control can be instituted relatively easily when compared with that achieved by the integrating of the product. This implies that adequate research, development and testing should be undertaken to validate the performance of the design.

The employment of A&R devices may be considered as a piece of public and private investment and involve great capital expenditure. Such an investment can be regarded as worthwhile if there is an acceptable return on the capital employed. Firms investing in robotic systems would need to consider the degree of plant dedication and the level of their own specialisation, since investment returns can only be maximised if the plant approaches full utilisation over its useful life, perhaps on several projects of differing natures. From the public point of view, the analysis might be to investigate if there is a benefit or a loss to the community. To determine whether a robot is economically and socially feasible, given that, cost benefit analysis should be carried out.

2. APPROACH TO INNOVATION OF AUTOMATION AND ROBOTICS IN CONSTRUCTION

The approach to A&R in construction may follow three paths. Firstly, it will involve an evolution of computer technology into existing procedures. Secondly, it will be to rationalise building design and thirdly, to modify the methodologies of construction. These approaches suggest that the way in which construction is presently done will have to be modified to support the application of A&R devices. The structure of the job site and area in which a particular work process is to be achieved will have to be pre-configured to accommodate the needs of the robot. 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 research.

The author has identified and studied the relationship between variables that influence the viability of applying A&R in construction and discussed them under three main headings [4], these are, 1) the environment 2) the technological development 3) the building process. The environment represents the economics, social and political developments at a given time in a certain community. The autonomous technological developments together with the environment are the main conditions for the stimulation or the impediment of A&R, one being the pulling power of the market and the other the pushing power of the technology.

In the construction process, the building team work together in a rather complicated process to produce the buildings that are needed. They are engaged in the building process but at the same time they are responsible for the success of their business, whether it be an architect practice or a building firm. They can react on the demands of the market and on the possibilities of technology either by actions for which they are responsible in the construction process or by actions in their own firm.

The building process , as all industrial processes, has to be evaluated in terms of time, cost and quality. The technological development on the other hand will be efficient if it is a rationale process, which depends on five innovative activities, these are: the degree of specialisation, standardization, repetition, mechanization and co-ordination. The expected sequence of steps for rationalizing the innovation of A&R in construction would be:

1. The necessity to confine the operation of robots to specific related functions. This will enable the cost of the robots to be more strictly controlled whilst permitting higher levels of productivity due to concentration on a limited number of tasks. However, due recognition should be given to the need design component products, assemblies and fabrications to permit appropriate specialists to be incorporated in the automated process to be adopted.

2. Standardisation and repetitiveness of the construction activities. The amount and type of repetition for each construction operation has to be analyzed and the decision is to be made upon the cycle of operations in each work. Moreover, there is a minimum number of production units that can optimise the success of implementing a robot. Otherwise some form of mechanised system would be more appropriate.

3. Mechanisation will establish the viability of utilising mechanised processes as opposed to the adoption of manual or semi-mechanised production. Criteria will need to be established which will be able to evaluate the gain which can be achieved by the introduction of machinery and equipment to undertake specialist processes which have been, to a greater or lesser extent, standardised to form a repetitive process. The ability to introduce greater sophistication and versatility are important and crucial factors. This may be achieve by the incorporation of on board intelligence and efficient drive mechanisms of sufficient capability to achieve stated performance objectives.

4. After mechanizing the construction operations, a further factor need to be related to co-ordinate the performance of robots undertaking specialised tasks. Therefore, the variable measuring the degree of co-ordination will be concerned with the various processes which are necessary to complete the project. Some processes may place at remote sites before they are brought together for assembly. Others will occur entirely on the project construction site. Clearly there must be a smooth and co-ordinated production flow from one process to another concerned with the relating to fit and fixture will require careful appraisal in association with a balanced production flow intended to avoid unnecessary bottlenecks and delays.

3. CONSTRAINTS

Almost all robots employed in the industry operate from fixed positions. The work pieces are brought to them by means of conveyors and other automated devices. In construction, the site environment is disorganized and sometimes chaotic and, therefore, the robots in any employment must move, or be moved, from one location to another. At the present time, the technology to support this argument is only at the developmental stage. As stated earlier, the study of how the structure of the job site and area in which a particular work process might be reconfigurated to enhance and simplify the demand placed on a mobile robot is a major area of potential research relating to the implementation of robotics in construction.

The mobility requirement can only be accommodated by employing sensors which can record specific features of the environment ie. walls, corners, openings etc. The features are compered, with the aid of computer intelligence, to the pre-programmed representation of the environment, and the program is modified on the basis of discovered discrepancies. It is true to state that the technology available for other industries such an airspace can handle sophisticated activities without human intervention. The question is, why can't this happen in construction. The answer is because of lack of multitude of electronic references which can provide metrology to use determine positions. The fundamental element of metrology is the frequency which impose a major problem on building sites because of noise. A way to overcome this problem is, obviously, to develop an equipment transponder to filter out spurious signals and process the relevant ones.

Research to develop a viable reference system (ie. a job site metrology) to allow the mobile job site robot to determine position is a prerequisite to highly autonomous robots operating on the construction site. In addition to knowing position, mobile equipment must be able to sense the location of objects and obstructions. Sensing the location of other objects on the site that are themselves mobile and reposition or reconfigure on a real time basis presents a more formidable problem. In effect, the mobile robot must have a real time ranging capability (eg. a type of radar) sensitive enough to detect other mobile entities (eg. human workers, material stockpiles, other machines). The synthesis of technologies to provide this capability to construction machines does not appear to be obtainable until the next decade or so.

Another constraints of implementing A&R in construction is the problem of the social factor. Innovative methods using new technology can be used to produce the same output with fewer inputs, including less labour. There would therefore be a threat to jobs, if demand for construction work were not rising. A risk to job security would understandably be resisted. However, because of the casualisation of the labour force, piece rate working and low levels of union participation resulting in weak union representation on many sites, resistance would tend to be minimised.

Nevertheless, investment in new technology would tend to increase the degree of dependency on labour. Expensive machinery needs to be combined with reliable and skilled labour. Indeed, new skills would be required. Obtaining trained labour is an investment which would demand improve working conditions and terms of employment. Otherwise a newly trained worker would tend to leave. As a consequence of the introduction of expensive robotic equipment on site, the amount of directly employed labour would be expected to increase, while the need for casual labour would be reduced, reversing current trends and reducing contractors' flexibility. The introduction of robots needs to be planned with the labour process in mind or the introduction will be at best costly and at worst unacceptable.

Another social aspect or A&R which should not be overlooked is the attitude of management, especially low level management, to the changes introduced by this process. Because of the volatile and unpredictable nature of the construction environment, there is always a tendency to use old and proven solutions instead of innovative methods and technologies. A study of the possible social implications of A&R in building must, therefore, examine the attitude of construction management at all levels to the various possibilities of robotisation.

4. SURVEY INTO CRITERIA CONCERNING THE APPLICATION OF AUTOMATION AND ROBOTICS IN CONSTRUCTION.

The author has designed a postal questionnaire that can provide a numerical rating to allow 24 construction operations to be compared with one another in terms of overall feasibility for A&R. The major factors of feasibility are identified as need, economic and technology. The characteristics supporting the need for A&R in construction, are: 1) labour intensiveness 2) vanishing skill 3) requires high skill 4)dexterity, 5) repetition 6) tedious & boring 7) unpleasant and dirty 8) Health & safety. The Economic benefits of R&A in construction are basically due to the following: 1) productivity improvement 2) quality improvement and 3) saving in skilled labour. The technological areas against which each construction process was evaluated include, 1) material handling 2) control software 3) control hardware 4) required sensors and 5) end effectors. The questionnaire was sent to 35 organizations including experienced practitioners, contractors and construction researchers. 14 questionnaire were fully completed and Table 1 show the average rating for the three feasibility criteria. High, moderate and low ratings were analyzed using the 'Box Plot' technique of the Minitab statistical package.

Table 1 -
Need, Economic and Technology ratings

Highly rated factors	Score out of 10	Moderately rated factors	Score out of 10
Material handling	7.00	Control hardware	5.90
Critical to productivity	6.60	End effector	5.90
Productivity improvement	6.50	Saving in labour	5.90
Control software	6.50	Labour intensiveness	5.90
Required sensors	6.50	Required high skill	5.90
		Dexterity	5.70
		Repetition	5.60
		Quality improvement	5.40

4.1 Technological Feasibility

Analysis of the result indicate that, the first factor driving the development of A&R in construction is the technological feasibility within the context of the existing or projected state of the art.

Table 1 show that material handling, control software and required sensors have scored very high as a result of the well developed technology. Certain characteristics of the processes that rank as highly feasible from a technological point of view were identified. Processes related to surface areas and require no heavy material application (eg. sandblasting, bush hammering, concrete placement, crane operations, painting, fireproofing, inspection, excavation) have desirable characteristics. For instance, the precision required in painting is very high. The parameters to be sensed are the points of application, consistency and thickness of the paint coats, and the rate of application. The environment in which the painting robot has to work is generally structured and the presence of corrosives, humidity, harsh temperature, dust etc. can generally be controlled. State-of-the-art sensors are able to handle the general requirements of painting. On the other hand, those processes that rank low in technological feasibility require complex operations involving the movement and attachment of solid objects to a fairly high level of precision (eg. Plumbing and structural pre-cast, steel structural).

4.2 Economic Feasibility

Analysis of the questionnaire indicate that the first factor in economic feasibility is productivity improvement. Productivity might be measured by the value of the finished building divided by the number of people directly employed on the project. Gross output may be said to be the value or price of the finished building. Net output is the value of gross output less the value of prefabricated components. In other words, net output is a measure of the value the contractors and sub-contractors add to components by assembling them on site. Response to the author's questionnaire indicates that, implementing A&R can improve the productivity of construction processes such as bricklaying, fireproofing, grading, inspection, masonry, precast processes and tunnelling.

The second factor that was considered high in economic analysis is saving in skilled labour. Processes such as bricklaying, fireproofing, inspection, masonry, painting and tunnelling require highly skilled labour, and automation can save in skilled labour costs. Saving in labour is a prime issue in justifying a robot in a long-term planning. High and rising labour costs can be expected to accelerate the utilization of labour-saving technology in general, and automation in particular. However, many intangible indirect costs associated with bringing a robot on the construction site and maintain it are often overlooked

The third factor is quality improvement. The automation is expected to improve the quality of inspection, precast processes and steel fabrication. Quality of a construction product can be measured by a numerical model that considers such characteristics as strength, dimension, colour, etc.

4.3 Need feasibility

Table 1 show that Labour intensiveness and requiring high skill have scored moderately high in the author's survey. Construction processes such as tunnelling, precast cladding, masonry, bricklaying and fireproofing) scored high against this economic set of variables. They are considered as highly labour intensive which require handwork of positioning, connecting, attaching and finishing which are a main working task of such processes. For instance, positioning a large cladding panel at the appropriate location and orientation, requires at least 3-4 workers. Connecting and attaching similarity require a high level of manpower skill for optimal installation. The level of skills required is very highly correlated to the level of precision required for different tasks. For instance, certain processes require a high level of skill to ensure evenness of adjoining surfaces in all directions.

Surprisingly, the issue of health and safety were only scored high to (sandblasting, fireproofing and tunnelling). All other processes were given either a low or moderate scoring. This was explained by the assumption that safety may have been seen as part of the management system and emphases should first be made on education and training rather than improving technology.

5. CONCLUSION

This paper has discussed the approach to innovation of A&R in construction and the constraints imposed on implementing this new technology. It became apparent that the efficiency in the construction industry is depending on the degree of efficiency of the building process, measured on the basic of evaluation of time, cost and quality and on the degree of the efficiency of the developed technology, measured by the degree of rationalization.

The potential for using A&R in construction is very great with associated benefits to owners, builders and labours. This paper has been concerned with critical analysis of A&R against the need, technology and economic feasibility. Analysis of the results indicate that material handling, control software and required sensors have scored very high as a result of the well developed technology. Tasks that require the movement and attachment of heavy objects are not feasible using the present technology.

The ability to recognize structure represents the key element in achieving greater A&R in the construction industry. It will require rethinking of how things are done and a serious consideration of how new technologies can aid in structuring construction processes. A new look at designing tasks and designing facilities based on the use of field automation is needed before this technology can be fully utilized. This issue needs further research.

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