THE FEASIBILITY OF CONSTRUCTION ROBOTICS IN FINLAND AND NORWAY

Lauri Koskela, Heikki Lempinen, Esko Salo

Technical Research Centre of Finland
Vuorimiehentie 5
SF-02150 Espoo, Finland

Thorvald Wetlesen

Bever Control Ltd
P.O. Box 58
N-3408 Tranby, Norway

ABSTRACT

This paper reports on the results of a Norwegian-Finnish feasibility project on construction robotics, carried out in 1988. The aim of this project was to determine and evaluate the most suitable robotization themes from the point of view of the construction industries in the respective countries. Functional requirements and preliminary technical solutions were charted for seven themes: crane automation; automation of the prefabrication of facade components; robotization in inner works; equipment for materials handling on site; masonry robotics; concreting automation; and measurement, positioning and navigation techniques in construction.

1 Introduction

The Norwegian-Finnish feasibility project on construction robotics was carried out in 1988. The project was realized by the Technical Research Centre of Finland (VTT), Norges byggforskningsinstitutt (NBI) and Senter for Industriforskning (SI). The aim of this project was to determine and evaluate the most suitable robotization themes from the point of view of the construction industries in the respective countries. From Finland, fifteen companies participated in this project, and from Norway three companies.

Firstly, experts from the construction industry were interviewed in order to collect needs and ideas for robotization. From these ideas, seven construction robotics themes were chosen for further analysis. The themes were crane automation, automation of the prefabrication of facade components, robotization in inner works, equipment for materials handling on site, masonry robotics, concreting automation, and measurement, positioning and navigation techniques in construction. The five first robotization themes were mainly addressed in Finland, and the remaining two in Norway. Prefabrication of components and robotics for inner works were analyzed in parallel.

Next, functional requirements and preliminary technical solutions were charted for each theme. This was done in collaboration with industrial working groups, composed of experts from the participating firms.

The project resulted with technical specifications for a preliminary robotized solution for each theme and corresponding project plans for further development.

2.1 Crane Automation

The feasibility study analyzed both the need for crane automation and its implementation possibilities. The central aim was either the partial or complete automation of the crane's working cycle, which, if properly realized will reduce the need for labor, increase work safety, improve the crane's ability to perform services and reduce the crane capacity required on site.

The study analyzed those operational stages of the tower crane that can be automated and their developmental targets. It also assessed the prerequisites for automation (for a wider treatment of these, see [1]), the need for development of methods and technology as well as the profitability of automation applications. Emphasis was given to three stages that are central to the automation of the crane's working cycle: automation of gripping and releasing, automation of motion control and automation of load positioning.

On the basis of the above analysis, concrete automation application ideas were developed, which were then worked into five suggestions for a pilot study:

- automatic attachment and release of load
- automated lifting accessories changing magazine
- computer-assisted manual control devices
- automatic motion control
- automation of installation-related support.

Automatic attachment and release of load was chosen as the final pilot study subject to which the idea of an automatic lifting accessories changing magazine is connected.

The pilot study, to be started on the basis of this feasibility analysis, aims at making the attachment and release stages of a load more efficient and quicker. It will develop a new type of attachment system where the attachment of the load to the hoisting cable is automatic and release is by remote control. The system is, in principle, applicable to all types of cranes - its use is not limited to tower cranes.

Technically, the aim is to design automatic control for the attachment and release of crane-hoisted loads and the associated aspects of

- mechanics: structures, attachments, locking devices, etc.
- sensors and electronics
- control system and method.

The functioning of the designed solutions will be tested by miniature or actual size test equipment that can be used to test the attachment and release functions of, e.g., concrete and steel components and concrete buckets. The gripping device design also takes into account the need for it to be able to operate jointly with the automatic lifting accessories magazine. The prototype equipment will be tested, if possible, in the course of the study at a selected location which might be, e.g., the stockyard of a component plant.

2.2 Automation in Prefabrication

The second robotization theme was flexible automation of unstandardized prefabricated facade components. The main emphasis was on concrete, but the results can be extrapolated to steel profile facades.

The production of prefabricated concrete facade components suffers nowadays from many problems. Clients expect increasingly individual architectural appearance of facades, quality and tolerance demands are increasing and the size of the production series of components is approaching one. This leads to time consuming, expensive and arduously controllable manual craftswork. Dusty and uncomfortable prefabrication plants do not offer much to attract employee candidates other than high salaries.

In the feasibility study, firstly, the production process of prefabricated concrete facade components was modelled. In total 13 separate work phases were listed. Work rate data were gathered for each phase and detailed material flow descriptions created. The present design process, production technology possibilities, clients' needs, delivery conditions such as the installation succession of the components on-site, production management methods and data transfer techniques were also charted. Efforts were made to take into account the anticipated changes within this environment over the next 5 - 10 years.

On the basis of these data, four outstanding development needs were identified:

* materials handling arrangements
  - the fundamental philosophies like JIT
  - production line solutions; should the frame tables remain immobile or should they be movable to specialized work cells
* framing techniques development
  - NC-machine tooling for frame production
  - automatic frame assembly
* dimensional quality assurance
  - frame dimension measurements during the framing phase
  - dimension checking of the completed product
* frame assembly, reinforcing, accessories fitting, concreting and surface finishing by a multifunctional automaton.

It seems that a gantry type robot could yield a basic answer to the problems of dimensional quality assurance and multifunctionality requirements. Nevertheless, questions regarding the production line and materials handling arrangements still remain. Furthermore, neither the present constructive structure of facade products nor market demands currently call for highly automated production lines.

If one is willing to automate under these conditions, the key word is flexibility. To reach the required flexibility, a further research project is being established. The project is fourfold:

* The structure of concrete facade components will be redesigned in view of the possibilities and limitations of automation.
* The production line alternatives will be verified by a simulation package. Both discrete simulations of the entire production line and kinematic simulations of individual machines are to be made.
* Production controllability, data transmission, and CIM-concept will be examined in an information management subproject, with emphasis on off-line -programming solutions (the aim is to link CAD-information to the control system of each automaton).
* The main features of the whole concept will be tested and evaluated by a pilot robot; the results will be especially pertinent to production line design.

2.3 Robotization of Inner Works

Inner works is a wide area to examine; consequently the industrial work group that was founded for this theme set some boundaries for the investigation. The featuring work phases were wall and ceiling surface treatments: (1) spraying works like painting, plastering and sand blasting, (2) grinding, polishing etc. works, (3) minor demolition works.

Essential factors to justify the robotization of these tasks are the following:
- the tasks are monotonous, severe and unhealthy
- the tasks are at present almost entirely carried out manually, which leads to the fact that no significant productivity increases can be expected
- the tasks are often on the critical path of the construction project and by catalyzing these processes, notable savings can be achieved.

Work process and work rate data were gathered for the basis of the feasibility assessment. None of these tasks can be said to be eminently viable for robotization in themselves. It was realized that each of these tasks is inherently non-static, requiring the craftsmen to remain typically only a few minutes in one place. This in itself constitutes considerable hindrance to robotization.

The working group stated that these requirements could be fulfilled by a solution, which can be compressed into four key elements: mobile; modular; multi-purpose; gradually autonomous.

The core of this kind of robotic system is a mobile platform, which in different versions
- should be autonomously guided within a limited working area inside the building
- could be utilized by itself as a material transportation device
- should serve as a basis for interchangeable manipulator arms with specific tooling.

The main problems concerning the concept, are quick task definition interface for the controller, the co-operation of the platform and programmable manipulator, navigation and positioning techniques and, especially in the plastering works, adaptation of suitable plastering material to ensure proper quality.

As the result of this feasibility study and earlier Swedish studies, a co-operative project between Norwegian, Swedish and Finnish research institutes and construction/automation enterprises was specified. In this project, the following targets have been set:

1. Motorized, remote controlled platform for materials handling.
2. Conceptual design of a manipulator family mounted onto the platform.
3. Design of a remote controlled and partly programmable manipulator for plastering or painting works; also an off-the-shelf industrial robot product may be directly applied.
4. Development of suitable tooling and material supply for the system.
5. Development of methods for automated navigation, positioning and controlling systems for the entire concept.
6. Piloting and evaluating the fundamental techniques of the concept for the basis of a product development.
7. Development of the methodology of construction robotics R & D -work.

The study was started at the beginning of this year (1989) and will continue until the summer of 1991. The participants in this study are the Technical Research Centre of Finland (VTT), the Royal Institute of Technology from Sweden and the Norges Byggforskningsinstitutt (NBI) and the Senter for Industriforskning (SI) from Norway.

2.4 Materials Handling

The group focussed here on materials handling in inner works. It was estimated, that the share of materials handling from the total work input in inner works is 25-30 %. Problems in materials handling were charted by means of site visits and interviews. One could state that especially the horizontal transfers are underdeveloped: workers still carry large amounts of material; knowledge on existing tools and equipment is scarce; disorder and untidiness make it difficult to move material.

Thus, in the short term it will be profitable to concentrate on practical development of present materials handling systems: enhanced planning methods, order and cleanliness, new delivery principles, and new packaging and palletizing methods.

For the purposes of long-term development, the feasibility of an automatic materials handling system was analyzed. The foremost idea is that the materials could be moved semi-automatically from their unloading place to the floor, and possibly to the final place of installation. Such a system was roughly specified. The following interconnected subsystems were sketched:

- an unloading platform
- an automatic warehouse
- an elevator for vertical transfers
- a motorized carrier (or AGV) for horizontal transfers.

In order to establish the economic feasibility of the system, a case building project, due to start in the spring of 1989, was chosen. The materials handling costs, when the present methods and alternatively an automatic system are used, were estimated for this project. The results from this calculation exercise indicated, that profitable use of at least some of the subsystems, mentioned above, in the near future cannot be barred. In order to verify these results, a follow-up of resource use for materials handling in the designated project is planned. Another useful approach would be the simulation of the functioning of the system.

The conclusion was, that the implementation of such an automatic materials handling system requires several phases, which may be profitable as such. The practical short term development of materials handling, as described above, is, however, a prerequisite. Partial systems for vertical and horizontal transfer can be developed and utilized. Only after these steps, can the total system be configured and implemented.

The development of horizontal transfer systems seems to be a feasible goal both in the short and long term. In the short term, the goals are:

- the motorization of the carrier for
    - load carrying capacity on stairs and other uneven terrain
    - providing for power source for manipulators and other devices connected to the platform, and
- an equipment product family, providing for tools to be mounted on the carrier for the
    - loading and unloading of pallets
    - gripping of special types of loads, e.g. boards, doors
    - hoisting and positioning of materials during their final installation.

In the long term, the carrier should be equipped with various navigation and positioning features, as well as with the necessary informational and mechanical interfaces for other parts of an automatic materials management system.

The development of a materials handling carrier as outlined is included in the research project described earlier in the section 2.3.

2.5 Masonry

The masonry robotics subproject is described in detail in [2].

2.6 Concreting

Three areas have been identified as requiring automation where the present day technology seems feasible. For all three areas, proposals for development projects or experiments have been formulated:

- Automatic control of a concrete distributor. Automatic control may have two levels: Control with a joy-stick by the operator, or automated distribution of concrete according to a predefined pattern.
- Self-adjusting levelling and vibrating beam. Levelling and vibrating is presently carried out manually using very simple equipment, and this is the stage in concreting which requires the most resources. A concept of an automatic levelling/vibrating beam, with a laser control for vertical adjustment has been devised.
- Autonomous trowelling machines. It is currently pertinent to test existing Japanese machines under Nordic conditions.

2.7 Measurements and Positioning

Data on position and dimensions are often a prerequisite for automation. Traditional measurement is time consuming and does not give continuous position data. Therefore, the potential of laser based continuous position registration has been investigated. The following applications have been addressed:

- 3-dimensional position registration for positioning and orienting a rock drilling machine.
- Vertical adjustment for road levelling equipment. In Norway, roads usually have widely varying degrees of camber. Thus in road levelling, 3-dimensional position registration is needed for vertical adjustment of the levelling blade.

3 Experiences and Observations

In contacts with industrialists during the project, a number of recurrent issues were raised. It turned out to be profitable to structure the discussions by means of three dichotomies, presented in Figure 1 as a cube. The issues addressed were the following:

1. Shouldn't we concentrate on mechatronization of the present construction machinery instead of aiming at real robots, impractical on sites?
2. Instead of trying to put up construction robots, shouldn't we develop and reorganize the whole construction process first so that robotization becomes possible?
3. Shouldn't we concentrate on relatively simple, specialized devices, which have proved profitable in the manufacturing industries, instead of on complex multipurpose construction robots?

In most issues, the critical aspect is that of the time frame:

1. In the short run, the mechatronization of present machines will surely provide for most technological and business opportunities. However, in the longer run, the area of technological and economical feasibility will grow considerably, and research is needed in order to prepare for that.
2. Adaptation of the present construction process and operations is certainly needed. However, in a situation where the competence in construction robotics is rare, it may be wise first to confine efforts to present construction technology in order not to launch too complex endeavours.
3. The trade-off between specialized and multipurpose machines should be considered case by case. Often the individual work operations have such short durations, that an economy of scope (instead of scale), and thus several functions, are needed.

Another interesting issue is that of the great number of latent needs and ideas unearthed during the project. It seemed as though contact between the worlds of construction and robotics has been hitherto minimally explored. Indeed, in this respect, a recent theory in innovation literature, called the innovation triangle (Figure 2), seems to be of great explanatory significance. The theory states, that the most fertile soil for innovation is where the problems of old products or processes, new scientific or technological possibilities and the real needs of the users are simultaneously considered [3]. This is best achieved by engaging respective research, producer and user organizations in the development process. Indeed, building-up of such innovation triangles should be included among the goals of national construction robotics programmes.

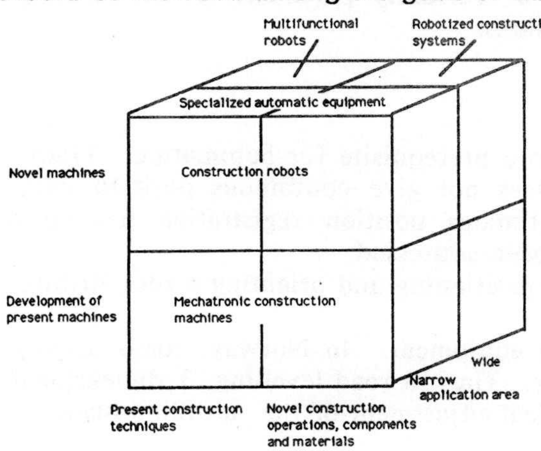

Figure 1. The construction robotics cube

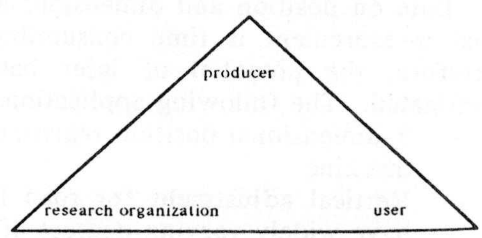

Figure 2. The innovation triangle

REFERENCES

1. Elsilä, M., Koskela, L., Lempinen, H., Pieskä S. & Salo, E.: An Integrated Approach to the Development of Construction Site Crane Operations. Proc. of the 5th ISRC, June 6-8, 1988. Tokyo, Japan. JSCE, AIJ, RSJ & JIRA. P. 643 - 652.

2. Lehtinen, H., Salo, E. & Aalto, H.: Outlines of two masonry robot systems. Paper to be presented at the Sixth International Symposium on Automation and Robotics in Construction, June 6-8, 1989, San Francisco.

3. Lemola, T. & Lovio, R.: Possibilities for a small country in high-technology production - the electronics industry in Finland. In: Freeman, C. & Lundvall, B.Å. (ed.), Small countries facing the technological revolution. London, Pinter, 1988. 303 p.