CONSTRUCTION AUTOMATION AND ROBOTICS IN AUSTRALIA - A STATE-OF-THE-ART REVIEW

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ABSTRACT

In this paper the current state of the art in the field of constructional robotics and advanced automation in Australia is reviewed. The status of general robotic engineering in Australia is firstly discussed and then the commercial applications scene is reviewed. The current extent of robotic use on site and off-site is surveyed and some studies of the implications of widespread robotics use are presented. The direction of current advanced thinking in building and constructional robotics is discussed. It is concluded that the potential of robotic technology in Australia is far from being recognised or exploited.

Keywords:- Robotics, construction processes, automation, mechatronics.

1. INTRODUCTION

Australia is a large, low rainfall, country with a low population density. It has advanced natural resources and mining sectors and has a large and sophisticated computer software industry. It does not however have a very large manufacturing or mechanical engineering industry but has a well skilled and well educated labour force and excellent urban and communications infrastructure. It is politically stable and there are no language difficulties throughout the country. Its indigenous markets are small and dispersed. Its export markets are far distant.

Against this background it is clear that constructional automation and robotics in Australia will have developed and be developing in a way relatively unlike developments in other areas in major industrial countries such as West Germany or Japan.

The aim of this particular paper is to review firstly some of the tangible achievements of constructional robotics and automation development in Australia and secondly to indicate by a review of some current research some of the current thinking of researchers in the industry as to future developments.

2. SOME PROBLEMS OF APPROACH

In attempting to define the state-of-the-art in this field some major conceptual dilemmas occur. Should one be using as measures such things as the number of constructional robots per person, the degree of penetration of "smart" machines into the workplace, the engineering impressiveness of projects, the commercial success of installations or the overall impact of "mechatronics" in the country? Each of these points of view will highlight different aspects of a countries development. Alternately should one try to rate a country in terms of the overall expertise that country can display in terms of overall robotic technology or in

terms of on-the-ground commercial installations?

The approach used in this paper will be a generalised one with perhaps a little bit of each of the above approaches. The term "robot" though will be used here not in the task specific automation sense (as perhaps used normally by the Japanese) but instead in the wider flexible-automation-reprogrammable-machine sense.

3. DEVELOPMENTS IN OVERALL ROBOTIC TECHNOLOGY

In broad, one can decompose the technology of practical robotics down into a quite small set of constituent elemental technologies. These may be considered to comprise sensor technology, control technologies, mechanical engineering technology, artificial intelligence technology and advanced computing technology.

In terms of elemental technology expertise the following items are perhaps worthy of mention in relation to the Australian scene:-

- In terms of overall robotics systems, the Australian Wool Board's work on automation of the shearing of Australia's ten of millions of sheep is proving to be one of the world most challenging commercial robotics projects in terms of total technology. The practical problems of emulating the complex actions of manual shearing on a size variable target item are very considerable. The solution of this problem has required a number of new robotic and sensor technologies to be developed. These include acoustic proximity and fail safe touch sensors as well as sophisticated adaptive trajectory control methods for overall process control. The sensor technology and the transputer based control systems for the automated sheep shearing project in Western Australia are of world note relative to this task which involves a non-traditional applications problem in a complex environment (Refs 1-2).
- The development of an underground emergency rescue vehicle, called the Numbat, for underground use especially in mines which may contain explosive gases (Ref 3) has involved some interesting technology items. These includes stereoscopic TV systems for the development of "tele-presence".
- At the level of the elemental robotic technology of computer vision, Australia's major steel manufacturer, BHP, has developed advanced computer vision systems that recognise numbers stamped on red hot steel billets as they pass through steel mills thereby allowing the use of computerised quality and process control methods in automated steel billet rolling operations.
- A number of interesting environmental sensing tools such as imaging tactile sensor are being developed at Monash University in Melbourne (Ref 4).
- Smart gripper technology is being developed for the handling of soft and delicate items for the Australian soft-fruit industry (Ref 5)
- The Australian Government department of Industrial Relations and Technology is supporting major development work through its "generic technologies" programme on programmable array manipulators - a new generic form of intelligent robot that can simultaneously manipulate and array objects under program and feedback control.

- A company in Perth has developed technology for extracting data from the environment using photogrammetry techniques based on cheap 35mm lens technology.

In terms of combining these elemental technologies into commercial applications in traditional and non-traditional areas the following projects may be noted:-

— The Australian Company of Machine Dynamics has over a period of years recently supplied some 47 "Journeyman "overhead gantry type robots to the Ford Motor company in South Australia for the fully automated manufacture and installation of automobile doors.

— Qantas airlines is currently using robotics to array food and cutlery items on airline passengers trays.

— The Australian Sugar Industries is exploring robots as a means of performance of some of the complex routine physico/chemical quality control screening processes needed for the mass production of sugar (Ref 6).

— Australia has a small niche robotics industry in the field of off- shore structure and ship cleaning. In this use remotely controlled equipment removes marine fouling from below and within the tidal and splash ranges.

— Australia has the world's highest usage of arc welding robots relative to population with the use of these items being predominant in small jobbing type manufacturing industries rather than in large production line systems.

— Overall Australia has a robotic population of some 1350 units - which is high in relation to its population.

— Australia has a sophisticated defence industry whose use of robotics is not fully disclosed. The Hover Rocket project for is an example of the sophisticated control technology in use.

4. SOME CURRENT COMMERCIAL BUILDING AND CONSTRUCTION APPLICATIONS

In contrast to what is achievable at the limits of engineering knowledge or in terms of industry and commerce in the general sense the current commercial applications of robotics in the field of Australian construction are perhaps quite restricted. They fall basically into two distinctive categories. Off-site constructional robotics and on-site constructional robotics.

4.1 OFF-SITE ROBOTICS APPLICATIONS

It is convenient when discussion off-site robotic technology relative to the building and construction industry to define three types of off-site operations.The first is automation within the various factories and manufacturing establishments that comprise the generic or non-customer specific building products and components industry. Included here, at the small products end, are such things as windows, tiles, panelling and so on. At the heavier end one has such things as large diameter concrete pipes, structural steel light standards and builder's site sheds.

A second style of off-site production may be considered to be products which are customised to a specific customer's specification and cannot be made in advance of specific

orders. This would include many type of precast concrete product and structural steel fabricates. It would also include such single technology activities as specialised timber truss manufacture, air conditioning duct manufacture and steel-piping fabrication.

A third class of off-site process could be considered to be prefabrication and assembly operations related to the synthesis of a number of technologies into the production of the specific assemblies and sub-assemblies involved in the construction of a facility. This might include such activities as the pre-glazing of windows, prefabrication of lighting fixtures and so on.

(A) AUTOMATION WITHIN THE NON-CUSTOMISED BUILDING PRODUCTS SECTOR

Quite a number of companies who supply generic or non-customer specific building component and products suppliers within Australia are using robotic technology within their manufacturing operations. These typically are based on standard static manufacturing robot technology supplied by international companies. The main applications encountered are in the fields of palletisation, hot-melt and other forms of gluing, cutting, welding, product transfer between work stations and product inspection and checking.

Some of the more interesting current application here include the use of robots in :-

i. The production of aluminium access scaffolding systems using a robot on a track such that it can reach 4 distinct workstations.
ii. The use of robots to remove hot ceramic sanitary-ware products from their firing kilns.
iii. The use of robots to polish the interior of polyurethane and other types of plastic bathroom vanity bowls.
iv. In the production of gates and stockyard fencing.
v. In the production of sets of rockbolts for underground ground support, some 3000 nuts and caps are jointed daily by a five axis robot.

(B) AUTOMATION WITHIN THE CUSTOMISED BUILDING PRODUCTS SECTOR

Some items of interest in this category are as follows:-

i. One of the few robotics developments that would be recognised by workers in the building and construction industry as addressing distinctively construction activity is the manufacture of pre- fabricated load bearing reinforced brickwork panel by a Panelbrick Industries Pty. Ltd of Sydney. In what may be one of the first commercial robotic applications in the world this company has had a "robot" based manufacturing system in operation since early 1990.

The operation involves a custom made robotic taking assorted sizes and types of bricks and placing them in variable layout arrays on a ground level tilt-up tray. These bricks are pre-reinforced with bars passing through the brick core holes prior to the action of the placement arm. After arraying the bricks superplasticed concrete is spread over the rear of the bricks to grout the reinforcing bars into position and to grout the joints in the bricks. Once cured the load bearing brick panels are tilted into the vertical plane and transported to site.

The exact disposition of bricks for straight panels, panels that include window or doors and special end panels is flexible and is determined by means of a CAD system.

ii. A second current application in the customised fabrication arena is the fully automated construction of the steel frames and roof trusses for brick veneered bungalows in project home construction. Full technical feasibility studies has been established by a major robot supplier but final commercialisation studies have not yet been completed. The application here involves the suspension of an industrial robot from an overhead gantry operating on programmable tracks. A CAD system driver defines the basic configuration of the frame elements and identifies the nodes to be welded and their geometry. Probes on an arc welding head establish its exact position for the fastening operation.

iii. Experimental comparisons between the productivities of manual and robotised welding of stud type shear connectors on steel beams for composite construction has shown a 300-400% advantage of the mechanised operation over the manual method

(C) AUTOMATION WITHIN THE OFF-SITE ASSEMBLY AND FABRICATION SECTOR

There are no known examples in this category at present although the robotic assembly of rockbolt systems cited above may fall into this class.

4.2 ON-SITE ROBOTIC APPLICATIONS

Whilst there are currently no known commercial site applications of constructional robotics in Australia there are possibly four developments in this area that are worthy of mention.

- Some decade or so ago, Mount Isa Mines in Queensland began experimenting with remote controlled load-haul-dump vehicles in mining. Whilst technically O.K. most of the time the machines occasionally went "mad". The problem for the human operators was being trapped in a tunnel with a "crazed" truck. Such difficulties are real and must be considered in practical field applications of fully autonomous machines.
- The Swedish firm Atlas Copco has from 1986 marketed a range of robotic boomers for underground construction which allow a rock face to be drilled fully automatically with no operator being present. Whilst these machines are highly advanced technically and are proven mechanically attempts to introduce this level of technology into the Australian underground construction have been unsuccessful to date. It would appear that the industry is currently unable or unwilling to accept the level of discipline these machines impose on the site in terms of the requisite planning, coordination and management functions. The result is that Atlas Copco has taken a technological step backwards and is now concentrating virtually totally on non- autonomous machines in which the technology merely assists an operator rather than replaces him.
- There is some considerable interest in the idea of fully automated trucks in the mining industry but this interest has yet to translate into actual practice.
- One major project that is directed specifically towards the problems of field construction and which is in its proto-type testing phase relates to the development of a range of general purpose large capacity/large reach programmable manipulators for

general site applications.

Extra information about these manipulators and the rationale behind them is given elsewhere in these proceedings (Ref 7). Suffice to say for the present that "Macro-manipulators" are a form of generic technology aimed at bringing robotics technology outdoors, where all weather operations and mobility needs prevail, and is aimed predominantly at the construction, forestry, off-shore, underwater and mining industries.

5. WIDER ROBOTIC RESEARCH AND SOCIOLOGICAL STUDIES

To date in this review attention has been focused on hardware developments and applications technology, a major study recently completed relates to the important area of the sociological implications of advanced automation and robotics in construction. Questions of labour displacement, union attitudes and social cost- benefits are important relative to the wise and appropriate use of robotics. Further a knowledge of the potential impact of mechanisation in the construction industry has implications for man- power planning, training and industry development.

In this context the work of Cecily Neil of the CSIRO is of note in that it is believed to be possibly the world's first major building and constructional robotics research study carried out by a professional sociologist. Sociologists have a different "mind-set" to that of engineers and can in some ways be more objective about the social cost-benefits of automation than persons with a science or engineering background. For example engineers are unlikely to think in their development programs about setting up sociological programmes to pave the way for development and to assist workers to cope with the advent of new technology.

Ms. Neil's study (Ref 8,9) for instance is a quite comprehensive study of all the factors that might relate to the introduction of an advanced technology into a traditional field. It includes discussion of :-

- The potential advantages of constructional robotics - taken across the board.
- The organisational characteristics of the Australian building and construction industry as they may relate to the robotisation process. This includes an analysis of the demographic characteristics of the industries workforce, Union attitudes, training issues, sub- contracting practices, the boom-bust nature of the industry and so on.
- Social implications of the introduction of robotics. This includes matters related to job displacement and loss, job satisfaction, control of the labour process, the possible growth of cartels and environmental issues.
- The strategies that might be applied by a nations leaders to maximise the social benefits of robotisation and to minimise its social disruption.

6. THE CURRENT PRIMARY THRUSTS OF AUSTRALIAN ROBOTIC RESEARCH.

Australia has a number of people with special interests in robotics but these interests are spread across all the engineering disciplines plus psychology and cognitive science. There are though only a very few active researchers or research groups with a special interest in the problems of the construction industry. The overall thrust of the existing groups may be considered to lie in four principal directions:-

i. An effort to the integrate the country's diffuse human resources in robotics into an synergistic whole. Thus for example at the University of New South Wales a hardwired computer connection is being developed between the robotics labs of the Schools of Civil, Mechanical and Electrical Engineering such that resource sharing can happen and researchers in cognitive science and artificial intelligence can access real manipulators and problems for study. Similarly applications workers can gain access to high levels of real-time computing power and AI strategists to supplement their energies.

ii. The continuing development of hardware for general purpose programmable manipulators suited to the industry's special needs.

iii. The exploitation of the country's expertise in the fields of computer software and artificial intelligence to control hardware. The CSIRO's main interest, for example, over the foreseeable future is in the provision at a national level of AI, expert system and neural network planning and control tools for robotic activity.

iv. The third thrust area is that of the development of technology for the demonstration of the feasibility of a complete integration of the building design and production processes through a coupling of CADD technology and constructional robotics technology such that a building can be produced fully automatically from a computer created blueprint. If we designate this coupling of technologies by the initials "CIC" (for computer integrated construction) then it is suggested that CIC is fully possible. Demonstrations at UNSW with CATIA (a CADD integrated robotics simulation tool) and an ABB robot are in the progress to yield a full scale complete demonstration of the practicability of CIC in construction. CIC is a process that is believed will eventually revolutionise construction activity worldwide.

7. CONCLUSIONS

In terms of basic research and applications potential the Australian robotics industry would seem to be both highly active and imaginative. At this stage though it would be fair to say that this knowledge and imagination has yet to be realised in terms of commercial systems and devices. Robotics in Australia is still significantly in its infancy and advanced automation and robotic technology has yet to begin to penetrate in any significant way into traditional on-site construction practice excepting perhaps in the fields of mining and tunnelling. Indications are that a major impetus for field robotics in construction in Australia is yet to come. At the moment there are only hints of the emerging revolution.

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