# DEVELOPMENT OF MACRO-MANIPULATOR BASED ROBOTIC SYSTEMS FOR GENERAL CONSTRUCTION USE

Jonathan O'Brien
Department of Civil Engineering,
University of N.S.W.
P.O. Box 1, Kensington, 2033
Sydney, Australia.

## ABSTRACT

This paper introduces the concept of macro-manipulators as the means whereby the full robotisation of construction may become practicable. Two examples of full scale machines which are in the process of commercialisation are presented to illustrate the feasibility of the technology. The paper examines in brief the applications potential of these devices in relation to the broad processes that comprise construction and draws the conclusion that M-M based robotic technology constitutes a new high technological frontier in the field of construction methods and equipment and that it offers considerable real future benefits to the building and construction industries.

Keywords: Manipulators, construction methods, robots, building systems, construction processes, automation, mechanisation.

## 1. INTRODUCTION

Given the undeniable success of robotic technology in the manufacturing and industrial sectors of the economy, many people have speculated that if analogous technology could be applied to the problems of building and construction that significant improvements in productivity, safety, quality and speed of construction could be achieved.

Whilst in principle the transfer of such technological ideas from an established industry to a new one would seem quite straightforward, in practice the construction industry has a number of features, such as scale and weather exposure, that make it quite different from the manufacturing sector. In addition the construction industry's cost- structure is considerably different from that which applies in the mass production industries. These primary differences generally combine to make the normal range of manufacturing industry robotic devices either technically unfeasible or commercially unsuited to the bulk of building and construction activity.

Taking this as a base point, it would seem that a whole new range of technological apparatus is required to be developed by the construction industry itself if the industry is to reap the benefits offered by robotic technology. The development of appropriate robotic apparatus, especially as it is required to be tailored to the special needs of the construction industry, is the subject of this paper.

## 2. THE PROBLEM OF SCALE

Figure 1 shows a typical manufacturing industry robotic machine. The unit illustrated is an ABB series IRB 2000 robot which is located at the University of N.S.W.

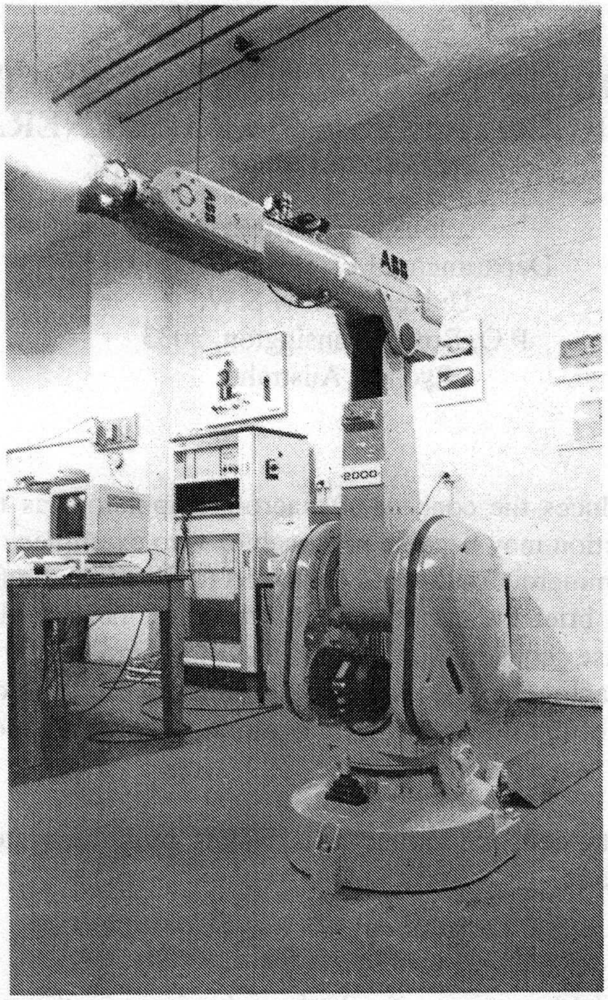

**Figure 1.** An ABB IRB 2000 series industrial robot

The ABB machine was installed in mid- 1990 and constitutes the state of the art in industrial robotic technology. The machine is capable of some amazing acts of manipulation and dexterity.

Sophisticated though this machine undoubtedly is, its utility to a construction engineer is extremely limited due to the fact that:-

i. The maximum cubical shaped object that it can work upon is only around 0.5 metres in side.
ii. It has a maximum effective payload of only a few kilogrammes. The result is that the maximum load that can be dealt with is of the order of scale of a normal single house brick. This is despite the fact that the machine itself weighs around 400 kg and needs around 300 kg of control equipment.
iii. The machine is bolted down into one place and hence all work must be brought to the machine rather than vice-versa.

This example illustrated the problems of scale and mobility in constructional robotics. Given that workpiece sizes in construction are of the order of tens of metres cubed and movable devices are required the "stock-standard" manufacturing technology has obvious limitations.

## 3. MACRO-MANIPULATORS AND THE IDEA OF APPROPRIATE SCALE

If one reflects upon the construction of the ABB robot it can be perceived that the robot is in fact comprised of two distinct parts as illustrated in Fig 2.

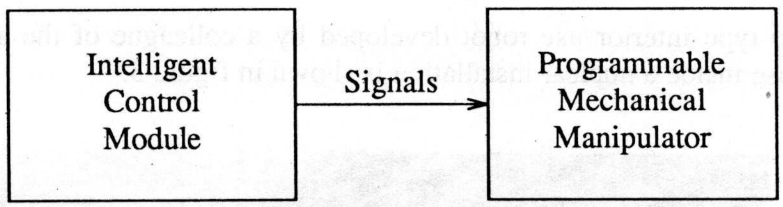


**Figure 2.** The functional elements of a robot system

The robot is comprised firstly of a (precision) manipulator that is programmable as to its geometric position and spatial configuration and secondly a computer based command power-signal generating system that through its programming produces a time series of positioning signals. The operational system thus comprises two parts - a computer "driver"/"intelligent controller" or "command module" and a "programmable manipulator".

If one now considers this system in relation to normal construction activities , it is clear that the only thing "wrong" with manufacturing type robots is that the scale of the manipulator is too small. What is needed by the construction industry is a **"macro"** manipulator" in lieu of the normal manufacturing industry scale arm.

Given an appropriate sized manipulator it is clear that the large work-pieces that typify constructional elements can be operated upon by robotic tools.

Additionally if the physical manipulator could be made freely movable, mobile between set-up points or self propelled and self-contained as regards to its power needs then a variety of normal constructional tasks could be attempted.

## 4. A SAMPLE SPECIFICATION FOR A MACRO-MANIPULATOR

In order to perform a reasonable range of construction activities a "macro-manipulator" (M-M) would need to have a reach of the order of tens of metres - say 10-20 metres, and a capacity of the hundreds of kilograms say 500-1000. With such a manipulator full scale construction work-pieces can be operated upon.

For example such a unit would be able to span a domestic residence and to pick up and place all the elements that constitute it. Similarly small industrial buildings and minor excavations could be handled.

In terms of positioning accuracy a manipulator which can smoothly position large loads to a 5 mm accuracy would seem to be acceptable for most forms of construction work.

## 5. THE PROBLEM OF DEVELOPMENT OF PRACTICAL SYSTEMS

### 5.1 SOME CATEGORIES OF MACHINE

In endeavouring to develop manipulators suited to the construction industry two distinctive conceptions of machine have been developed by the author.

1. The conception of an "interior" manipulator

### 5.2 A PROTO-TYPE INTERIOR-USE MACRO-MANIPULATOR/ROBOT

For working within structure and buildings a manipulator that is both large enough to work on large work-pieces and job-tasks yet small enough to manoeuvre through doorways and fit between normal floor and ceiling heights is required.

A proto-type interior use robot developed by a colleague of the authors and which is in commercial use inside a nuclear installation is shown in figure 3.

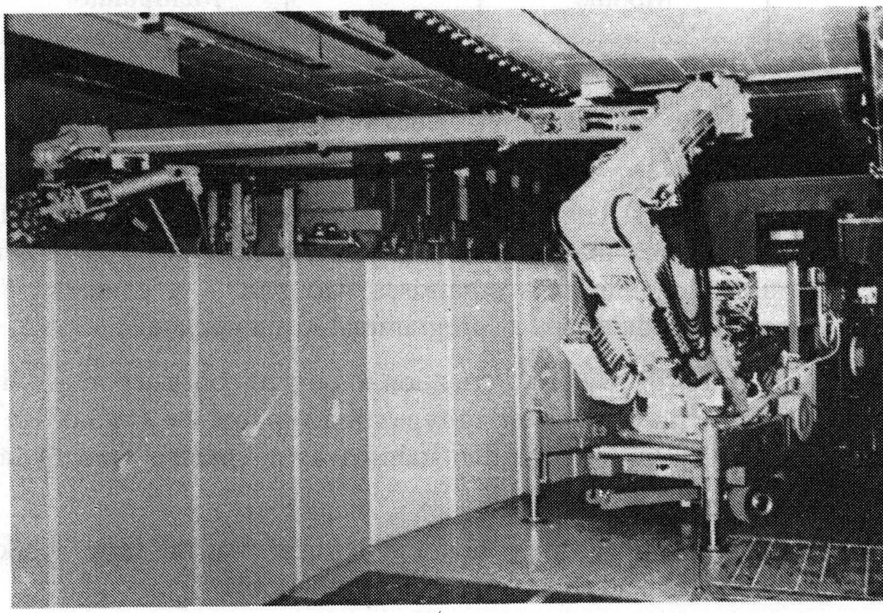

**Figure 3.** A proto-type interior use macro-manipulator

The machine shown has a number of advanced features in that it is mobile, is of the scale required for normal construction activity and is capable of doing some very refined work under remote control. An idea of the sophistication of the unit can be obtained from the fact that the twin-armed tool at the extreme end of the main arm comprises two units capable of undoing the holding down bolts on a machine, say an electric motor, preparatory to its removal. The machine can also work around and behind obstacles.

If one imagines such a unit suitably directed through an intelligent command module one can see it as the basis for perhaps a genuine mobile general purpose interior-use constructional robot.

### 5.3 A PROTO-TYPE EXTERIOR-USE MACRO-MANIPULATOR SYSTEM

#### THE IDEA IN CONCEPT

In work-zones basically free from obstructions and confining surfaces, considerable larger forms of manipulator can be contemplated. Such machines have to be designed for all-weather use and ideally need to be readily movable from site to site. The size of these machines, if they are to be effective in the building of whole structures, would put them in the class of giant machines or giant robots.

#### ATTEMPTS TO DEVELOP A PROTOTYPE VERSION

For some time now the author and his colleagues have been active in trying to develop a prototype macro-manipulator unit that would establish the essential feasibility of this class of device and permit explorations of its capabilities both under manual and computer control. It is pleasing to be able to report some recent success in this endeavour. Some aspects of this work will now be presented.

THE BASIC DESIGN CONCEPT

Whilst the concept of a macro-manipulator can perhaps be relatively easily developed the problem of realisation of such items in terms of hardware is a major technical and mechanical engineering challenge.

The concept developed by the authors design group to meet this challenge revolves around the idea of a large programmable-boom structure and precision end-effector combination which is capable of being mounted on a variety of support platform. These base units can comprise such things as the tower section of a normal high-rise building type tower crane or tracked or rubber tyred mobile travel unit such as comprise the bases of mobile cranes. Alternately it may be bolted down totally as for example on an off-shore oil rig.

BASIC STRUCTURAL FORMS

THE LOWER BOOM PORTION

Two basic schemes are available (Figure 4). Scheme 1 utilises a major telescoping boom element as the basis of its boom section whilst scheme 2 utilises articulated boom technology in the first part of the boom.

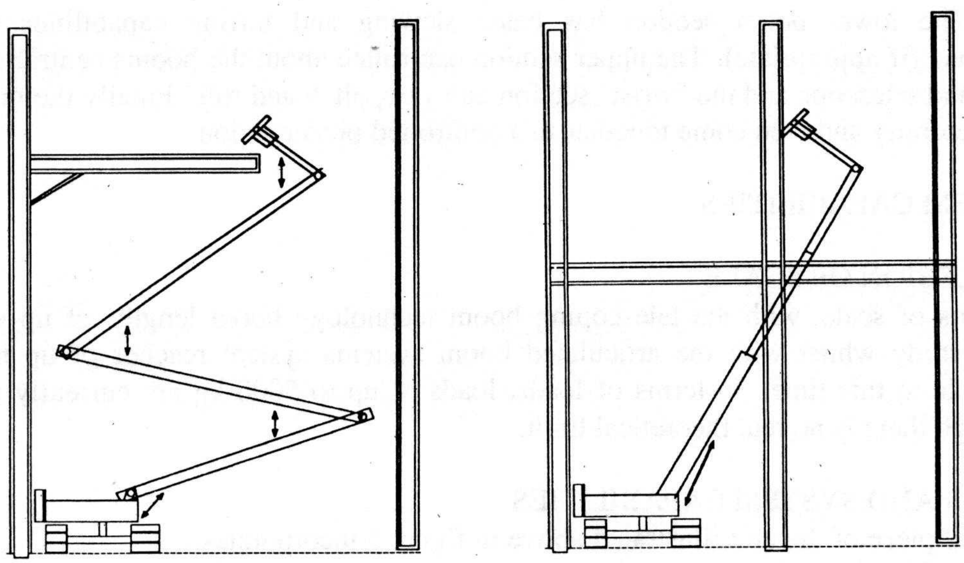

**Figure 4.** The articulated boom and telescoping boom based manipulators

THE UPPER BOOM PORTION

A detailed view of the upper end of one design of manipulator showing the arm/hand unit region and the telescoping mounting boom that connects to the lower boom section is shown in figure 5.

GENERAL FORM AND MODE OF ACTION

The basic manipulator is conceived of as a 10-11 degree of freedom implement - in that it requires

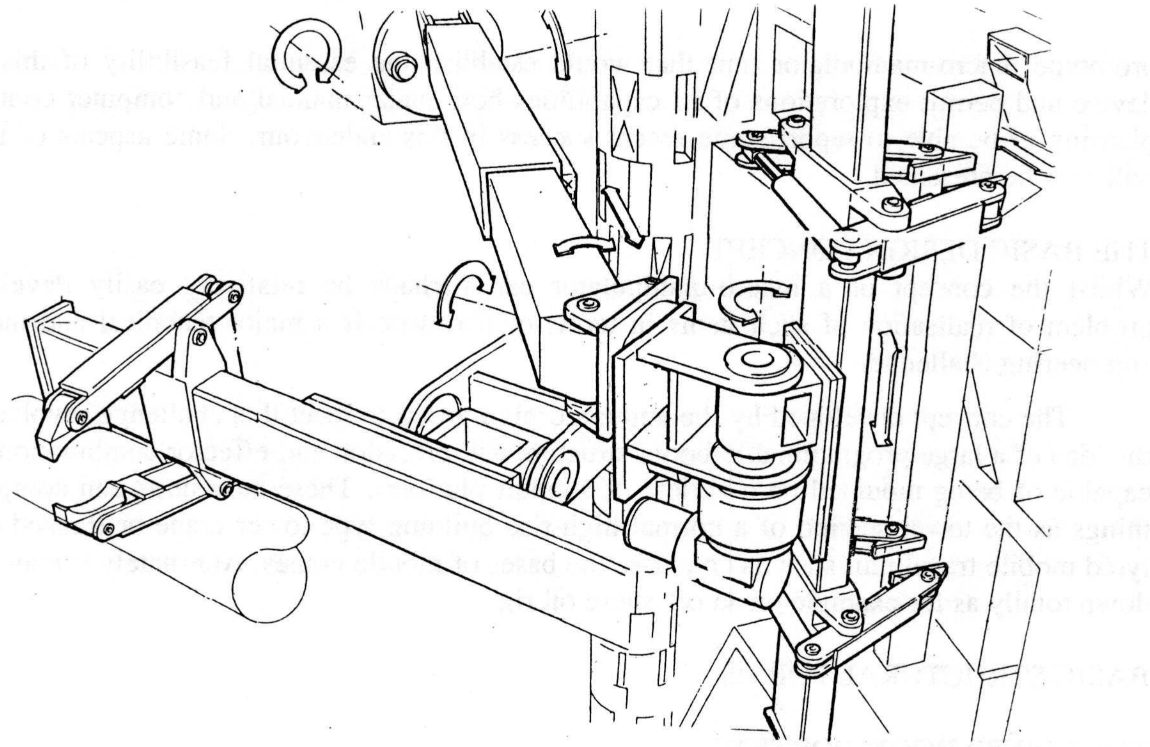

**Figure 5.** A close up view of a proto-type system's upper boom

are needed if the boom telescopes.

The lower boom section has basic slewing and luffing capabilities and telescoping functions (if appropriate). The upper section can rotate about the booms central axis, bend out of plane and telescope and the "wrist" section can yaw, pitch and roll. Finally the grippers can move apart laterally and then come together in a controlled pincer action.

## SYSTEM CAPABILITIES

### DISCUSSION OF SCALE

In terms of scale, with the telescoping boom technology boom lengths of up to 50 metres are under study whilst with the articulated boom systems system reaches of up to 25 metres are available at this time. In terms of loads, loads of up to 5000 kg are currently thought possible although there is no real theoretical limit.

### TOOLS AND SYSTEM CAPABILITIES

The end piece of the unit illustrated above in figure 5 incorporates:-

- A detachable end gripper piece that is freely interchangeable with a host of other tool types. The tool illustrated is one of a beam/gripper system. This can be removed and replaced by a full variety of tools such as diamond drills, hydraulic cut-off saws, needle guns and sanding and grinding discs. Alternately an end-piece specifically adapted to the carrying of sand-blasting or shotcreting nozzles can be provided.
- A vacuum plate for the handling of sheets of glass or thin metal is an additional simple option.
- Precision bolting tools, such as have already been illustrated in conjunction with the interior robot, can obviously be connected.
- A feature that allows quick release of tools and automatic pick up of tools

- The system is fully computer programmable as to all functions.

## 6. THE POTENTIAL IMPLICIT IN MACRO-MANIPULATORS

This paper so far has only introduced the concept of macro- manipulators and discussed some of the hardware forms such devices might take. The potential applications of these devices, the benefits that might stem from their use and the challenges they may pose the construction industry are the subject of this section.

A close study of construction processes as currently carried out reveals that the activities of :- tool manipulation and manoeuvring, workpiece movement, workpiece support, work component movement, materials and component transfer and gross and fine object positioning comprise virtually all the work tasks required to be performed.

If one looks at all of these items that involve large masses or reaches beyond the capacity of an unaided man to handle or are extremely repetitive and/or dirty, dull or dangerous then the potential for macro-manipulator technology becomes apparent.

Furthermore if one recognises that macro-manipulators are fully computer controllable and are capable of performing the same range of complex tasks as normal factory robots then the potential for this technology becomes apparent. With this technology it would seem practicable to virtually eliminate labour accidents on sites, to improve quality in repetitive and boring work and to build faster. All of these are the prospective benefits of robotic technology.

It is not possible within the confines of this paper to explore in detail all the possible applications of M-M based robot technology however the following example is given in illustration.

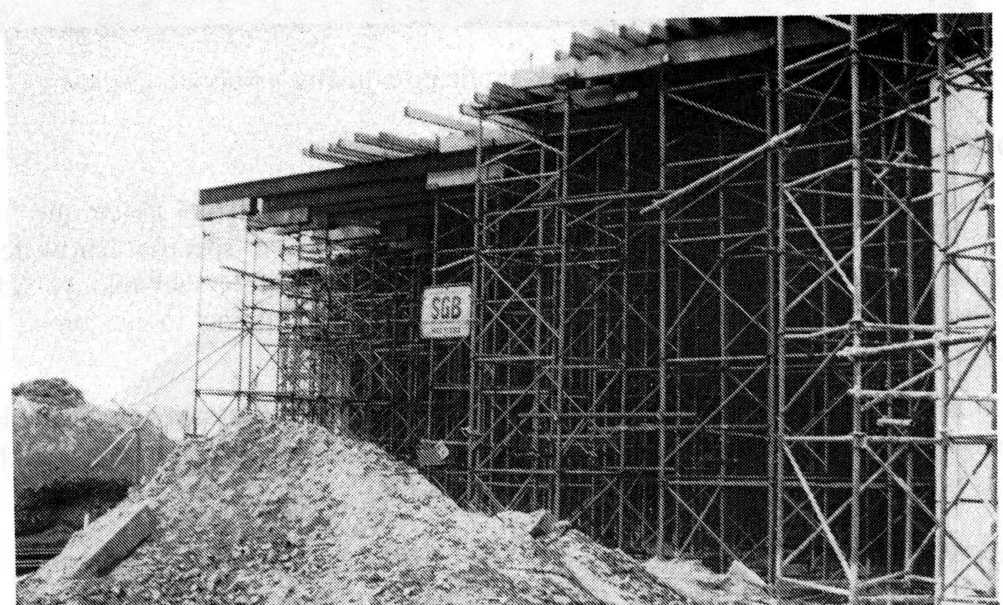


**Figure 6.** A typical bridge falsework system

The bridge falsework system as illustrated utilises the PAL stackable metal frame falsework system. It is considered that such a falsework assembly can, at present, be fully automatically produced using a macro-manipulator based robotic system.

In addition to this example, a multitude of other applications ranging from the placing of sheets of glass in high rise buildings through sandblasting and shotcrete to the automated maintenance of overhead railway power structures come easily to mind as one reflects on the possible use of this technology.

Figure 7 illustrates the possibility of placing concrete formply automatically using the vacuum sheet materials gripping capabilities of a large manipulator. Also heavy duty forms of manipulator as are currently under design will be able to position all but the heaviest structural steel members.

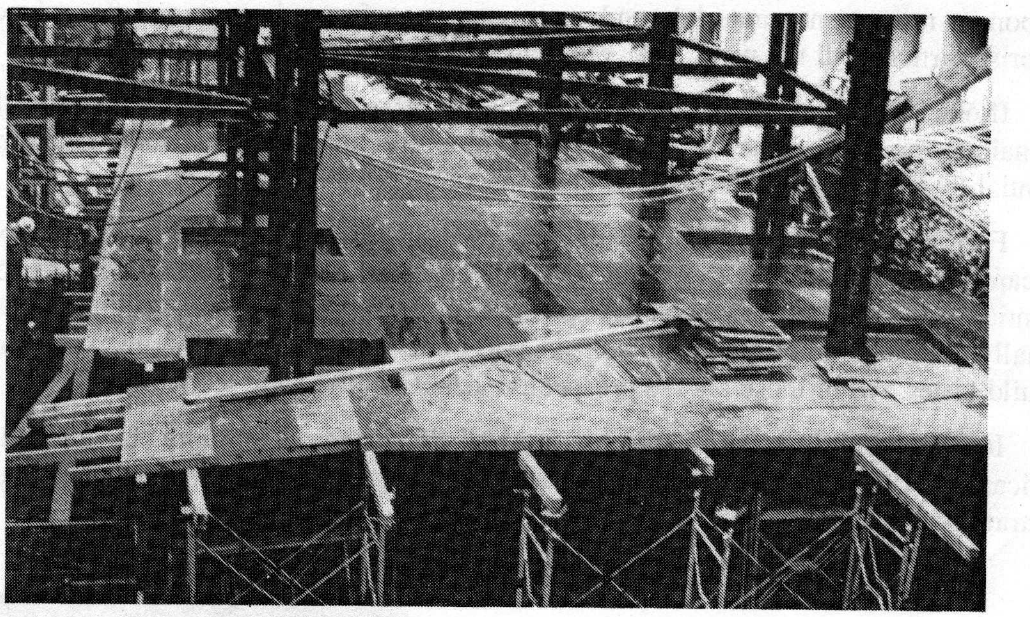

**Figure 7.** A concrete formwork application involving plywood sheets

## 7. CONCLUSIONS

This paper has introduced the concept of macro-manipulators as the means whereby the robotisation of construction may become practicable. Some specific hardware examples of practical machines were presented to illustrate the feasibility of the technology. Additionally, the applications potential of these devices was examined in relation to the broad processes that comprise construction.

It is concluded that M-M based robotic technology constitutes a new technological frontier in the field of construction methods and equipment and that it offers considerable real future benefits to the building and construction industries.

## ACKNOWLEDGEMENTS

The kind permission of Mr. Kevin Hunt of Remote Engineering Systems Ltd and CERN in allowing the use of photographic material is acknowledged.

.....