The 9th International Symposium on Automation and Robotics in Construction June 3-5, 1992 Tokyo, Japan

FULL SCALE TRIALS OF A LARGE GENERAL PURPOSE CONSTRUCTION MANIPULATOR WITH PRECISE MOTION CAPABILITIES

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ABSTRACT

Large reach, large capacity, versatile and precise construction manipulators with computer control capability have recently been proposed as potentially very useful construction industry tools. But none has yet been economically realised. This paper describes the development of a such a machine. The manipulator described has a lift capacity of more than 100kg coupled with a reach of more than 10 metres. The machine has now reached its final mechanical engineering testing stage. The equipment has been designed for general construction use under all weather conditions and is capable of moving large and heavy loads to a high accuracy with effectively zero backlash.

The unit is intended for general heavy materials handling operations on building and construction engineering sites but has special applications in the fields of reinforcement placement, formwork placement and stripping, light gauge structural steelwork handling and building cladding operations.

The paper describes the physical testing of the unit in terms of movement envelopes, static and dynamic load handling performance, accuracy of load control and positioning as well as computer controllability factors. Trial applications of the machine to selected building and civil engineering tasks are also reported.

Comments on the potential economic application of this form of machine are also given.

1. INTRODUCTION

In a previous paper (Ref 1) the author has argued that the traditional, structurally highly stiff, robotic machinery used in the manufacturing industry is not sufficiently large or generally appropriate for general use in construction. What is needed for construction is a new range of precise action robotic tools, with large reach and high carrying capacity, which are designed especially to suit the difficult conditions that apply on construction and building site conditions and which are also designed to incorporate the specific needs of the industry in terms of machine safety requirements. In summary the earlier paper argued that the construction industry needed to develop a whole range of macro-scale robotic arms for general use.

Now whilst it is quite easy to say that the industry needs giant robots it is quite a different thing to realise these machines in hardware terms. The development of large mechanical arms with the precision needed for robotic action and with the robustness needed by the construction industry however poses some severe mechanical engineering problems and some extremely complex electronic control problems. It is the authors perception though that these problems are not insurmountable, they are only difficult and it was this perception that caused him and some colleagues to begin a research project to try to build a giant robotic arm for construction use.

The aim of this current paper is to report on some early stage performance trials of a prototype macro-scale robotic arm which has been developed. The aim of the prototype is to explore the mechanical engineering and control issues associated with the construction of giant robotic arms.

2. DESIGN SPECIFICATIONS FOR A PROTOTYPE GIANT ROBOTIC ARM

After consideration of the needs of the industry and possible uses for the machine a set of design parameters were developed upon which the initial arm was based. The performance parameters that were established for the initial design of the test machine were as follows:-

• Lift capacity	1 tonne in any quadrant
• Positioning accuracy	2-5 mm under full load
• Backlash under full load	zero
• Lifting radius	10 metres or more
• Number of working planes	1
• Number of degrees of freedom	6
• Control systems	Full real-time computer. all actuators independently controlled
• Cost	Low

3. DESCRIPTION OF THE MECHANICAL HARDWARE

In response to these design parameters settings, a large fully computer controlled mechanical arm was designed. The basic form of the machine is illustrated in figure 1.

The lower part of the machine is a 360 degree rotating turn-table base which has can be set on a set of rail bogeys or can be placed on a wheel and axle or crawler base.

Mounted on the turn-table is the robotic arm proper. This is made up of telescoping action boom and gripper system on a jointed lower section. The whole boom can luff at its base and pitch, roll and yaw at intermediate points

4. DESCRIPTION OF THE PERFORMANCE TESTING PROGRAMME UNDERTAKEN

4.2 Introduction

After completion of the design, manufacture and erection of the full mechanical arm and after comprehensive testing of all its mechanical sub- systems, computer control hardware, software and communications linkages, full scale trials of the whole system became possible.

The strategy for testing involved a graded set of trials involving firstly pure mechanical engineering tests and then applied behavioural trials which relate to specific building and construction tasks.

4.2 Details Of The Mechanical Engineering Trials Program

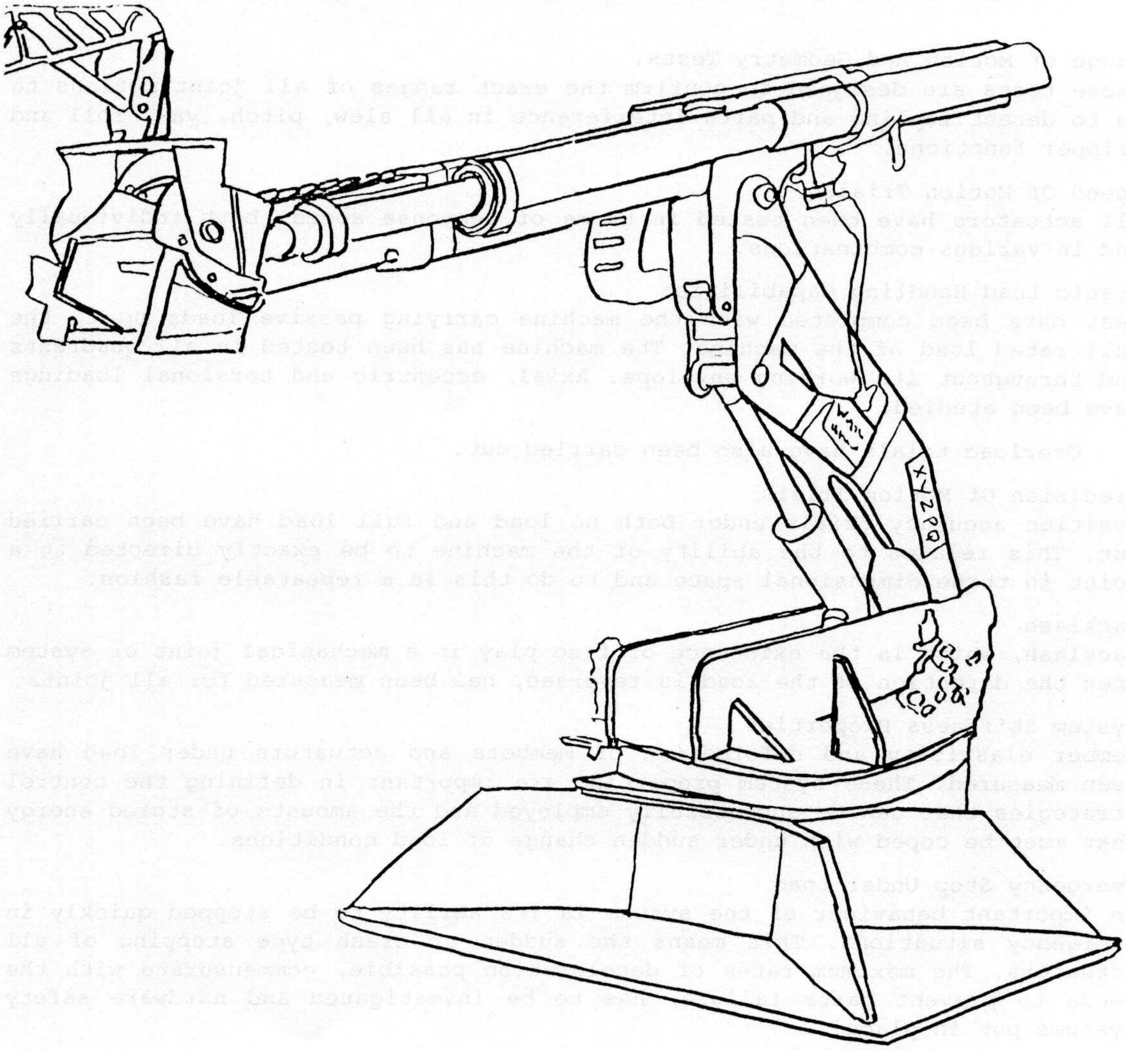

Figure 1. A general view of the prototype machine

4.2.1 Varieties Of Trials Possibilities

A wide variety of possible performance evaluations trials can be carried out on a specific piece of robotic equipment depending on the "dimension" of the characteristic being evaluated. Thus one can test load handling characteristic, control characteristics, reliability or safety performance.

Alternately one can define test programmes that are based on practical issues. Thus one can divided groups of performance trials into classes based on load. Thus one can have :-

a. No load and free field trials
b. Trials under varying load

Alternately one can conceptualise the trials into firstly static and dynamic tests involving passive loads and then secondly static and dynamic tests involving active or dynamic loads.

4.2.2 Test Program Completed To Date

To date a variety of tests have been completed on the prototype system. These include:

a. Range of Motion And Geometry Tests.
These tests are designed to confirm the exact ranges of all joint motions to as to detect fouling and parts interference in all slew, pitch, yaw, roll and gripper functions.

b. Speed Of Motion Trials
All actuators have been tested in terms of response speed both individually and in various combinations.

c. Static Load Handling Capabilities
Test have been completed with the machine carrying passive loads up to the full rated load of the machine. The machine has been tested in all quadrants and throughout its working envelope. Axial, eccentric and torsional loadings have been studied.

Overload trials have also been carried out.

d. Precision Of Motion Trials
Position accuracy trials under both no load and full load have been carried out. This relates to the ability of the machine to be exactly directed to a point in three dimensional space and to do this in a repeatable fashion.

e. Backlash
Backlash, which is the existence of free play in a mechanical joint or system when the direction of the load is reversed, has been measured for all joints.

f. System Stiffness Properties
Member elasticity and deformation of members and actuators under load have been measured. These system properties are important in defining the control strategies that can be successfully employed and the amounts of stored energy that must be coped with under sudden change of load conditions.

g. Emergency Stop Under Load
An important behaviour of the system is its ability to be stopped quickly in emergency situations. This means the sudden or crash type stopping of all actuators. The maximum rates of deceleration possible, commensurate with the needs to prevent parts failure, has to be investigated and hardware safety systems put in place.

h. Performance of Fail-safe Systems
Heavy and large lifting systems need to incorporate fail-safe systems to allow for full load-holding in the event of possible failure of the primary power system. Such systems are often made obligatory by law to meet construction safety regulations.

In the current system fail-safe load-holding systems are incorporated into each actuator systems. These were tested in operation under full load.

i. Creep under load
For full effectiveness, manipulators need to be able to hold heavy loads in a static position without creep. This performance characteristic has been evaluated.

j. Cross talk between controls.
Interaction within and between control functions can sometimes be a problem in robotic machines. This cross talk between channels needs to be evaluated in real machine systems.

k. System Reliability Trials

To succeed in practice on construction sites robotic arms must be fully rugged, reliable and not subject to breakdown. Extensive test-bed trials of robotic arms under dynamic conditions are necessary to establish possible reliability problems. The current system is currently being passed thorough such trials and is being subject to breakdown and trouble-spot analysis.

l. Measurement of Control Transfer Functions.

Extensive measurement and performance trials are necessary to establish the transfer function between control signal settings and system behaviour. Speed of response needs also to be determined for each degree of freedom.

In addition to simple transfer function measurement it is noted that interactions between actuators occur in systems where the primary power system is shared. Interaction effects such as these need to be evaluated and defined in full combinatorial terms.

m. Sensor Performance and Reliability

An important feature of a prototype system is the performance of the sensor systems and their susceptibility to failure, false signals or to drift. These features need to be evaluated in trial models.

n. Mechanical Impedance Characteristics

In addition to trials with static loads, attempts are currently being made to determine the full mechanical impedance of the system in response to time varying loads. Thus the machine is being subject to sudden loadings and sudden release of loads to simulate step function loadings of the system.

o. External Vision Systems

Performance trials with miniature TV camera based vision systems for the giant robotic arm indicate that resolution and response are fully adequate for fine control purposes. This equipment is of third party manufacture and has been performance tested by the manufacturer.

4.3 Construction Task Based Trials

To date a full set of trials of the machine as applied to typical building and construction activities have not been completed. A limited set of simple trials of the machine however have been undertaken. For these the robotic arm has been equipped with simple tools such as grippers, drills, jaw cutters and reciprocating and circular saws as end elements.

Tests with these simple systems has permitted quite a comprehensive analysis to be made of the robotic arms performance in terms of directional precision, tool feed capabilities, oscillatory load response, vibration, tool chatter, response to shock loadings and so on.

5. RESULTS

So far the result of this comprehensive set of trial has been most encouraging. The machine has met it design specifications immediately or with only minor design modifications.

Precision under load and no-load is excellent and the primary control transfer functions are closely linear. Crash stop performance is excellent and all fail safe systems work as intended. Few reliability problems have been encountered so far.

Also the physical performance of the robotic arm when applied to real-life construction tasks has been most encouraging with structural rigidity problems being minimal.

6. CONCLUSIONS

The successful completion of a comprehensive of set of performance trials on a full scale prototype arm gives great confidence to the idea that high performance rugged mechanical arms with characteristics suited to full robotic control are practically and economically realisable with current technology.

In addition the results of early construction task trials with the giant robotic arm give great confidence to the idea that large precise action robotic arms will turn out to be highly useful performance enhancing tools for the construction industry.

On the successful completion of both kinds of performance trials- technical and applications- it is now firmly concluded that macro-scale robotic arms can be technically and economically realised. Given this the author is now highly confident that such advanced machines will have a very exciting and important place in the near future of the international building and construction industry.

REFERENCES

[1] O'Brien J.B. "Development of macro-manipulator based robotic systems for general construction use" 8th Intl. Symp. on Automation and Robotics in Construction, Stuttgart, June 3-5 1991. p431 ff.

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