The 5th International Symposium on Robotics in Construction June 6-8, 1988 Tokyo, Japan

ADVANCED ROBOTICS IN THE FIELD OF SURVEY/INSPECTION MAINTENANCE AND REPAIR OF BUILDINGS AND STRUCTURES

R A Radevsky, Manager Structural Surveys
and F K Garas, Project Leader DTI AR Project
Taylor Woodrow Construction Ltd.,
345 Ruislip Road, Southall, Middlesex UB1 2QX, United Kingdom

ABSTRACT

With increasing resources being devoted to the field of inspection and maintenance of buildings and structures, the use of robots to carry out this type of work is a natural development.

In order to carry out survey/inspection maintenance and repair, it is currently necessary to gain access to the faces of buildings and structures by scaffolding, abseilling, mechanical access platforms or other similar means. This is invariably, time consuming and may limit the tasks that can be carried out. In some cases access to parts of a structure may be extremely difficult and dangerous by conventional means.

When placed in conditions that are far from ideal, the quality of work undertaken by engineers and construction workers may deteriorate owing to fatigue or distraction. In addition, the process of manual recording of data during surveys or installation of repair materials is often subject to human error and the level of skill of the operator. Human beings also have a limited ability to repeat tasks with precision over an extended interval or on similar structures. They are also limited in the number of operations they can undertake at any one time. Many of these problems are potentially solvable by developing and deploying robots in place of human beings.

As part of the British Department of Trade and Industry's Advanced Robotics Initiative, Civil Engineering and Construction Project, the required performance and capabilities of such a robot are being examined. Vehicle configuration, methods of mobility, sensors, instruments and tool requirements are being assessed, together with power supply, on board and off board computing capability and communication systems.

Consideration is being given to building and structure surface characteristics, survey, maintenance and repair objectives, currently available robotic systems and hardware, and probable future developments in relevant technologies in general.

This work is being led by Taylor Woodrow Construction Limited in a co-ordinated programme with participants from a wide cross section of the industry. Although the study is at an early stage, the paper describes the work and approach adopted in the project, particularly addressing the enabling technologies.

1. Introduction

1.1 Following the postwar construction boom much attention has turned in Europe, North America and increasingly in other parts of the world towards the field of Repair and Maintenance of structures. According to statistics published by Department of Environment in 1985, repair and maintenance accounted for nearly 50 % of the total construction output in Great Britain. Whilst much of this was associated with housing, a considerable proportion was expended on industrial structures, commercial buildings and infrastructure.

1.2 The widespread use of relatively recently developed materials such as reinforced concrete has produced new problems. Environmental attack mechanisms and the use of deleterious constituent materials have caused millions of pounds worth of damage. Techniques for assessing the extent of damage to structures and for carrying out maintenance and repairs are continuously being developed.

1.3 Development work has already produced means of computerising the measurement and recording of survey and inspection data. New instruments are also appearing which can map the sub surface condition of structures largely without the need for physical penetration. Such devices are well suited for miniaturisation and automatic operation, and thus ideal for incorporating into a robot whose primary limiting factor will be a restricted payload.

1.4 This paper examines the approach adopted for the Project Definition Study of the Department of Trade and Industry's Advanced Robotics project into the use of robotics in survey, inspection, maintenance and repair work.

2. Current State of Survey Inspection Maintenance and Repair Technology

2.1 At present, survey, inspection, maintenance and repair tasks carried out on the surfaces of buildings and structures are designed around manual operations. Access has to be provided to the location where the task is to be carried out, and the tools, instruments and materials used are in general designed for hand use.

2.2 Means of access vary depending upon the configuration of the structure being worked on, the exposure conditions, in terms of wind and weather and the nature of the task being undertaken. Traditionally, scaffolding has been the most commonly used method of access, being adaptable for use on almost any structure. The use of scaffolding however incorporates a number of significant disadvantages, namely that it often requires detailed design. It is bulky and awkward to transport and site preparation and skilled erectors are necessary. Furthermore, it is sometimes the case that the cost of providing scaffolding exceeds the cost of actually carrying out the survey or repair, causing the work to become disproportionately expensive.

2.3 Access may also be achieved by using hydraulic platforms. These provide rapid access to many locations within a short period of time and into difficult areas. They usually require a flat stable area, however, for the base unit and are limited in the load they can carry as well as being relatively costly. Recent developments include special under bridge deck access platforms mounted on a vehicle located on the deck.

2.4 In areas where permanent provision is made for access such as to the face of high rise buildings, there are a variety of systems available, often in the form of gondolas suspended from cables. New equipment is frequently being introduced into the market. In addition new methods are occasionally introduced such as the use of abseilling, where mountaineering techniques are used. This method can be extremely cost effective on difficult structures. It does however require specially trained personnel and the range of work that can be carried out is limited.

2.5 Once at the location where survey, inspection, maintenance and repair tasks are to be carried out there are numerous techniques that can be employed involving an enormous range of instruments and tools.

2.6 On reinforced concrete structures alone the following inspection techniques are frequently used:

Visual Inspection
Photography
Video
Thermography
Radar
Ultrasonic pulse velocity
Cover measurement
Electrochemical potential measurement
Carbonation Testing
Temperature and humidity monitoring
Crack width measurement and monitoring
Drillings to produce dust samples for chemical analysis
Coring to produce core samples for chemical and physical analysis
Pull off testing
Insitu permeability testing
Schmidt Hammer
Resistivity
IDD - Delamination Detection
Soundings

Overall the number of techniques currently in use for the survey, inspection, maintenance and repair of structures of all materials is huge.

2.7 Most of these operations involve the use of small hand held instruments perhaps connected to logging devices but normally with an overall size and weight small enough for one man to operate. Once access has been gained to the location where measurements are to be taken some preparatory work is usually required followed normally by the recording of a single parameter. Readings are subject to error from a variety of sources including human error in locating and using an instrument and recording the result, and possible miscalibration or malfunction of the measuring device. Operations are normally restricted to daylight hours and are often subject to restrictions imposed by safety considerations. Limitations include operator fatigue and daily work cycles. Manual dexterity also affects the nature and complexity of work that can be successfully completed. These factors all have a direct bearing on cost.

2.8 Similar restrictions apply to maintenance and repair tasks. In this case not only can effort be wasted by incorrect use of equipment but damage can be caused to a structure if, for example repair techniques are incorrectly implemented. The tools used in maintenance and repair tasks vary widely in complexity from a window cleaning cloth and bucket to remotely operated vehicles currently used in underwater and contaminated environments.

2.9 Maintenance and repair tasks differ from survey and inspection techniques in that they normally involve the movement of materials. Dirt and debris must be removed from the structure and repair mortars paints etc. must be delivered to the repair area (surveys also can require the removal of samples, however with increasing sophistication of techniques, the need for sample removal is being minimised and may eventually be eliminated). In addition maintenance and repair tasks often have larger power requirements than for survey and inspection work. The provision of materials requires a constant flow to and from the working location and can introduce the need for additional specialist access equipment. The provision of power such as electricity or compressed air is normally relatively easily achieved.

2.10 In extreme cases the provision of access can account for an extremely large proportion of the cost of a survey, inspection, maintenance or repair project. Instruments, tools and techniques have to be designed with the limitations of the operator in mind. This means that highly sophisticated techniques may have to be abandoned owing to their vulnerability to operator error, fatigue, dexterity limitations etc. It is often the case that the most effective approach is to aim for simple but reliable information. To attempt new and complex tasks, even if their potential value is considerable, can result in resources being wasted through the failings of the human input.

3. Potential for Robotisation

3.1 In considering the advantages of robotisation of survey, inspection, maintenance and repair tasks, it is necessary to bear in mind the associated timescale. In the long term it would appear probable that systems incorporating robotic devices will be developed which can carry out all the tasks currently carried out by humans. These will capable of determining the need for survey and inspection, determining the need for maintenance and repair tasks and carrying out those tasks. The complexity of the numerous elements associated with this scenario suggests that a timescale of 20-40 years would be appropriate.

3.2 In the shorter term a series of intermediate stages can be expected in which parts of this scenario are achieved.

3.3 At first it seems inevitable that survey, inspection, maintenance and repair robots will work as the sophisticated tools of humans. They can be expected to progressively replace greater and greater proportion of the the human input of this type of work. In addition, by removing the need for tasks to be tailored to human operators the field will be opened to a wider variety of new ideas, using more complex and sophisticated techniques than are currently in use. The initial stages of development work in this area appear to fall into three categories as follows:-

3.3.1 The means of gaining access to the surfaces of buildings and structures.

3.3.2 The development of existing and new techniques for carrying out survey, inspection, maintenance and repair tasks

3.3.3 The development of software to make decisions as to which tasks are necessary and how these tasks are to be carried out.

3.4 The latter area is already under development to assist engineers in making their decisions. The results of such work will be relevant to both human operations and robotic operations and are likely to be produced irrespective of the development of robots.

4. Objectives of the DTI AR Initiative in Civil Engineering and Construction

4.1 A feasibility study on the Application of Advanced Robotics (AR) to Civil Engineering and Construction produced by the Construction Industry Research and Information Association (CIRIA July 1987) concluded that inspection of buildings and civil engineering structures was the most promising application area for advanced robotics. The study had been carried out as the first stage of a three stage process envisaged by the Department of Trade and Industry (DTI) Advanced Robotics Initiative, Civil Engineering and Construction. It formed one of a series of application areas examined under the DTI Initiative, which also included tunnelling, nuclear, underwater, firefighting and rescue, space and medical and health care application areas. (R Egginton 1987).

4.2 The second stage of the DTI's Advanced Robotics Initiative in Civil Engineering and Construction is a Project Definition Study to examine the application of advanced robotics to survey, inspection, maintenance and repair of buildings and structures.

4.3 This study will address the means by which access can be gained to the surface of buildings and structures, and the survey, inspection, maintenance and repair tasks that can be carried out by a robot having arrived at the appropiate location.

4.4 The Project Definition Study will produce a proposal for an Industrial Development Project including R & D requirements, design schematics, a market analysis, work share proposals, cost estimates and a detailed project plan. The Industrial Development Project (the third stage of the initiative) is intended to result in the production of a prototype advanced robotic device.

4.5 The timescales involved are approximately 15 to 18 months for the Project Definition Study and at least 3 years for the production of a prototype. These timescales have assisted in defining the constraints to the level of development that can be achieved within the Project. The objectives of the Study have therefore been set at a mid point between the development of a highly sophisticated device, employing technologies that will not be fully developed for some time, and a relatively simple device which can be produced within a matter of months.

5. Details of the Project Definition Study

5.1 The Project Definition Study has been divided into a series of tasks which relate to the management of the project, the development of target applications and concepts, enabling technolgies, overall design, market survey and economics, and the Industrial Development Project which is to follow.

5.2 To date a variety of target applications and associated concepts have been considered. These have included cable/umbilical suspended devices, and self supporting clambering devices, both with and without umbilicals. These devices would be intended to provide access to all areas of the surface of a structure, and to provide a stable platform from which survey inspection maintenance and repair tasks could be undertaken.

5.3 The enabling technologies to be studied encompass Delivery Mechanism, Adhesion Mechanism, Power Supply, Sensing and Navigation, Control and Communication Systems, Vehicle Structure and Survey Inspection Maintenance and Repair Tasks. In addition, co-ordination and a System Design task has been included which involves integration of the different elements and the preparation of an overall specification. It will also consider such topics as payload and balance, health and safety, and inter-system interference.

The enabling technologies are of particular importance to the success of the project. It is intended that, wherever possible, use will be made of existing developments in the form of existing systems components and software in order to avoid duplicating research which has already been carried out. It is however recognised that it will be necessary to undertake some basic research in areas where knowledge is currently limited.

5.4 Investigation and evaluation of the aforementioned enabling technologies is being addressed as follows:

5.4.1 Delivery Mechanism

A number of different types of delivery mechanism are currently being considered, and include walkers, clamberers, tracked vehicles, two pad vehicles, cable movers etc. Each of these is to be evaluated in terms of their reach, velocity, load carrying capacity, ability to bridge gaps and negotiate uneven surfaces. Their power requirements, weight requirements and complexity of operation and control is to be examined and compared with the robot's requirements. This is to include exploring methodes by which the robot can make best use of its environment to assist it to move. In addition, the technical suitability, cost and availability of components are to be studied.

5.4.2 Adhesion Mechanisms

This technology relates to the robot's need to transmit load to the structure over which it is moving. A variety of adhesion mechanisms are to be reviewed including suckers, magnets, adhesives, grippers and clamps. Their load carrying capacity and suitability for different surface profiles is to be reviewed,and adhesion requirements for the robot examined in terms of the number of anchor points required, load carrying capacity, and the characteristics of various structure surfaces and surface materials over which the robot will move.

5.4.3 Power Supply

Different forms of power supply are to be examined in terms of availability at sites, and characteristics such as stability, and potential for being transported as part of the robot's payload. The robot's power requirement is to be reviewed so that the minimum number of different types of supplies are used to cater for all the on board systems. Safety constraints and power failure back up requirements are to be determined within this area of the study and as part of the overall design. In addition a review is to be carried out of the technical suitability, cost and availability of components.

5.4.4 Sensing/Navigation

An extensive range of sensors will be required by the robot to monitor both its external and internal environments. The options for sensor types and associated components is to be examined in terms of technical suitability, power requirement, weight durability and robustness, cost and availability.

The sensor information will be continuously analysed by computer to enable movement decisions to be made. This will involve producing and updating computer models of the robot's environment. Route strategies and problem solving such as would occur in the event of component or adhesion failure, will also be considered.

5.4.5 Control/Communication Systems

The requirement for control/communication systems for all aspects of the robot's operation is be examined both in terms of hardware and software. Wherever possible, existing software is to be used. Once the structure of the software has been determined an estimate will be made of the computing power required from which the balance of on board to off board computing can be determined. Hardware components will be examined in terms of capacity, speed, power and cooling requirements, robustness, ability to tolerate aggressive environments etc. The various communications needs for successful operation is to be reviewed,and it is envisaged that several communication systems will be recommended together with assessments of the associated component parts.

5.4.6 Vehicle Structure

To provide the skeleton onto which the robot's systems can be attached a vehicle structure will be required. This will need high strength and low weight. It may need to incorporate compartments with controlled environments. The material from which the structure can be produced, it's structural form, the loading regime to which it will be exposed, it's tolerance to openings and cable penetrations, the means of fabrication and cost are all to be examined.

5.4.7 <u>Survey, Inspection, Maintenance and Repair Techniques</u>

Investigative work is to be carried out into the ways in which existing survey, inspection, maintenance and repair equipment can be modified by miniaturisation and automation for use by the robot. This is to include the potential for undertaking chemical and physical testing of materials in situ, whereas traditionally this testing has been carried out in a laboratory. This work is also to examine how new techniques which have not been suitable for human operators, might be employed by the robot, for example the simultaneous recording of multiple parameters. Consideration is to be given to the means of supplying and removing materials to and from the robot, either by a system of continuous conveyance such as piping or by the use of secondary robots.

5.5 The Project Definition Study is to be undertaken by a collaborative group consisting of construction companies, consulting engineers, academic institutions and equipment suppliers.

6. The Future

6.1 The present need for survey, inspection, maintenance and repair work springs from the nature of the buildings and structures that have been constructed and the materials that have been used. As engineers develop theirs understanding of the way in which materials deteriorate and as new designs and new materials are introduced, the requirement for survey, inspection, maintenance and repair work is likely to change.

6.2 It seems probable that, in future, maintenance-free materials will be introduced which would obviate the need for this type of work. Conversely, there is a tendancy to design buildings and structures with a shorter life such that they can be frequently replaced in order to keep in step with everchanging use requirements. This could increase the need for survey, inspection, maintenace and repair as the margins between design life and functional life are reduced. Although competition for surveys and inspection is likely to come from monitoring systems built into new structures, maintenance and repair work will continue to be required on the exterior of buildings and structures for a long time to come.

6.3 Changes in the availability of survey, inspection, maintenance and repair services are also likely to affect the market. The introduction of cheap, rapid, accurate and easily repeatable survey and inspection techniques using robots may create a demand in itself. Building and structure owners currently tend to adopt a reactive approach to maintenance rather than looking to predict deterioration problems before they occur. By reducing the cost and inconvenience of regular inspections the viability of preventative maintenance is improved.

6.4 The Project Definition Study for the DTI's AR Project in Civil Engineering and Construction is the second step towards producing a prototype advanced robotic device. Within a few years the widespread use of robots for survey, inspection, maintenance and repair work will become a reality. The potential benefits should not be underestimated by the owners and managers of existing buildings and structures and those involved in the commissioning, design, and construction for the future.

REFERENCES

1. Construction Industry Research and Information Association (CIRIA). "Feasibility Study on the Application of Advanced Robotics to Civil Engineering and Construction" for the Department of Trade and Industry, final report July 1987.

2. R Egginton Advanced Robotics Coordinator DTI. "UK Advanced Robotics Programme" August 1987.