Automation and Robotics in Construction XI
D.A. Chamberlain (Editor)

A robotic manipulator for inspection and maintenance of tall structures.

N.R.Bevan[a]BEng(Hons),Prof.A.A.Collie[b],T.S.White[a]BEng(Hons),B.L.Luk[b]BEng(Hons).

[a]Portsmouth Technology Consultants (Portech) Ltd., 70 Solent Road, Havant, Portsmouth, Hampshire, PO9 1JH, U.K.

[b]University of Portsmouth, Portech Mobile Robotics Laboratory, School of Systems Engineering, Anglesea Building, Anglesea Rd., Portsmouth, PO1 3DJ, U.K.

Abstract

A succession of wall climbing robots have been built by the designers at the University of Portsmouth and Portech Ltd. This paper describes the latest machine, SCOUR, which has been designed to inspect and maintain large vertical or horizontal curved surfaces. Machines of this type are used where human access is either hazardous or expensive. The paper describes the design and performance trials of the SCOUR robot which was recently completed. The main purpose of the project was to develop a robot that would enable work on tall structures without endangering the work force, and would also reduce the vast costs which are inherent when scaffolding and 'tenting' large structures to ensure that Health and Safety standards are met.

1. Introduction

There are a number of reasons why the development of robots for performing remote tasks can be justified, two factors which are always evident are the *health and safety* and *economic* factors.

When dealing with tall structures such as high rise flats, office blocks, ships or storage tanks the working environment is not always as kind to the *human worker* as it could be i.e. cold, dusty, dirty, wet etc.

Climbing robots are not easily bothered by such environmental hazards and in fact are able to cope with seriously hazardous environments such as chemical, heat or radioactive dangers.

SCOUR is largely based on the NERO [1][3][4] development but in this case has much more control incorporated and is able to cope with vastly differing surfaces. In fact the robot is capable of walking on surfaces which are inclined at 90° (positively or negatively) and can also cope with convex and concave surfaces up to a radius of 2.5m.

In other developments, it was required that the operator was in control at all times and that no movement operation would be carried out without the operators input. In this development however, due to the large areas which may need to be worked on, a large amount of semi-autonomous operation has been built in to the robotic system with the operator keeping a watchful eye on proceedings at all times. Although the robots control system is semi-autonomous it will not allow the vehicle to perform movements which will cause it to become detached from the surface or damage any part of the structure. The schematic layout of the SCOUR system is shown below in figure 1.

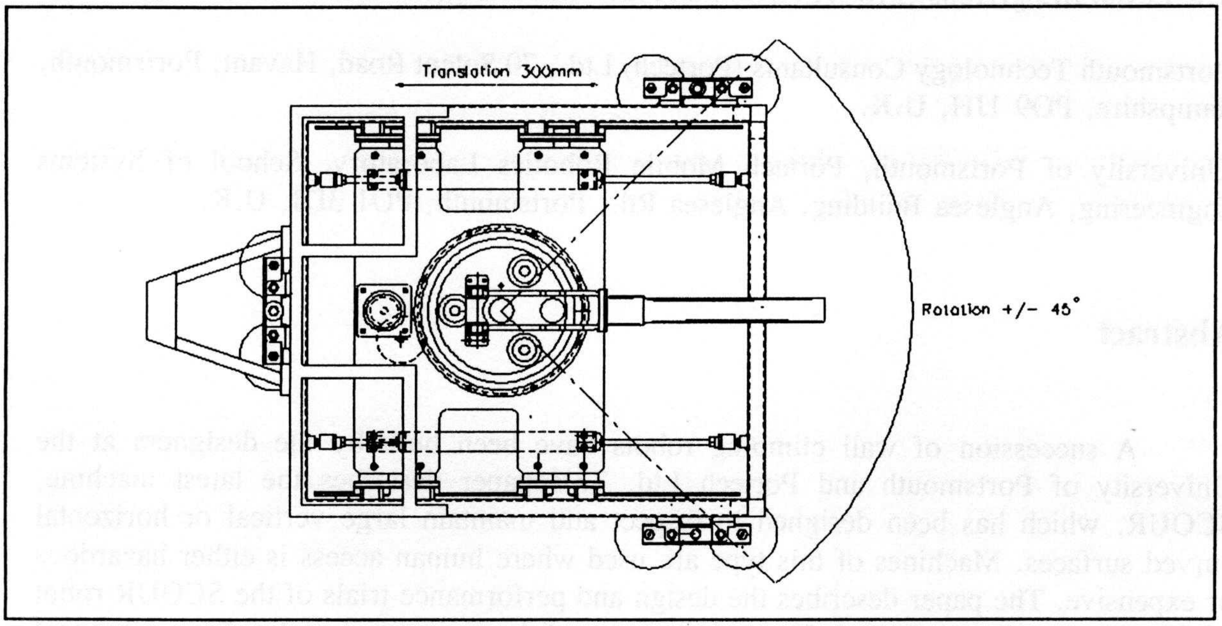

Figure 1. Schematic layout of the SCOUR robot

2. *SCOUR* specification

The robot has two sets of vacuum feet (six feet per set), one on the shuttle and one on the frame.

These feet are able to translate in relation to each other and thus enable the robot to walk, the power for the translation is via two large bore pneumatic cylinders. These cylinders are double ended rod cylinders which are supported by the end 'frame' of the robot. The main body of the cylinder is connected to the inner section of the robot 'the shuttle'. The shuttle is supported within a plate which travels on a pair of linear bearings, these bearings provide a translation bed from one end of the robot to the other. The frame and shuttle are also able to rotate with respect to each other. This is achieved using a powerful DC servo motor and a harmonic drive gear unit. This arrangement provides the power required to enable a 33 kg load to be manipulated at a distance of 0.90 m from the centre of the robot via a boom arm, the angular speed range at which the boom arm can rotate is from 1 mm/s - 375 mm/s. The physical specification for the SCOUR robot is given in table 1.

SCOUR specification	
• Payload weight	33 kg
• Minimum concave radius (long axis)	2.5 m
• Minimum convex radius (long axis	2.5 m
• Obstacle step over height	50 mm
• Maximum overhang (angle from the vertical)	90°
• Minimum walking speed	75 mm/s
• Length	1.5 m
• Height	0.3 m
• Operating environment	
Temperature - maximum (°F)	120°
Temperature - minimum (° F)	20°
Humidity (% - non condensing)	95%
• Air consumption	35cfm @8 bar
• Power	
Volts	110
Frequency (Hz)	50/60
Amps	5

Table 1. SCOUR specification

Because the operating surface is largely unknown in any particular area, the foot placement routine relies on a force controlled system which allows the feet to move towards the surface until contact is gained. Once a reliable vacuum is achieved, the foot placement routine is complete and the robot can begin its next movement or operation. This force control methodology allows the robot to operate on convex, concave and flat surfaces and also limits the force which is applied to the surface.

2.1 SCOUR control system

The SCOUR system is controlled via a PC and an operators control console. The PC and the control console communicate with the robot via a dual serial link to two separate single chip microcontroller cards. These cards provide the low level control required to operate the robot and also provide A/D conversion and the digital input and output to the robot.

SCOUR's teleoperation system is similar in principle to that of earlier designs, although this unit has a number of different functions. These will be highlighted later in the paper. The control system allows for two modes of operation i.e. manual and automatic. Both these modes are described in sections 3.1 and 3.2 of this paper.

3. SCOUR operation

In normal circumstances the robot would operate in automatic mode, only needing operator intervention when a problem arises.

3.1 Manual Operation

In this mode the operator has specific control of all individual actuations and is able to command each of these in terms of force and position. The manual mode is primarily for use when turning the robot or when manoeuvres in a confined space or where precise positioning is required.

Each movement is aided by the use of the teleoperation console and the control screen. The teleoperation screen provides the operator with a mimic diagram of the robot, this shows the relative positions of each component i.e. shuttle position, boom rotation angle etc. The screen also provides a simple command based menu screen which enables the operator to control the individual actuations of the robot. A message screen is also provided to the operator which indicates the robots current movement sequence and displays messages when errors occur. The layout of the teleoperation screen is shown in figure 2.

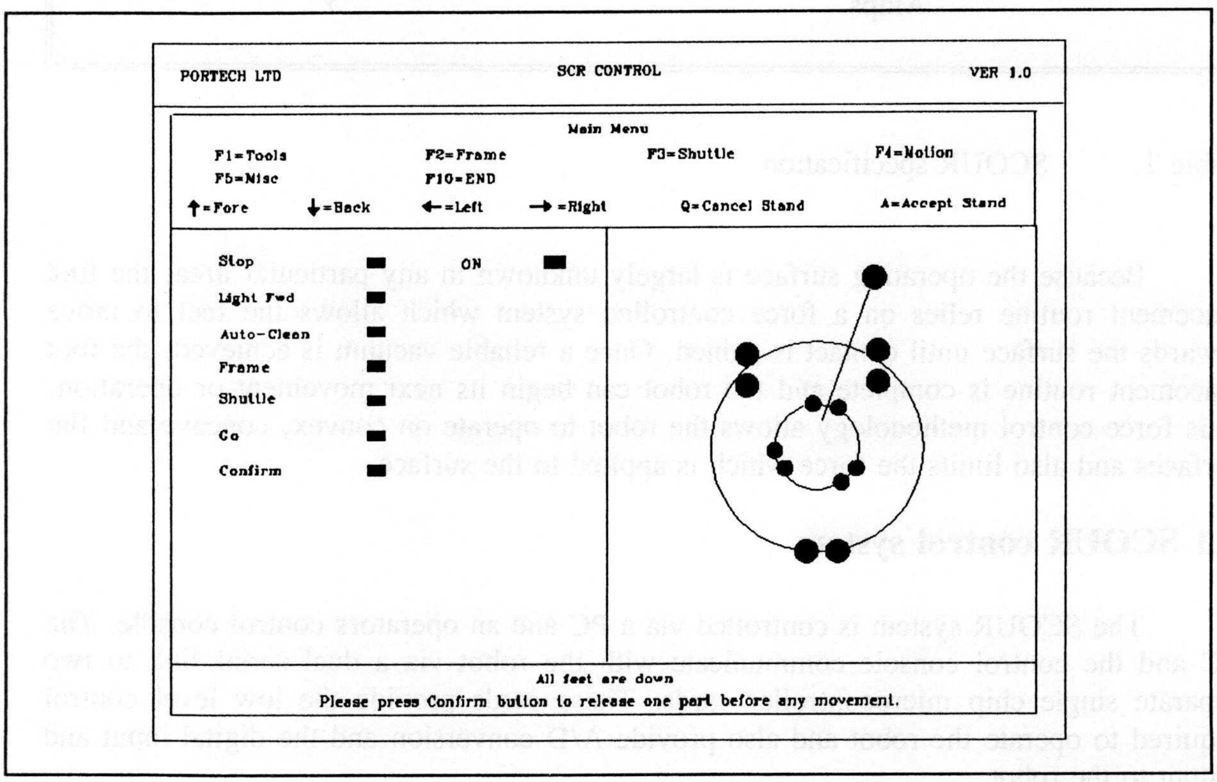

Figure 2 SCOUR teleoperation menu

3.2 Automatic Operation

During automatic operation the robot performs a repetitive set of tasks, relying on sensors to establish whether it is in a safe position to make its next move or not. An example of a typical cycle is shown in table 2.

Sensors on the robot allow all movements of the workpackage to be closely controlled, the sensors also provide a means of controlling the forces which are applied to the workpackage by the robot and the force which is applied to the structure itself by the cylinders of the robot. Another function of the robot which is controlled by sensors is the steering of the robot. When working on near vertical surfaces, inclinometers are used to provide a degree of self steering, thus enabling the robot to follow predetermined paths, this routine is generally implemented when inspection or maintenance in various positions is required or long distances in the same direction need to be travelled.

SCOUR automatic operation cycle	
1.	All feet in suction, shuttle at the rear endstop.
2.	Lift shuttle feet.
3.	Move forward x mm.
4.	Perform cleaning or inspection operation.
5.	Repeat operations 3 and 4 until the shuttle reaches the front endstop.
6.	Place shuttle feet on surface and check vacuum.
7.	Lift frame feet.
8.	Move frame forward to end stop.
9.	Place frame feet on the surface and check vacuum
10.	Repeat operations 1-9 until stopped.

Table 2 SCOUR automatic operation cycle

4. The Health and Safety issue

The two major issues associated with the development of a vehicle such as SCOUR are *economic* and *health and safety*. Of these two factors, health and safety is at the fore. At present, work on tall structures is performed manually in conditions where it is difficult to be effective. Inspection and maintenance during an abseil or on a swinging platform cannot be easy, and it is likely that the operator's attention will be on safety rather than on the task.

It is thought by the team at Portsmouth that a remote inspection and maintenance vehicle would provide a means of overcoming these problems. A remote inspection vehicle has the following advantages :

- Climbing robots are able to carry more instrumentation and undertake measurements more precisely than a man could.
- It will be able to cover more 'ground' in one day than a man could and is able to work continuously. Where access is particularly difficult or where space is limited this is even more accentuated
- The robot will not be subject to fatigue and will therefore provide a more thorough and accurate survey or repair.
- Climbing robots such as SCOUR will be able to work in environments where humans could not, for example in radioactive or chemically contaminated environments. The robot will also be able to make use of materials which could be hazardous to man without skin protection or breathing apparatus.

The inspection tasks which SCOUR could be used to carry out have not been defined as this is not the main concern of this paper. However, a list of possible activities is given below :

- Remote visual inspection.
- Concrete cover metering.
- Measurement and location of structural components and fixings.
- Probe inspection of wall cavities.
- Sampling.
- Inspection, removal and replacement of gaskets.
- Paint removal and application.
- Cleaning of large surfaces i.e windows.
- Mapping of faults to enable precise location for further work or later inspection.

This list is by no means exhaustive and is probably only a small proportion of the possible tasks which could be undertaken. The researchers at Portech and the University of Portsmouth have not as yet concentrated on the specific inspection tasks, but have concentrated on the development of a means of getting there.

5. The Economic issue

The health and safety issues addressed in the previous section have in the past represented a major contributory factor to the cost of inspection or maintenance in remote areas i.e. tall structures or confined spaces. It is felt by the designers at Portsmouth that costs would be reduced in the following areas.

- Scaffolding and tenting of large structures to contain debris.
- Increased productivity.
- Increased accuracy.

It is not hard to see that given a reliable robotic vehicle, these costs could be reduced drastically and would in turn provide further justification for the development of further robotic devices.

The present expenditure on inspection and repair in the UK construction industry is £17.5 billion out of a total industry revenue of £35 billion. Of the repair revenue it is estimated that some £500 million is for specialist repair services. It is difficult however to estimate how much of this would be suitable for remote vehicles, but it would not be unreasonable to place this at a very conservative 10%. Additionally it is estimated that 0.3% of the total revenue is for inspection, thus giving an available revenue for inspection and maintenance in the order of £76.25 million in the UK alone. These costs are only based on findings of the construction industry in the UK, other areas where significant costs are incurred because of inspection and repair are the nuclear, chemical and offshore industries.

It is estimated that after the development costs have been incurred, a suitable climbing vehicle for simple inspection and repair tasks could be manufactured for around £10 thousand whilst more complex vehicles would cost around £40 thousand.

6. Conclusions

The development of a large number of robotic climbing vehicles for a number of remote applications is inevitable. To this end Portech and the University of Portsmouth are cooperating with several universities, including the University of Kaiserslautern (Germany), the University of Lodz (Poland) and the University of Southern Queensland on the development of a robotic vehicle for use in hazardous environments i.e. nuclear.

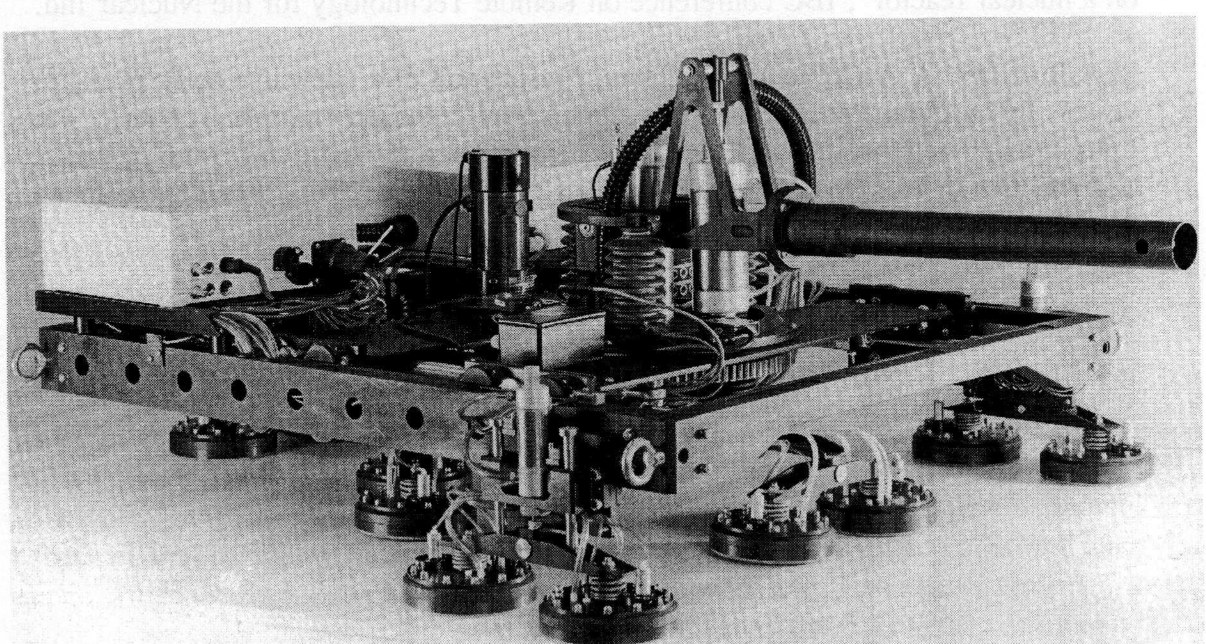

Figure 3. The SCOUR robot

Portech are cooperating with an industrial partner in the US on the SCOUR project for the inspection and maintenance robot, and are also cooperating with the Technical University of St. Petersburg in the development of a wall climbing vehicle specifically for construction maintenance.

Performance trials of the SCOUR robot shown in the photograph in figure 3 have now been completed and the vehicle meets the specification as defined in section 2 of this paper.

The robot has been fully tested on a full range of angles from vertical to horizontal. The next stage of the development will be the integration of the various work packages with the robot and further development of the automatic operation functions.

SCOUR is due to be tested in site conditions in early May, it is hoped that the results of this test will be available during the conference and that a Video will also be available.

7. References

1 T.S.White, A.A.Collie, J.Billingsley, B.L.Luk, and D.A.Moseley, "A Robot climbing vehicle and its Man-Machine interface for use in the nuclear industry", The 8th International Symposium on Automation and Robotics in Construction, 3-5 June 1991, Stuttgart, Germany, pp 851-859.

2\. N.R.Bevan, A.A.Collie, B.L.Luk, T.S.White "A sensor based autonomous climbing vehicle for unstructured environments", The 10th International Symposium on Automation and Robotics in Construction, 23-25 May 1993, Houston, Texas, USA.

3 A.A.Collie, B.L.Luk, T.S.White and N.R.Bevan, "Experience of climbing robots on a nuclear reactor", IBC conference on Remote Technology for the Nuclear Ind.

4 M.S.Burrows, A.A.Collie and A.Curry, "Inspection of a nuclear reactor pressure vessel by vacuum attached and magnetically attached mobile robots", 4th International Symposium on Offshore, Robotics and Artificial Intelligence - Telerobotics in Hostile Environments, 11-12 December 1991, Marseille, France.