Development of a Large Scale, Tool-Deployment-Manipulator for Construction Applications

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Abstract

This paper reviews the design philosophy and mechanical engineering behind the full commercial development of a heavy payload, hydraulic-robot-based, tool deployment manipulator with internal arterial services. The system has been developed specifically for construction and nuclear industry applications. The paper describes an evolutionary product development process, which has taken place over an 8-year period. The development has involved cooperating engineering and funding groups in Australia, in Europe and in the UK. The 6 DOF servo-controlled robotic or telerobotic system that has been developed as an industrial product is now going into commercial service in the diamond cutting and drilling industry, in the hazardous area operations industries and in the nuclear decommissioning industry.

1 Introduction

Robotics as a modern technology has obvious potential for use in such industries as civil engineering, mining, forestry, shipbuilding and similar industries. Robots can be used for the 3 dimensional manipulation of inanimate materials and unit loads as well as for the manipulation of various heavy power tools that can do work on natural or artificial workpieces.

Unfortunately however, most existing commercial robots are either fixed base, too small, too non-rigid or too non-fail safe to perform the tool manipulation function. Alternately, the robot is only able to absorb a small working torque or has to be festooned with umbilical services that impede the use of the machine and catch on obstructions [O'Brien 95]. Further, typical tool wielding manipulators can only operate in one orientation plane and cannot get into confined areas or operate to complex angles of attack. An even greater problem in terms of field robotics is that most industrial robots are not suited to all weather and outdoor use or to mobile operation under rugged conditions.

This paper reviews the development of the machinery system shown in figure 1, which one can describe as a heavy-duty tool systems carrier or tool deployment arm. The tool manipulator is capable of handling active tool systems of up to 200 kg in mass and supporting their action through the use of internal arterial supply systems for electric power, control signaling and for hydraulic power and cooling water. The machine also features a tool faceplate with quick release couplings and tool auto-connect features. The robot will carry its load in a full operational hemisphere and will sustain large load and tool torques as well as large static and dynamic tool reaction forces. The trade name for the mechanical embodiment of the system shown in figure 1 is 'Starlifter'.

Designed in the first instance to be teleoperated (but later robotically equipped), the Starlifter system has functionalities that are similar to the small and very agile, Schilling Titan II manipulator that is used extensively in the nuclear and underwater industries (figure 2). The Shilling machine however can only operate at +/- 15 degrees to the vertical plane and cannot absorb significant torque at its base nor can the joints be locked to provide a rigid fail-safe tool reaction structure. Additionally, it can only handle small payloads and is not suited to impact hammer or kick back tool use.

Conceptually, the Starlifter machine has been developed to operate in either a stand-alone mode (either with fixed or mobile base) or as the front end of a larger robot or load delivery structure.

These alternative modes of use are illustrated in CAD figures 3 and 4.

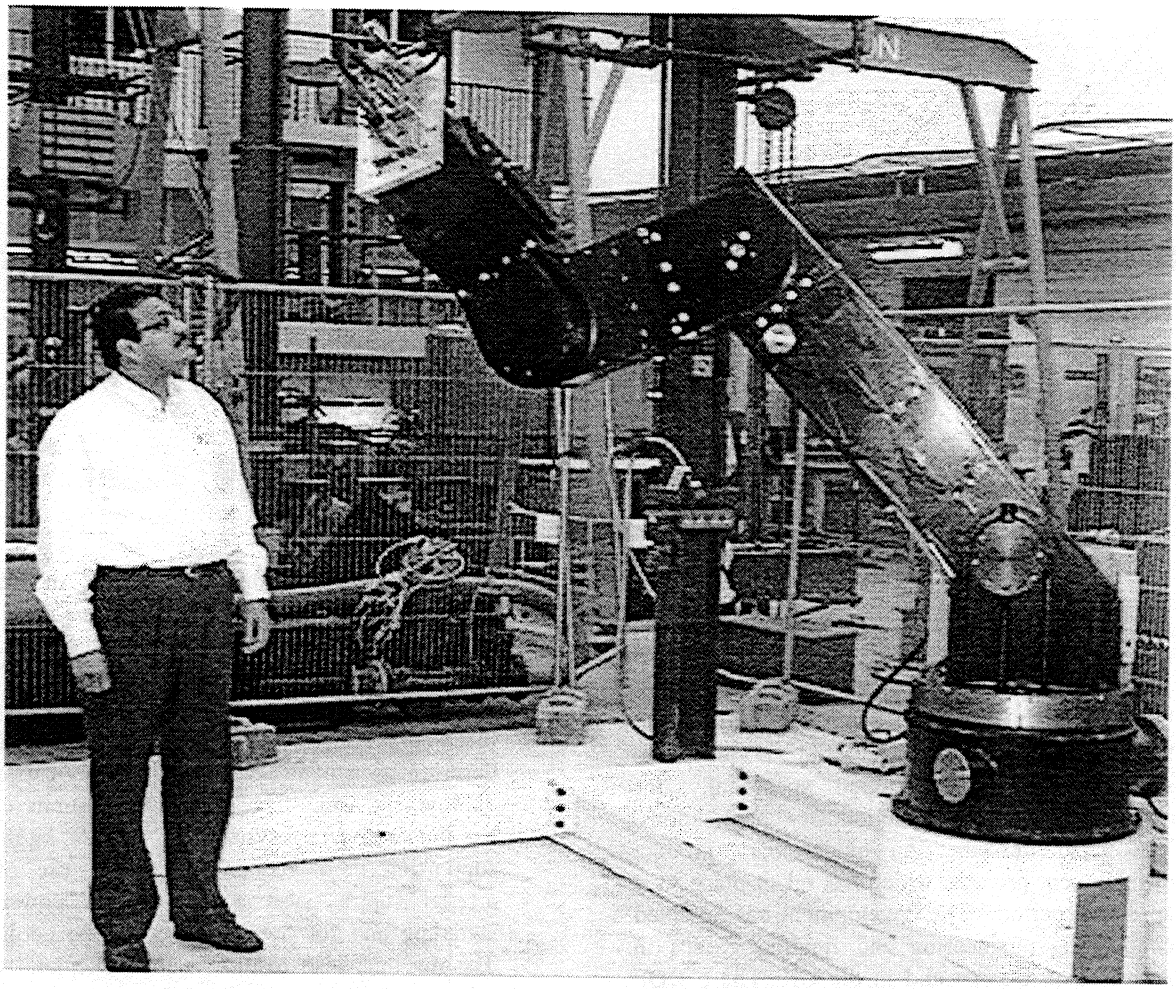


Figure 1 – The Starlifter tool deployment manipulator showing serviced faceplate and fully enclosed services. The machine can be used in any orientation.

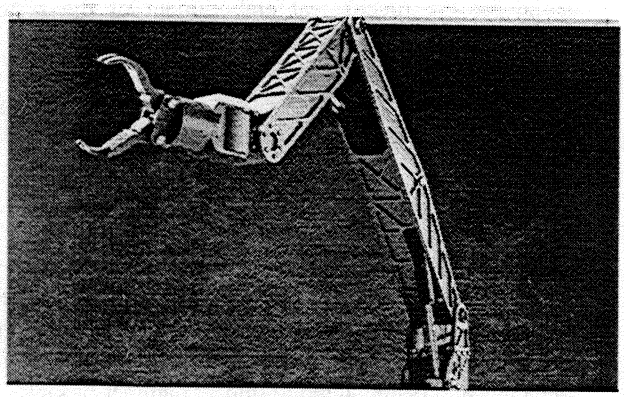


Figure 2 – The Schilling Titan manipulator

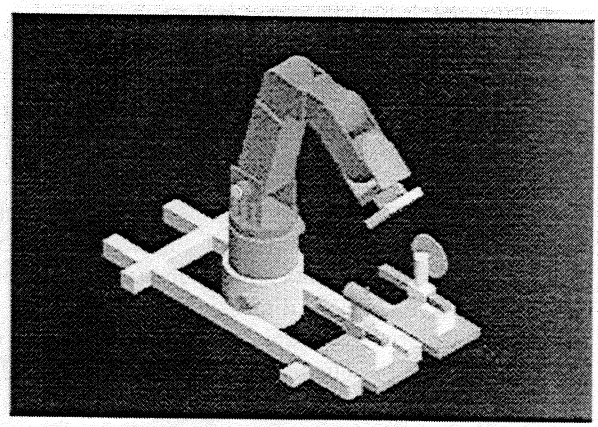


Figure 3 – Stand-alone mode of use

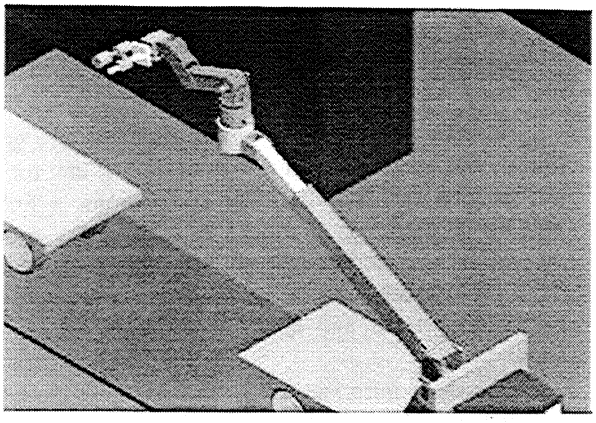


Figure 4 – End of boom mode of use

Figure 5 show a standard construction industry rough terrain crane that could be used as a large capacity load delivery unit.

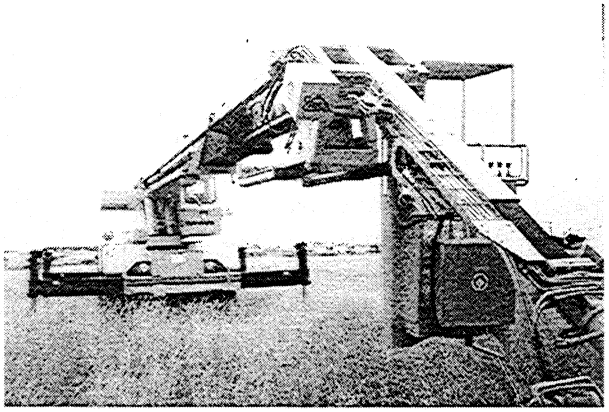


Figure 5 – Rough terrain mobile crane with pipe manipulator end attachment

2. General Concept

A tool deployment manipulator can be thought of a as a special purpose robot arm designed to carry heavy power tools - such as diamond saws, power drills, angle grinders, shears and so on in addition to normal, fixed or exchangeable, robotic pincer grippers. The add-on tools are 'active' in the sense that they are interactively in contact with a workpiece and they cause reaction forces, suffer tool judder and vibration and occasional jamming. Construction tools are typically heavy with all up weights of up to 200 kg. They are typically powered and must be supplied with hydraulic, electric or pneumatic power in addition to electronic signals for control and data communication purposes.

In teleoperated systems, additional technology in the form of pairs of stereo TV cameras, ultrasonic transducers and other sensing systems are typically provided and can be powered from the machine's faceplate

A schematic of a multi-tool carrying manipulator is given in figure 6. The figure is derived from an earlier paper by the author on the subject of 'robotic action heads'[O'Brien 94].

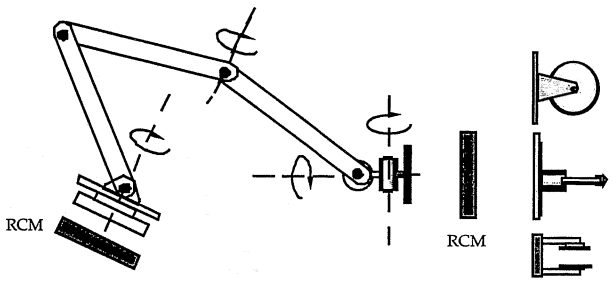


Figure 6 - Schematic of a variable front-end form of boom unit showing optional remote connect/disconnect modules (RCM's).

In this diagram we have a fixed "base" module and an exchangeable or variable "front-end" module or tool system. The general form of this arrangement is shown in figure 6. Optional in this set-up is the use of two separate remotely controlled engagement-disengagement modules to allow action-heads and tooling systems to be remotely changed or switched under computer program control.

3. Internally Provided Services

Within systems of this type, a tool can be either be supplied with power, cooling water etc from a separate services umbilical or, as in this case the Starlifter robot, services can be provided from internal hidden 'plumbing'. The Starlifter system, as developed, has a unique feature in that it can supply a tool directly from a multi-power-point equipped faceplate. Remotely operable, rapid changing features for the tool system can be provided.

The principal mechanical engineering challenge in developing Starlifter was in development of large deformation joint designs that allow for the passage of fluid power and electrical power and signaling facilities whilst maintaining a compact form without any backlash. To meet this requirement, a system based on Helac, helical hydraulic rotary actuators, with fluid slip rings was devised. Internal hydraulic seal leakage was an important design parameter and a complex set of pilot valve based interlocks was developed. Where needed for large torques, a hydraulic ram powered rack and splined shaft gear system with precision made components was used.

4. Illustrative Payloads

The tool deployment manipulator system is designed to accommodate most forms of standard construction power tools without any modification to them save

development of mounting base. Most construction tools nowadays are based on hydraulic or electric power.

A typical type of construction tooling system that can be readily deployed by Starlifter is the 20 kg diamond coring tool of figure 7.

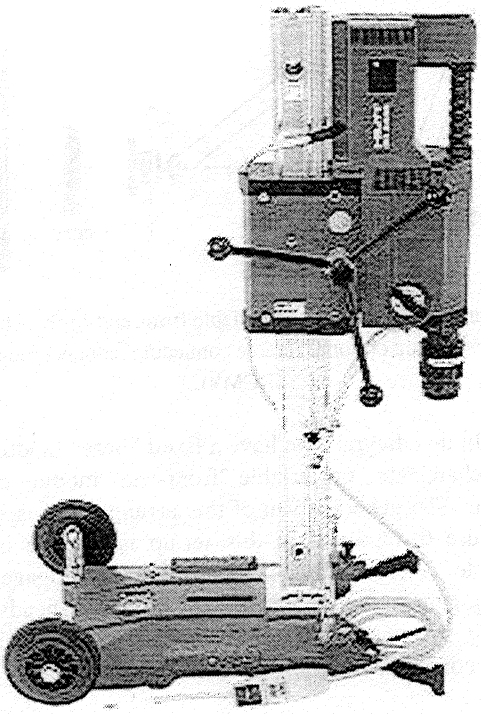


Figure 7 – A typical diamond drill coring system

In normal manual operations, a diamond core drill is typically bolted to the workpiece to keep it steady and to prevent tool wander. In the case of the tool deployment manipulator the arm has to hold the drill steady against reaction forces. In use, diamond core drill requires a source of power plus a generous supply of cooling water.

Figure 8 shows another type of tool system that can be deployed by Starlifter which is an electrically operated impact hammer. The figure shows a small unit but much larger sizes - up to 200 kg can be accommodated.

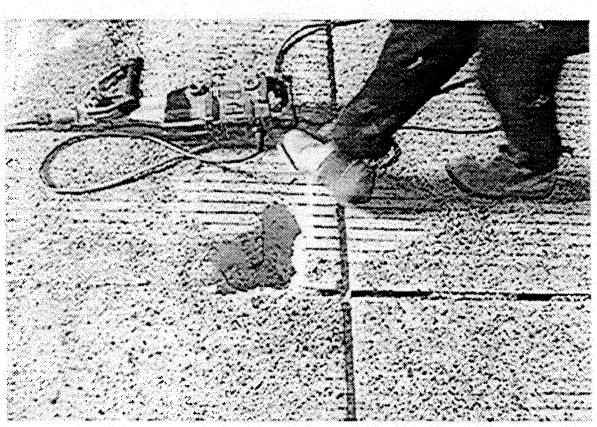


Figure 8 Small sized impact hammer

5. Results of some early trials

To test the feasibility of development of a general-purpose add-on robotic action head (RAH) unit for heavy construction and site building applications, a full-scale modular system was produced in 1994. The prototype was developed to validate the idea and to test, in fine detail, the capacity of the machinery to effectively wield construction tools and to do useful work on real-world sites.

For these purposes a 3 DOF RAH base module was developed with variable front-end tooling features. The system was mounted on a large fully programmable, slewing, telescoping construction crane based system with the whole being set up for full telerobotic or external computer systems operation based on triple TV camera data gathering facilities. The result was a 7DOF, 250 kg payload carrying machine with a reach of about 10 metres, with millimetre positioning accuracy and with zero system backlash.

The elements of the system are illustrated schematically in figure 9. Figure 10 shows the 3DOF "wrist" system employed as the RAH base module. Three different tooling systems in the form of a saw, a drill and a gripper/cutter-shear system were developed and deployed.

All functions of the base machine and the action head and tooling system were set up under a remotely controllable, continuously variable action, electro/hydraulic valve systems. In addition the action head system used an 'anti-backlash lockout' system to physically lock all joints during tool operation and to eliminate fine motion and vibration in the system during reactive force operations.

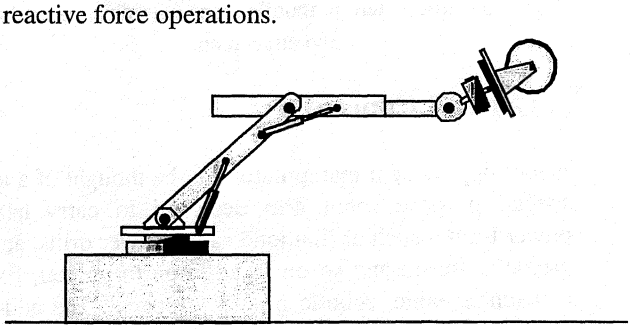


Figure 9 - The overall system - made up from three independent functional systems

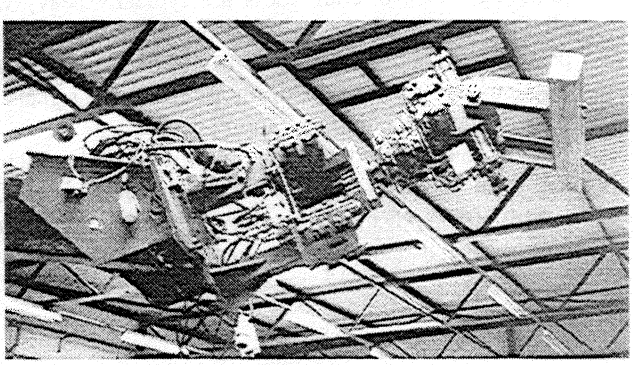


Figure 10 – The prototype system carrying a 250 kg test mass

The 3DOF manipulator unit shown in fig 10, weighs about 250 kg and has a payload to self-weight ratio of less than 1. The module is readily transported in a car-hauled box trailer. The system is fully self contained and can be connected to the base machine by one man through snap and screw type connections. The connection operation takes about 10 minutes. The system provides +/- 180 degree motion on the roll axis and +/- 90 degree motion on pitch and yaw axes.

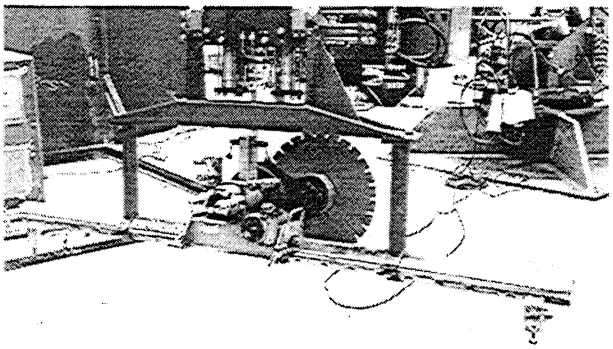
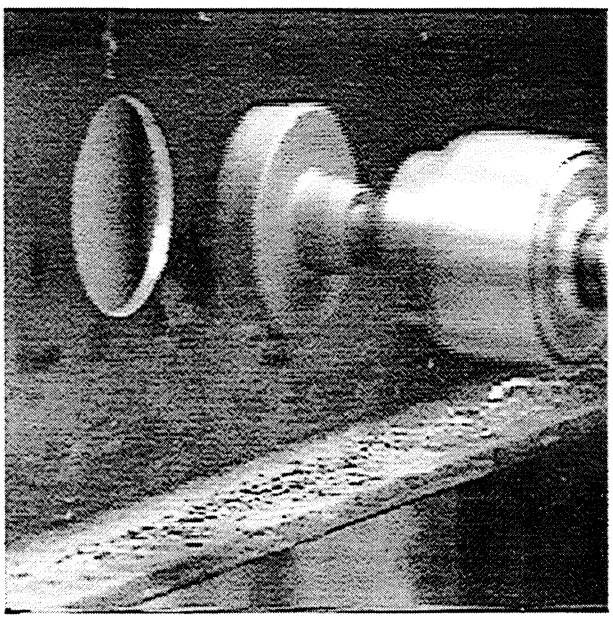


Figure 11 - Illustrative tool system comprised of a hydraulic rotary diamond-cutting saw with indexing system

Figure 12 shows the results of remote drilling operations in the form of a 50 mm hole that has been drilled through the vertical web of a structural steel girder. Note the cleanness and accuracy of the hole edges. In contrast, figure 13 shows the remote shearing operations. Shown is a 40 mm steel pipe that was severed by a set of hydraulic shears/cutters and thence grabbed and held by a parallel, immediately adjacent, set of programmable pipe seizing jaws.



Figures 12 Remotely drilled hole in the web of a steel girder {photo grabbed from videotape}

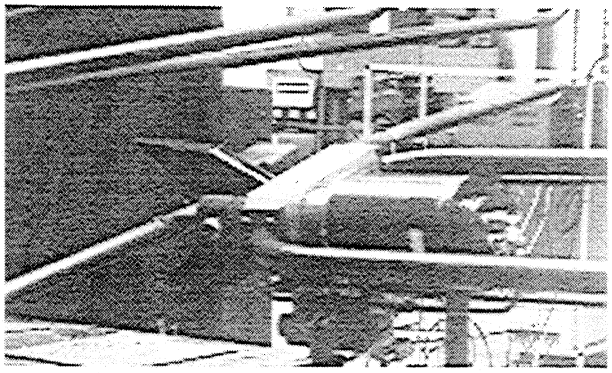


Figure 13 Remote hydraulic shearing and holding of 40 mm steel pipe

6. The evolution of the Starlifter tool deployment system

Developing out of the writer's patented prototype system (cf. figures 9 to 13) the Starlifter system has been developed by robotics interests in the UK into the world's first commercial heavy construction tool deployment system. The central development work was done (in some secrecy) within the nuclear decommissioning industry context by Construction Robotics Limited (CRL is a company founded by the writer. It was later subject to a hostile take over by UK Robotics Limited). All mechanical engineering was done by CRL's own team with specialist control skills know-how coming in from UK Robotics. The field performance of the resultant Starlifter machine, in term of its rigidity, controllability and tool system supply features, has been exemplary [CRL 99].

Apart from teleoperation, full robotic control for the machine was developed by UK Robotics Ltd. in conjunction with British Nuclear Fuels Limited. Robot systems performance was modelled and simulated using the IGRIP CAD system from the US firm Deneb Robotics

The Starlifter machine is currently under further development at the University of Lancaster in the UK where it is being equipped with additional sensors and on-board intelligence and programmed for autonomous operations in various construction task-space.

7. Conclusions

After an 8 year or so gestation period a large-scale tool, deployment boom of a type suited to use by the construction, mining, shipbuilding and allied industries is now a commercial reality. The machine was conceived of in Australia as a device for use by the construction industry. However initial demand has taken it into the nuclear and hazardous work area industries where it has

become an essential tool. The challenge is now to recover this technology for application in the standard construction, mining, forestry, shipbuilding and allied industries.

Acknowledgements

Figure 1 is from Lancaster University's Construction Robot Laboratory. It represents the state of development of the machine in February 2000. Figures 3 and 4 are also from Lancaster University.

REFERENCES

[O'Brien 95] O'Brien J. B. "Large Scale, Computer-Controlled, Manipulators For Field Based Applications" 26th International Symposium on Industrial Robotics (ISIR) Singapore October 4-6 1995 pp 79-84.

[O'Brien 94] O'Brien J. B. "Robotic Action-Heads - New forms of device for attachment to existing construction machines" Proc. 11th International Symposium on Automation and Robotics in Construction, Brighton England, May 24-26, 1994 pp. 690-700.

[CRL 99] Construction Robotics Ltd (UK) - Company promotional video 1999.

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