DESIGN AND PERFORMANCE OF THE PORTSMOUTH CLIMBING ROBOT

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Summary

The Portsmouth climbing robot, Robug II is a prototype research vehicle designed to demonstrate the feasibility of an articulated-limb climbing machine. Its architecture mirrors the structure of an insect. A central body which will support inspection or other equipment is carried to the required location by four (or more) fully articulated legs. These are mounted at the corners of the body and suspend it clear of the surface.

Each leg has a suction cup foot powered by an ejector vacuum pump. Additional suction feet are fitted to the body so that it may be locked in place while inspection is taking place, or between paces where the terrain is difficult. Intelligence is distributed, each leg being provided with individual microprocessor control. Foothold is tested before weight is transferred. The legs are able to step over obstructions and negotiate changes in level.

Introduction

There are many occasions when large structures have to be inspected, cleaned or repaired. This can be a dangerous and time consuming activity involving suspended work platforms or the erection of scaffolding. An alternative approach is to use a robot which can climb the structure carrying with it the tools and equipment to perform the required task. Such a robot must be light so that its weight does not strain the structure, yet rugged enough to work in an exterior environment and powerful enough to carry the necessary payload. A suitable robot has the potential for achieving considerable cost benefits compared with traditional methods.

A spider-like articulated leg machine fitted with an appropriate gripper foot has engineering appeal. Legged locomotion does not require a continuous or level path of support. For all but the simplest of structures the ability to find foot holds and move over gaps and obstacles is an essential requirement. It is true that the necessary control system is of a much higer order than that needed for wheeled vehicles, but these needs can be amply and inexpensively provided by the microcomputers now available.

The above considerations have led to an outline specification for a research machine which will test the feasibility of a climbing-robot and the communication structures associated with its control.

Conceptual specification.

The robot must have the following properties:

Light weight
capable of being handled easily by one man

Power/weight
able to lift at least twice its own weight

Body size
as small as possible, determined by the control system dimensions.

Inherently stable
centre of mass must be low

Rugged
self calibrating and unaffected by minor mechanical damage

Reach
able to step over window sills
able to extend legs substantially in all directions

Gripper
able to support whole body weight with one or two legs only on a smooth surface

Remote control
a command console must provide an operator interface

Local control
autonomous foot placement and obstacle detection must be implemented by microcomputer systems which are expandable to meet future needs

Power consumtion
Low electrical power consumption.
The robot should use a non-critical unregulated low voltage supply resistant to interference.

In many applications the need for an umbilical link is no impediment. Where this must be avoided the robot might carry its own power supply and communicate by means of a radio link. Such schemes are feasible using available technology but with the limited budget available the effort is more appropriately applied to the fundamental problems of mechanics and control.

The engineering problems presented by the above set of requirements are indeed formidable. However the researchers started with the experience gained from earlier work at Portsmouth Polytechnic on a pneumatic hexapod walking robot (Ref.1). The hexapod used the idea of individual intelligent limb-systems, linked by a communicating supervisor. The new robot is composed of modular limbs which may be assembled together in any convenient arrangement. A limb-system consists of a leg mechanism, a gripper system, a set of linear pneumatic actuators and valves, a set of sensors, and a microprocessor controller linked to the coordinator.

The articulated limb

The biological mechanisms of many specialised climbing creatures show one common characteristic. The limbs leave the body in such a way that the belly of the creature may be close to the ground while in motion.

Inherent stability is an important consideration. In beetles this is achieved by a wide spread of the legs, often extending to more than three times the body width. In spiders the body hangs below the 'knees' and the limbs can adduct to little more than the body width and still maintain stability. Other workers are investigating the reptilian geometry with a Gecko like machine (Ref 2), but an up-and-over spider-like arrangement appears to have better potential for negotiating obstacles. The body can be raised and lowered and the reach of the legs can easily be made to exceed the body length.

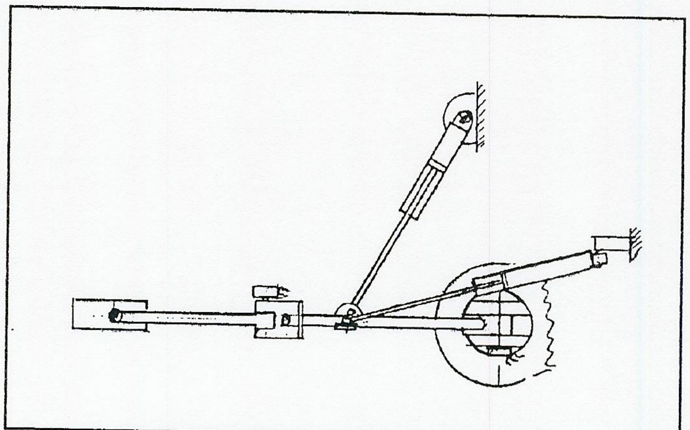

Figure 1 Plan

Figures 1 and 2 show the arrangement of a limb with three degrees of freedom. The control system allows the addition of a further section for extending the reach at a later date. The limb consists of two struts and three pneumatic double acting cylinders. The upper leg consists of one strut fitted to the hip swivel-joint. The other strut forms the lower leg. A hinge between the struts functions as a knee which is always higher than the hip. Sensors are connected to the joints so that angles corresponding to knee extension, hip extension and hip abduction can be measured.

In the experimental model the assembly arrangement can be modified and the leg-struts readily changed so that alternative geometries can be tested. For example the stride can be increased at the expense of tractive effort by moving the knee cylinder attachment away from the foot.

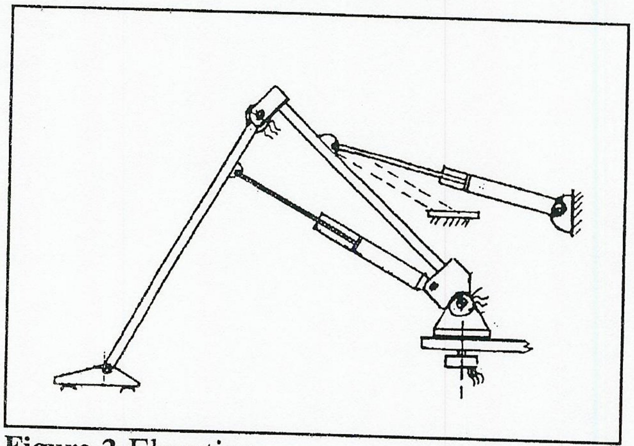

Figure 2 Elevation

A feature of the mechanism is the way in which the hip and abductor cylinders together share the loads on the upper-leg. The Portsmouth robot employs a tetrahedral structure to achieve parallel linkage to the knee, giving a force distribution which is always well conditioned. The anchorage points of the hip and abductor cylinders and the hip joint are thus widely separated reducing the stresses in the chassis and permitting a lighter construction. The control system is able to apportion the hip load appropriate to each cylinder for all positions of the leg. The arrangement is somewhat analogous to that of the muscle attachments around the hip of large animals.

Actuators

The use of pneumatic actuators is central to the design. Compared with geared electric motors they are lighter, simpler and environmentally more rugged. Pneumatic cylinders provide high thrusts directly, without the need of gearing. Those used in the model can provide thrusts up to 400 N and weigh under 500gms. A further advantage gained by the use of pneumatics is the simple way in which compliance can be introduced. With compliance, loads are shared more equitably and the machine is more tolerant of abuse.

A great benefit of compliant control system is that the robot can accommodate mechanical imperfections both in itself or on the surface it is contacting. This reduction in the need for precision engineering is further enhanced by an automatic set up and calibration procedure which extends and contracts each limb to its end stops. During this process the limit values of the sensors are noted and the range and zero errors adjusted in software to a uniform percentage scale.

Control system

An essential feature of the control system is its hierarchical structure. At the macroscopic level, the system is seen to break into a dedicated microprocessor to control each limb, linked by a communication bus and efficient protocol to a coordinating desktop machine. Each microcomputer has three joints under its control, all handled in a like manner. The structure is illustrated in figures 3 and 4.

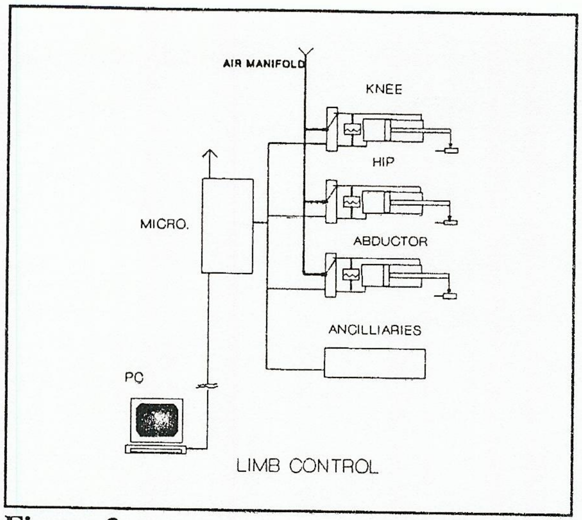

Figure 3

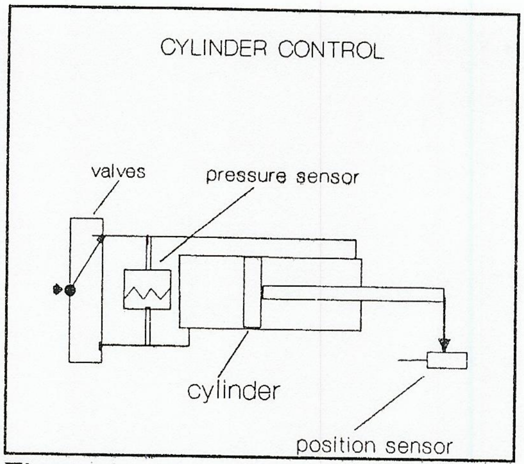

Figure 4

Within the software, the same modularity is seen to be reflected. Communication primitives are handled by a simple subroutine call, having syntax "Send codebyte". From elementary submodules, further routines are built up to handle leg selection - "Limb leg", joint selection, "Knee", and command of a specific control action such as "Push 40". Results-sensitive routines are similarly formed within this syntax, such as "Getagrip" for intelligent foot adhesion, building to a repertoire of high level manoeuvres readily defined in language which is intuitively clear at operator level.

The primitives are received by the limb microprocessors, which perform valve switching operations, capture and return of position and pressure information or enter closed loop control modes in their own right. The system is able to control the position and force of each part of the leg and to use force feeback to feel for foot holds and obstacles.

Navigation

Foot position information can be obtained from the joint angle sensors. An inverse kinematic programme has been written for the leg computers so that "dead reckoning" can be used for general navigation. Additional sensors for more precise navigation are under investigation.

Gripper foot

The present grippers will admit of considerable improvement; to save on development effort the model uses commercially available components. These are powered rubber sucker pads driven by compressed-air vacuum ejector-pumps. Two pads in line ahead are used on each foot. For the smooth surfaces used in the tests these have been a good lightweight solution providing a pull-off force corresponding to 80% atmospheric pressure. On the larger pads this is equivalent to 300 N. Alternative grippers for specific application may be substituted; flux-switching rare-earth magnetic feet are currently being developed by a commercial organization.

Additional sucker feet are mounted under the base to lock onto the surface while the feet search for a foothold or while any onboard equipment requiring a stable work platform is being used.

The foot connects to the leg by a ball joint "ankle". Provision has been made to add an actuator to align the foot when later experiments require the robot to negotiate the corner between horizontal and vertical surfaces.

The whole model

From the modular structure described, two pairs of limbs have been connected to form a four-legged device. With little elaboration, the number of limbs can be increased for any specific application. Articulated chains of leg pairs would be appropriate for carrying long loads, exploiting the provision in the design that the thoracic joint angles between adjoining sections can be controlled by additional channels of actuators. Alternatively, rings of eight legs have an arachnid appeal! Moreover, the number of legs can also be reduced. The first leg-pair was successfully demonstrated to move in a versatile fashion, two further suckers providing grip at the "buttocks".

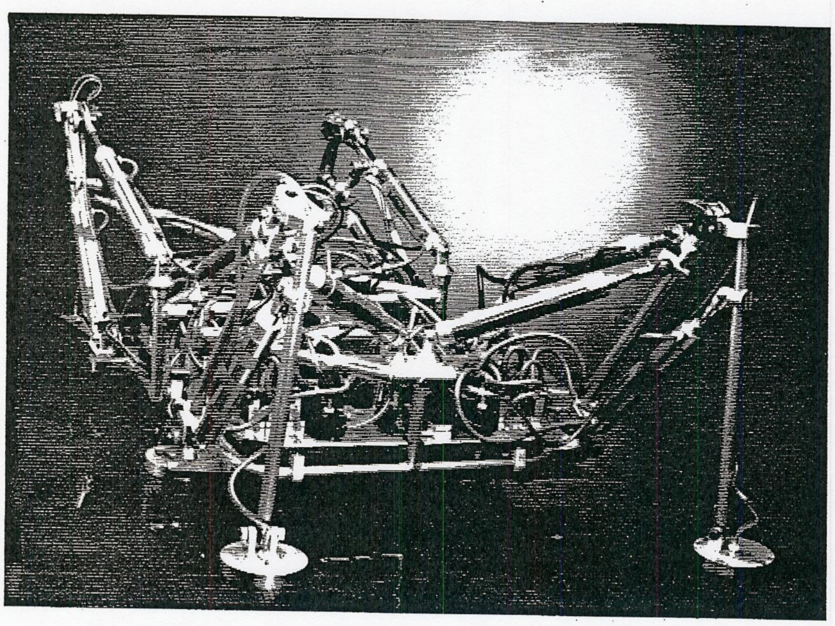

Figure 5 ROBUG 2

The photograph shows Robug 2 in its present state. It weighs 17Kgs. In the configuration used for the trials the struts are 335mm in length; the robot is 1000mm long and 700mm wide when the legs are fully flexed. Fully extended it is 1700mm long or 1600mm wide. A typical pace is 200mm, that is about two thirds of the maximum possible. Air is supplied via a light 8mm bore flexible pressure hose from a small portable compressor.

When the configuration of the robot is changed, for example by moving the cylinder attachment points on the struts, the robot has to be "taught" the new foot cordinates relative to the joint angles and limits of travel. This is a simple exercise in which the foot is placed manually over a few points marked on a board. Generally the legs are identical and only one leg need be taught. For some applications it may be desirable to vary the structure of individual legs, or legs may have been deformed by damage; each leg computer can memorize its own leg's configuration.

Performance.

Currently the robot is able to climb smooth surfaces, seeking and verifying foot holds. Alternative gaits are possible. If only one leg is moved at a time a maximum grip can be maintained. A more rapid gait moves the legs in pairs. To call this a gallop, although technically correct, is misleading! The climbing speed of the present motion is one metre per minute, although with each experiment this is being improved through software refinement and enhanced valving.

Although designed for "tameness" and ease of handling, the robot has considerable strength and its power-to-weight ratio enables it to pull double its mass up a vertical surface. A trivial increase in cylinder diameter will multiply the forces many times over, at practically no cost in increased mass.

References.

1) Collie A, Billingsley J, Hatley L 1986, The development of a pneumatically powered walking robot base. Proc. IMech.E Conference C371/86 pp137-143.

2) Hirose S,Sato M,1989, Coupled drive of the multi-DOF robot 1989 IEEE Conference on Robotics and Automation Vol. 3 pp1610-1616

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Note. Robug 2 is the subject of patent applications.

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