

Snake-arm robots and the perception of dependability

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Abstract

Various forms of snake-arm robot have been built and tested since the 1960s, but none have been a significant commercial success. OCRobotics is aiming to change that by developing a family of flexible snake-arm robots with the intention of making snake-arm robots a mass-produced item.

Since 2000 OCRobotics has won significant contracts with the UK Ministry of Defence and Uddcomb Engineering AB, a Swedish company, to develop and supply snake-arm robots.

This paper reports on the results of the nuclear project, focusing on the practical issues of delivering 'advanced robotics' solutions into demanding environments. The sub-plot is whether the work to date will provide a different direction from which to approach the issue of dependable robots for use in human environments.

The basis of the design, that underpins the whole OCRobotics family of slender flexible snake-arm robots, originated from the desire to produce a controlled path endoscope for keyhole surgery (e.g. colonoscopy). In such applications safety is paramount and interaction with humans, both the patient and the operating team, form the central part of the technical specification.

For purely commercial reasons the first users of snake-arm robot technology have not been in the field of surgery or interaction with humans generally, but rather in the field of bomb disposal and remote nuclear activities. However, these applications may indicate how robotic technology could be changed, either in physical implementation or in human perception, to become dependable; dependable enough to make the transition into typical human environments.

Dependability

What does it mean for a robot to be dependable – assuming the aim is to provide a butler rather than a serial killer? To the one who is doing the depending the word probably indicates a perception of reliability and availability; the car that starts every morning whatever the weather. It also implies a sense of familiarity and acceptance; a sense of ease. This might indicate a level of understanding on the part of the user where the user knows what to expect (no surprises) and finds this acceptable. Dependability infers a sense of benign constancy.

Robots seem to have two Joe Public stereotypes: the sci-fi humanoid in T3, and the painting-welding-car-producing-machine. Neither of these images sits particularly well with a robot as a dependable butler. In an image conscious world, what the robot looks like is probably going to have as much impact on the perception of dependability as the technology within.

Unfortunately the technical challenge of robotics is not what the packaging looks like but rather what it does. More specifically a robot to be used within a typical home, for cleaning or carrying, will have kinetic and potential energy and the capability to injure. To the designer dependability can be translated into a requirement that this energy is controlled so that it cannot cause undue harm to the user.

Clearly there are myriad ways of achieving this: from a light and a beeper to indicate that the robot is coming or an array of onboard sensors that stop the robot when an obstacle is detected, and all the way to a sensor guided 'intelligent' response. Another approach is to minimise the rate of energy transfer whilst still enabling the desired function to be performed.

Technology

The use of the phrase snake-arm robot to describe a range of flexible robots establishes a link with ground based snakes and provides a number of visual cues for potential users who have no interest in the underlying engineering. Within the research community our snake-arm robots might be described as serial hyper-redundant continuum mechanisms or flexible redundant manipulators. There are broadly two types of these robots – those that are totally self-supporting, like an elephant's trunk, and those that take advantage of a certain level of support from the environment, like a tree snake. Both are flexible and both can carry a payload, but the tasks that can be achieved by each are quite different.

These flexible mechanisms are ideally suited to working in human environments because they can be designed to be more compliant than people whilst still carrying a relevant payload. In the event of collision between a person and the mechanism the result must be that the mechanism loses gracefully. However, in the process of losing, the mechanism should not be damaged and must not lose track of where it is.

In designing flexible robots there is a self-evident trade off between flexibility or compliance and the amount of deflection caused by arm self-weight and payload. The requirement for delivering a payload is to carry the payload with an acceptable level of repeatability as defined by the task. Repeatability may be enhanced by software compensation for the inherent flexibility of the robot, without increasing the passive stiffness of the device. This can be used to increase the payload capacity of a device or to reduce possible human/robot passive interaction forces.

Figure 1 shows the OCRobotics prototype demonstrator that was completed in November 2001. It is a 5 segment arm, with each segment having 2 degrees of freedom. The arm is 1m in length with an external diameter of 35mm and an internal 15mm diameter working channel that runs the entire length of the device. The shape of each flexible segment is independently controlled by a number of actuators connected to the relevant segment by wires.

The design of the bending element that forms the basis of each segment is critical, both in terms of achieving mathematically tractable motion and a design that can be manufactured in volume for an acceptable cost. In addition, the adopted design enables certain manufacturing parameters to be changed in order to vary the flexibility of the arm considerably.



Figure 1 - 5 segment prototype

By early 2004 OCRobotics had won two significant contracts. The first was with the UK Ministry of Defence to build an arm for remote bomb squad operations. The second was to supply two types of snake-arm robot to a Swedish company to perform a repair in a nuclear utility.

Nuclear application

The task to be achieved was to deliver a variety of tools and fixtures into a very confined space and to conduct very precise positioning of these parts (delivery and extraction) and also to conduct tack welding and final inspection.

The work area is exceedingly congested – comprising 157 200mm outside diameter tubes on a regular square grid of 305.5mm pitch rounded off to form a circle. With additional tubes the maximum access space is a corridor 86mm wide with no direct line of sight to the work zone.

The tubes were themselves contained within a very confined area called the CIR – reached from below through an 800mm by 500mm access hole and another small doorway. Within the CIR there is only space to crawl around the outside of the 157 pipes on hands and knees. Further complications included a room temperature of 35 degrees centigrade and time constraining levels of contamination requiring multiple layers of overalls, masks and gloves.

The approach taken was to design two snake-arm robots. The first snake-arm, called the Overhead Arm, Figure 2, gains access from within the CIR itself. The second called the Underneath Arm gains access from the room below through some fortuitously available 62mm diameter holes.

The Overhead Arm comprises, an 8 DoF snake, a 3 DoF wire driven wrist and vertical and prismatic axes forming a standard gantry. The motors and associated electronics to control 17 motors are housed within the fully sealed OA Box. This box is 82mm wide, 650mm long and 350mm high. The snake-arm is 60mm in diameter, 800mm in length and has a payload of about 10kg and motion resolution, as measured by the customer during trials, of better than 50 microns.

The function of the Overhead Arm is to deliver tools and fixtures into the work site, including placing various fixtures very precisely in order to constrain certain pipes during cutting and welding operations.



Figure 2 - Overhead arm in situ

The purpose of the Underneath Arm, in fact two Underneath Arms working side by side, is to position (and reposition) cameras so that the operator has a view of the worksite. Additional views were also supplied using fixed cameras. The Underneath Arms are 1m in length and 35mm in diameter with a payload of less than 500g. The arms were designed to more compliant than the Overhead Arm in order to gain access to the worksite.

Figure 3 shows one Underneath Arm snaking into position through the 62mm hole in the floor. These pictures were taken during training and acceptance tests on a mock-up built to simulate the working environment.



Figure 3 - Underneath arm snaking into position

The Underneath Arms comprise a 10 segment, 20 DoF snake-arm, a 2 DoF wrist and a vertical axis.

Control of all motors is by means of an OCRobotics CAN based distributed amplification and servo control board.

Both robots are controlled using the same software. The operator is able to control both arms in a variety of modes: path following, where the body of the device follows the tip; Cartesian motion of the tip in world or tool space; joint space, i.e. segments; and motor space (for maintenance only). All modes of operation were completely stable and the user was able to move between all modes of operation in any order.

Observations on the perception of dependability

Robots designed for a nuclear environment have to pass rigorous tests and extensive use before being allowed to be used within the reactor. Using the Overhead Arm within the reactor containment indicates the level of dependability that has been reached with the OCRobotics technology.

More generally from observing the interaction of users with the snake-arm robots described above in the mock-up area it is clear that the robots are not perceived as being threatening. This can be ascribed to a number of features.

1. The robots do not look like T3 or a painting-welding-car-producing-machine. They look different, non-robotic and generally benign.
2. All the motors are contained and the snake-arm is smooth, continuous and has no trapping points.
3. The robots are easy to clean and fully sealed. Services are run internally.
4. The robots operate without guarding and the user can interact with the robots whilst the arms are powered and enabled.
5. Robot motion is slow and smooth. The robots appear to be slower than the operator. Most of the time they are.
6. When something goes wrong – as can happen when commissioning new equipment – the aberrant motion is stopped very quickly.
7. More importantly, when something goes wrong it only takes a flick of a button for normal service to be resumed... as if nothing significant had happened.
8. The robots have no user maintainable parts and the covers hide all the technology!

Conclusions

Whilst operating all three robots within the reactor containment there would be 63 DoF of snake-arm robots within an area less than a meter cubed. The robots are ideally suited to the environment because they are designed to gain access to very restricted access.

Whilst snake-arm robots will be used in a variety of industrial applications in future, it also appears possible for snake-arm robots to be used in 3-dimensional human environments, e.g. in the home and in the retail and leisure sectors. In particular, the inherent compliance of these devices means that soft collision as an expected operating mode is easily achieved. If coupled with sensory feedback then the arms can be reasonably compliant whilst also having a significant payload to achieve real tasks.

The more specific conclusion from this work is that having built and delivered the snake-arm robots into the nuclear industry it is clear that they are dependable and can be used in close proximity to the operators.