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Snake arm robots for flexible delivery

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OCRobotics has recently launched a new type of robot, called a 'Snake Arm Robot'. The name captures the essence of the design - it is a self-supporting arm that is slender and flexible, like a snake. It is also computer-controlled so that it can get into confined spaces along complex paths. For NDT applications it is a tool that can deliver sensors and tools into complex structures to conduct in situ tests and repairs.

Just like nature's snakes, the snake arms can come in a variety of different sizes, from 6 mm-diameter devices similar to a borescope to a much longer arm measuring many metres capable of carrying a substantial payload. These devices belong to one family sharing the same design concepts and using identical software.

A snake arm robot is effectively a cross between a borescope and a standard robot. The difference between a snake arm robot and a flexible borescope is that the configuration of the whole of the device is known and controlled and not just the tip. In practice, this means that a snake arm robot can be controlled to follow complex paths - usually in order to avoid colliding with objects within the workspace.

Whilst such devices also have applications in the nuclear industry, space, surgery and general industry, one of the key sectors being targeted is aerospace.

The aerospace concept

Engines

With the advent of 'power by the hour' the pressure to keep engines in the air for as long as possible has increased. There is a recognised need to reduce downtime by developing maintenance procedures and, where possible, diagnosing whether maintenance is required or can be safely delayed.

Physical inspection continues to play the key role alongside secondary indicators of performance such as emissions analysis, but physical inspection is costly due to the time taken to gain access to the parts in question. Borescope ports allow partial access but the majority of tasks require disassembly. This means that routine maintenance, taking minutes and requiring limited disassembly, is available only for a small range of tasks, and tracking the degradation of plant is virtually impossible.

Snake arm robots are set to have a significant impact on maintenance procedures by being able to reach further into an engine, using either borescope ports or the air path, opening up opportunities for much faster interventions on both hot and cold engines.

The challenge of reaching deep into an engine using the air path should not be understated. A device for this task, which currently exists as a series of designs and concepts within a patent application, would have to be very slender and flexible in order to weave between the blades. However, the snake arm robot shown in Figure 1 demonstrates that it is achievable.

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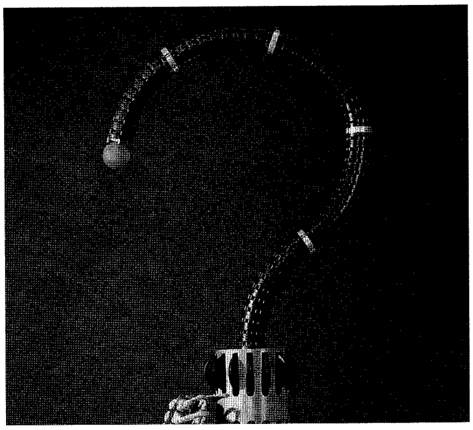

Figure 1. The question is: what is a snake arm robot? Read the accompanying text to find out

Once it becomes possible to reach inside an engine there still remains the challenge of taking the measurements or conducting the repair. Vision (2D or 3D) would draw upon standard scope technology, but there will be a need to miniaturise tools, for example for grinding or crack testing. A snake arm robot may also create the opportunity to develop new tools for specific applications.

Wings

The scale for wing applications of snake arm technology is quite different to that for engines. Instead of diameters of 6-8 mm required for engines, an airframe device might require a length of many metres with a diameter of 50-100 mm. In addition, larger payloads will be required to conduct the necessary tasks.

Clearly, inspection of components is again a valid exercise, but applications could stretch beyond this to include repairing leaking seals or replacing wire harness, cleaning and repairing corroded parts, even component replacement.

Cost benefit

The cost benefit of reducing downtime by being able to conduct inspection and repair tasks 'in wing' or 'on wing' remotely with as little dismantling as possible is substantial. There would be the need to ensure that such remote techniques do not themselves incur a different type of time penalty or become ensnared in approvals procedures. Certainly, the latter is an issue that would need to be addressed.

These challenges, plus the need to develop the snake arm technology to a point where these ambitions are achievable, indicate that widespread use of this exciting technology will not occur overnight, however OCRobotics is already discussing detailed specifications for tasks that would immediately benefit from and pay for the application of snake arm robots.

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OCRobotics technology

Within the wider family of devices the robot that has been built occupies the middle ground. The OCRobotics snake arm robot shown in Figure 1 has 10 degrees of freedom and is just under 1 m in length. It has a constant outside diameter of 36 mm with a 15 mm hollow bore. The device comprises five segments each with two degrees of freedom. Each segment can bend through 100 degrees and hence the total curvature for this device is 500 degrees. Whilst the device is the first machine it could, without modification, be produced in volume. A more likely scenario is that the next device will be built according to a specific customer's specification.

The next machine will be more slender and the length can be varied - either shorter or longer. OCRobotics has designs for devices that would compete with flexible borescopes (<10 mm outside diameter) and devices that are 4 m long. By adding more segments and changing the characteristics of each segment, it is possible to create an even more flexible device, alternatively increasing the arm diameter would allow a long arm to carry a substantial payload.

The arm design incorporates a 15 mm diameter hollow bore for any services required, including use with existing flexible borescopes. An arm can be mounted on a mobile vehicle, a linear slide, on another robot or simply attached to part of an aircraft.

The OCRobotics snake arm robot comprises two major components. The first is the actuation system (computer, power supplies and motion systems). The second is the arm itself. A key design feature of the arm is its simplicity – it is completely passive and hence relatively inexpensive. The design can also include a quick release mechanism so that arms can be interchanged. It would then be possible to have a range of arms for different tasks, a bit like having a set of tools for a Dremel. Arm materials can also be easily changed to create a non-magnetic arm, or a sealed device for underwater applications.

Controlling the motion of the arm is perhaps the most important issue for simplicity of use. The operator uses joystick control to steer the tip of the device with visual feedback supplied by a tip-mounted chip camera. The computer then converts the joystick motion into the necessary actuator motion that controls both the tip and shape of the remainder of the device. Since the tip is effectively tethered to ground, the operator is informed when limits are reached. Alternative path control techniques include off-line path planning for regular tasks, *ie* if a component within a wing requires regular monitoring a programme can be created to take the arm back to the same place.

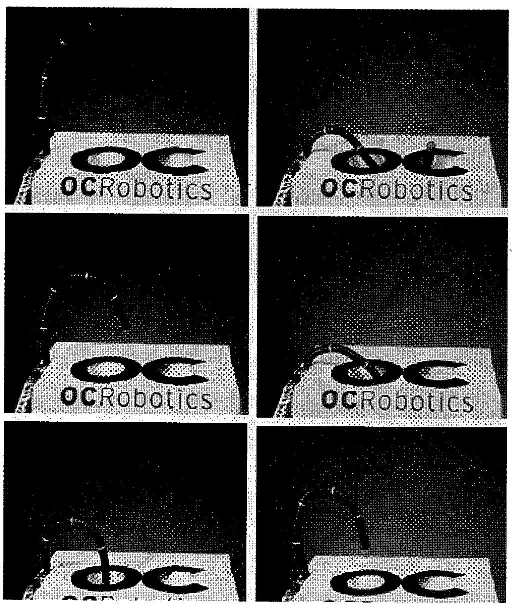

Figure 2. Motion capabilities of the snake arm robot

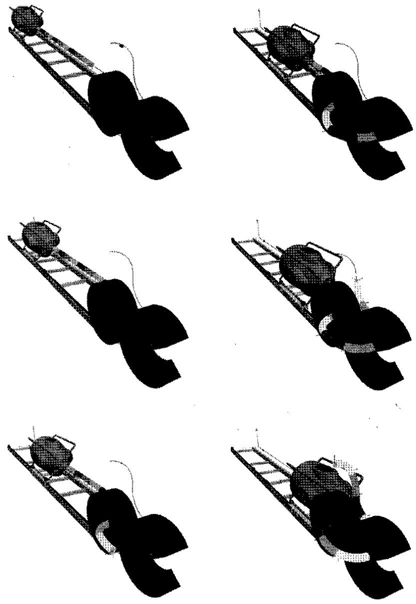

Figure 3. The snake arm robot can be controlled to follow complex paths

The motion capabilities of the existing arm are indicated in the series of pictures in Figure 2. This series of clips shows the device passing through two holes.

More complex motion is shown in the series of computer-generated images for an 11-segment device, Figure 3. These pictures are generated directly from the software that would be used to control an actual device. The same software is used to control the five-segment hardware. In this example, the base unit of the snake arm robot is moving along a linear slide. (Note: the arm can start from a coiled position to save space as required.) As the base of the device is advanced along the slide the configuration of the arm is changed so that the arm stays on or near the path. In this case the path described comprises a series of six 90 degree bends.

Next steps

As of March 2002 the prototype has been operating for over four months with considerable interest being shown from around the World. A substantial part of this interest relates to the aerospace sector - mostly in the UK, but with some enquiries from as far afield as China. The equipment has been widely demonstrated and will be on show at the Aerospace NDT Symposium being held at Bristol in April 2002.

This exposure to a large customer base is recognised as necessary to move beyond the *status quo*. It is believed that snake arm robots will become an important cost-effective tool for the aerospace industry.

Acknowledgements

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