I BET YOU DIDN'T KNOW...

What small magnetic robots can do

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You have probably seen robots in documentary programmes or in TV dramas, but have you ever wondered what makes them move? To start an object moving, stop it moving, change the speed or direction of the movement, or to change its shape, requires a force. Such a force could be caused in many ways, including use of electricity, magnets, gravity, air (hydraulics) or liquids (pneumatics).

A typical robot has a movable physical structure, a motor of some kind, a power supply (probably electricity) a sensor system, and a computer 'brain' called a central processing unit (CPU) that controls all these elements. You could investigate how different forces cause objects to move (suggestions are provided in the *Teacher Guide, downloadable via the PSTT website*).

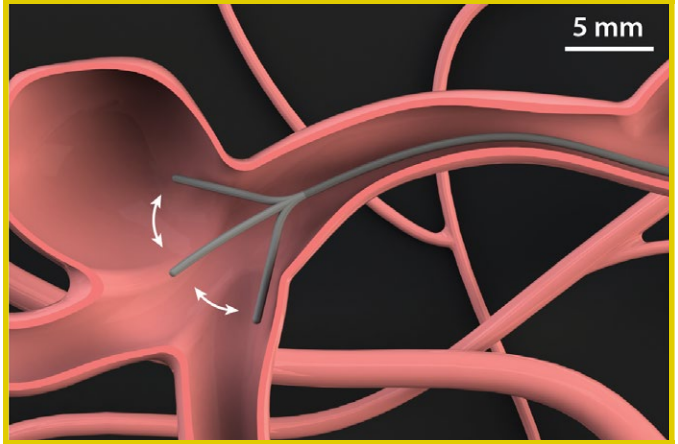
Snake-arm robots, also described as continuum robots, have continuously curving manipulators that can move like the arm of an octopus, bending and sometimes twisting at any point along their structure. These have been developed to reach into confined or dangerous spaces not accessible to traditional robots. They are being used for repair and maintenance in the nuclear industry, car and aeroplane manufacturing, bomb disposal, and search and rescue. Steering occurs either by a system of opposing pulling wires and springs (Figure 1) or by controlling embedded magnets. Small-scale continuum robots capable of navigating through complex and constrained environments have great potential for medical applications. Surgeons can access sites inside the body such as arteries around the heart and lungs for making diagnoses and non-invasive treatments. However, miniaturizing continuum robots is difficult because it is problematic to manufacture the antagonist wires or magnets to sub-millimetre diameters. Their relatively large size makes them too large for accessing blood vessels in the brain or spinal cord (neurosurgery).

Figure 1. An elephant trunk robotic arm which is operated by a system of guide wires and springs.

Soft-bodied robots made of silicone with internal chambers using hydraulic or pneumatic systems are also being developed. Inside one type of soft-bodied robot, hydrogen peroxide washes over tiny flecks of platinum, producing gas through a chemical reaction. The gas flows through the chambers, inflating and moving the robot's arms (see 'Octobot' online). Such robots could one day be used for oceanic search and rescue or climate sensing. Their uses in surgery are limited because they are also difficult to miniaturize below millimetre scales.

Recently scientists have developed 'ferromagnetic soft robots' with a diameter of less than 1mm that can travel through small vessels inside the body (Figure 2). The

Figure 2. A soft continuum robot inside a blood vessel.



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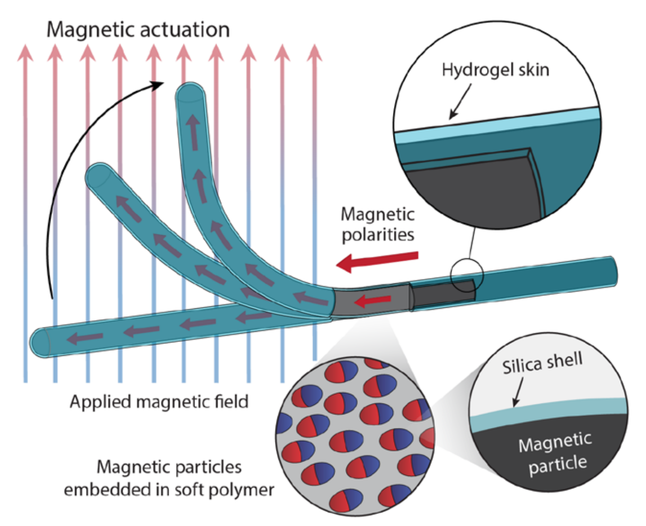
robots are made from microparticles (less than 5µm in diameter) with a high iron content which means that they can be magnetised. These particles are embedded in a soft gel-like material (silicone or thermoplastic polyurethane (TPU)). When these materials are mixed, they form a paste and the robot can be made by printing or injection moulding. The tip of the robot containing the magnetic particles moves when a magnetic field is switched on remotely (Figure 3).
The thickness of the silica shell coating increased the volume of the magnetic particles. You might wonder why the scientists did this, when these robots need to be kept extremely small to be used inside tiny blood vessels. The answer is because the magnetic particles have a high iron content and iron is highly corrosive (reactive) in a wet environment. The corrosion of iron could be explored in the classroom (see details in the Teacher Guide): rust (iron (III) oxide) is an example of a chemical irreversible change that results when iron is exposed to water (e.g. from damp air). A thin film of oxide forms on the iron; this protects the metal from further corrosion by slowing the rate of oxidation.

The researchers tested the movement of the robot through a series of rings using a single magnet to control its movement. They compared different diameters of robots, and different types of soft materials at the tip, to find a robot that can make sharp turns and will be able to move complex blood vessel systems.

Figure 3. The structure of the magnetic robot. Magnetic particles arranged in the same direction are embedded in a soft material (bottom left circle). Each magnetic particle is surrounded by a silica shell to prevent the magnets corroding (bottom right circle). The surface of the robot is covered by a water-loving gel (hydrogel) skin to reduce friction when the robot moves through vessels (top circle). The magnetic tip of the continuum robot moves when a magnetic field is switched on.



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They then tested the movement of the soft robot through silicone tubes filled with a blood replica (which they called a 'vascular phantom'). They measured the forces required to pull a cylindrical object with and without a hydrogel skin through the phantom vessels and showed that the hydrogel was important for reducing friction. They compared the soft robot with traditional guide wire robots and showed that the traditional robot was jerky and took longer to travel through the phantom vessels. They also included an optical fibre to demonstrate that magnetically steerable laser treatments might be possible in neurosurgery the future.

In the classroom, it would be possible for children to create models of these soft robots travelling through rings or tubes and use them to explain their understanding to others. Plastic or cardboard tubes are easily sourced and paperclips or a split pin attached to a string representing the robot could be steered using a cylindrical or bar magnet. Investigations could include which is the 'best' magnet to control movement or the 'best' robot body for navigation.

The research paper which inspired this work was:

**Ferromagnetic soft continuum robots* By Yoonho Kim[1], German A. Parada[1,2,] Shengduo Liu[1], Xuanhe Zhao[1,3]

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