EU-funded researchers have invented a robot that will help neurosurgeons to perform some of the most delicate and exacting operations they are called on to undertake on the human brain. The research, involving the complex interaction of precise controls, feedback sensors and machine intelligence, will also have a big impact on robotics for medicine generally.

In theory, robots are the perfect candidates to assist in brain surgery. They can perform extremely precise manoeuvres, they have prodigious memories and they can think fast. Of course, they do not need to have the perspiration wiped from their forehead either. They could easily and rapidly increase the number of surgeries that medical centres can perform.

If only it were that simple.

'Developing a robotic surgical assistant is an extremely challenging task,' says Giancarlo Ferrigno, coordinator of the EU-funded 'Robot and sensors integration for computer assisted surgery and therapy' (Robocast) project. 'The design must factor in a large number of variables and the process demands extreme precision. There is minimal margin for error.'

The Robocast project, which received EUR 3.45 million of its EUR 4.55 million budget from the EU, focused on a particularly precise task, namely robot-assisted keyhole neurosurgery, a technique performed through a very small hole in the skull called a burr hole.

This type of surgery is used for many brain interventions. In endoscopy, surgeons use a keyhole to insert a camera to examine part of the organ directly, while biopsy takes samples of suspect tissue through the keyhole.

The technique can be used to place needles for blood and fluid sampling, as well as cryogenic and electrolytic ablation, which remove tissues using extreme cold or direct electrical current.

Brachytherapy places a radiation source close to the treatment site while deep brain stimulation
(DBS) installs a brain pacemaker.

These techniques have dramatically advanced treatment of tumours, hydrocephalus (a condition where fluid builds up in the brain), dystonia (a neurological movement disorder), essential tremor, Parkinson's disease, Tourette syndrome, clinical depression, phantom limb pain, cluster headache and even epilepsy.

It is a huge and expanding field, but it is also one of the most demanding. It requires high intelligence, extreme dexterity and a very cool nerve.

'Neurosurgical procedures are nowadays really at the boundary of human capabilities, only new technology can allow surgeons to overcome themselves,' explains Dr Ferrigno. 'Vital functions like sensing, movement, speech and memory can hide within brain tissue that is just a few tenths of a millimetre wide, where damage could lead to permanent injury.'

Developing a reliable, safe and effective robotic assistant could potentially improve safety and would increase the number of operations that could be performed. This will be even more important over the next 20 years, as Europe's population ages rapidly and the incidence of brain disorders rises.

Mechatronic intelligence

The Robocast team developed both software and hardware. Hardware is called mechatronics in robotics because it consists of mechanical parts and electronic circuits. While the mechatronics makes up the body and nervous system of a robot, the software provides the intelligence.

The complete system consisted of a human-computer interface, with intelligent context-sensitive communication and a haptic, or force feedback, control mechanism. There was a multiple-robot unit, an autonomous trajectory planner, a high-level controller and a set of field sensors.

The mechatronic phase of the project developed a modular system, ensuring a small footprint, with two robots and one active bio-mimetic probe. Bio-mimetic systems use biological models to inspire engineering design. The three elements cooperate in an integrated sensory-motor framework to act like a single unit.

The first robot can position its miniature companion robot through six 'Degrees of freedom' (DOF). Degrees of freedom define the directions an object can move in three-dimensional space and six DOF represents the most complete range of movement. In real terms, six DOF means the robot has three linear movements comprising up and down, left to right and backward and forwards; it also has the three rotational movements of tilting forward and backward, side to side, or turning left and right. The robot can combine these movements simultaneously to position its companion at any point in 3D space.

It can also place the miniature companion robot at any point in a surgical theatre. The miniature robot then holds the probe to be introduced through the keyhole. Optical trackers follow both the end of the probe and the patient. The robot can control both the position and the force applied using a combination of sensors.

The Robocast researchers also developed the intelligence side of the robot to be able to define the trajectory of the surgical implementation, a vitally important part of this work. People take trajectory for granted but it is a very tough problem in robotics. Instinctively, our brain performs the complex calculus required to locate objects in 3D space, and it performs this calculation while the object is moving, literally 'on the fly', in real time. When a ball is thrown toward us we catch it, most of the time. That is an immensely complicated process.
Robocast developed a control system that can autonomously provide path planning, both outside and inside the patient’s body, by analysing preoperative diagnostic information.

The path inside the brain is planned on the basis of a 'risk atlas'. The atlas reproduces a fuzzy representation of a brain atlas that relates brain structures to a 'level of danger'. The fuzziness stems from the vast inherent variability of individuals, defining danger in levels from very high to very low. Constructing the atlas relies on cognitive learning, and the system can provide the surgeon with explanations for any suggested action.

The robot can semi-autonomously update the plan in order to adapt to any unforeseen changes that occur during surgery. These updates are based on information gathered and processed during the operation using technologies such as ultrasonic imaging. The surgeon, of course, retains overall control and responsibility for the operation, and can specify any additional constraints to the path planner.

In this way, the final path plan inside and outside the body stems from the interaction between the surgeon and the intelligent core of the system. The interface between the system and the user requires minimal interaction. But it provides all the necessary information using an intuitive design that uses context-based interpretation of the surgeon's commands.

In a demonstration in February 2011, the Robocast team showed the robot in action, performing an intervention on a dummy in a real operating room. The technology works and the project achieved all its objectives. Now it needs to be refined and validated for use in a live operating theatre setting.

'The project was hugely challenging, particularly in integrating the work from scientists distributed all over Europe and Israel,' notes Dr Ferrigno. 'It was like managing an orchestra of extremely high-quality solo players. We overcame this through great coordination and cooperation from all the partners. We also swapped researchers between institutes for weeks at a time, and that helped a lot.'

Now a follow-up project, called ACTIVE, will research robotic neurosurgery for patients who are to remain awake during surgery. The bio-mimetic probe also received funding from the European Research Council (ERC) for further development, while the path planner is in use in clinical practice.

It is a major advance in robotic engineering and, thanks to Robocast, it will not be long before medical centres are paging Dr Robot, brain surgeon.

The Robocast project received research funding under the EU's Seventh Framework Programme's (FP7) sub-programme for 'Cognitive systems, interaction and robotics'.


- Country: ITALY
- Information Source: Giancarlo Ferrigno, Robocast project coordinator
- Date: 2011-08-18

Share this page