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Controllable microcatheters

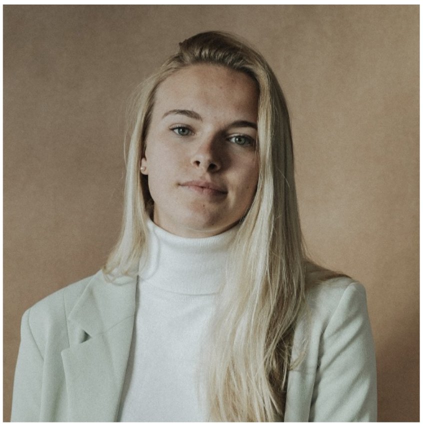
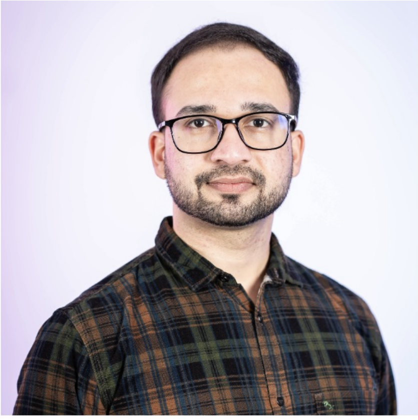
Robotic control of surgical instruments using magnetic resonance imaging

Catheter-based examinations and surgical procedures are severely limited by the restricted controllability of conventional instruments and harmful radiation exposure to both patients and medical staff caused by prolonged exposure to radiation during fluoroscopy. EndoSurge, a Stuttgart-based start-up, has developed innovative robotic microcatheters that can be precisely controlled using the magnetic field of an MRI device. This breakthrough enables radiation-free interventions, significantly enhancing safety and precision in catheter-based procedures.

Minimally invasive catheter-based procedures have become indispensable across all medical specialties and are used to introduce diagnostic and therapeutic instruments into the body through the inner lumen of a flexible tube. This facilitates the examination of hollow organs such as the urinary bladder or heart, targeted delivery of medications and collection of tissue samples. They can also be used for targeted therapeutic interventions, also known as interventional measures. In the field of angiology (vascular medicine), these interventions often involve stopping bleeding, dissolving blood clots, widening blood vessels or placing stents to restore proper blood flow.

Radiation-free alternative to fluoroscopy

Catheterisation of blood vessels is always image-guided, and monitored in real time using radiological imaging. "The gold standard for interventional procedures, such as cardiac catheterisation, is the prolonged exposure to radiation during a procedure known as fluoroscopy," explains Dr. Martin Phelan, CEO of EndoSurge, a spin-off from the Max Planck Society. "However, this procedure involves ionising radiation, which poses significant health risks not only to patients but especially to medical staff." To address these challenges, EndoSurge is developing a groundbreaking alternative that leverages radiation-free magnetic resonance imaging (MRI) for real-time imaging. This approach has previously not been feasible because conventional instruments that contain metal are incompatible with the powerful magnetic fields of MRI systems, necessitating the use of specially developed and costly tools.

Dr. Martin Phelan, Lisa Stuch and Siddhant Kadwe (from left to right) are in the process of founding EndoSurge. The company is developing innovative robotic microcatheters that can be guided with the help of the magnetic field of an MRI device, thus enabling radiation-free interventions.

Dr. Martin Phelan, from the Max Planck Institute for Intelligent Systems (MPI-IS) in Stuttgart, began developing novel MRI-compatible medical instruments during his doctoral studies at Carnegie Mellon University in Pittsburgh, USA. "Our approach leverages the permanent magnetic field of an MRI device to steer or control our tools, using a mechanism based on a DC (direct current) motor," explains Phelan, a mechanical engineer who is co-founding the start-up alongside business information scientist Lisa Stuch and robotics engineer Siddhant Kadwe from the German Research Centre for Artificial

Intelligence (DFKI). "By integrating current-carrying microcoils into the tips of medical instruments, we can generate local electromagnetic fields that can be controlled precisely and actively in any direction." This innovative technique is rooted in the principles of the Lorentz force, and the foundational research was published in the prestigious journal Advanced Science. [1)]

Special arrangement of microcoils allows MRI-controlled navigation

Since the magnetic field of an MRI device is static, movement occurs only when a current-carrying wire is oriented nearly perpendicular to the field. This limitation can be overcome by equipping the innovative microcatheters with multiple coils oriented in different directions. This design ensures full controllability, regardless of the catheter's position. The deflection of the catheter tip is precisely controlled by adjusting the strength and direction of the current passing through each coil, allowing for versatile and accurate maneuvering.

The tips of robotic instruments warm up over time, rather like a motor generates heat. "This isn't an issue when body fluids are circulating around the catheter and dissipating the heat. However, it can pose a risk to nearby tissue," explains Phelan. "To address this, we've optimised the electrics of the coil design, ensuring that self-heating does not exceed 44 °C."

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The innovative microcatheter operates within the permanent magnetic field (B_0) of the MRI device. The local magnetic moment (m, represented by red arrows) is generated by the current applied to the relevant coil pair by the cardiologist using the system. This induced magnetic moment produces the controlled movement of the catheter. © Martin Phelan

Remote control possible

Based on their research findings, the international EndoSurge team – comprising engineers, physicians, scientists and industry experts – has spent the past two years developing a comprehensive solution for medical applications. This includes a suite of cardiovascular tools, specialised software and various user interfaces for remote control. This system no longer requires medical staff to stand directly beside the patient to manually manoeuvre the catheter through the vessels. Instead, they can control it remotely using a joystick or touchscreen. Additionally, the robotic system is designed to simplify the learning curve for interventional procedures, enabling doctors to perform these complex techniques earlier in their training.

This promising technology has already attracted significant interest and the founders are actively building a global network with connections to clinics across Europe, Asia, the USA and Africa. While the start-up is currently focusing on cardiology applications, the system is designed to be easily adaptable for use in other medical specialties in the future. "We've already hit a major milestone by successfully performing catheterisation under real-time control on a live pig in collaboration with Freiburg University Hospital," says Phelan. Despite this success, further data collection is needed before the system can be approved for use in human patients.

Convincing magnetic robot control concept

MRI scanners have traditionally been significantly more expensive than fluoroscopes and are not yet available in every hospital. To address this challenge, the researchers are collaborating with the robotics company KUKA to explore ways to reduce the cost of these devices and make them more accessible. Their innovative project has been shortlisted for the prestigious KUKA Innovation Award 2025.[2)] EndoSurge also won the 2023 Falling Walls Lab Baden-Württemberg competition for their groundbreaking contributions to medical technology.[3)]

The innovative technology offers numerous advantages. MRI-controlled visualisation of soft tissue structures is far superior to conventional fluoroscopy, making catheter-based interventions more precise. Additionally, the absence of ionising radiation makes the technology safer, allowing procedures to be carried out on vulnerable patient groups, such as pregnant women and children. Moreover, the remote-controlled microcatheters, which can be miniaturised to less than 1 mm in diameter can access previously hard-to-reach areas of the body, including the brain and extremely fine blood vessels.

"In the long term, we also plan to integrate artificial intelligence into the system," adds Stuch, Head of Artificial Intelligence at EndoSurge. "Our goal is for the robotic catheters to be able to navigate autonomously under the control and supervision of medical staff." "We are part of a new generation, and our mission is push the boundaries to make medical procedures safer," says Phelan, summarising what motivates the team.

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Dr. Ruth Menßen-Franz

Further information

EndoSurge
Max Planck Institute for Intelligent Systems
Heisenbergstraße 3
70569 Stuttgart
Email: phelan(at)is.mpg.de; lisa.stuch(at)web.de

- EndoSurge

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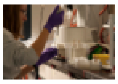

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