## Towards Multifunctional Ingestible Devices: An Ultrasound Endoscopic Capsule

Ingestibles are a new category of biomedical devices that do not fall neatly under the wearable or implantable category. They have their own challenges in system integration, sensor readout circuits and data/power communication. While some early-stage ingestible devices have been commercialised in the last few years (e.g., Medtronic's PillCam for simple white-light imaging), they have not yet been used for more advanced diagnosis of the gastrointestinal (GI) tract. Particularly, the potential to replace the standard ultrasound colonoscopy with an ingestible capsule has not yet been materialised. Existing coloscopy procedures are costly, time-consuming, require multiple medical staff and are extremely uncomfortable for the patients. After each procedure, the entire long tube of an endoscope requires several steps of cleaning and disinfection, which further increases cost and waiting time.

Funded by successive UK and EU grants (https://www.autocapsule.eu/), we have been working for over six years to develop a miniaturised capsule for ultrasound endoscopy[1]. This is an extremely complex process, including gastroenterologists and ultrasound transducer manufacturers. Engineers specialising in Circuits and Systems are an integral part of this design process. Developing this novel device requires understanding low-power AFE, power management, wireless power transfer, localisation, robotics and many more. In this tutorial, I will provide a glimpse of these various contradictory design specifications and the steps we have taken to achieve some of the intended outcomes.

I will primarily focus on the circuits and system design associated with manufacturing an ultra-compact AFE for the micro-ultrasound (>20MHz) transducers necessary for GI tract monitoring. Ultrasound systems are typically not designed to be small and battery-operated, particularly for such high frequencies. In contrast, the operation of the intended capsule device can be either tethered or wireless and necessitates several high-voltage circuits at the tip of a standard ingestible capsule. This includes the pulser and receiver circuits in an ultrasound signal processing unit[2]. I will describe the design solutions in power management and wireless power transfer that could make this possible. Next, I will explain the techniques used to precisely locate the capsule inside the body, an integral requirement to observe bowel cancer or other GI tract abnormalities. This will include a novel mechanism of using the variation of wireless power itself as a means of determining the position of the capsule[3]. I will then explain the challenges in the integration of a large number of ultrasound transducers within the small form factor of an ingestible capsule.

I will then discuss the requirements related to the shape of the capsule, imaging the circumference of the GI tract, and that of a linear transducer array. This will include robotic manipulation of a tethered capsule in an animal experiment[4]. Finally, I will conclude with an overview of other sensing modalities (e.g., electrochemical, optical) that are being incorporated in a capsule to provide a multifunctional device. Such devices will provide the much-needed detailed diagnosis of the GI tract necessary for advances in gut health.


1. C. Moldovan, M. V. Turcanu, **S. Mitra**, and S. Cochran, "Ultrasound technology for capsule endoscopy," in Endorobotics, vol. Chapter 9, L. Manfredi, Ed., Academic Press, 2022, pp. 215–240. doi: 10.1016/B978-0-12-821750-4.00009-8.

2. B. Abaravicius, S. Cochran, and **S. Mitra**, "High-Efficiency High Voltage Hybrid Charge Pump Design With an Improved Chip Area," IEEE Access, vol. 9, pp. 94386–94397, 2021, doi: 10.1109/ACCESS.2021.3091808.

3. L. Yao, S. R. Khan, G. Dolmans, J. Romme, and **S. Mitra**, "High Accuracy Localization for Miniature Ingestible Devices using Mutual Inductance," IEEE Transactions on Biomedical Circuits and Systems, pp. 1–16, 2024, doi: 10.1109/TBCAS.2024.3361045.

4. N. J. Greenidge, C. Benjamin ….**S. Mitra**, C. Cochran, P. Valdastri, "Harnessing the oloid shape in magnetically driven robots to enable high-resolution ultrasound imaging," Science Robotics, vol. 10, no. 100, p. eadq4198, Mar. 2025, doi: 10.1126/scirobotics.adq4198.

## Biography

Prof Srinjoy Mitra holds the position of Chair of Neurotechnology and Medical Electronics at the Institute for Micro and Nano Systems, University of Edinburgh, UK. He received his B.S. degree in physics and electronics from Calcutta, India and his M.Tech. in microelectronics from the Indian Institute of Technology, Bombay, India. After spending a short time in the electronics industry (in India and Japan), he received his Ph.D. from the Institute of Neuroinformatics, ETH Zurich, Switzerland, in 2004. Between 2008 and 2010, he worked as a postdoctoral researcher at Johns Hopkins University, Baltimore, USA.

He then joined the medical electronics team at IMEC in Belgium as a senior scientist and took on leadership roles in various projects related to medical/neural electronics. Electroencephalography (EEG) measurement ICs and high-density neural recording probes developed by his team have been successfully validated in a clinical environment and are now commercialised. Many of these tools are now routinely used in neuroscience labs across the world. He moved to the University of Edinburgh in 2017 and leads a team that specialises in wearable and implantable devices. In particular, his team has been working on ingestible ultrasonic capsules for the past six years and has published several articles on this topic. He is the Program Director for the MSc in Sensors and Imaging Systems and the convenor of the Curriculum Decolonisation at the College of Science and Engineering.