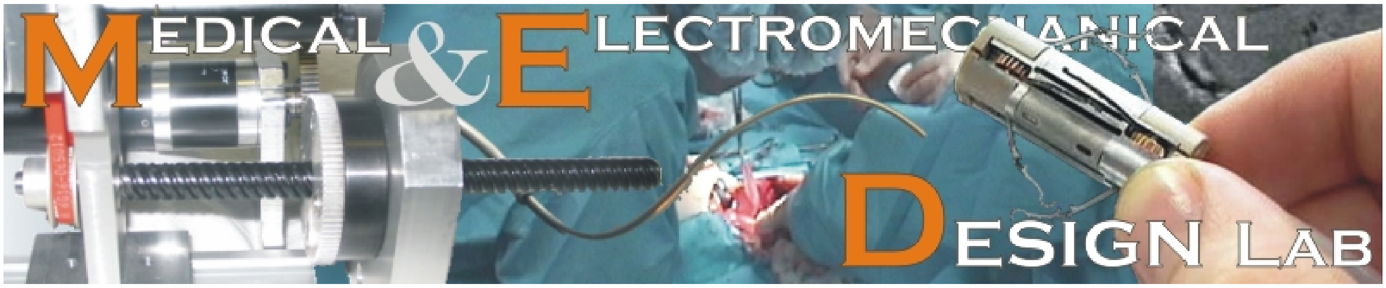

A Wireless Insufflation System for Capsular Endoscopes

Jenna L. Toennies and Robert J. Webster III, Vanderbilt University, Nashville, TN, USA

Swallowable capsule-based cameras (e.g. Given Imaging PillCam and competitors) are rapidly becoming the gold standard for diagnosis in the gastrointestinal (GI) tract. However, definitive diagnosis is still often precluded by the inability to control capsule position and orientation. This has inspired a number of active positioning strategies including augmenting the capsule with legs or other appendages (see Figure 1), or incorporating magnets which can apply forces and torques in response to an external magnetic field (see [1] for an overview of both approaches). Furthermore, the loose, mucous coated, elastic intestine is generally deflated during capsule passage, making it challenging to view the entire internal surface adequately without the insufflation that is relied upon so heavily in traditional endoscopy.

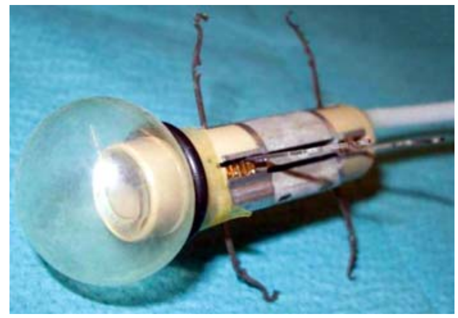

Figure 1. Legged capsule robot from prior work, showing tether inflated frontal balloon, which houses a wireless CCD camera. Image courtesy of the CRIM Lab SSSA, Italy.

To address these challenges, we propose a new fluid-powered system that permits insufflation from a wireless capsule platform. This is accomplished by carrying a small reservoir of biocompatible liquid onboard the capsule which vaporizes and expands when released through a small onboard solenoid valve (see Figure 3). The internal components of the capsule are shown in Figure 2, and the fluid used in initial experiments is biocompatible Perfluoropentane. This fluid, developed for lung lavage, is a liquid at room temperature and becomes gaseous at body temperature. We note that pneumatic pressure produced in this way may be used for a wide variety of objectives, including powering biopsy collection devices or other mechanisms within the capsule, or being vented to inflate the intestine. Here, we harness the pressure to inflate a balloon at the front of the capsule which distends tissue and can improve image quality. In the experiment shown on 3(c) only 0.2 ml of fluid was consumed in inflating the balloon to sufficient pressure to distend porcine intestine. Optimization of the capsule body is currently underway, and with a wireless camera, all components are expected to fit within the dimensions of a commercial PillCam.

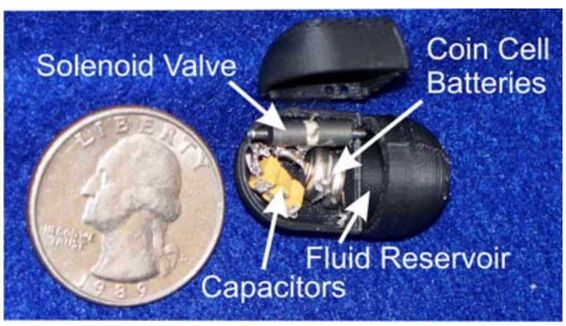

Figure 2. Internal components of the insufflation system: two 3V batteries charge 3 capacitors that fire the solenoid valve. In our initial proof-of-concept study we have packaged all components in a 26 mm long by 11 mm diameter capsule.

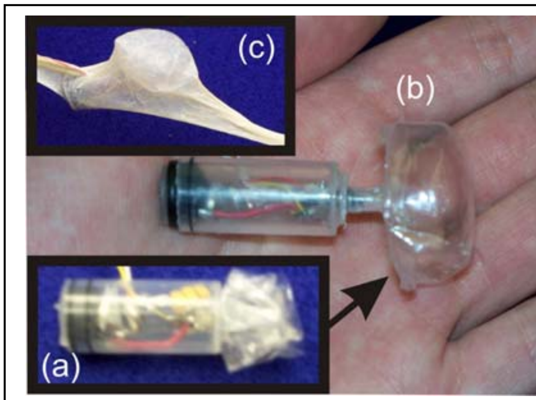

Figure 3. Proof of concept capsule showing (a) initial deflated state (b) balloon inflation when valve activates, and (c) inflation within ex vivo porcine intestine.

[1] Quirini, M., Webster R.J. III, Menciassi A., and Dario P, 2007, “Design of a Pill-Sized 12-legged Endoscopic Capsule Robot,” IEEE Int. Conf. on Robotics and Automation, pp. 1856-1862.

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Jenna L. Toennies and Robert J. Webster III
Medical & **E**lectromechanical **D**esign **Lab**, Vanderbilt University

VANDERBILT UNIVERSITY

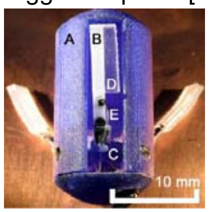
Motivation

• "Capsule-cameras" – currently the gold standard for small intestine diagnosis.

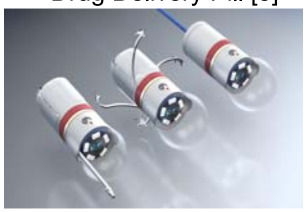
• Smart capsules and interventional capsules – active areas of research. Examples:

Legged Capsule [1]

Drug Delivery Pill [3]



Anchoring Capsule [2]

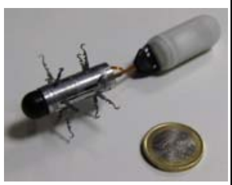


Interventional Capsules [4]

Problem: Power!

• Lack of a sufficiently small and energy dense power source limits development of locomotion and intervention mechanisms.

M2A Pill (Given Imaging, Inc.) – batteries in orange.



Legged capsule with battery "trailer" [1].

Problem: Lack of Insufflation

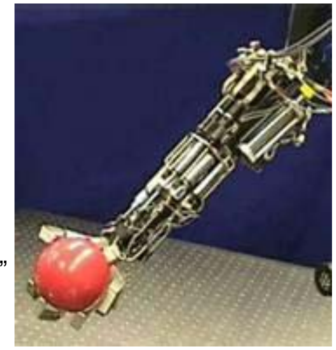
• Capsule can become trapped in deflated intestine.

Image courtesy of CRIM Lab, Scuola Superiore Sant'Anna, Italy.

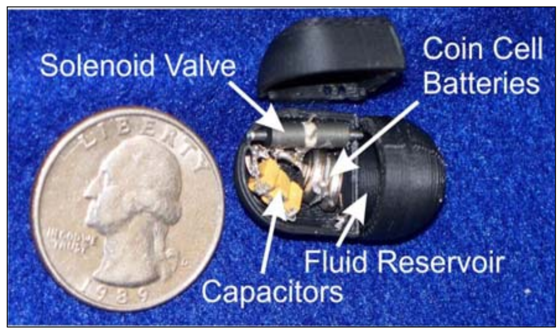
Solution: Fluid Power

• **Fluid power offers an order of magnitude higher energy density than batteries** [5].

• It can enhance the duration of use of prosthetic arms between "recharges" but has yet to be applied to capsules.

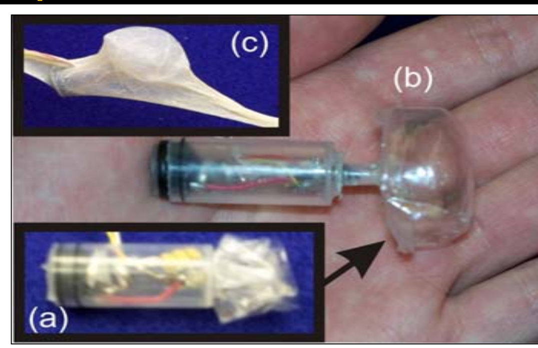


System Components



Fluid-power capsule proof-of-concept: Insufflation

Experimental Validation

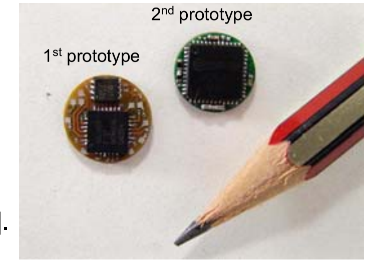


Proof of concept capsule showing (a) deflated state (b) balloon inflation when valve activates, and (c) inflation within ex vivo porcine intestine.

Future Work

• Capsule body and component optimization.

• Integrate with microelectronic control boards [6].



• Combine with external magnetic guidance of capsule robots [7], to enable passage through collapsed lumen.

• Fluid power has the potential to enable many new interventional capsule abilities, including biopsy, injections, drug delivery, clip deployment, polyp clipping, etc.

Conceptual interventional capsule from [4]

Clip deployment capsule [8]

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[1] P. Valdastri et al. "A New Mechanism for Mesoscale Legged Locomotion in Compliant Tubular Environments," IEEE Trans. Robotics (In Press).
[2] P. Glass et al. "A Legged Anchoring Mechanism for Capsule Endoscopes Using Micropatterned Adhesives," IEEE Trans. BME, 55(12):2759-2767, 2008.
[3] More information at www.philips.com.
[4] More information at http://www.vector-project.com.
[5] M. Goldfarb et al. "Design and Energetic Characterization of a Liquid-Propellant-Powered Actuator for Self-Powered Robots," IEEE/ASME Trans. Mechatronics, 8(2):254-262, 2003.
[6] E. Susilo et al. "A Miniaturized Wireless Control Platform for Robotic Capsular Endoscopy Using Advanced Pseudokernel Approach," Sensors and Actuators A: Physical, 2009 (In Press).
[7] Ciuti et al. "Robotic Magnetic Steering and Locomotion of Capsule Endoscope for Diagnostic and Surgical Endoluminal Procedures," Robotica (In Review).
[8] P. Valdastri et al. "Wireless Therapeutic Endoscopic Capsule: in-vivo Experiment," Endoscopy, Vol. 40, pp. 979-982, 2008.