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A magnetic drug delivery capsule based on a coil actuation mechanism

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Abstract

Current Wireless Capsule Endoscopic systems (WCE) provide only diagnostic tools, but in the future, advanced functionalities such as controllable drug delivery could be available for clinicians. This work introduces a Magnetic Drug Delivery Capsule (MDDC). The MDCC is based on a coil actuation mechanism that enables the deployment of a drug chamber from the device body. In this work, we present the prototype design and the results of bench trials that demonstrated the device ability to trigger the drug deployment by characterizing the magnetic field and resulting force.

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Keywords: Capsule endoscopy, drug delivery, magnetic actuation

1. Introduction

Existing Wireless Capsule Endoscopic (WCE) systems are used to diagnose diseases in the Gastrointestinal (GI) tract. They embed a camera, a battery, and electronic circuits that allow physicians to collect pictures of the GI tract while they move through it. Unfortunately, this technology has not yet been developed to the point where clinicians are able to perform an accurate therapeutic treatment**.** However, there is the clinical need to target and treat specific pathologies, such as Crohn's disease, obscure gastrointestinal bleeding (OGIB), and small intestinal tumors. Controllable drug delivery systems would enable the release of a specific amount of a given drug at an exact place in the GI tract. Hence, endeavors have been made by researchers [1-6] to perform regional drug absorption and to deliver a medication to a specific region of the GI tract such as the jejunum, ileum, ascending

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colon, or descending colon through the progressive release of medication. In this work, we present a Magnetic Drug Delivery Capsule (MDDC) for use in the release of common drugs in a solid form in the small bowel. The MDDC has a delivery mechanism based on magnetic attraction controlled by the current flow through an embedded copper coil. The MDDC consists of a cylindrical body in which the electronics and the batteries are embedded. At the top of this cylinder, the copper coil and a magnet are held, along with a separate drug chamber with the matching magnets. While the attraction between the magnets remains, the drug chamber maintains its connection to the body of the capsule. When the magnets repel one another, because of the force produced by the coil, the chamber is pushed outwards, allowing the delivery of the drug from the chamber to the target area of the GI tract. The MDDC does not require a motor for actuation and can hold extra sensors to enable real-time localization, thus ensuring an accurate on-site drug release [6].

2. PRINCIPLE OF OPERATION

Referring to Figure 1(a), the approach we propose for the MDDC takes advantage of two separate parts magnetically coupled: the capsule body and the drug chamber. In particular, while the capsule body embeds all the electronics modules, battery source and the drug releasing mechanism, the drug chamber can host up to 2.4 ml of drug. In order to prevent the drug from being delivered, four pairs of permanent axially magnetized NdFeB N-42 magnets (height = 2 mm, diameter = 1 mm, D101-N52, K&J Magnetics, US) are mounted to hold the drug chamber together with the body. The couples of magnets are mounted with a distance d of 4 mm between each other, resulting in the magnetic attractive force F_M. We can express the attractive force F_M as a function of the distance d, with Equation 1, (8):

$$F_M = \frac{\pi\mu_0}{4} \cdot M^2 \cdot R^4 \cdot \left[\frac{1}{d^2} + \frac{1}{(d+2t)^2} - \frac{2}{(d+t)^2}\right] \cdot n = 0.0033 \cdot 4 = 13.33\, mN \quad (1)$$

where R and t are respectively the magnet radius and thickness, μ_0 is the magnetic permeability of space and M is the magnetization of the magnet, and n the number of magnets. The distance d was chosen such that, when a drug release is triggered, as shown in Figure 1(b), the current, I_C, flowing through the coil generates the force F_C, enough to cancel out the attractive force F_M. We can express the force F resulting on the system, neglecting the x and y components with Equation 2:

$$F = F_M + F_c \quad (2)$$

The resulting force F is negative only when the inter-magnetic force F_M is acting on the system and becomes positive when the coil is activated.

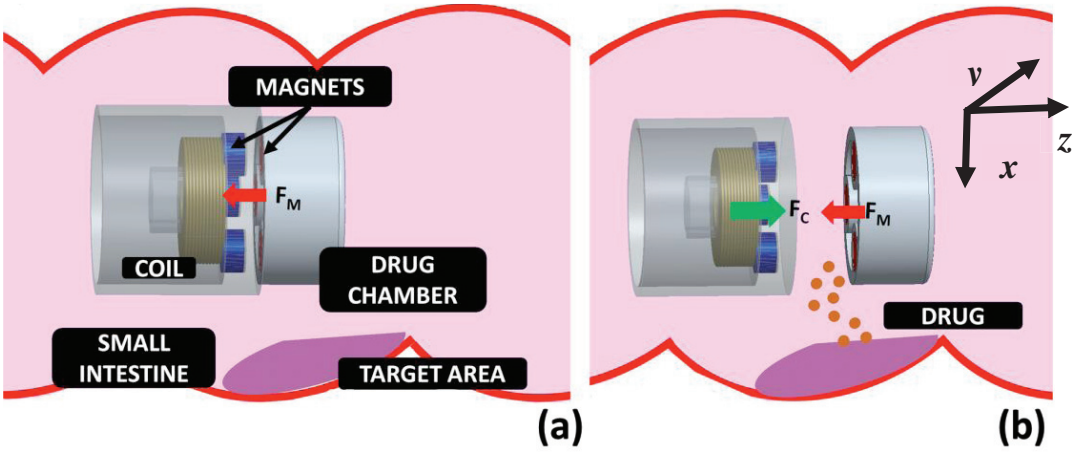

Fig. 1: (a) The capsule body and the drug chamber hold together by the force F_M. (b) The coil is remotely activated and greater than F_M, triggers the release of the drug chamber.

A schematic view of the MDDC prototype is presented in Figure 2 with its main components. It has a cylindrical shape (13 mm in diameter, 30 mm in length, 12 g total mass). The cylindrical plastic shell and the drug chamber have been fabricated by rapid prototyping (OBJET 30, Objet Geometries Ltd, USA). The shell holds the embedded electronic circuit, a rechargeable battery, and the release mechanism. The embedded electronics consist of a flexible circuit [8] which hosts a microprocessor (MSP430, Texas Instruments, USA), a 433 MHz radio transceiver (CC1101, Texas Instruments, USA), a MOSFET to drive the coil (AO3442, Alpha Omega Semiconductor, China), and a LiPo rechargeable battery. The coil (ID 4.95 mm, OD 13.85 mm, h = 9.40 mm) has been manually wound and it consists of a copper insulated wire (d= 0.2 mm, R_{tot} = 8.6 ± 0.05 Ω, 695 loops), such coil was designed in order to provide a force F_c strong enough to decouple the magnets once activated ($F_c > F_m$). Figure 3 shows a picture of the final prototype with all the components, the lateral connectors are used only for the programming stage, they are cut away before folding the capsule.

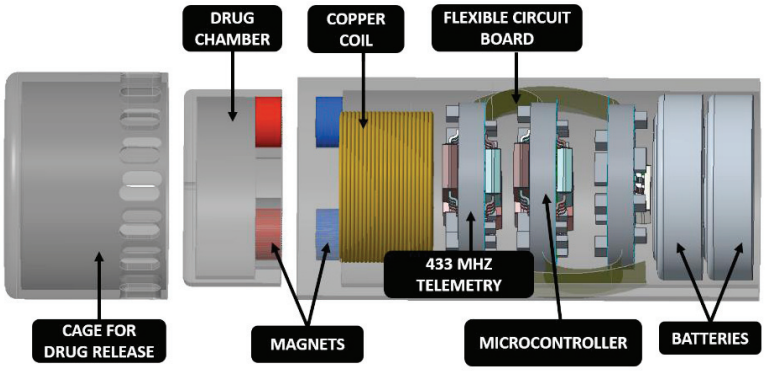

Fig. 2: A schematic view of the MDCC prototype.

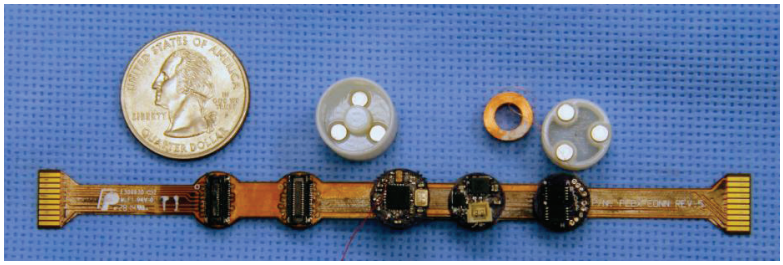

Fig. 3: The MDCC prototype assembled before being folded into the shell.

3. Experimental Assessment

The MDCC mechanism was characterized on bench with the platform shown in Figure 4(a). The platform consists of a six Degree of Freedom (DoF) robotic manipulator (RV6SDL, Mitsubishi Corp., Japan) and an aluminum piece holding the drug chamber with the robot end effector. The rest of the release mechanism (the coil and the embedded electronics) was fixed to the manipulator table. To characterize the mechanism performance, a magnetic probe (KOSHAVA 5, Wuntronic, Germany) and a 6-DoF load cell (NANO17, ATI Industrial Automation, USA) were mounted to measure the resulting magnetic field and attractive/repelling force respectively, the drug deploying mechanism was triggered with current impulses of 580 mA±10 mA with a voltage of 3.3 V and a duration of 4s. Figure 5 (a) and Figure 5 (b) show respectively the resulting magnetic field and force on the system for one of the trials. The magnetic field, when the mechanism is not activated, is equal to -8 mT ± 0.25 mT, and reaches a value of +0.5 mT ± 0.25 mT when the coil is activated. As the plot shows, the magnetic field generated by the embedded magnets is canceled when the coil is activated, and the force increases from -12.6 mN ± 0.4 mN (attractive) to +4.55 mN ± 0.52 mN. The attractive force results in a relative error of 4 % of what expressed by Equation 1. The trial

showed how the coil was able to generate a magnetic field sufficient to cancel the magnetic coupling between the capsule body and the drug chamber, and thus, to release the drug by separating the two parts.

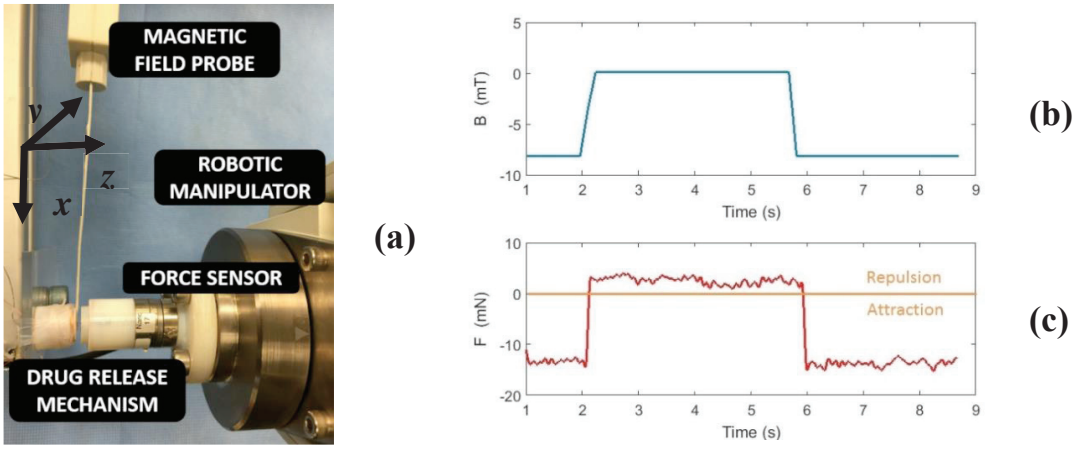

Fig. 4: (a) The experimental platform to characterize the MDCC. (b) Measurements of the resulting magnetic field B, and force F (c).

4. Conclusions and future works

In this work we presented the MDCC, a device that can be wirelessly triggered to deploy a drug in the GI tract. We presented the design of the MDCC prototype, and then we characterized the force necessary to deploy the drug along with the resulting magnets and coil interaction magnetic field. Bench testing showed how the embedded fabricated coil enables the two parts to detach from one another. In the future, magnetic localization [7] can be integrated into the device to trigger drug deployment in the desired spot as well as to manipulate the capsule in the GI tract [9], and anchor the device to release all the drug by the same spot. Future works will aim to reduce the device size and to control the quantity of the drug released.

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