Magnetic PillCam

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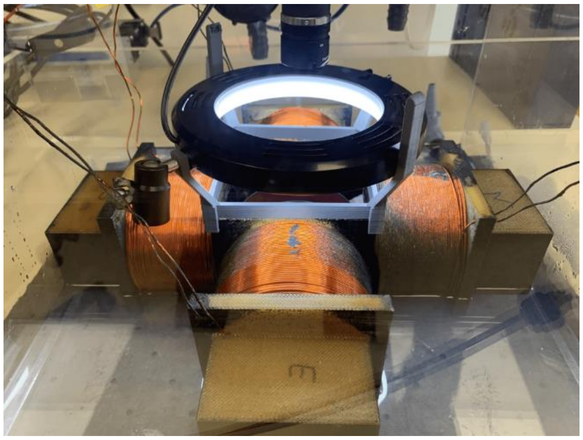
IMERSE

Background

The PillCam is a minimally invasive device developed as an alternative to endoscopic devices. The pill cam is a capsule that you swallow and it contains a small camera. This camera captures images at a frame rate of 2 to 6 frames per second (fps) based on the capsule speed. The camera takes pictures as it passes through the body and transmits the pictures to a data recorder which is worn as a belt. The pill cam is used to produce clear images of the esophagus, stomach, small bowel, and colon. However, there is no robotic control on the PillCam so its movement is completely reliant on passive body movements. The pill cam comes in a model with a camera on one end and another model with a camera on both ends.

MagnetoSuture is a device that consists of four electromagnetic coils in a plane separated by 90 degrees and it is able to use electromagnetic fields to control the motion of a magnet in the space between the coils. The current in each of the



electromagnetic coils is controlled by a wireless remote controller and the current ranges from -20A to 20A each. By activating one of the coils, the electromagnetic field will align in the direction of that coil, moving the magnet in that direction. Using this wireless controller that controls all 4 of the coils, a magnet should be able to move in any direction within that space and also be able to rotate in any direction as well. Additionally, this technology can be extended to include two more coils at the top and bottom in order to control an object in 3D space.

Finite Element Method Magnetics (FEMM) is an open-source finite element analysis software package for solving electromagnetic problems. This can be used to model electric fields and visualize electromagnetic forces very accurately. We can use it to simulate the magnetics relating to the MagnetoSuture device to get a better understanding of how the PillCam will interact with it.

Problem

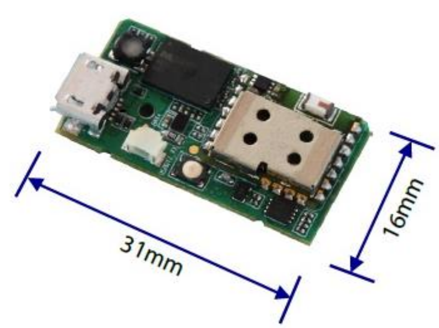
The PillCam is becoming more popular because of its ability to capture internal images in a non-invasive manner. With the addition of magnetic control on the PillCam, we would be able to improve the device significantly which would lead to a higher usage rate of the PillCam.

Approach

<u>IMU</u>

For this device, we need to place an IMU, microcontroller, and some way to send out the IMU data wirelessly, along with the batteries required to power the device while keeping it as small as possible. From looking at **A localization method for wireless capsule endoscopy using sidewall cameras and IMU sensors** we got our first ideas for the system to use Radiofrequency to send out the IMU data, but reading further into the device we found that the assembly was 28 x 28 x 8mm without including a battery while the pill cam is 26 x 11 x 11 mm which massively increase the area it will take up in the chamber. We looked at other alternatives to make the device smaller and found **A wireless micro inertial measurement unit (IMU)** that was 18 x 16 x 4mm with all the parts required to construct the device were listed however, those parts were not in stock and did not include the battery in the total size of the wireless IMU. After looking to determine what is available to purchase during our timeline that could be easily put together to ensure it fits our size requirements, we found **LPMS-B2 9-Axis IMU AHRS Motion Sensor with Bluetooth 2.1 & 4.1 Connectivity**

LPMS-B2 OEM:

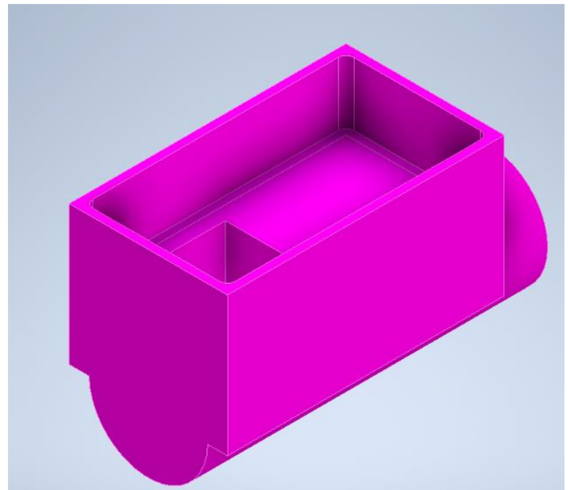


which had all the parts put together in one part that was 31 x 16 x 4mm without the battery. We decided to go with this option since we could order it without having to worry about the construction of the device on a smaller scale than any of us had experience with.

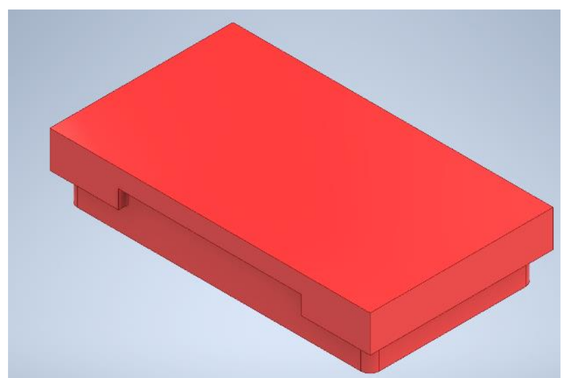
Housing Design

For the magnetic placement, we decided to make four rods of neodymium iron boron magnets and store in inside the casing. The casing was designed to be open to the magnets when the pillcam is not in the case, but once inserted, the magnets are locked in place. We decided to have four rods of magnets to have an even distribution and ensure that the magnetic dipole is through the center of the pillcam.

For the IMU housing, we needed a space to attach the imu to the PillCam with enough space for all the parts and the battery for the device. We decided to go with a press-fit compartment that would house the electronics and batteries with the idea that this would be almost waterproof by design, except that 3D printed parts are not known for being waterproof themselves so we would be conscientious about what we could do to further waterproof this.



The housing attaches to the Pillcam and places the battery axially behind it as the battery has the same diameter as the PillCam. For the top and bottom parts to fit together we found that if they had the same dimensions they would fit together with the most consistency.

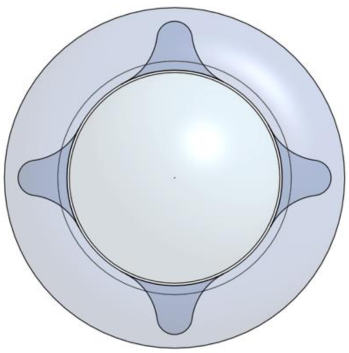


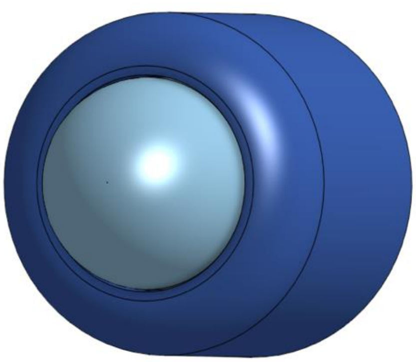
We filleted the corners at 1mm to remove any sharp corners from our part to help make fitting the top and bottom parts easier.

Magnet Housing Design

For the magnet placements, we decided to place 4 small magnets in 4 equally distanced positions along the side of the PillCam with the housing holder in place to secure all four magnets. The position of the magnets would allow for the magnetic forces to be concentrated in the center of the PillCam and allow for equal control. The magnets are placed within the divots designed on the inside of the housing and would not have any openings as long as the PillCam is placed within the design as well.

Wii Remote Control



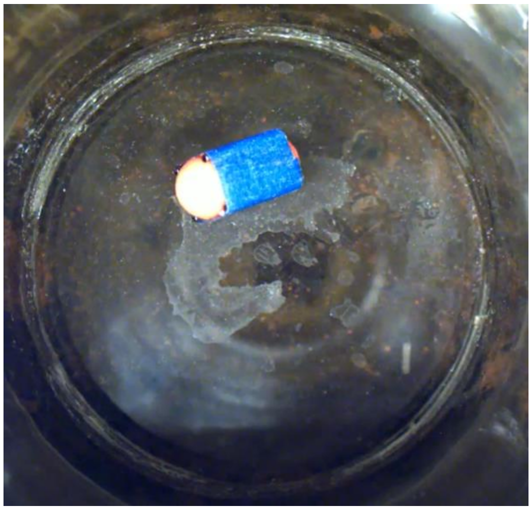


The potential for the integration of the Wii remote is an important next step for the movement of the PillCam. Currently, the device is controlled using an Xbox controller with the joystick. However, the accelerometers and sensors in the Wii Remote provide a critical user interface in which the PillCam can be controlled. With the integration of the Wii Remote into the overall system, a user can now control the PillCam simply with the tilt motion of the controller. This is much more intuitive compared to the joystick and the sensitivity of the motion can be felt more clearly by the user as well.

Testing

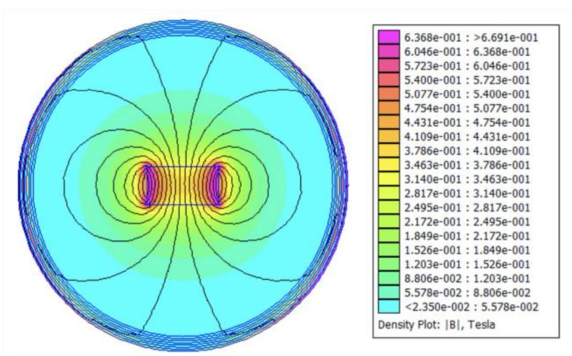
Movement Testing in the Magnetosuture

Using MATLAB and Arduino, we were able to test the PillCam in the MagnetoSuture The PillCam was unable to move around and be properly controlled at first, but with adjustments made to the electricity traveling through the electromagnetic coils and sensitivity of the joystick, it was able to work. Additionally, 3D control of the PillCam was implemented. This was done through the use of a z-axis electromagnet being controlled by buttons on the joystick. The MATLAB code was also adjusted to also take into account the z-axis control. Wii remote control is in the process of being implemented allowing for wireless control of the pillcam through magneto suture. MATLAB code was written to integrate the Wii remote control through the Bluetooth and other drivers installed on windows.

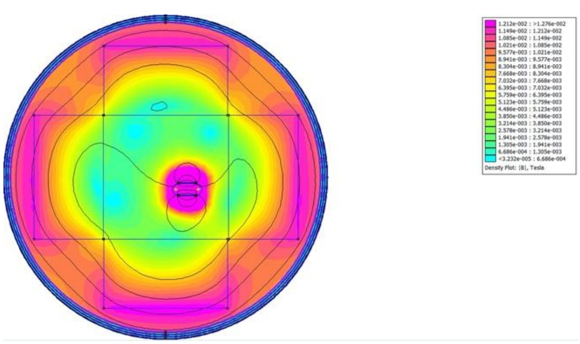


FEMM

A model of PillCam with the neodymium iron-boron magnets was first created on FEMM.



Then, a Magneto Suture model was created with and without the PillCam in the middle.



Using the information from the two models, we were able to calculate the magnetic dipole moment of the PillCam. With that information, the torque and force on the PillCam at each point was found. This used the data from the magnetic field of the magneto suture model and the value of the magnetic dipole moment. This helped us understand and predict the movement of PillCam at any location within the MagnetoSuture.

Waterproofing

Testing the device went over many iterations to achieve the press-fit between the top and bottom parts holding the IMU. Once the two parts fit together a paper towel was put into the part such that we could tell when the water had entered the system. We did this by holding the part underwater for 5 minutes after we pulled it out and then inspected the paper towel to determine if it was wet. We found our design waterproofed for the static conditions by itself. Next, we moved on to bumping the part underwater against the walls for two minutes and found the air escaped the system and the paper towel was wet. To combat this we purchased Marine Grease to coat the walls of the parts to create a seal to keep the water out. We found that a generous layer against the walls is required to keep the inner cavity dry during the two-minute test.

Management Summary

Who did what?

Mark Gonzales worked on developing the IMU system, including the power supply. Mark also worked on developing the housing for the IMU. Mark also handled the testing of the waterproofing of the system.

Jack Yue worked on the development of the CAD profiles for the iterations of the models of the PillCam and the container prototypes for the PillCam itself as well. He also worked on the integration with the Wii Remote controller along with the technical drawings/documentations for the project.

Bharath Heggadahalli worked on identifying the best suited magnets for PillCam. Also, Bharath worked on the testing using MATLAB and Arduino with the MagnetoSuture. Additionally, Bharath worked on modeling the PillCam and MagnetoSuture on FEMM and analyzed the models as well.

Planned vs Accomplished

We planned to develop the mechanical and electrical system with the IMU, magnets and the PillCam in mid-march in order to be able to focus on the development of the control system by Wii controller and finally be able to write a full paper on the work.

We ended up falling behind on the electrical system due to the difficulty of finding an IMU, microcontroller and Bluetooth/RF transmitter that were in stock and fit our size requirements. We then moved forward placing in the magnets and designing the housing for the IMU once we found one, but the delay in receiving the IMU made us move towards designing the Wii remote controller without having completed the electrical system.

What is next

Once the IMU comes in, we will attach everything to the system and determine what the dynamics of the system are and how we can control the 6 degrees of freedom with the wii controller telling the magnetosuture what to do.

What you learned

We learned that the getting all the parts needed to get the project as soon as possible. The lack of having an IMU slowed down our progress with being able to successfully do the next steps of the project. We also learned that there are many avenues for progress in a project even while waiting for components to arrive. Models can be used in place for the actual device while we wait for them to arrive, and we can hit the ground running once the necessary components do arrive.