Tracking System for Targeted Drug Delivery

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Introduction

Our senior design project focused on developing a system for targeted drug delivery. The motivation behind the design of such a system is to help increase drug efficacy in medicines used in the treatment of intestinal ailments such as Crohns' disease or intestinal cancer. Additionally, by developing a system that is capable of precise medication delivery within the GI tract, this senior design project also aims to lay the groundwork for a more advanced healthcare platform of the future.

There are many targeted drug delivery systems that have already been invented and are in use today. Many of these systems are highly specific to a certain disease or medicine. Additionally, many of these systems use tracking methods such as gamma ray scintillation or x-ray imaging, which are both impractical for use in repeated human trials. For more information on these systems, please refer to this page.

The most widely used method of drug delivery today is the gelatin capsule. With this capsule, the location of medication delivery is controlled by the rate at which the gelatin shell dissolves. However, many medications would be made more effective if they were released at specific locations within the intestinal tract. In order to be able to release medicine at a specific location, we propose a noninvasive tracking system that is capable of locating a capsule's location and orientation inside of the body.

The system proposed in this study uses magnetic fields to determine the location and orientation of the capsule. A small permanent magnet is placed inside of the capsule and acts as a marker. Since this magnet is inside of the capsule, the magnetic field emanating from the permanent magnet will be a function of the location and orientation of the capsule itself. Magnetic sensors are then used to detect the magnetic field of the permanent magnet and a magnetic source imaging algorithm is used to triangulate the position of the capsule.

Since the capsule should be small enough to safely consume, the magnet that is placed inside of the capsule must be fairly small. As a result, the sensors that read the magnetic field strength outside of the body must be very sensitive. If less-sensitive sensors are used, the system may not be able to resolve small changes in capsule location. This is one major drawback of the tracking system, because although sensitive sensors exist, they can be quite expensive or require intensive cooling systems. We were able to demonstrate tracking using off-the-shelf-sensors with a resolution of 2-3 mm in XY and ~6 mm in Z.

Theory of Operation

Physical Foundation

In order to develop a system that is capable of estimating the location and orientation of a small permanent magnet, we must first understand the physical and mathematical framework that this system relies on. As mentioned before, the system uses a small permanent magnet as a beacon of sorts for the tracking system. All permanent magnets emit magnetic fields as a result of the alignment of magnetic domains within the material. With strong permanent magnets, there will be strong alignment of these domains, and the resulting magnetic field that this material produces will be larger in magnitude. This magnetic field will be strongest near the magnet, and weakest further away from the magnet. The exact strength of the field is determined by the distance from the magnet and by the individual strength of the magnet. As such, using a stronger magnet will in fact make it easier to accurately detect.

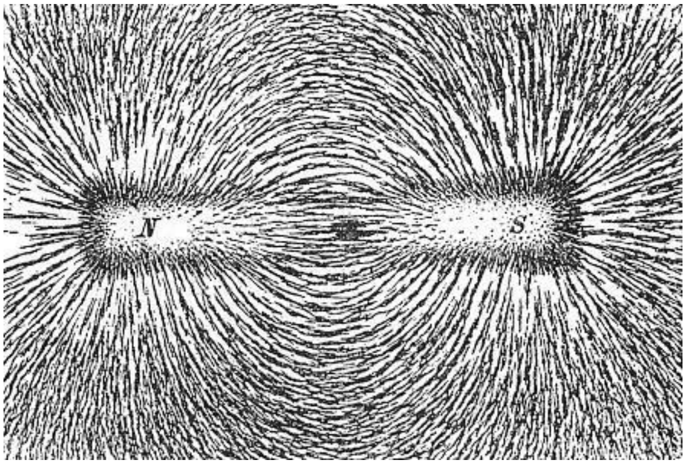

Figure 1 - Visualization of the magnetic field of a bar magnet.

The magnetic field that is produced by a permanent magnet is complicated to model precisely. This is because the total magnetic field is a result of many small magnetic domains, and as a result, the field will not be perfectly symmetric. This is especially noticeable when we move closer to the magnet, since the non-symmetric domains will have a larger magnetic field strength at closer distances. This is important, because if we only plan to sense the magnetic field at relatively far distances (0.1 or 0.2 meters) then the fringing fields that are caused by these asymmetries will have less of an impact on the net magnetic field. This means that we can use a simple mathematical model to estimate the real magnetic field of a small permanent magnet.

Localization

Now that we have a foundation to work from, we can see that in order to determine the location of the magnet in space, we need to find a relationship between magnetic field strength and location. By placing magnetic sensors in known locations, we can correlate any data that these sensors acquire to the known locations of each sensor. The goal from this is then to make educated guesses about the relative location of the magnet based on the readings that the sensors acquire. The mathematical model of the magnetic field that was described above is then used to inform these guesses. The location and orientation of the permanent magnet is at first completely unknown, so a computer program iteratively guesses and checks various locations and orientations until it finds a set of values that would theoretically produce a magnetic field that matches the magnetic field that the sensors actually detect. This process is known as nonlinear regression fitting.

System Overview

The theory of operation above details the foundation from which a magnetic field tracking system can be built and iterated upon. An overview for a proof of concept design is shown below with the goal of providing an overview of the most important aspects of the system.

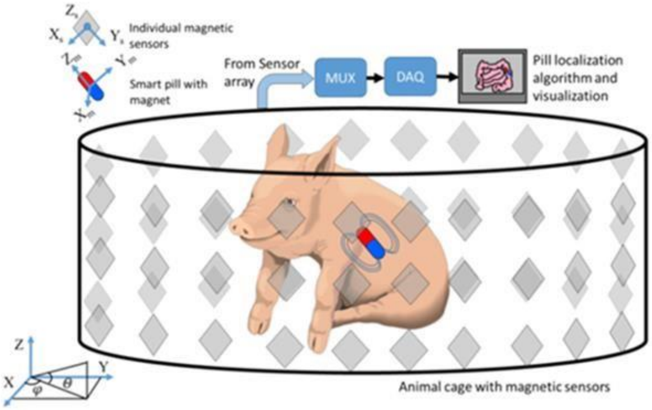

Figure 2 - System architecture shows pill inside of the GI tract of a pig. Fixed to the cage are magnetic sensors that read the magnetic field of the capsule and send the data to a computer for tracking and plotting.

The system seen in the above figure was used as a proof-of-concept design to demonstrate the viability of such a tracking system. In this senior design, we used 8 magnetic field sensors which connected to a piece of hardware called a digital acquisition board (DAQ). This DAQ acted as a mediator between the sensors and computer. The DAQ handled the details of acquiring data directly from the sensors, and sent this data to a computer which subsequently converted this data into location and orientation estimates.

Results

There are many aspects of the tracking system that could be characterized and reported on, however the spatial resolution is perhaps the most important. To demonstrate the system’s ability to track in real-time, a 3D plot of location data is shown in Figure 3 wherein the capsule was slowly moved in a rectangular path. The system tracked the locations of the capsule and marked the locations with color-coded timestamps.

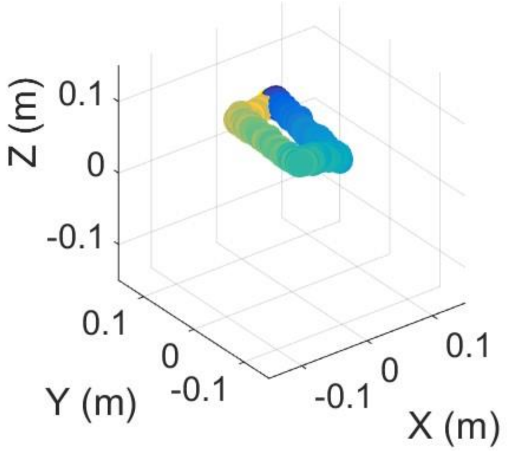

Figure 3 - Location data acquired from the proof-of-concept design. The capsule was moved around the testing region in a rectangular path, where the blue data points are earlier locations and the yellow data poitns are recently acquired locations.

Additional experimentation was conducted to determine the resolution of the system. Since the system uses magnetic fields as a means of tracking the capsule, the resolution was complicated to evaluate. Magnetic fields are nonlinear in nature, and as such, the resolution of the system is not uniform throughout the testing region.

Conclusion

This system shows promise as a proof-of-concept device; however, certain attributes can be significantly improved upon. For instance, if the sensors had a higher sampling rate, then the system would be able to acquire data more quickly and the resolution of the system would be improved dramatically. This would also open up the doors to more complicated signal processing techniques that could potentially improve the system performance.

Other improvements include taking into account sensor positional uncertainty, modeling higher-order magnetic field components, using parallel data acquisition (rather than time-multiplexed acquisition), and improving the mechanical structure (housing) of the system. If all of these improvements are made, this system may very well form the foundation of a targeted drug delivery system.

References

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