Orin H Council
#1415990

Design and Construction of 6-Coil System for Electromagnetic Manipulation of Micro-Robots

Progress Report – Special Topics Class I

Summary: The goal of this project is to build a device similar to shown in figure 1. This device will be used to control the position (track) of a collection of magnetic spheres along a defined trajectory. Progress so far includes the development of a mathematical model for motion and control (1) , a hardware interface for the current controllers to the control PC (2) , a vision capture and tracking system (3) and a physical structure to hold all required components (4). Construction of the electromagnetic coils has proven challenging and two options are now being investigated. One is to purchase a custom coil from a manufacturer and then second is to use an automatic coil winder in another department.

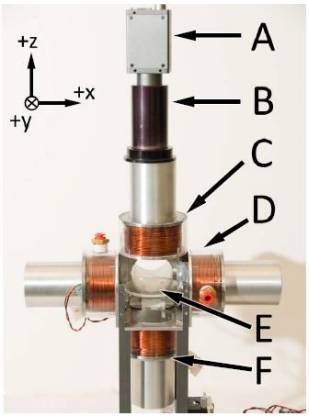

Figure 1, Magnetic coil system, from [1]

To begin designing the control system, I derived a simple state-space expression of the system from first principles. Equation 1 is the state-space expression for motion in the x-axis. A identical expression is used for motion in the y-axis. Typically, drag is a non-linear expression with velocity of the mass as a squared term. However, since the sphere is moving at slow speeds in oil, the assumption of highly linear flow (Reynolds number less than one) is valid and therefor drag can be expressed as a simple linear equation. This equation is known as Stokes' Theorem. The input force to this expression is the magnetic field gradient in which the sphere exist within. Equation 2 is the relationship between force and magnetic field gradient. Equation 3 is the expression for magnetic field gradient is function of distance along the center axis of the coil.

$$\begin{bmatrix} \dot{x} \\ \dot{v}_x \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 0 & \dfrac{(-6\pi\mu r v_x)}{m_s} \end{bmatrix} \begin{bmatrix} x \\ v_x \end{bmatrix} + \begin{bmatrix} 0 \\ \dfrac{1}{m_s} \end{bmatrix} u(t)$$

Equation 1 – State Space Matrix

$$F = (M \circ \nabla) B$$

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Equation 2 – Force Equation

$$\frac{dB}{dx} = \frac{((u_o N I R^2)(-3x))}{(R^2 + x^2)^{2.5}}$$

Equation 3 – Magnetic Field Gradient

Next, I built a Simulink model which implements Equations 1,2, and 3 into a function blocks along with a feedback PID controller to control DC current commands to the current controllers. Figure 2 is the overall block diagram of the control system. Figure 3 shows the tracking performance of this control system. Additionally, a video capture and analysis system is implemented in Simulink. This system provides the actual position of the sphere and compares it to the output of the model. Further work is required to integrate this system into the overall control strategy. Figure 4 shows the current work.

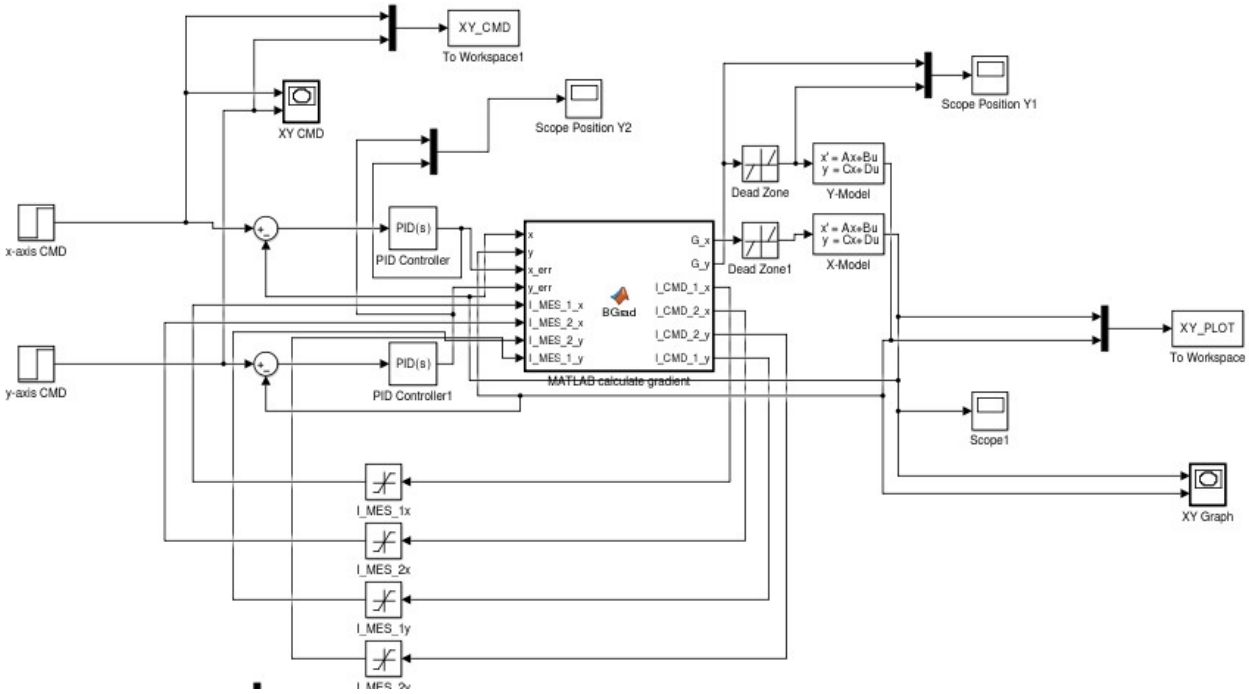

Figure 2 – Simulink Model of PID Controller

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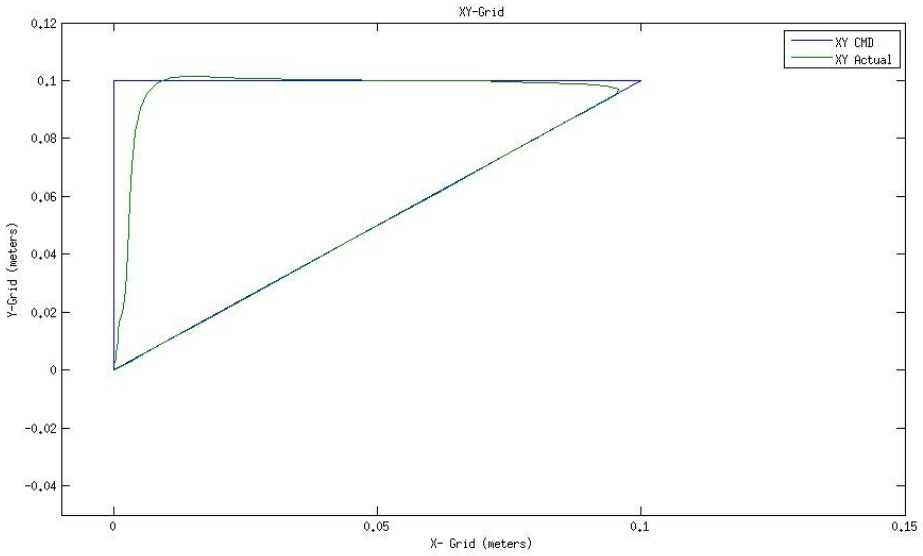

Figure 3 – Track Plot of Controller Output

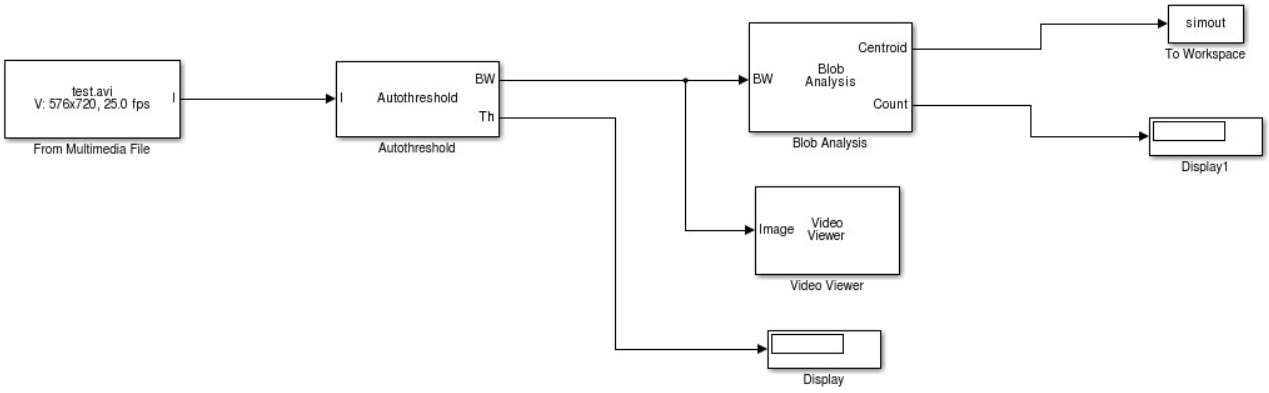

Figure 4 – Current Image Capture and Tracking Block Diagram in Simulink

The hardware setup for this project remains incomplete, however, some sub-systems are complete. Figure 5 is a photo of the current controller connected to the Arduino micro controller. Several attempts were made over the summer semester to construct coils with very limited success. This remains one of the major challenges for the hardware setup in the project. The next step in this process will be ordering

coils made by Custom Coils and should be on hand with the next couple of weeks. Theses coils are approximately 8 cm (Outer diameter) and 6 cm long with 1200 turns using 18 AWG wire. A iron pipe will be placed in the center of the coil to increase the field strength.

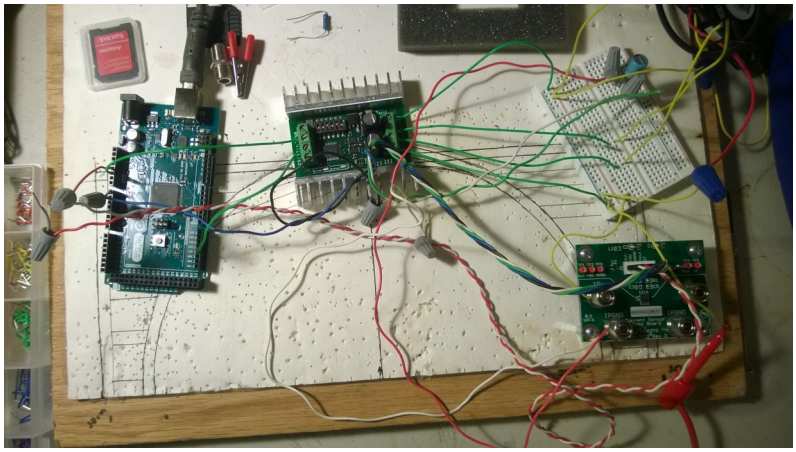

Figure 5 – Hardware Setup testing the current controller

Overall, this project has resulted in useful computer models, hardware interfacing to open source controllers and partial physical construction of critical components. With additional time provide by the full semester in the fall, the project has a high chance of success.

[1] C. S. Pawashe, “Mag-Bots: Magnetic Micro-Robots Capable of Mobility, Manipulation, and Modularity, “ Carnegie Mellon University, 2010