

# MAGNETO

A stylized graphic consisting of several orange curved lines that intersect to form a central purple coil-like structure, resembling a magnetic field or a coil of wire.

Control Interface for Autonomous Robotic Brain Surgery  
using Magnetically Stimulated Particles

**Weinberg Medical Physics Sponsors**

Dr. Chad Ropp, Olivia Hale, Dr. Lamar Mair, Brad English, Dr. Irving Weinberg

**GMU Senior Design Team**

Elizabeth Ankrah, Minh Quan Do, Victor Huynh, Bassam Mutawak

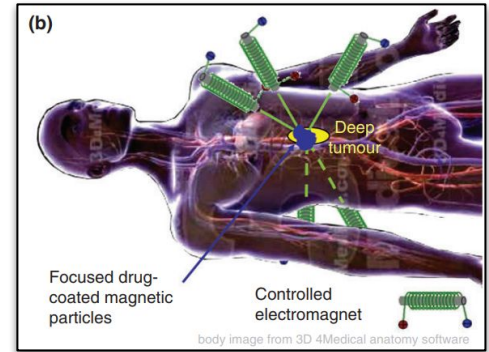
**GMU Advisors**

Dr. Nathalia Peixoto, Dr. Qi Wei

# Background

## Magnetic Particle Delivery

- Significance:
  - Transport of magnetic nanocarriers using external magnets
  - Potent form of noninvasive surgery; carriers loaded with various therapeutic payloads
- Limitations:
  - Crossing physiological barriers
  - Magnetic field attenuation affects deeper delivery
  - Impracticality of manual magnet array operation



**Fig 1.** Using magnetic fields to focus therapy to a deep tumour[1]

# Relevance

## Control Interface (CI) for Magnetic Control System (MCS):

- Weinberg Medical Physics (WMP) constructs electropermanent MCS
- CI enables autonomous magnetic particle delivery from nose to deep brain

## Project Impact:

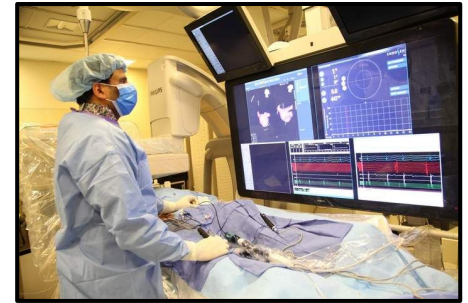
- ☑ Reduces surgical complexity
- ☑ Support research on deep-tissue particle delivery
- ☑ Enable autonomous control of magnetic particles

# Objectives

1. Design software modules for MCS operation
2. Design interactive GUI for surgeon usage



**Fig 2.** Electropermanent bi-planar MRI under construction



**Fig 3.** Surgeon using a computer interface to implant a wireless pacemaker.

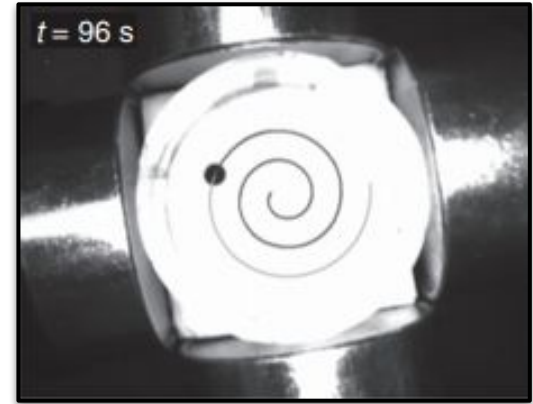
# Requirements

## Software Modules:

- Must collect and segment MR images to determine particle location
- Must guide particles along user-defined path
- Must output MCS commands for particle translation and activation

## Graphical User Interface:

- Must display particle locations in real-time
- Must support 3D path input on MR images
- Must allow for manual termination



**Fig 4.** Ferrofluid droplet moving along a spiral path using magnetic coils[10]

# Team

**Elizabeth**



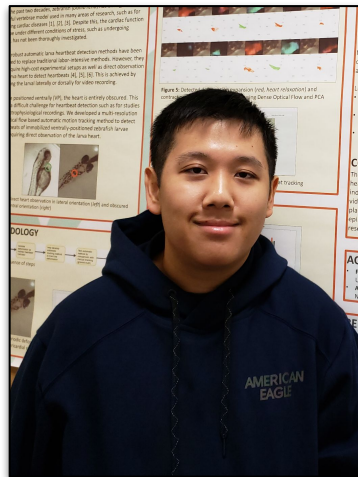
**Testing & Evaluation**  
Front-end Design  
Back-end Design

**Minh**



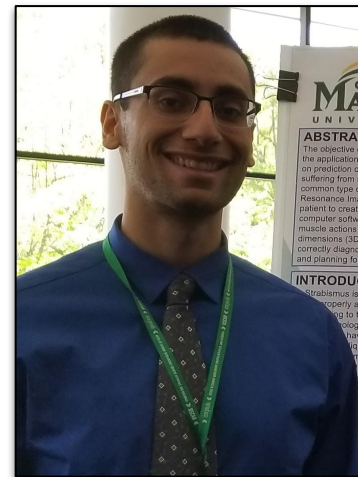
**System Design**  
Back-end Design  
Testing & Evaluation

**Victor**



**Front-end Design**  
Back-end Design  
System Design  
Testing & Evaluation

**Bassam**



**Back-end Design**  
System Design  
Front-end Design  
Testing & Evaluation

# Project Scope

## Semester 1:

- 2D particle translation through user input path
- Optical imaging
- Translate particles with induced magnetic fields via solenoid coils

## Semester 2:

- 3D particle translation through user input path
- MR imaging
- Translate particles with electropermanent magnets

# Testing Criteria

## GUI

- All buttons successfully perform their specific functions.
- Users is able to design a path across multiple image slices
- Path can be modified mid-operation (when operation is paused)
- Acquired particle location coordinates are accurate and represented correctly by real-world distance
- Particle location is displayed on GUI in real time



# Testing Criteria

## Image segmentation

- Locates particles in image slices with maximum 5% positional error
- Processes and output images at a maximum period of 20 ms/image

## Control Module

- Computes correct distance vectors to move particles through delivery path
- Communicates distance vectors to physics module
- Determines corrective actions if particles are not clustered around desired path location
- Executes operational commands from user (i.e. pause/terminate operation, redraw path, etc.)

# Engineering Characteristics

## Structural Division of Function

- ✓ Codebase must be split into separate modules
- ✓ Each module must have unique functionalities

## Modular Hardware Connection

- ✓ System can operate using a variety of hardware components
- ✓ Seamless transition from one hardware component to another

## Platform Independent

- ✓ Software performance should be consistent across major operating systems

## Safe System Operation

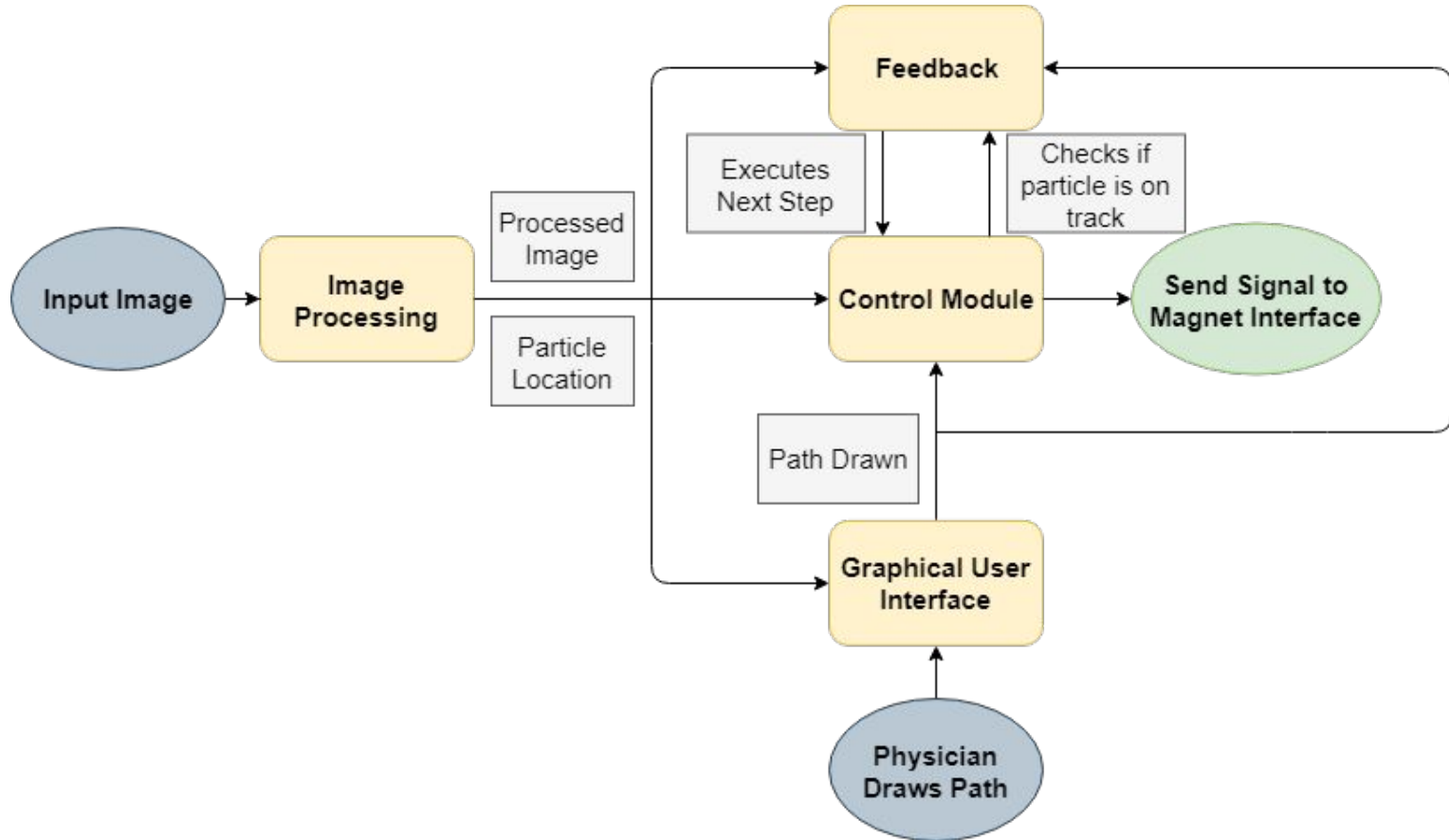
- ✓ Module safety checkpoints with sensitive error detection
- ✓ Effective actions to mitigate detected errors (gives user ultimate control)

# Standards and Codes

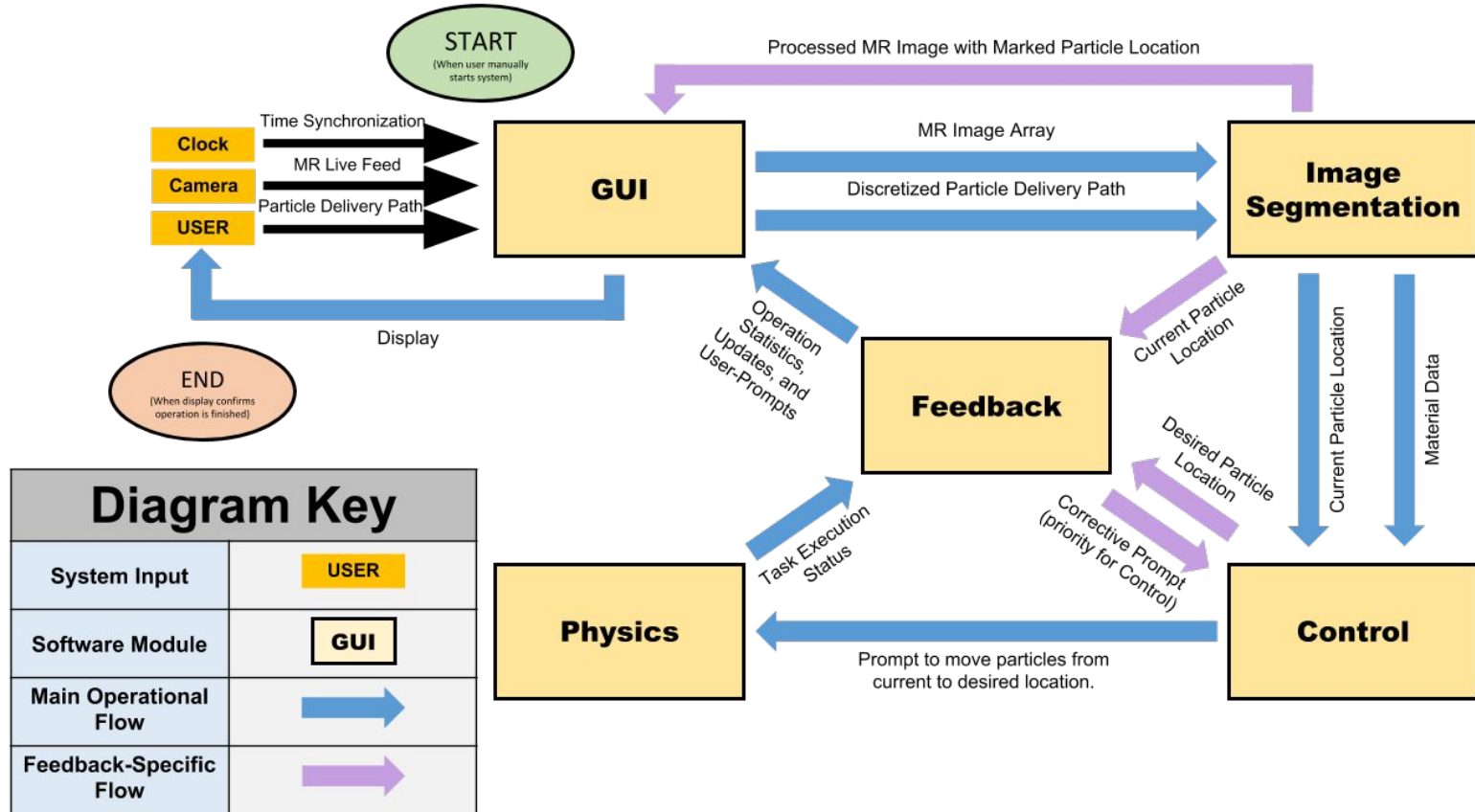
**Project will conform with FDA guidelines for medical software devices.**

- Guidance for Industry and FDA Staff: Guidance for the Content of Premarket Submissions for Software Contained in Medical Devices (2005)
- Software as a Medical Device (SaMD): Clinical Evaluation Guidance for Industry and Food and Drug Administration Staff (2017)
- General Principles of Software Validation; Final Guidance for Industry and FDA Staff Document issued (2002)

# Approach 1: Control Centric Design

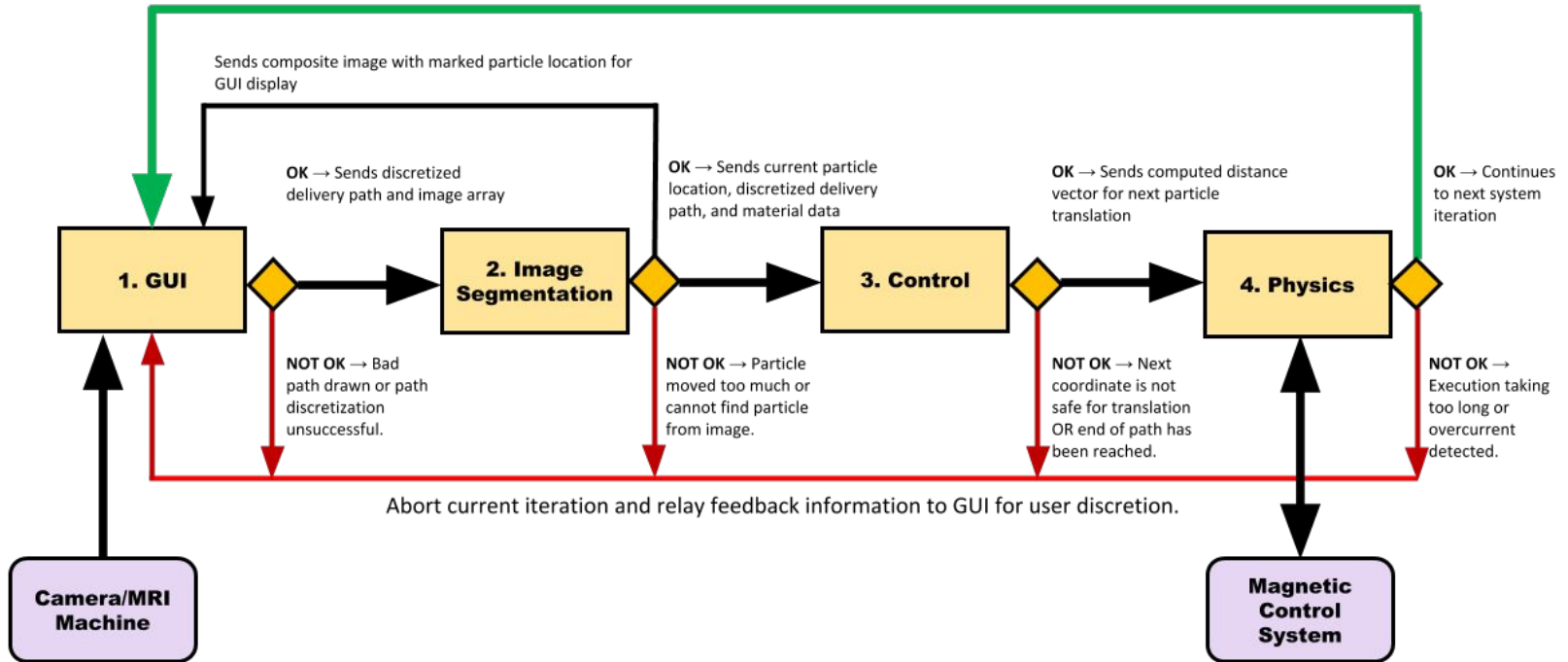


# Approach 2: Feedback-Centric Design



# Approach 3: Linear Operation with Regular Safety Checkpoints

Particle translation executed successfully and relayed to GUI. System is ready for next iteration.



# Alternatives - System Architecture

DECISION MATRIX SCALE					
0	1	2	3	4	5
Does Not Meet Objective			Fully Meets Objective		

	Clear Information Flow	Operational Speed	Simple Hardware Communication	Integrated Safety	Responsiveness to Feedback	TOTAL SCORE
Control Centric Design	2	<u>4</u>	<u>5</u>	2	3	16
Feedback Centric Design	3	<u>4</u>	4	2	<u>5</u>	18
Linear Operation Design	<u>5</u>	2	<u>5</u>	<u>5</u>	<u>5</u>	<u>22</u>

# Alternatives - Programming Language

DECISION MATRIX SCALE					
0	1	2	3	4	5
Does Not Meet Objective			Fully Meets Objective		

	Object Oriented	Image Analysis Support	GUI Library Support	Hardware Library Support	Integration with Client Codebase	TOTAL SCORE
C++	4	<u>5</u>	<u>4</u>	<u>5</u>	<u>5</u>	<u>23</u>
JAVA	<u>5</u>	3	3	3	3	17
PYTHON	3	<u>5</u>	<u>4</u>	4	2	18
MATLAB	2	4	3	3	3	15



# Alternatives - Image Segmentation

DECISION MATRIX SCALE					
0	1	2	3	4	5
Does Not Meet Objective			Fully Meets Objective		

	Computational Efficiency	Additional Components	Ease of Implementation	Supported Documentation	Accuracy	TOTAL SCORE
Early Image Subtraction	4	<u>5</u>	<u>5</u>	3	4	<u>21</u>
Kalman Filter	3	2	3	3	<u>5</u>	16
Template Matching	2	<u>5</u>	4	<u>5</u>	3	19
Meanshift Tracking	<u>5</u>	2	3	4	3	17

# Alternatives - Graphical User Interface

DECISION MATRIX SCALE					
0	1	2	3	4	5
Does Not Meet Objective			Fully Meets Objective		

	Cross Platform Support	Open Source	3D Graphics Support	Widget Toolkit	Access to Multiple Libraries	TOTAL SCORE
Qt	<u>5</u>	3	<u>4</u>	<u>5</u>	<u>5</u>	<u>22</u>
wxWidgets	4	<u>5</u>	3	4	4	20
FLTK	3	<u>5</u>	2	3	2	15
GTK+	3	<u>5</u>	3	2	2	15

# GUI Description - Main Window

Welcome to Magneto Control Interface! You will need to perform setup before starting the operation. Start by pressing "Link Stream" to confirm the stream connection.

Stream loaded!

Current Settings				
Field of View: 79.953 x 60 x 0 (mm)	Distance Per Pixel: 0.0965616 mm/pixel	Delivery Tolerance: 3.74276 mm	Filter Threshold: 100	Bounding Box Size: 26.7343 mm x 26.3595 mm
Image Resolution: 828 x 621	Total Path Distance: 63.1093 mm	Coil Locations (mm): X+: (39.8222,22.3807) X-: (17.3386,22.0205) Y+: (29.3778,11.5248) Y-: 0	Min Particle Size: 1.8739 mm	Max Particle Size: 11.3683 mm

TERMINATE OPERATION

Data Log

Date: Mon Dec 10 2018

Event Time -> Event

15:55:35 -> Loaded stream: "CAMERA"

15:57:07 -> Drawn path successfully exported.  
Path length: 63.1093 mm

15:58:25 -> Image segmentation parameters have been set

15:59:14 -> Image segmentation parameters have been set

Progress: 0%

Operation updates and notifications appear here...

Load Previous Log

Fig 5. GUI Main Window

# GUI Description - Creating Delivery Path

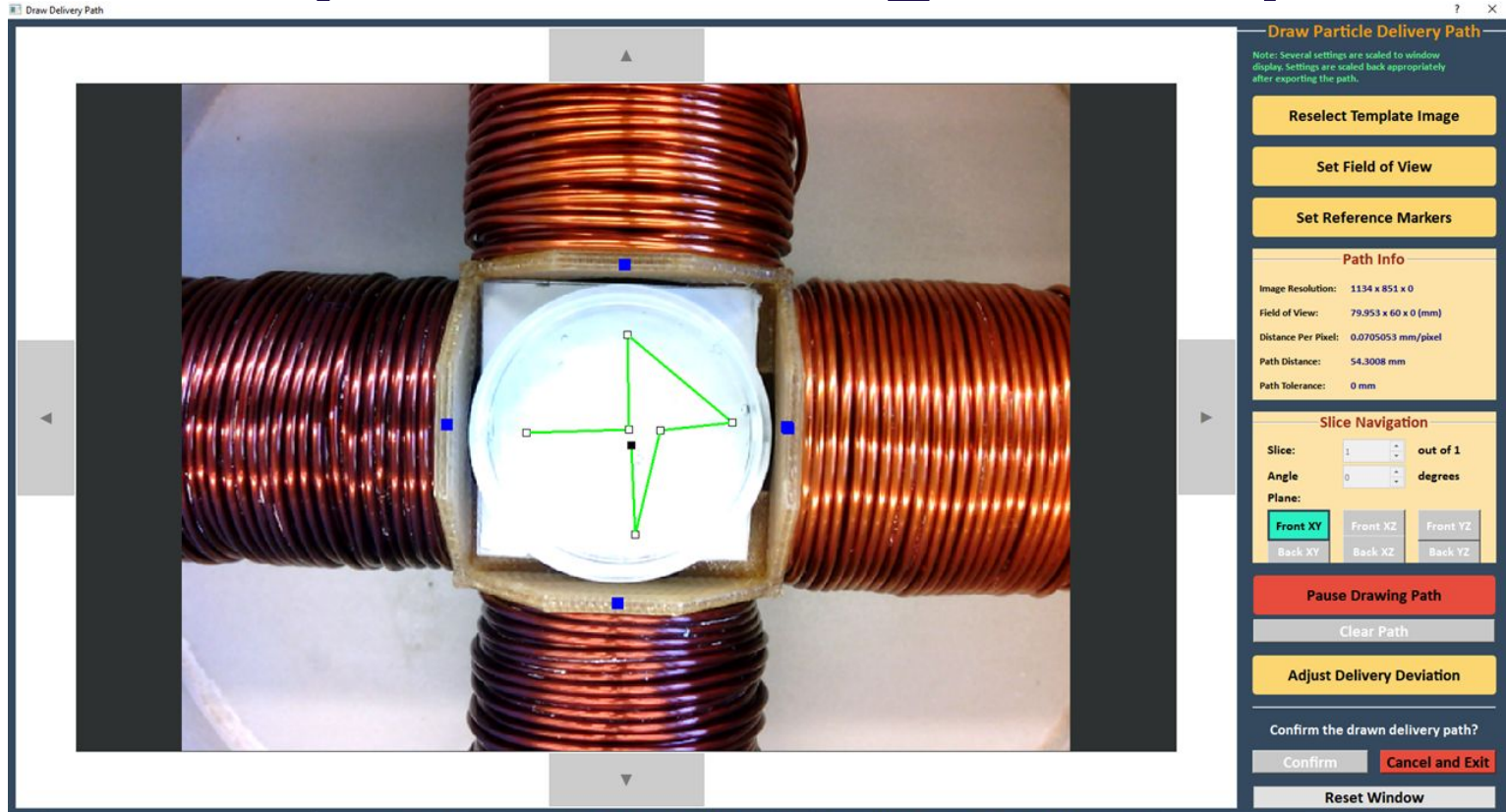
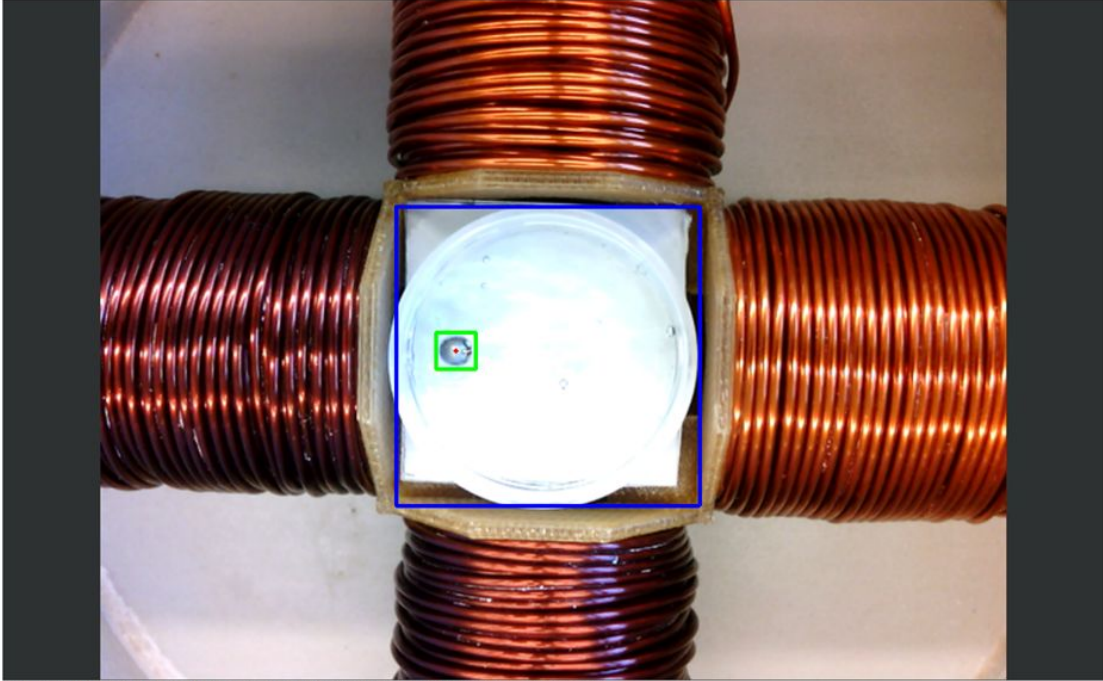


Fig 6. GUI Pathing Window

# GUI Description - Tracking Configuration

Confirm Particle Location

Press "Draw Particle Bounding Box" or adjust sliders/spinboxes to set parameters. Press "Preview" to preview image segmentation results. Adjustment parameters until particles are consistently located. Then click "Confirm" to finish.



Selected Background Bounding Box--> Starting Point: (372,260), Width: 382, Length: 376

**Particle Tracking Setup**

Note: Several settings are scaled to window display. Settings are scaled back appropriately after confirming parameters.

Reselect Clean Image

Draw Background Bounding Box

**Image Segmentation Settings**

**Draw Particle Bounding Box**

Filter Threshold (0 - 255)

Minimum Particle Size (0 - 200)

Maximum Particle Size (0 - 200)

**Preview**

**Preview Stream Parameters**

Filter Threshold: 100

Minimum Particle Size: 48

Maximum Particle Size: 163

Last Updated: 15:57:42

Confirm image segmentation parameters?

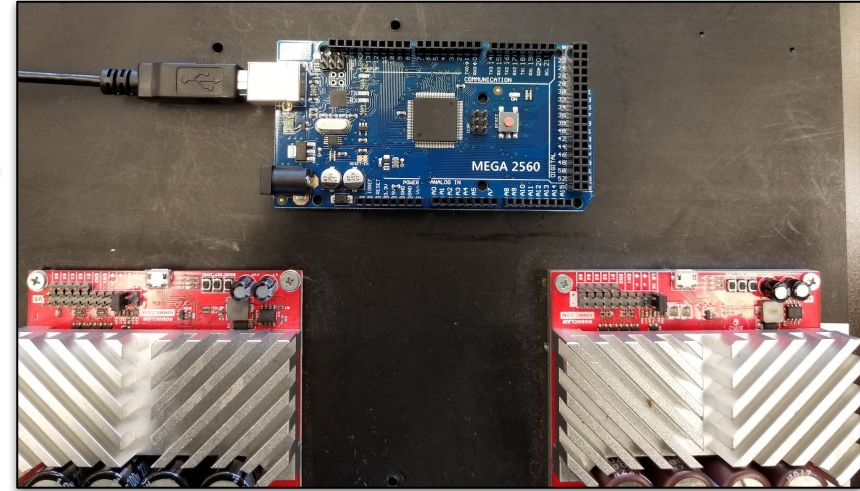
**Confirm** **Cancel and Exit**

Reset Window

Fig 7. GUI Image Segmentation Configuration Window

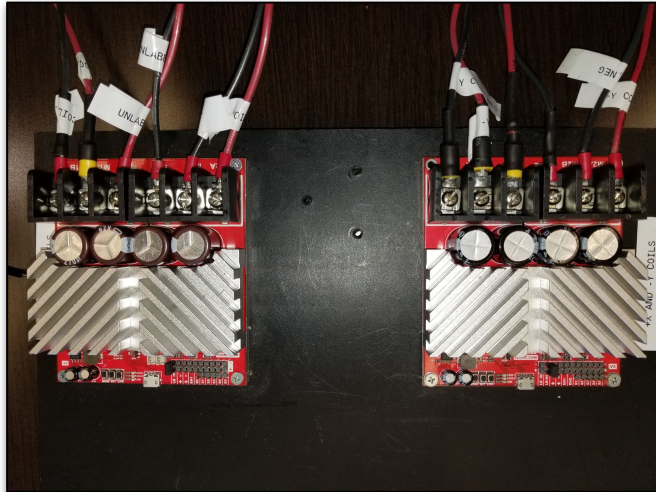
# Hardware Description

**1. Arduino receives instructions from GUI via USB-C**



**Fig 8.** Arduino (top) and motor controllers (bottom)

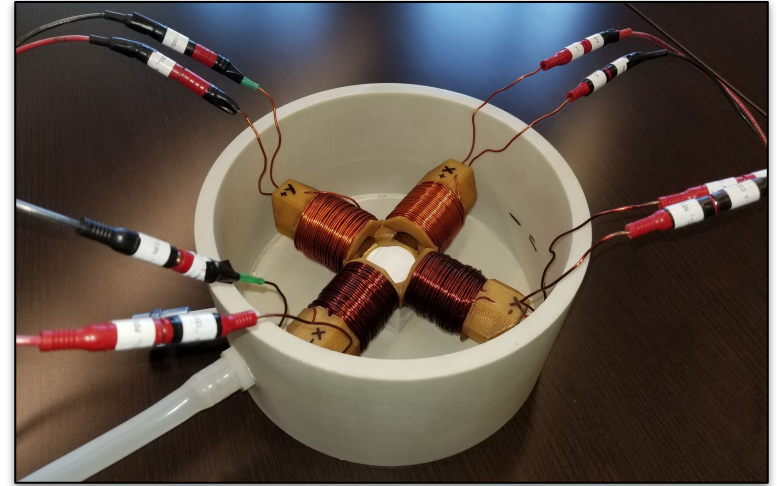
**2. Arduino sends commands to motor controllers**



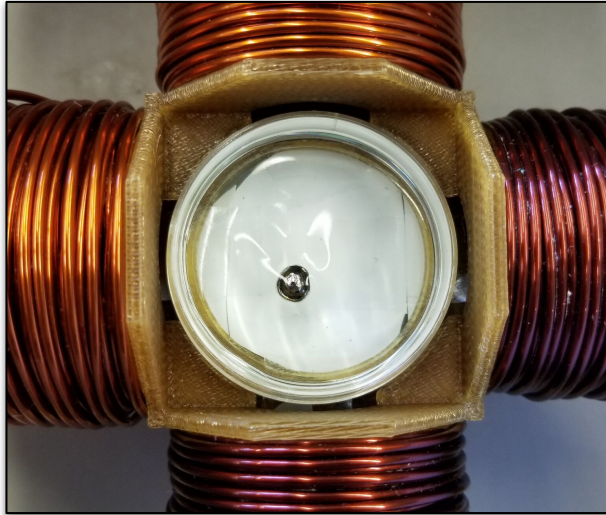
**Fig 9.** Motor controllers and solenoid connections

# Hardware Description

**3. Motor controllers run current through connected solenoid coils**



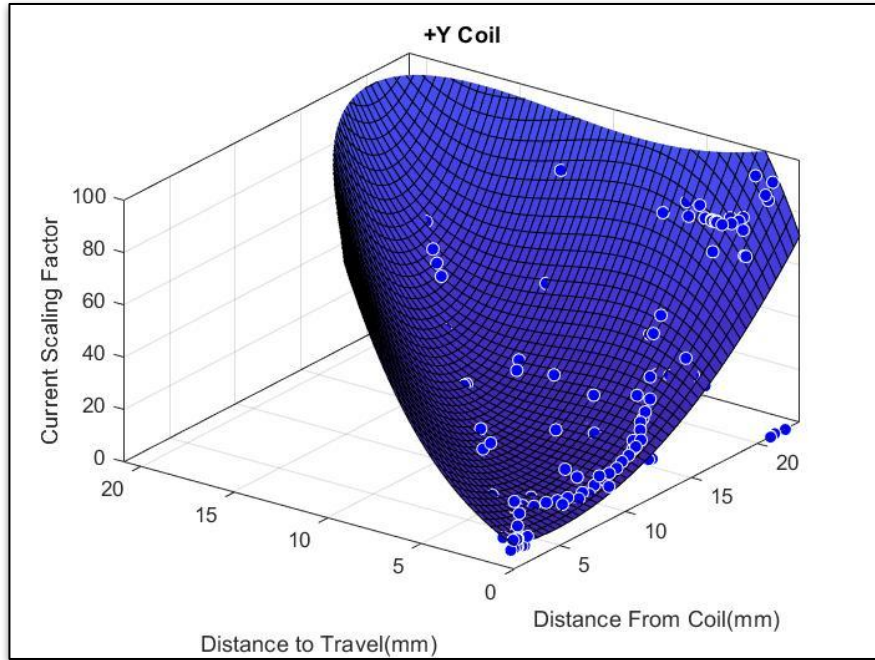
**Fig 10.** Four coil array with solenoid connections placed within fluid housing



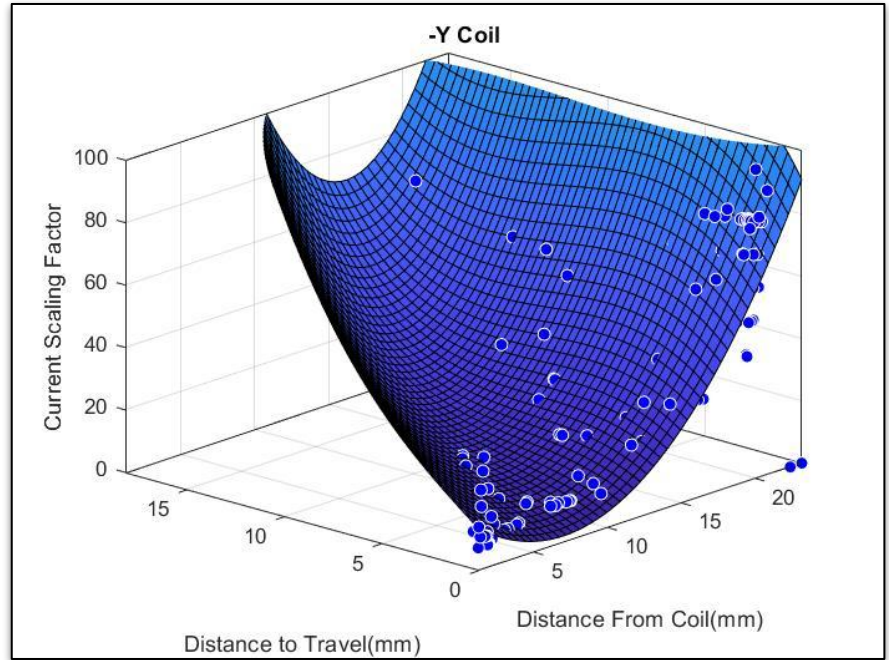
**4. Induced magnetic fields translate permanent magnets**

**Fig 11.** Neodymium sphere magnet suspended in a solution with viscosity  $23,000 \text{ m}^2/\text{s}$

# Particle Movement Plots



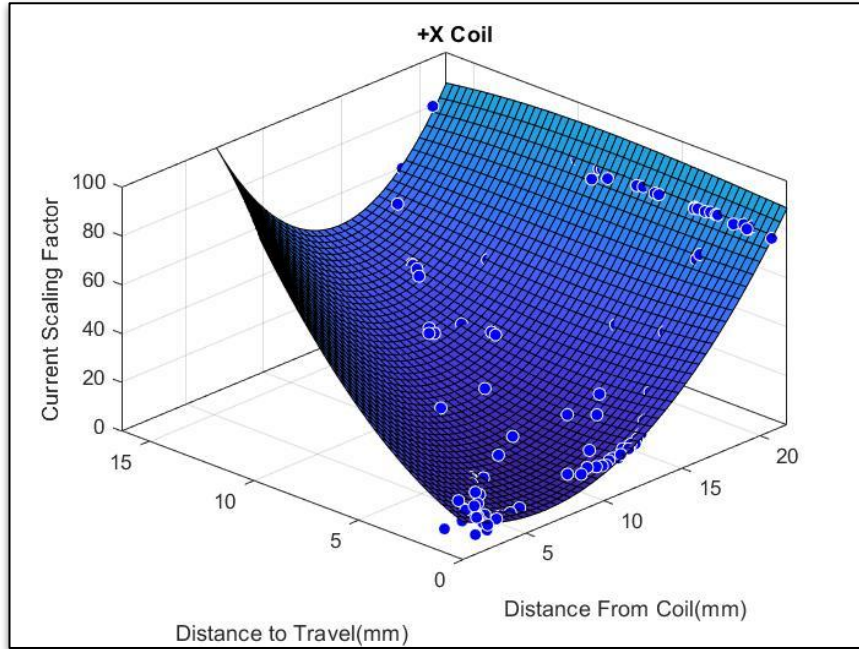
**Fig 12.** Optimum Current Scaling Factor vs Distance to Travel (mm) vs Distance From Coil (mm) for Particle Translation in +Y Direction



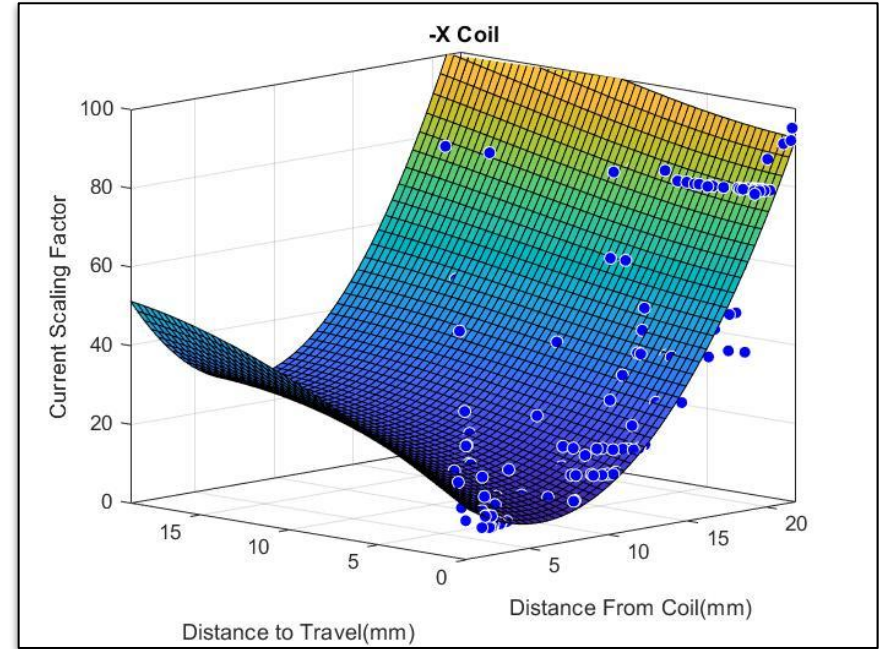
**Fig 13.** Optimum Current Scaling Factor vs Distance to Travel (mm) vs Distance From Coil (mm) for Particle Translation in -Y Direction



# Particle Movement Plots

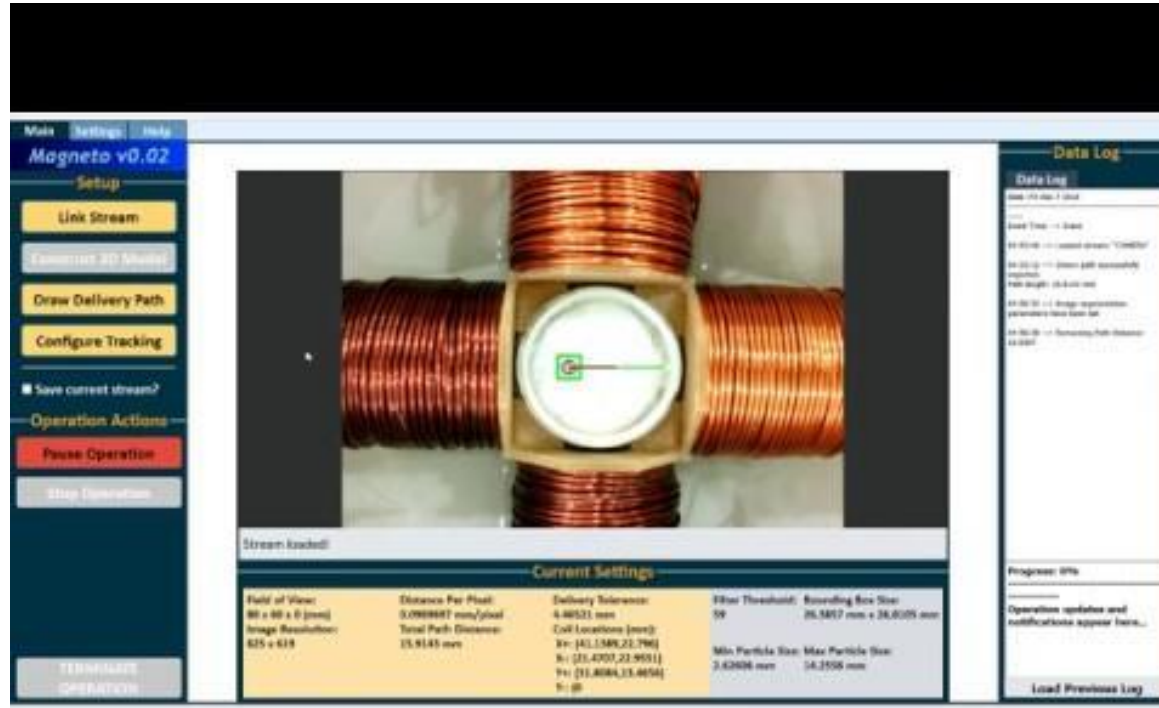


**Fig 14.** Optimum Current Scaling Factor vs Distance to Travel (mm) vs Distance From Coil (mm) for Particle Translation in +X Direction



**Fig 15.** Optimum Current Scaling Factor vs Distance to Travel (mm) vs Distance From Coil (mm) for Particle Translation in -X Direction

# Prototype Demonstration



The screenshot displays the Magneto v0.02 software interface. The central window shows a 3D model of a coil assembly with a white cylindrical component in the center. The interface includes a left sidebar with navigation and control buttons, a central data panel, and a right sidebar with a data log.

**Left Sidebar:**

- Menu Settings Help
- Magneto v0.02
- Setup
  - Link Stream
  - Download 3D Model
  - Draw Delivery Path
  - Configure Tracking
- Save current stream?
- Operation Actions
  - Pause Operation
  - Stop Demonstration
- TERMINATE OPERATION

**Central Panel:**

Stream loaded:

Current Settings

Field of View:	Distance Per Pixel:	Delivery Tolerance:	Filter Threshold:	Recording Box Size:
80 x 60 x 0 (mm)	0.000007 mm/pixel	4.46521 mm	50	25.5417 mm x 28.4205 mm
Image Resolution:	Total Path Distance:	Coil Locations (mm):	Min Particle Size:	Max Particle Size:
625 x 618	15.9145 mm	X: [41.1389,22.796] Y: [21.4707,22.4651] Z: [11.4084,13.4654] N: 0	3.62006 mm	14.2558 mm

**Right Sidebar:**

Data Log

Time: 2014-07-17 10:00:00

2014-07-17 10:00:00 --> Load stream "100000"

2014-07-17 10:00:00 --> Draw path successfully completed

2014-07-17 10:00:00 --> Draw operation successfully finished

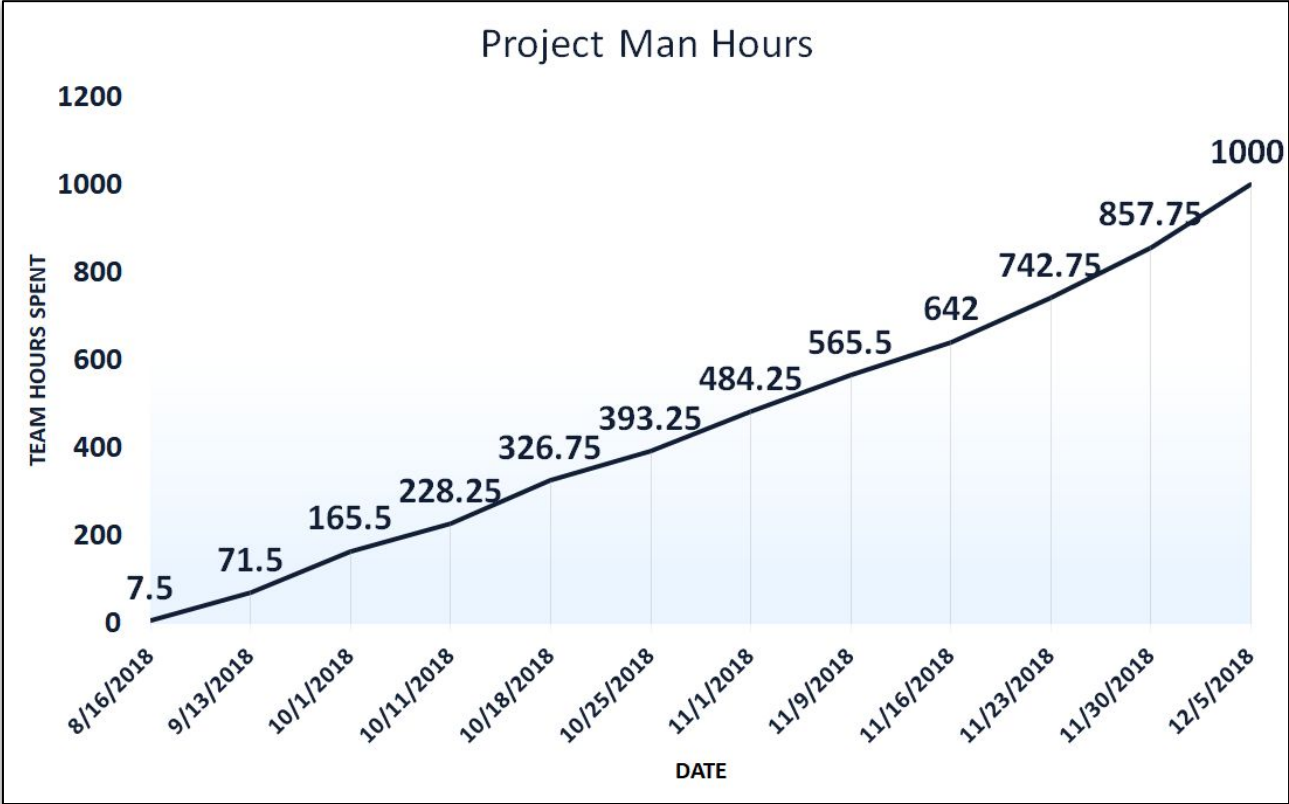
2014-07-17 10:00:00 --> Recording Path Distance: 15.9145

Progress: 0%

Operations updates and notifications appear here...

Load Previous Log

# Man-Hours to Date

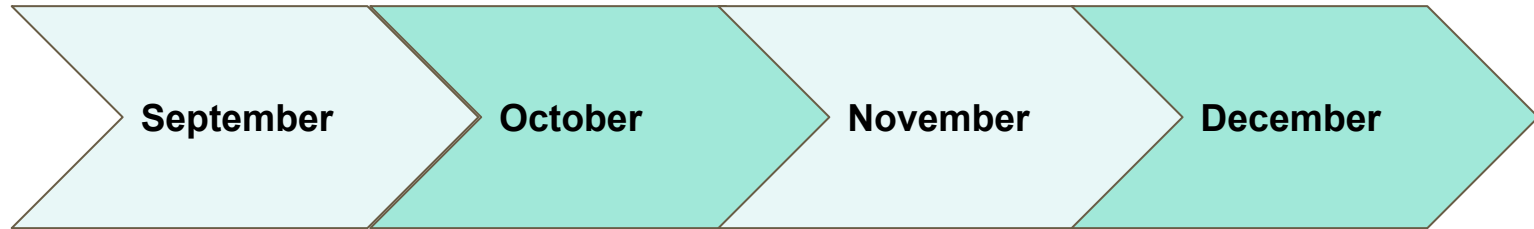


# Budget

Item	Quantity	Cost
Qt Development Environment	4	\$0
Microsoft Visual Studio 2017 Community	4	\$0
OpenCV	4	\$0
Sourcetree Version Control (AWS)	4	\$0
K&J Neodymium Magnets	5	\$7.50
Arduino MEGA 2560 Microcontroller	1	\$10
Roboclaw 2x60A Motor Controller *	2	\$0
Ipevio Ziggsi USB Webcam *	1	\$0
4 Coil Array System *	1	\$0
<b>Total Cost</b>		<b>\$17.50</b>

\* Supplied by Weinberg Medical Physics, LLC

# Semester 1- Timeline



## Planning

- Identify sponsor Requirements
- Determine design of project

## Software Design

- IM: particle detection
- GUI V1 Design
- AWS git repository set up
- Website for progress updates
- Control Module

## Hardware Setup

- Hardware obtained
- Configured hardware communication with GUI

## Finalization

- Integration with GUI V2
- Conduct tests with hardware to obtain data for particle translation

# Semester 2

January

February

March

April

May

## Redesign

- Refine path input algorithm
- Migrate project to GitHub to improve collaboration with WMP

## Software- Hardware

- 2D → 3D
- Obtain MRI system from WMP
- Establish communication between GUI and new system

## Finalization

- Testing and Validation
- Sponsor and academic Requirements

# References

- [1] B. Shapiro, S. Kulkarni, A. Nacev, S. Muro, P. Y. Stepanov, and I. N. Weinberg, “Open Challenges in Magnetic Drug Targeting,” *Wiley Interdiscip Rev Nanomed Nanobiotechnol*, vol. 7, no. 3, pp. 446–457, May 2015.
- [2] E. Y. Yu et al., “Magnetic Particle Imaging: A Novel in Vivo Imaging Platform for Cancer Detection,” *Nano Lett.*, vol. 17, no. 3, pp. 1648–1654, Mar. 2017.
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- [4] J. D. Opfermann et al., “Semi-autonomous electrosurgery for tumor resection using a multi-degree of freedom electrosurgical tool and visual servoing,” in *2017 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, 2017, pp. 3653–3660.
- [5] J. Dong, Y. Shang, K. Inthavong, H.-K. Chan, and J. Tu, “Numerical Comparison of Nasal Aerosol Administration Systems for Efficient Nose-to-Brain Drug Delivery,” *Pharm Res*, vol. 35, no. 1, p. 5, Dec. 2017.
- [6] X. A. Si and J. Xi, “Modeling and Simulations of Olfactory Drug Delivery with Passive and Active Controls of Nasally Inhaled Pharmaceutical Aerosols,” *J Vis Exp*, no. 111, May 2016.
- [7] U.S. Department Of Health and Human Services, “Guidance for the Content of Premarket Submissions for Software Contained in Medical Devices,” May 2005.
- [8] U.S Department Of Health and Human Services, “Software as a Medical Device (SAMd): Clinical Evaluation - Guidance for Industry and Food and Drug Administration Staff,” June 2017.
- [9] U.S. Department Of Health and Human Services, “General Principles of Software Validation; Final Guidance for Industry and FDA Staff,” January 2002.
- [10] A. Nacev et al., “Towards Control of Magnetic Fluids in Patients: Directing Therapeutic Nanoparticles to Disease Locations,” *IEEE Control Systems Magazine*, vol. 32, no. 3, pp. 32–74, Jun. 2012.