MAGNETO

Control Interface for Autonomous Robotic Brain Surgery using Magnetically Stimulated Particles

Weinberg Medical Physics Sponsors
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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

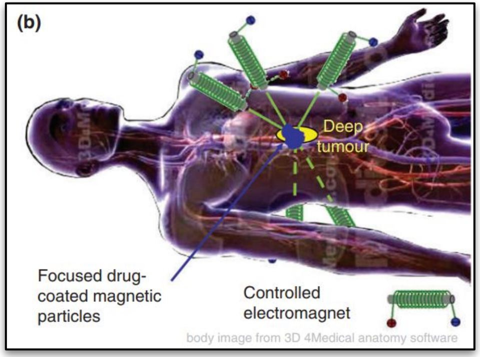


Fig 1. Using magnetic fields to focus therapy to a deep tumour[1]

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

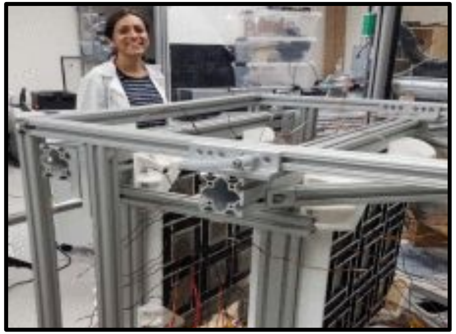


Fig 2. Electropermanent bi-planar MRI under construction

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

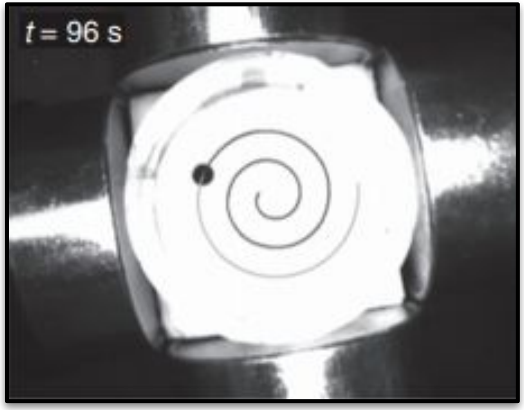


Fig 4. Ferrofluid droplet moving along a spiral path using magnetic coils[10]

Graphical User Interface:

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

Team

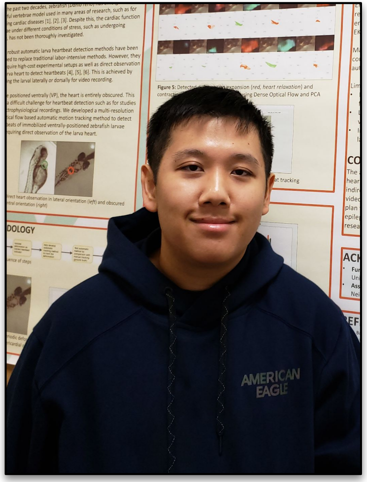
Elizabeth

Testing & Evaluation
Front-end Design
Back-end Design

Minh

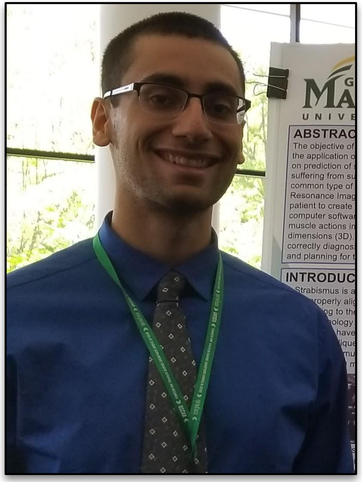
System Design
Back-end Design
Testing & Evaluation

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

<u>GUI</u>

- 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

Modular Hardware Connection

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

Structural Division of Function

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

Safe System Operation

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

Platform Independent

- Software performance should be consistent across major operating systems

Standards and Codes

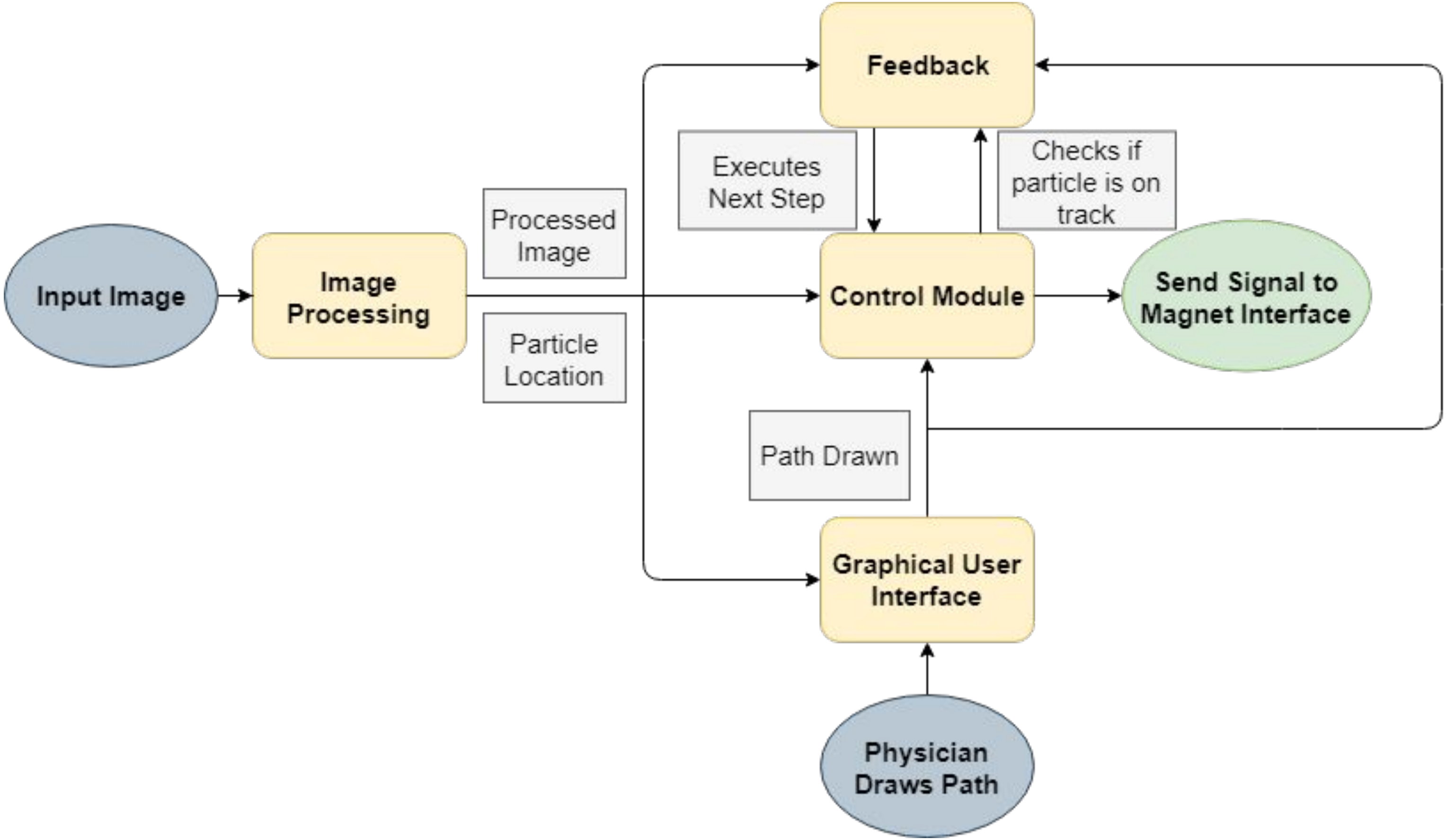
Project will conform with FDA guidelines for medical software devices.

- Guidance for Industry and FDA Staff: Guidance for the Content of Premarket Submissions for Software Contained in Medical Devices (2005)

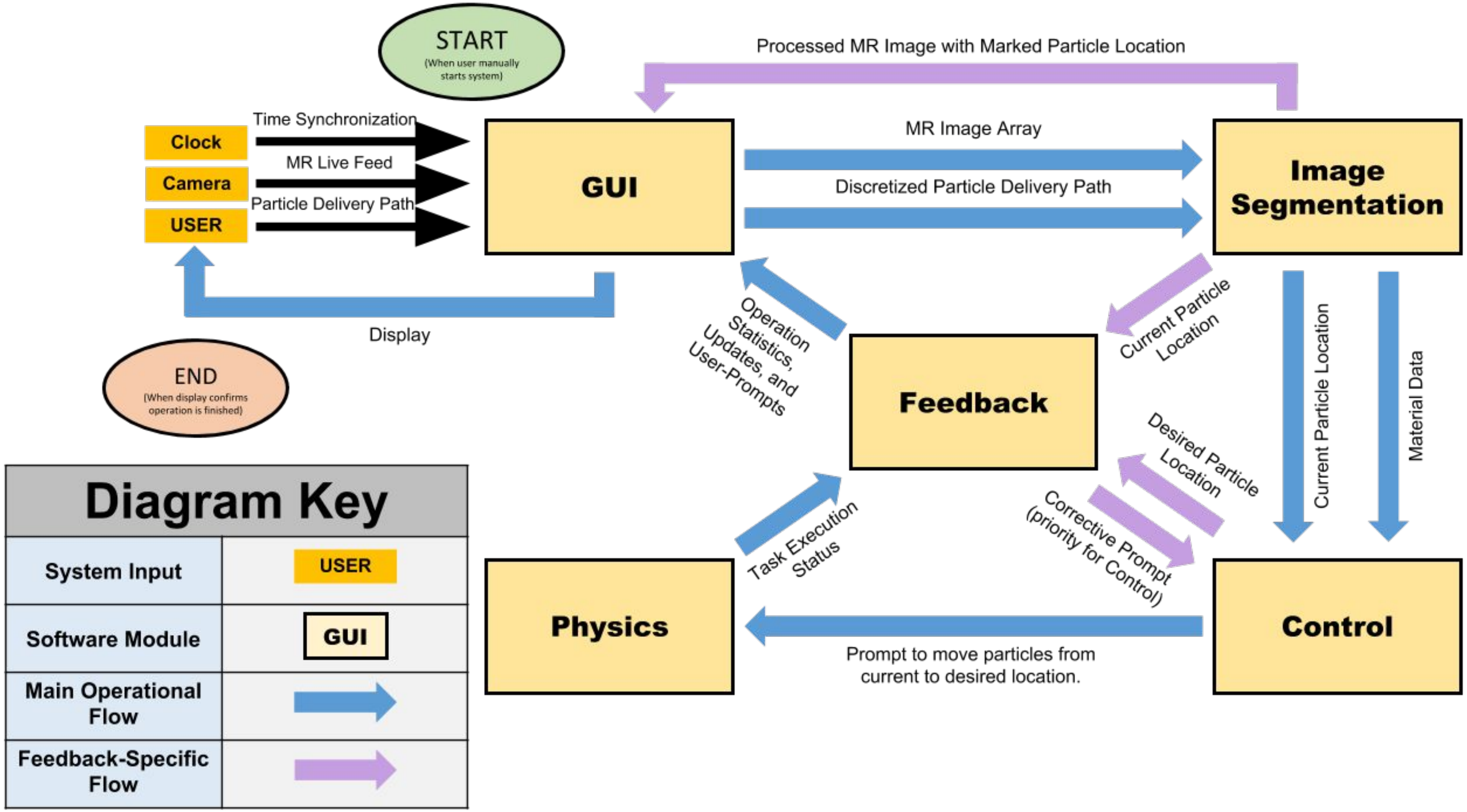
- Software as a Medical Device (SaMD): Clinical Evaluation Guidance for Industry and Food and Drug Administration Staff (2017)

- General Principles of Software Validation; Final Guidance for Industry and FDA Staff Document issued (2002)

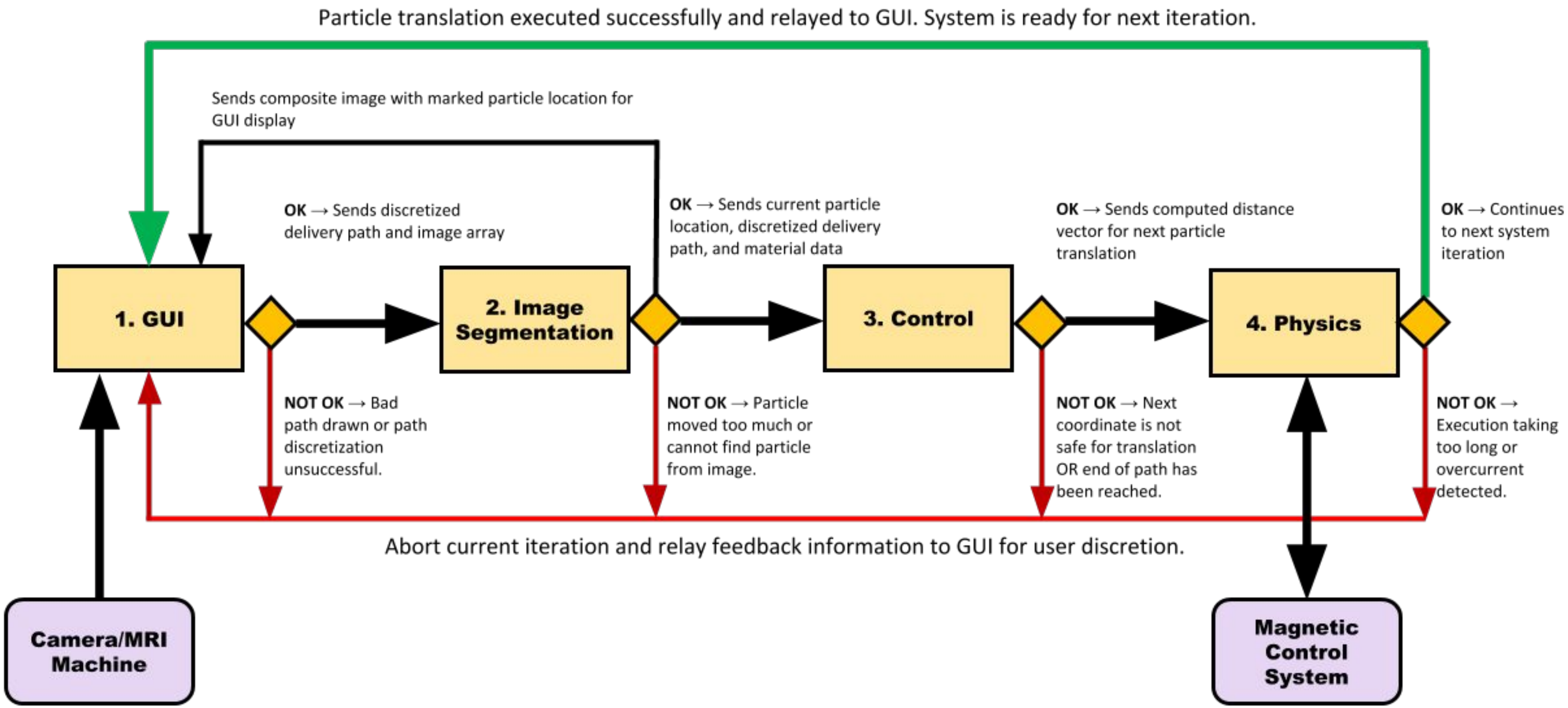
Approach 1: Control Centric Design



Approach 2: Feedback-Centric Design



Approach 3: Linear Operation with Regular Safety Checkpoints



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	4	5	2	3	16
Feedback Centric Design	3	4	4	2	5	18
Linear Operation Design	5	2	5	5	5	22

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	5	4	5	5	23
JAVA	5	3	3	3	3	17
PYTHON	3	5	4	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	5	5	3	4	21
Kalman Filter	3	2	3	3	5	16
Template Matching	2	5	4	5	3	19
Meanshift Tracking	5	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	5	3	4	5	5	22
wxWidgets	4	5	3	4	4	20
FLTK	3	5	2	3	2	15
GTK+	3	5	3	2	2	15

GUI Description - Main Window

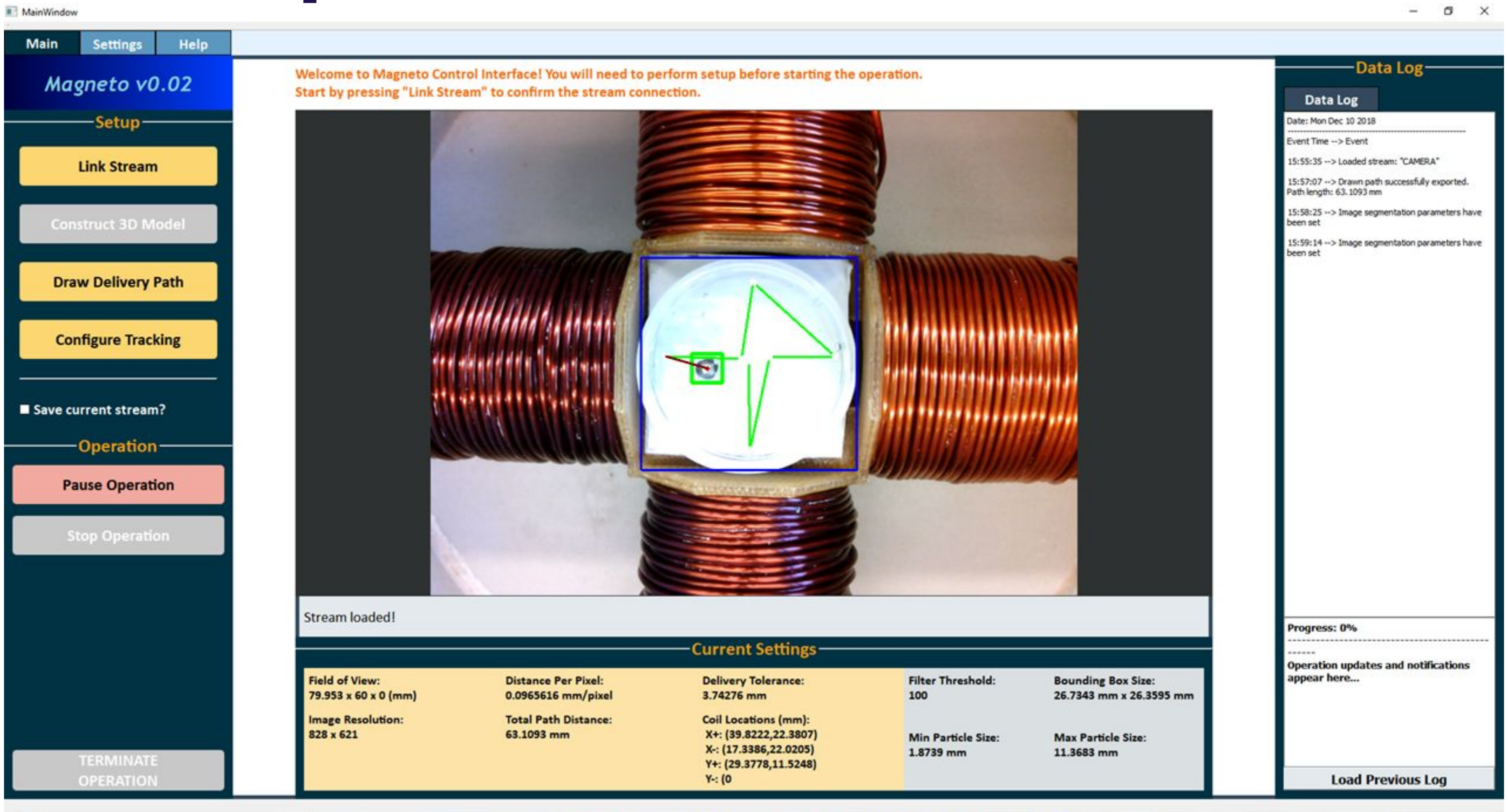


Fig 5. GUI Main Window

GUI Description - Creating Delivery Path

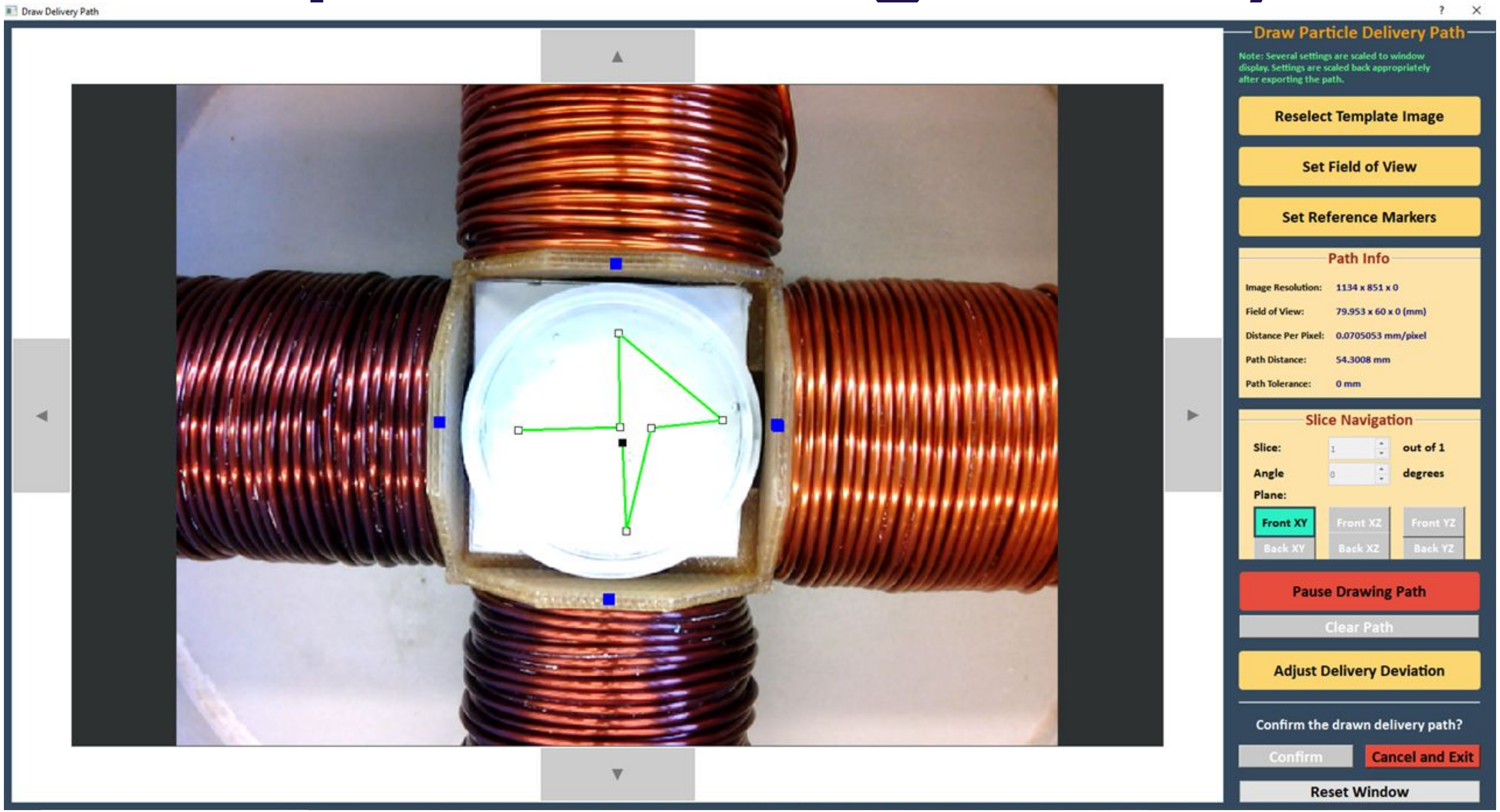


Fig 6. GUI Pathing Window

GUI Description - Tracking Configuration

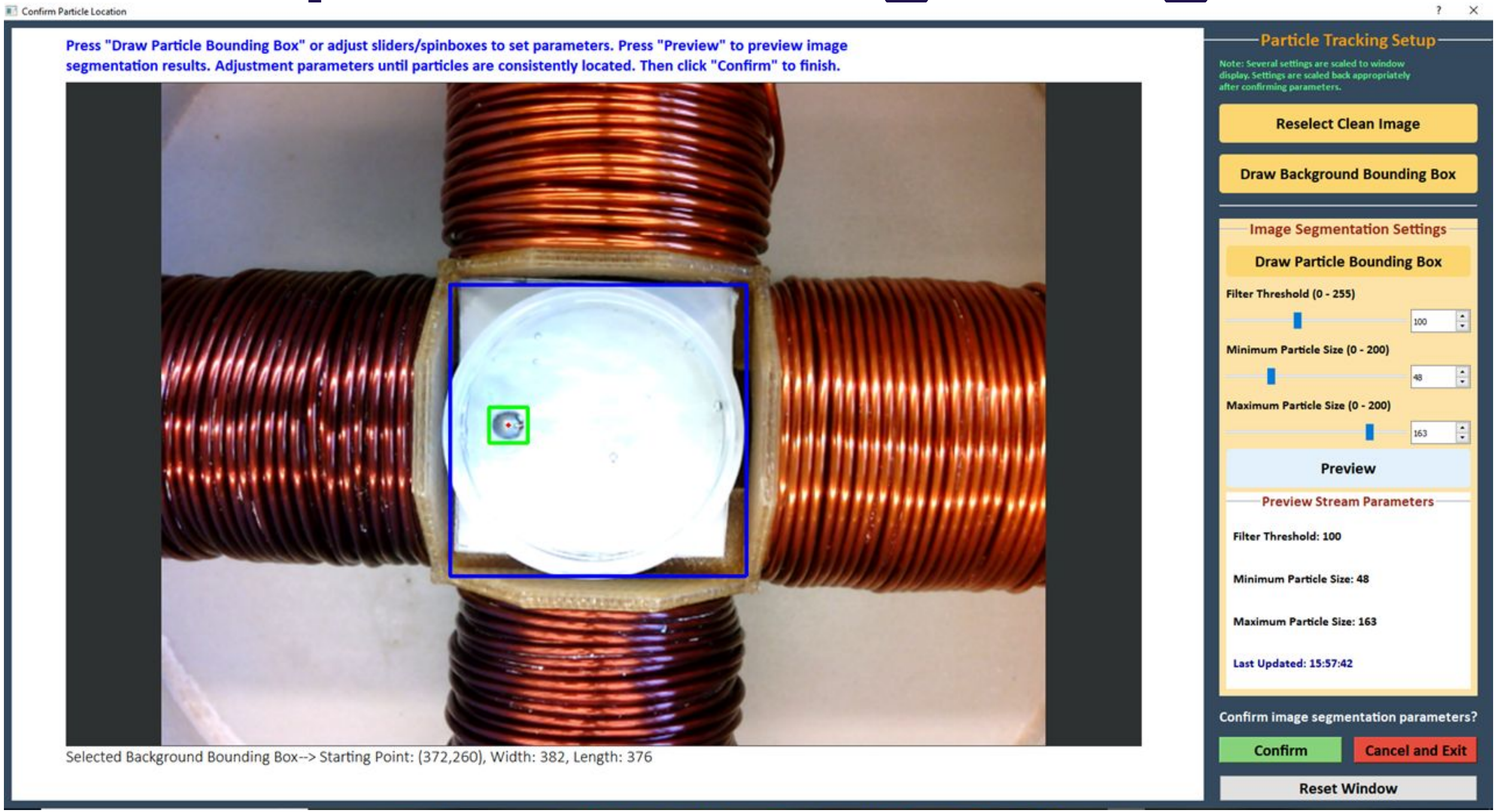


Fig 7. GUI Image Segmentation Configuration Window

Hardware Description

1. Arduino receives instructions from GUI via USB-C

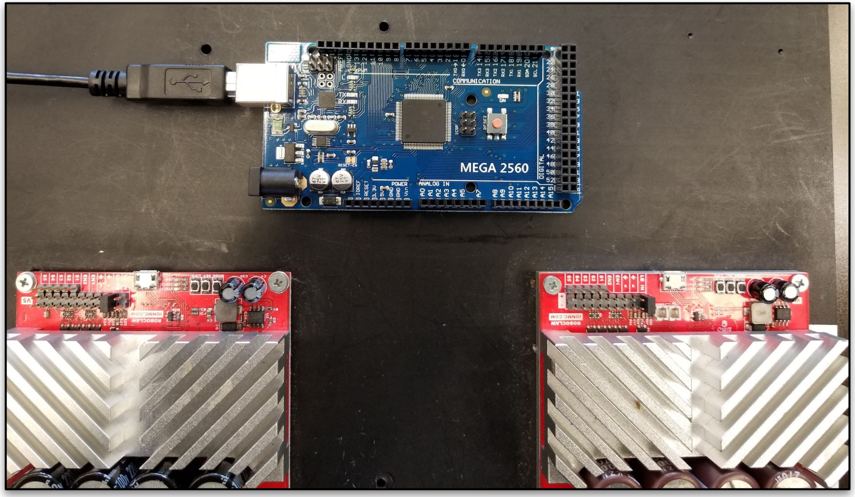


Fig 8. Arduino (top) and motor controllers (bottom)

2. Arduino sends commands to motor controllers

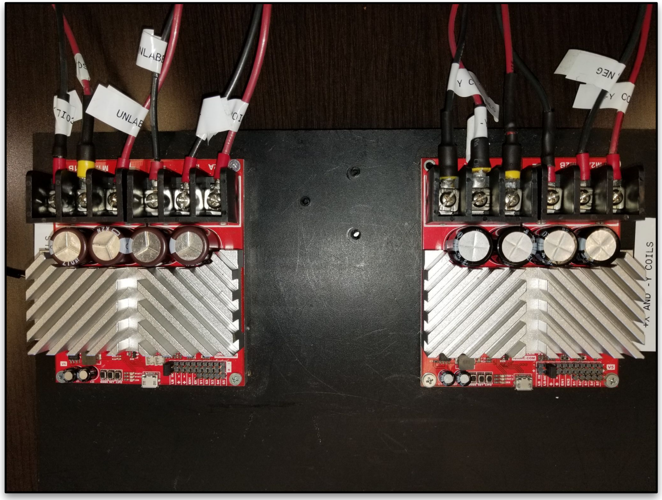


Fig 9. Motor controllers and solenoid connections

Hardware Description

3. Motor controllers run current through connected solenoid coils

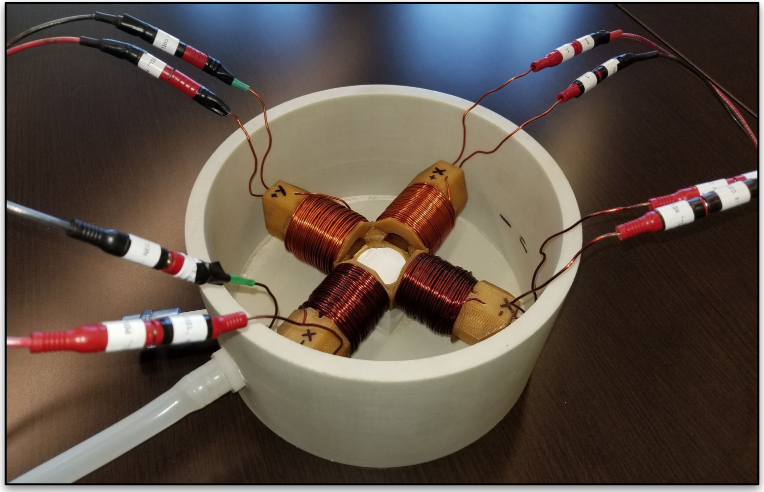


Fig 10. Four coil array with solenoid connections placed within fluid housing

4. Induced magnetic fields translate permanent magnets

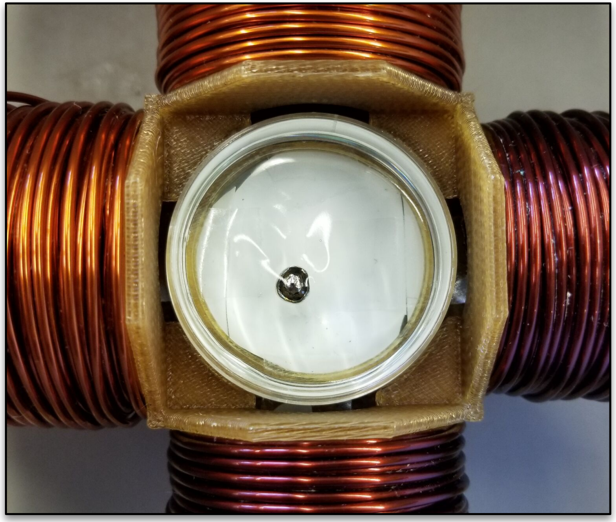
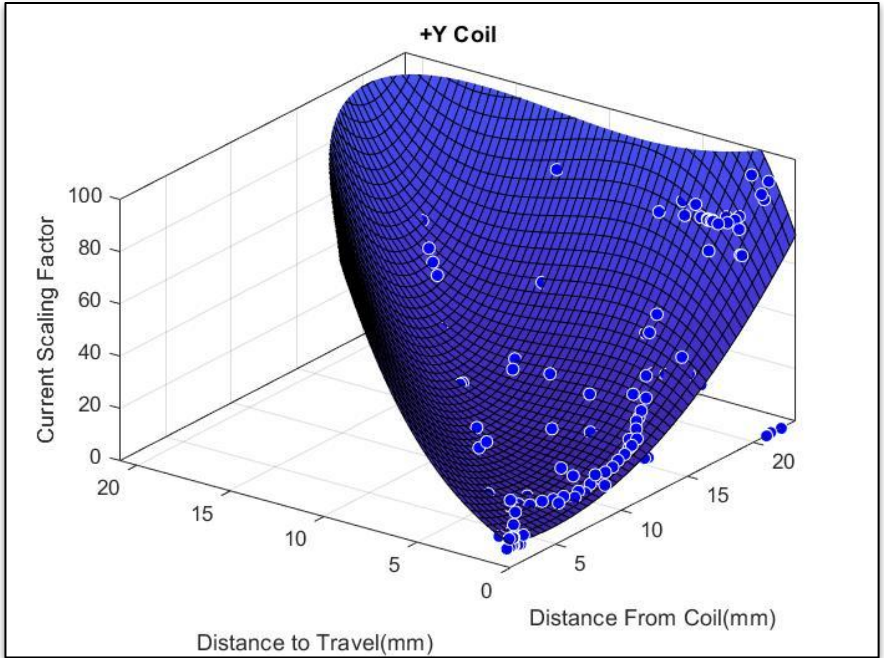


Fig 11. Neodymium sphere magnet suspended in a solution with viscosity 23,000 m^2/s

Particle Movement Plots



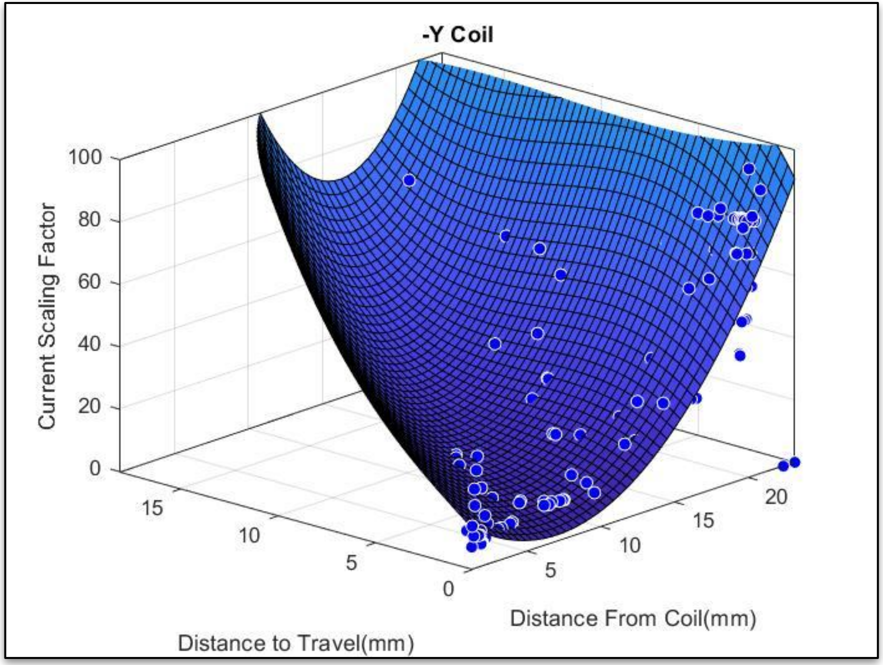


Fig 12. Optimum Current Scaling Factor vs Distance to Travel (mm) vs Distance From Coil (mm) for Particle Translation in +Y Direction

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

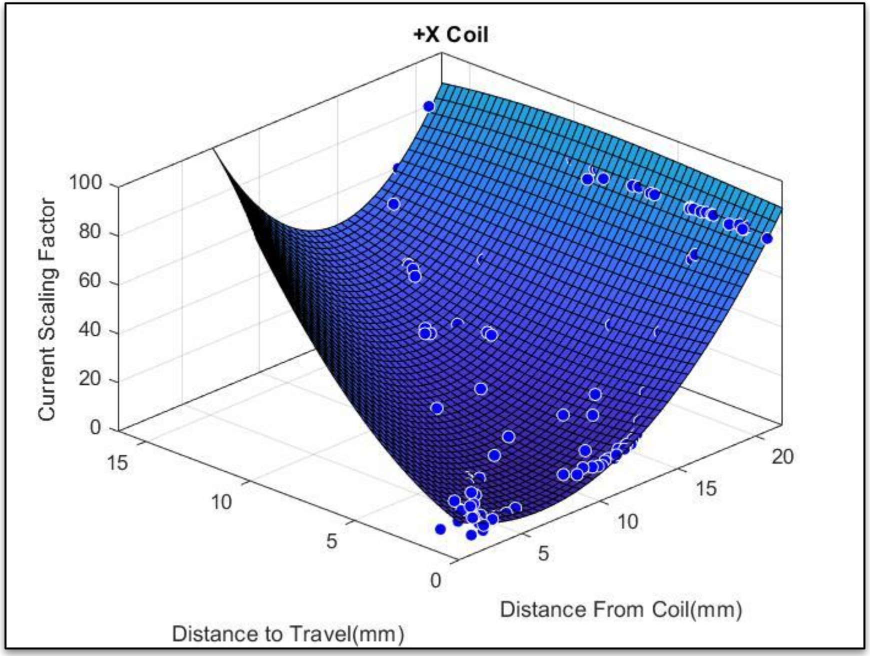


Fig 14. Optimum Current Scaling Factor vs Distance to Travel (mm) vs Distance From Coil (mm) for Particle Translation in +X Direction

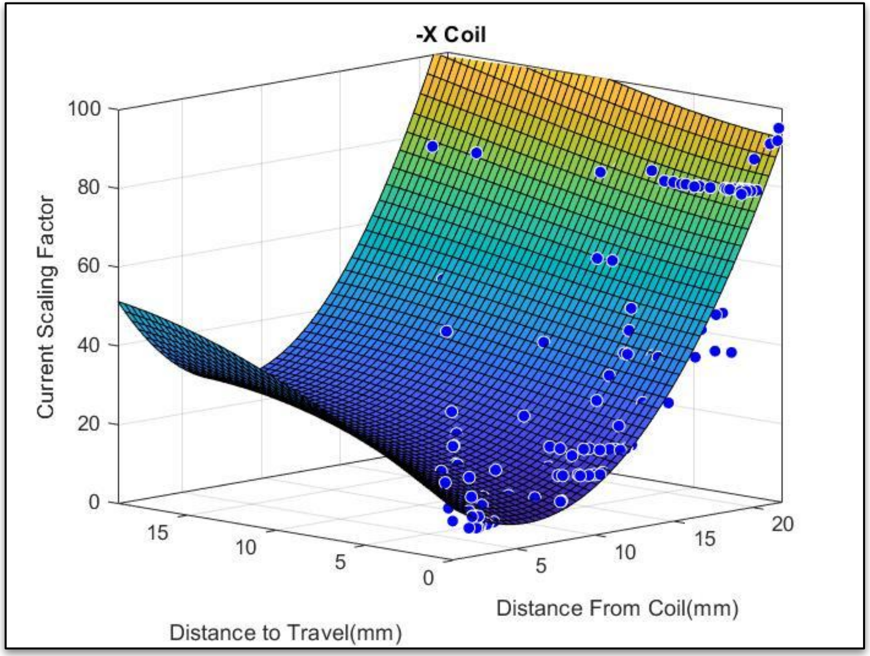
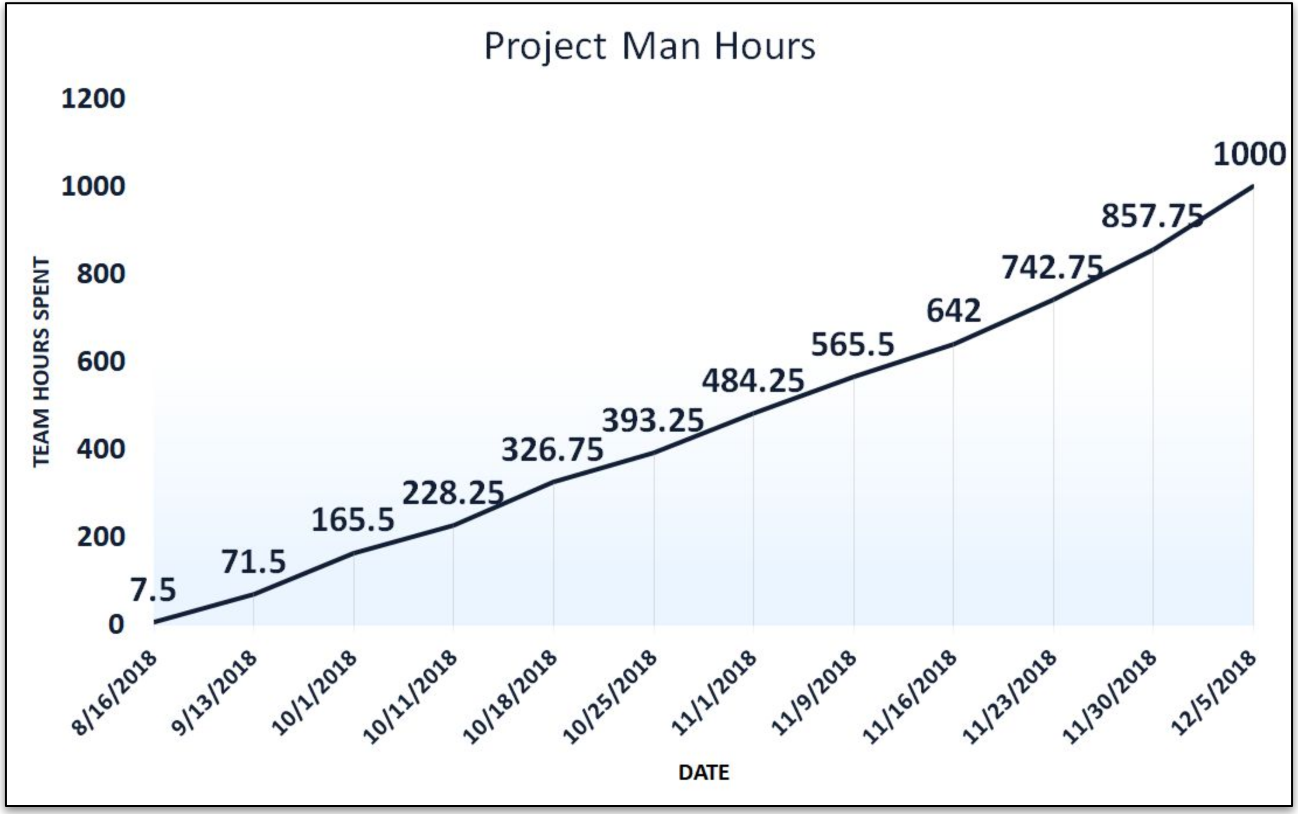


Fig 15. Optimum Current Scaling Factor vs Distance to Travel (mm) vs Distance From Coil (mm) for Particle Translation in -X Direction

Prototype Demonstration

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 Ziggi USB Webcam *	1	$0
4 Coil Array System *	1	$0
Total Cost		$17.50

* Supplied by Weinberg Medical Physics, LLC

Semester 1- Timeline

September	October	November	December
Planning	**Software Design**	**Hardware Setup**	**Finalization**
• Identify sponsor Requirements • Determine design of project	• IM: particle detection • GUI V1 Design • AWS git repository set up • Website for progress updates • Control Module	• Hardware obtained • Configured hardware communication with GUI	• 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

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[3] S. Jafari et al., “Magnetic drilling enhances intra-nasal transport of particles into rodent brain,” Journal of Magnetism and Magnetic Materials, vol. 469, pp. 302–305, Jan. 2019.

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[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.

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[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.