GEORGE MASON UNIVERSITY
Volgenau School of Engineering

Magneto Control Interface

Team Nson – Weinberg Medical Physics, LLC

GEORGE MASON UNIVERSITY VOLGENAU SCHOOL OF ENGINEERING M 2019

Objectives & Benefits

Background:
- Magnetic Particle Delivery is the in vivo transport of nanocarriers via external magnets. Although it is a promising method for the noninvasive delivery of therapeutic payloads, many limitations (e.g. physiological barriers, magnetic field attenuation, impracticality of manual control) are holding the technology back from clinical implementation. Weinberg Medical Physics (WMP) is constructing an MRI-guided magnetic control system (MCS) to overcome these limitations.

Purpose:
- Design and build a precursor software control system for WMP's future MCS. The software will control WMP's 4 coil array MCS as a test platform.
- Improve control of the 4 coil MCS by automating and increasing accuracy of its particle translation.

Significance
- MAGNETO lays the foundation for automation behavior, control flow, and user interaction for future MCS.

Technical Requirements & Engineering Characteristics

Graphical User Interface (GUI)

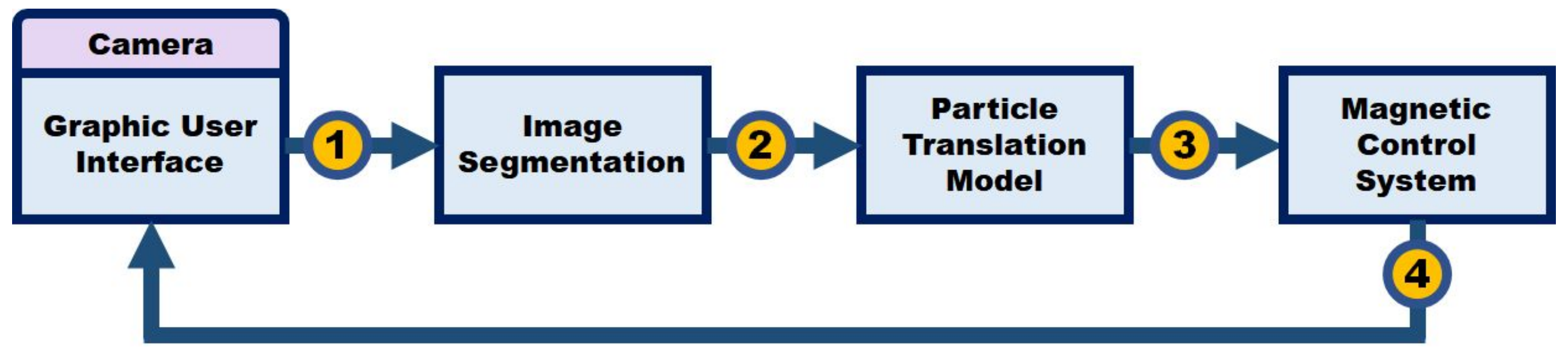
- Optical image streaming at > 30 frames per second
- Consistent detection of objects-of-interest against various lighting
- 2D user path drawing and processing (e.g. discretization, loading/saving)
- Particle delivery automation protocol (e.g. sequence of events, safety features)
- Real-time data collection (particle translation fields, UI high-level interactions)

Particle Control

- Bidirectional hardware communication with GUI
- Operating system independent control scheme
- Simultaneous control of multiple hardware components
- Consistent translation across user-defined path
- Consistent translation model output given identical state inputs

Figure 1. Particle translation concept.

System Operation Overview

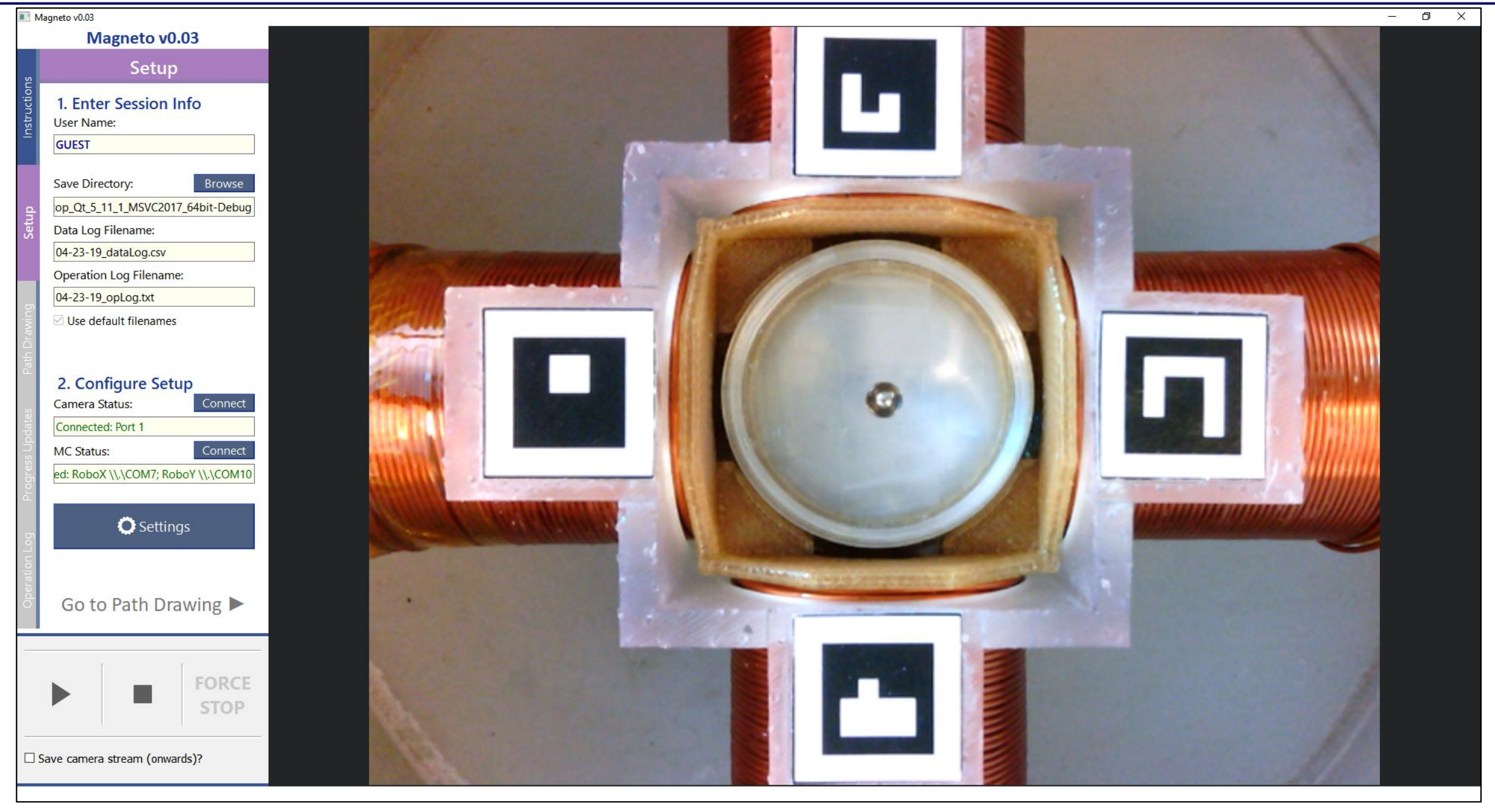

Camera

Graphical User Interface → 1 → **Image Segmentation** → 2 → **Particle Translation Model** → 3 → **Magnetic Control System** → 4 → back to **Graphical User Interface**

Figure 2. High-level diagram of system operation. After the user performs basic setup, the system will run this cycle autonomously until delivery completion or user discretion.

1. **Graphical User Interface (GUI)** continuously receives and streams camera frames. A system clock controls the frequency of particle translation. On every clock timeout, the GUI first checks that all other system components are ready for translation and then signals to the Image Segmentation module to provide the current particle location.
2. **Image Segmentation** continuously tracks the particle by processing streamed camera images. To prepare for translation, the current detected particle location is acquired and converted to physical coordinates. A data check using this location is performed to assess delivery progress along the path. If no system errors are detected, location parameters are passed into the Particle Translation Model.
3. **Particle Translation Model** uses the location parameters to calculate the necessary hardware instructions to perform the desired translation. Using information from previous translations, feedback features are applied to both augment and regulate the model's outputs.
4. **4 Coil Array Magnetic Control System** executes hardware instructions to run current through connected solenoid coils using motor controllers. Different currents can be applied simultaneously to multiple coils. After successful execution, motor controller status is set as available for the next translation.

Graphical User Interface


Magneto v0.03

Magneto v0.03

Setup

1. Enter Session Info

User Name: GUEST

Save Directory: op_Qt_5_11_1_MSVC2017_64bit-Debug

Data Log Filename: 04-23-19_dataLog.csv

Operation Log Filename: 04-23-19_opLog.txt

☑ Use default filenames

2. Configure Setup

Camera Status: Connected: Port 1

MC Status: ed: RoboX \\.\COM7; RoboY \\.\COM10

☐ Save camera stream (onwards)?

Figure 3. GUI design layout consisting of a space-efficient 5-tab widget and large camera viewport. Operation control panel is located in the bottom-left.

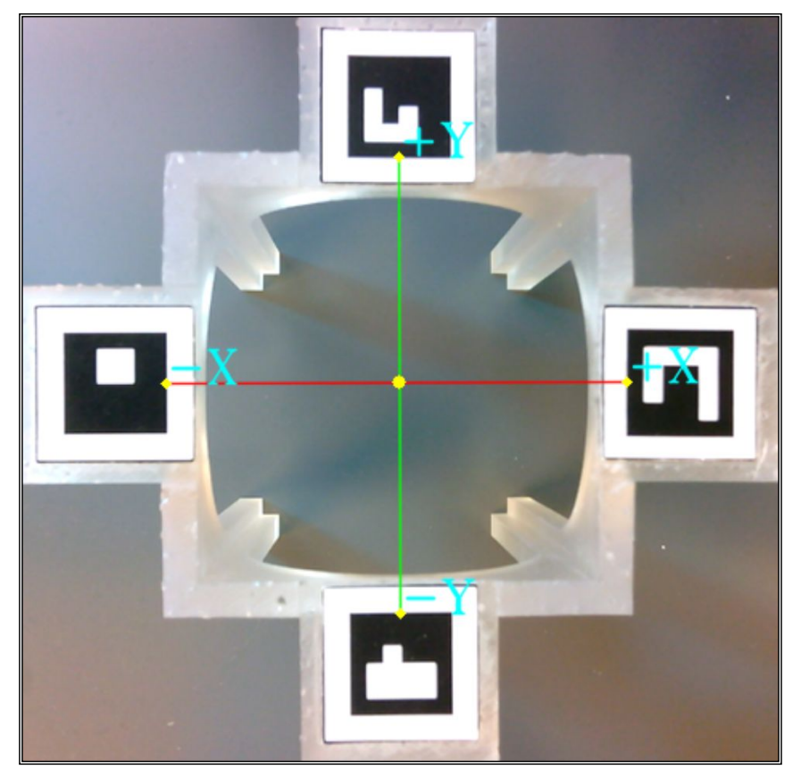


Figure 4. ArUco marker platform for coordinate system calibration.

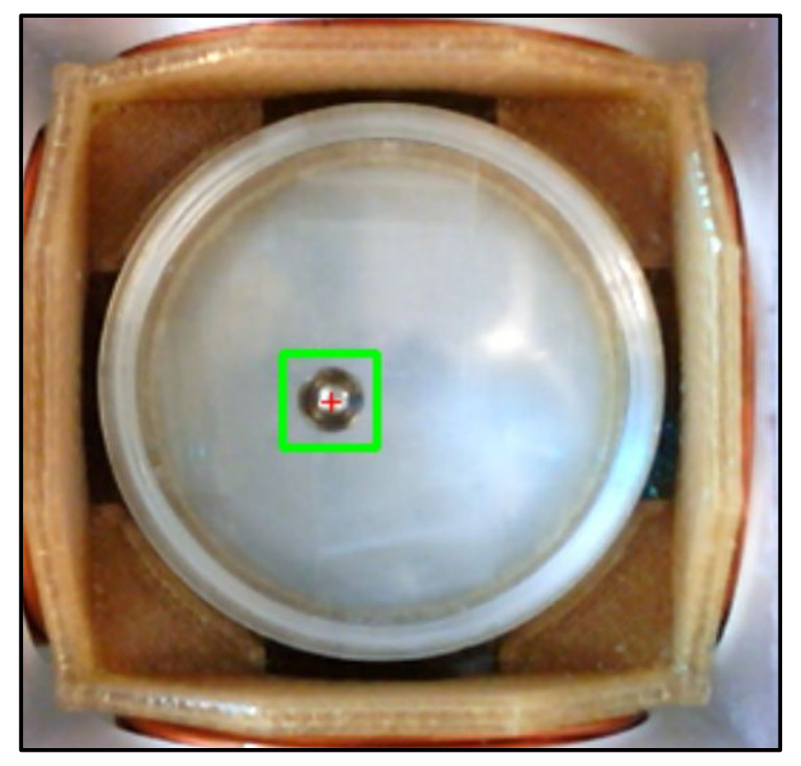


Figure 5. Particle detection via modified image subtraction approach.

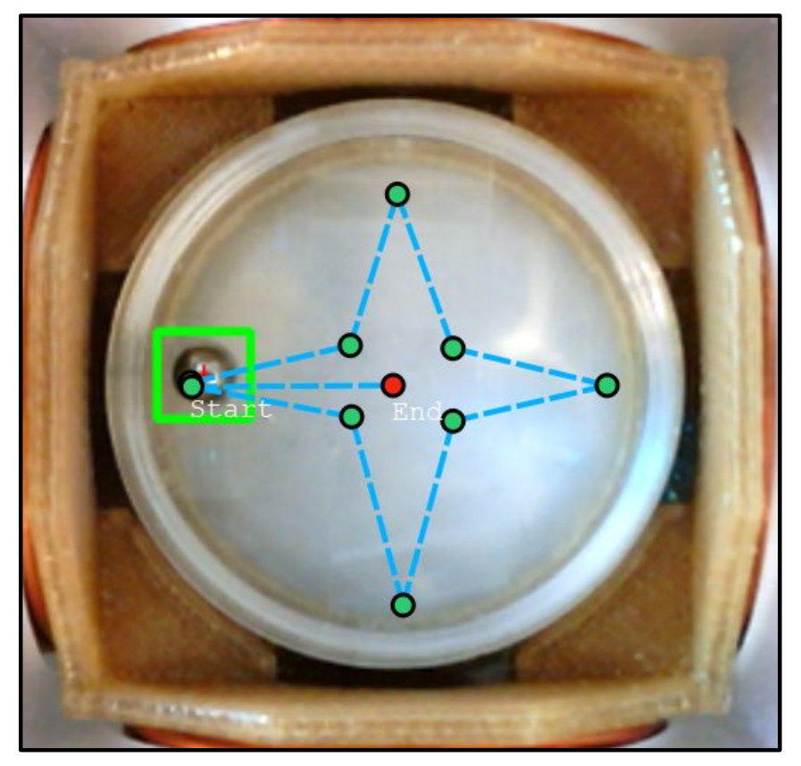


Figure 6. Delivery path drawn using manipulatable graphics scene markers.

Technical Approach & Alternative Designs

Translation Model

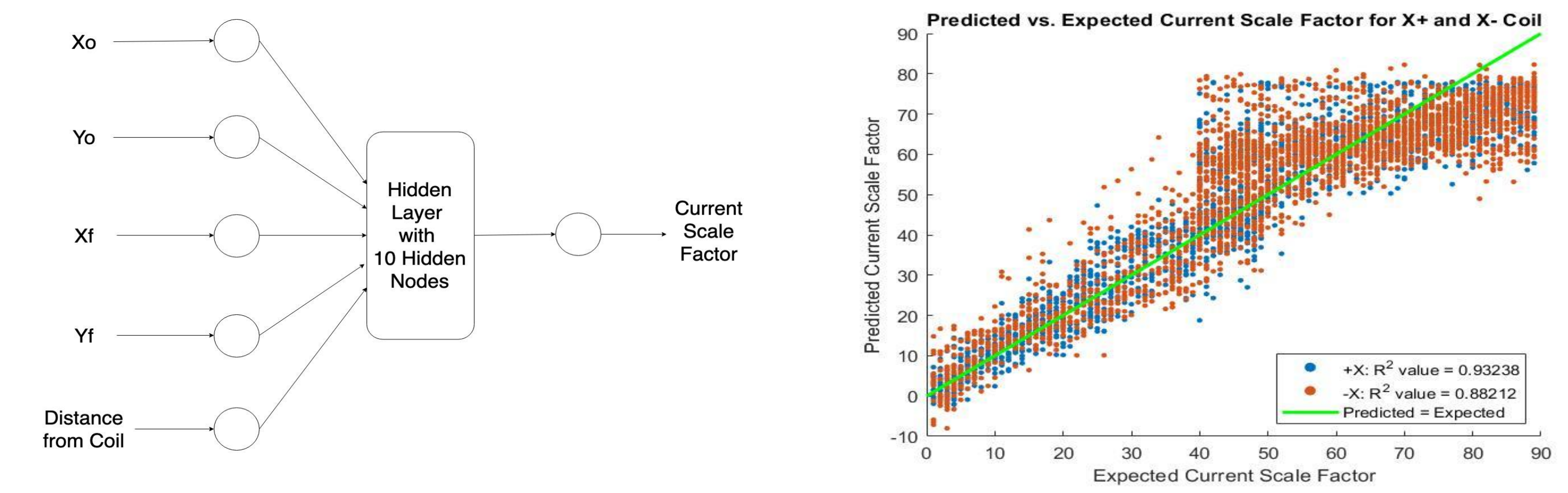


Figure 7. Single coil neural network architecture (left) and resulting training regression plot (right). Inputs are: initial and final particle coordinates and distance from coil; output is current scale.

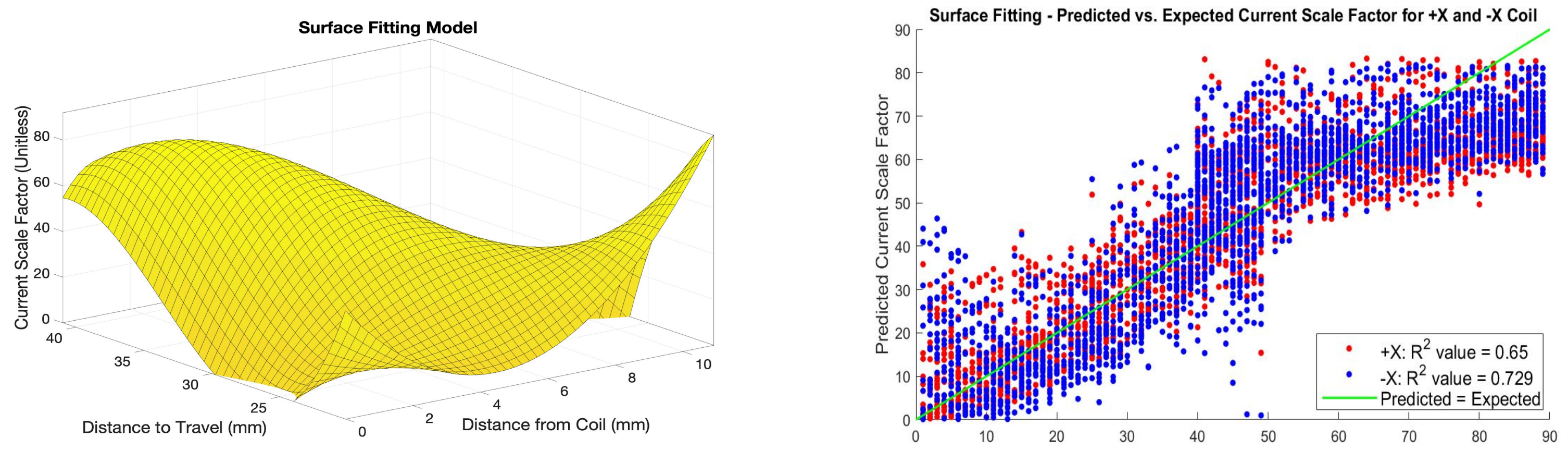


Figure 8. Single coil surface fitting model representation (left) and result training regression plot (right). Inputs are: distance the particle needs to travel and distance from coil; output is current scale.

Hardware Setup

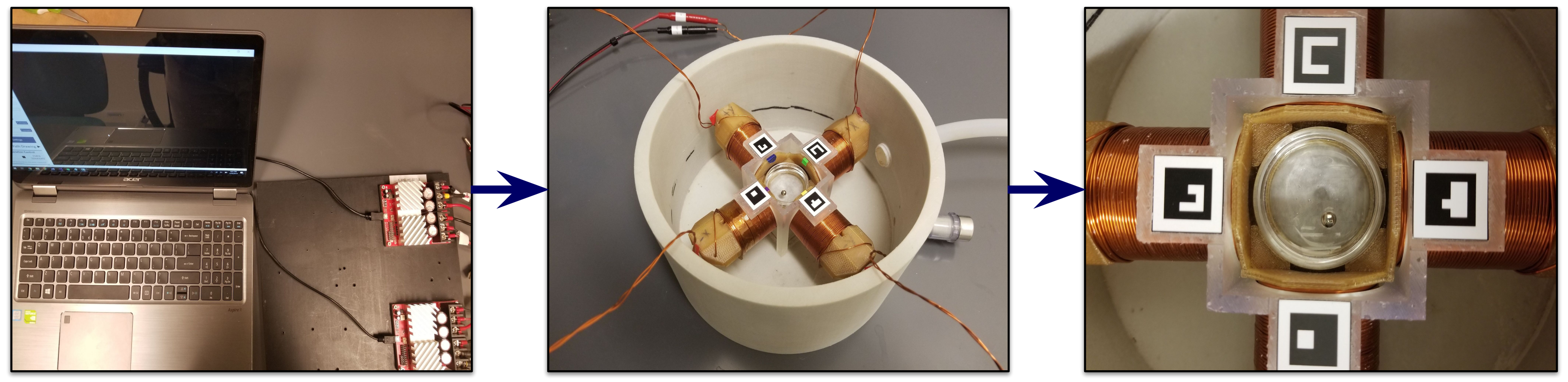


Figure 9. General hardware information flow diagram. GUI sends instructions simultaneously to both motor controllers (left), motor controllers run current through connected solenoid coils (middle), and induced magnetic fields translate permanent magnets (right).

Results & Conclusions

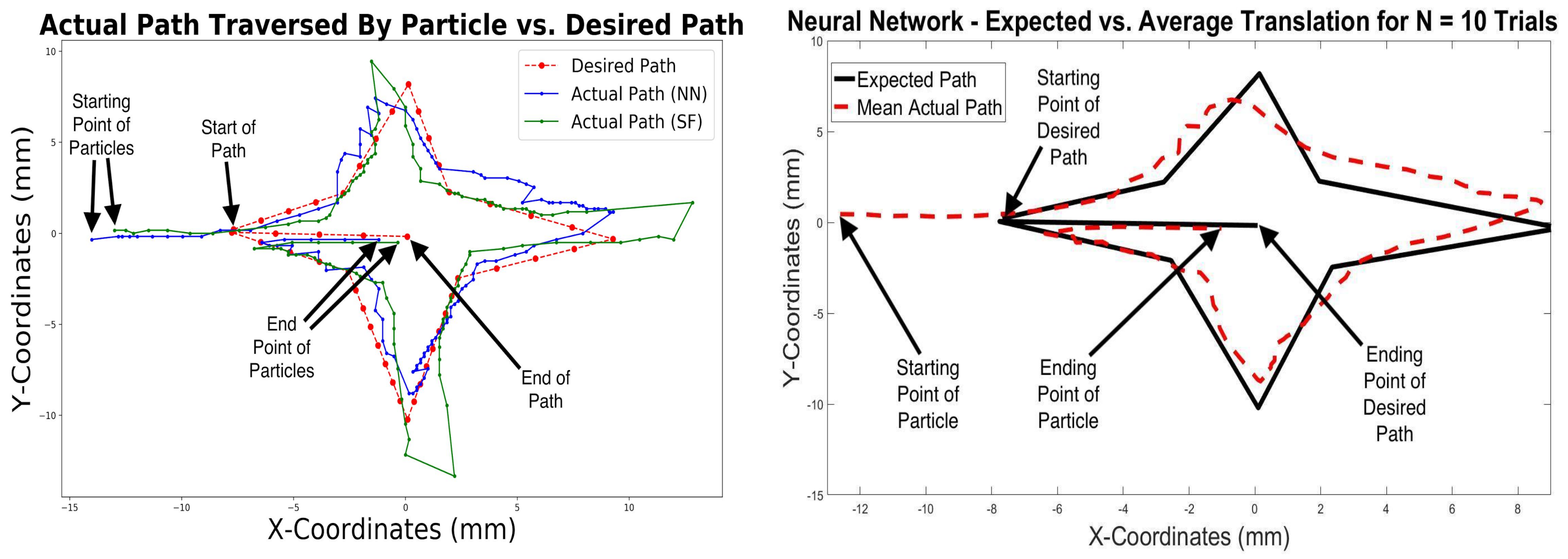


Figure 10. Path traversal comparison of neural network and surface fitting models (left) and average neural network path traversal vs. expected path traversal for N = 10 trials (right).

	R^2 Correlation Coefficient	
Trained Coil	Surface Fitting	Neural Network
+X	0.65	0.931
-X	0.729	0.886
+Y	0.735	0.887
-Y	0.827	0.934
AVERAGE	0.73525	0.9095

Figure 11. R^2 of surface fitting models vs neural network models. Higher R^2 implies more accurate model predictions.

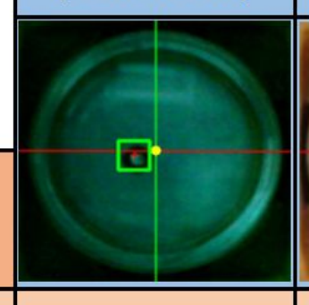
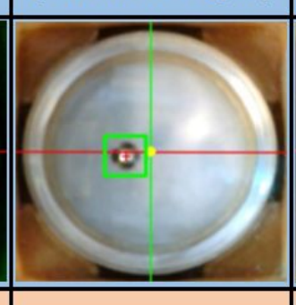
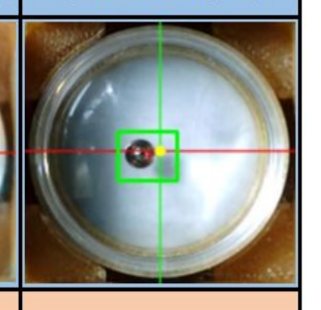
	Lighting Condition		
	6 Lux (Dark Room)	80 Lux (Ambient Light)	220 Lux (Direct Light)
Detected Feature			
Particle Location Deviation (mm)	0.3432	0.0521	0.1337
Coil Marker Deviation (mm)	0.0049	0	0.0266

Figure 12. Deviation of detected particle and coil marker (ArUco) locations under various lighting conditions

Results

Translation Model

- The neural network particle translation approach outperformed surface fitting with more accurate model predictions (Figure 11) and low average 0.85 mm path deviation across 10 translation trials (Figure 10). A neural network approach was chosen as the final particle translation model.

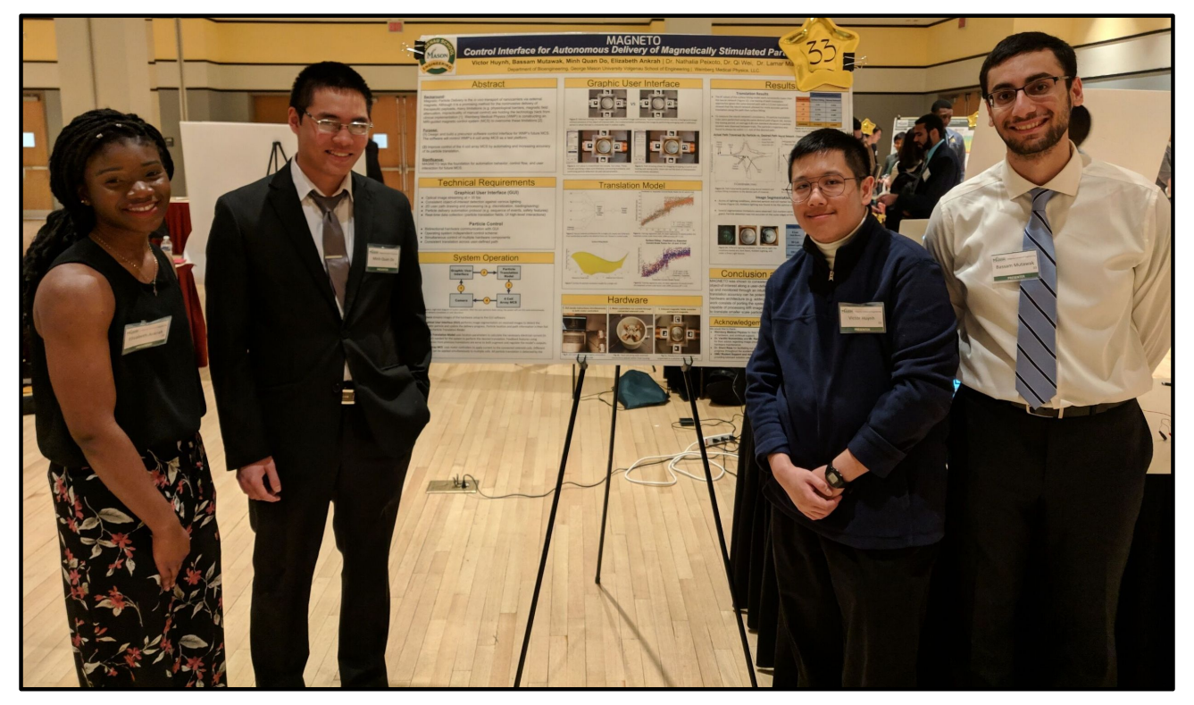
Image Segmentation

- In all tested lighting conditions, detected particle and coil marker locations within collected images deviated less than 0.4 mm (Figure 12). Ambient lighting was found to be the optimal detection environment.
- Several limitations were observed. Coil markers were undetectable if physically obstructed. Particle detection was not consistent at the outer edges of the petri-dish nor under non-uniform lighting.

Conclusion

- MAGNETO can successfully and consistently track and guide a magnetic object-of-interest along a user-defined delivery path. However, further improvements to translation accuracy can be made, potentially through translation model refinement and altering hardware architecture (e.g. adding in coils to eliminate translation dead zones). Future work consists of porting the system to WMP's future MCS. Future iterations will be capable of processing MR image batches and activating more complex magnet arrays to translate smaller scale particles.

Acknowledgements



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Weinberg MEDICAL PHYSICS

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