Mapping Magnetic Field Topography in Microrobotic Control

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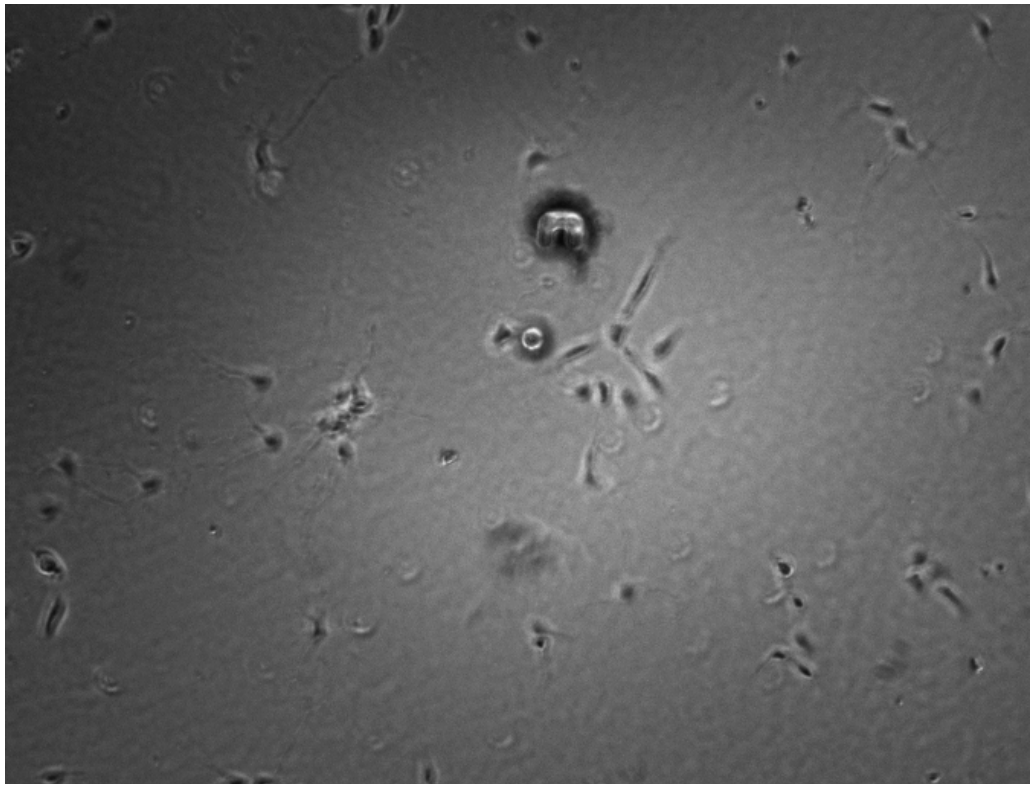
Outline

- Microrobotic control
- Extended soft-magnetic cores
- COMSOL core justification
- Field characterization
- Magnetometer
- Experimental setup
- Model implementation
- Future work

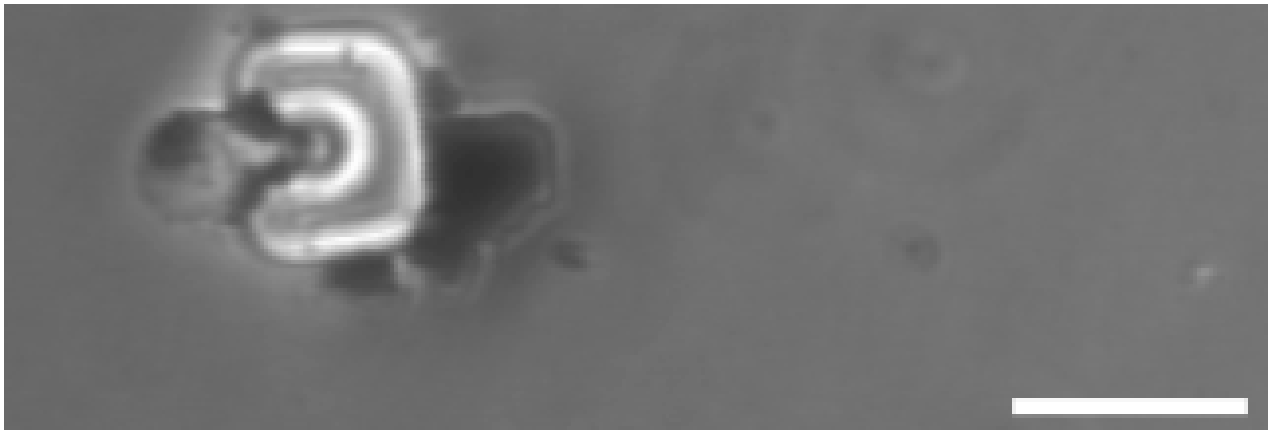
Microrobots

- Used to manipulate micro-organisms *in vitro*
  [Sitti et al 2008], [Nelson et al, 2005]
- Requires non-contact forces for external control



Microrobots

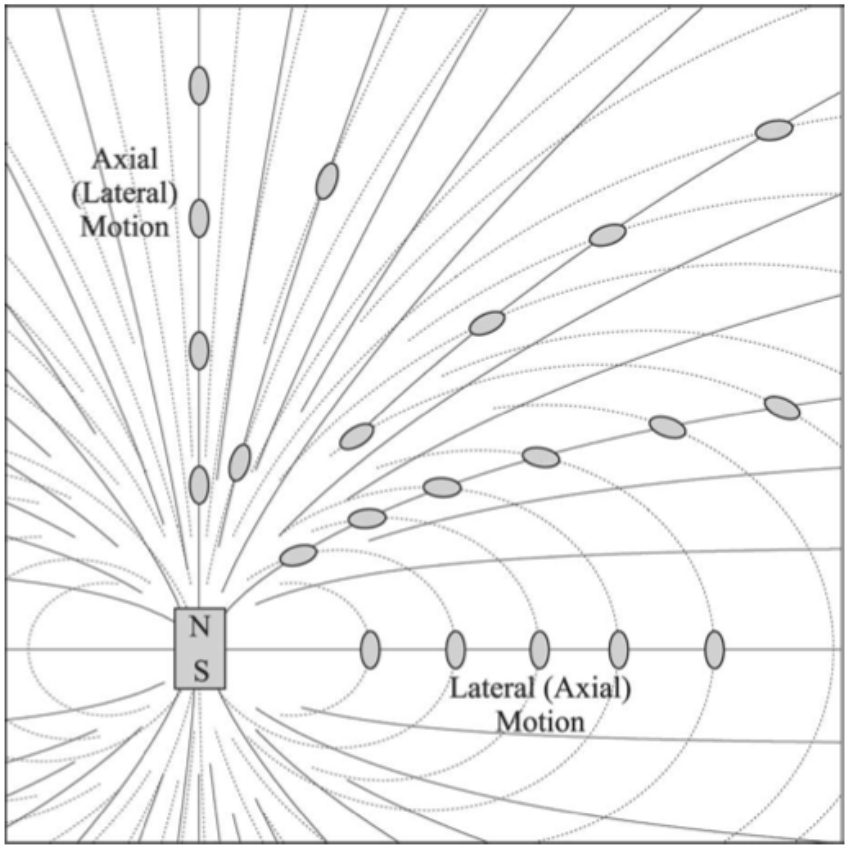
- Scale: $30\mu m^3$
- Workspace: $150\mu m^2$
- Robots composed of Iron (II,III) oxide nano-particles
- Magnetic manipulation with ferromagnetic composition
- Previous work required feedback term in control [Kumar et al, 2011]
- Goal of this study: understand and characterize field for better control



[Kumar et al, 2011]: Scale bar in figure is $25\mu m$

Microrobotic Motion

- Solid lines indicate field
- Dashed lines indicate gradient
- The magnetization vector of the ellipsoid is along the long axis



Source: "**Modeling Magnetic Torque and Force for Controlled Manipulation of Soft-Magnetic Bodies**" Jake Abbott, Olgac Ergeneman, Michael Kummer, Ann Hirt, Bradley *Nelson*

Microrobotic Motion

- Microrobots orient along field lines
- Microrobots move in the direction of increasing field gradient
- **T**: torque
- **M:** magnetization
- **B:** external field,
- V: volume of robot
- **F:** force

$$T = M \times B$$

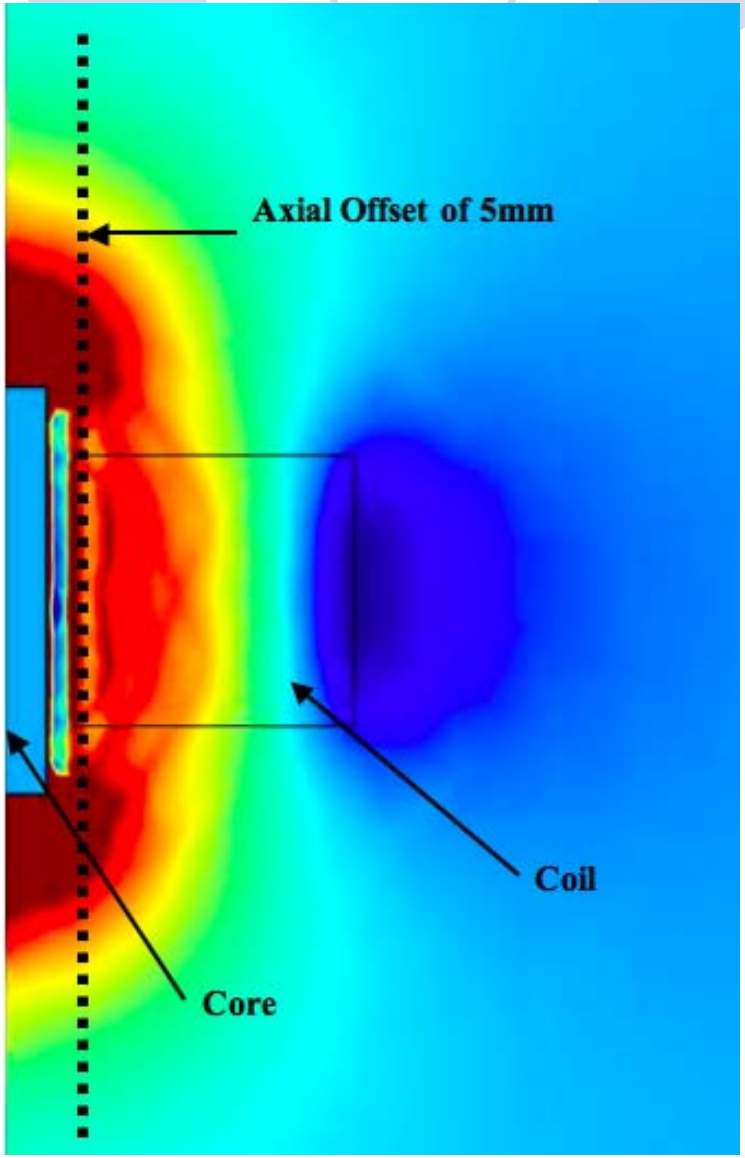
$$F = V (M \cdot \nabla) B$$

Extended Soft-Magnetic Core

- Magnetic field limitations:
  - Heat produced by coils affect micro-organisms
  - Coils inhibit motion of the microscope objective
- Soft-magnetic cores (cores that do not readily maintain magnetization) are used to extend field
- Ferrite (Fe) cores were employed
- COMSOL was used to theoretically validate field extension

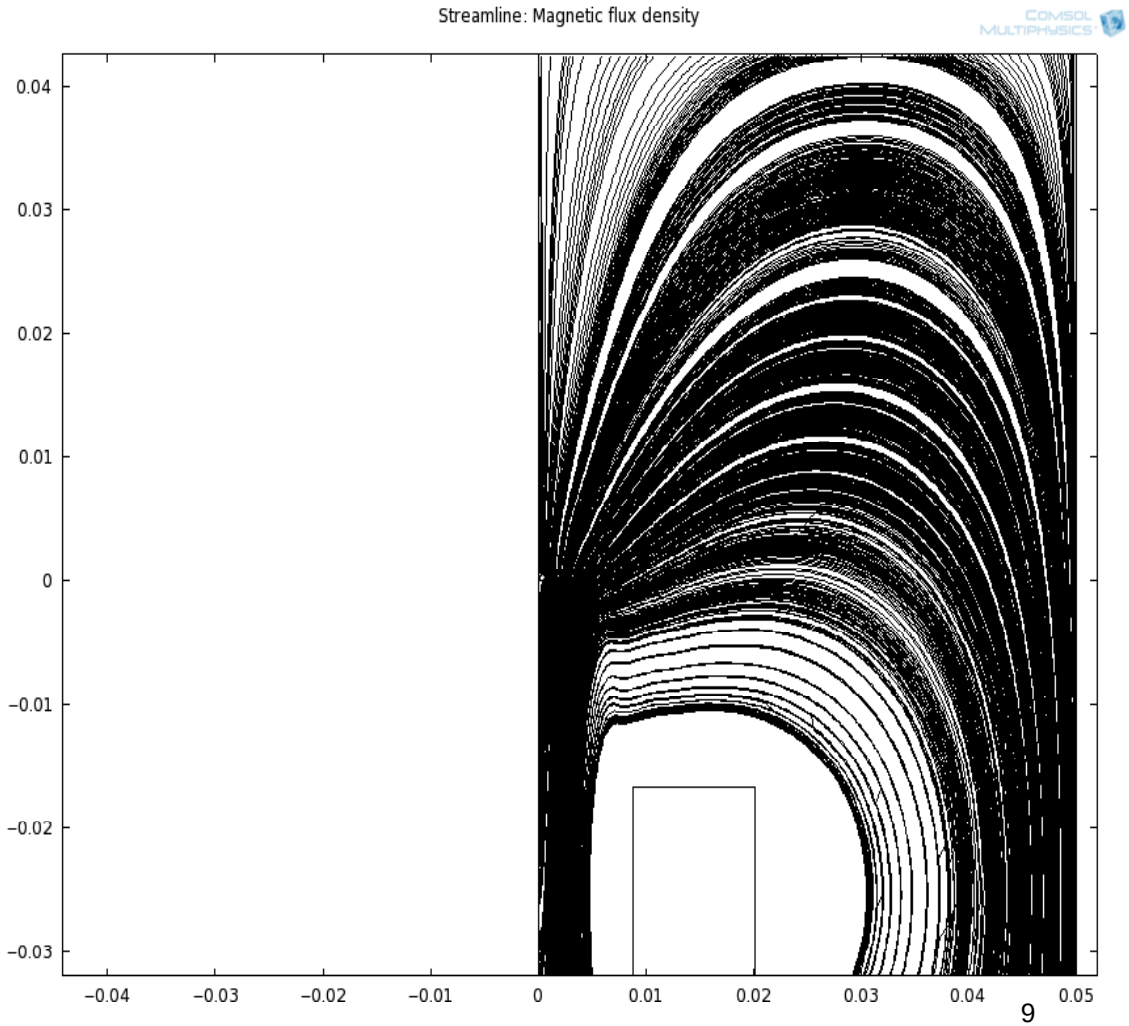
COMSOL Core Justification

- Figure: COMSOL model for axial component of B field
- Field is extended and reshaped
- Design space has diameter of 1cm and is centered on the dipole moment axis



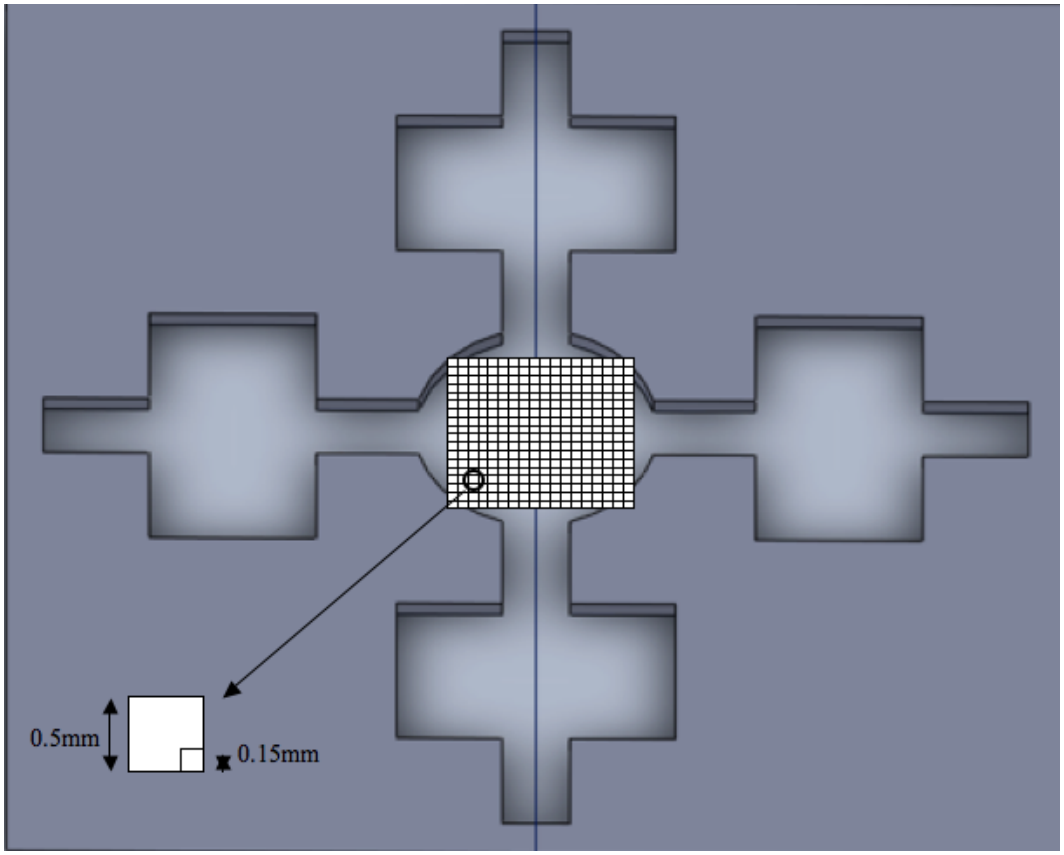
COMSOL Core Justification

- 5000pt mesh of field streamlines
- Design space at 11mm from core end.
- In design space its expected that the gradient and field lines are parallel



Field Characterization

- Figure: FEM model for a four coil/core system
- 21x21 grid space
- Lagrange polynomials fit to experimental data used to model Design space



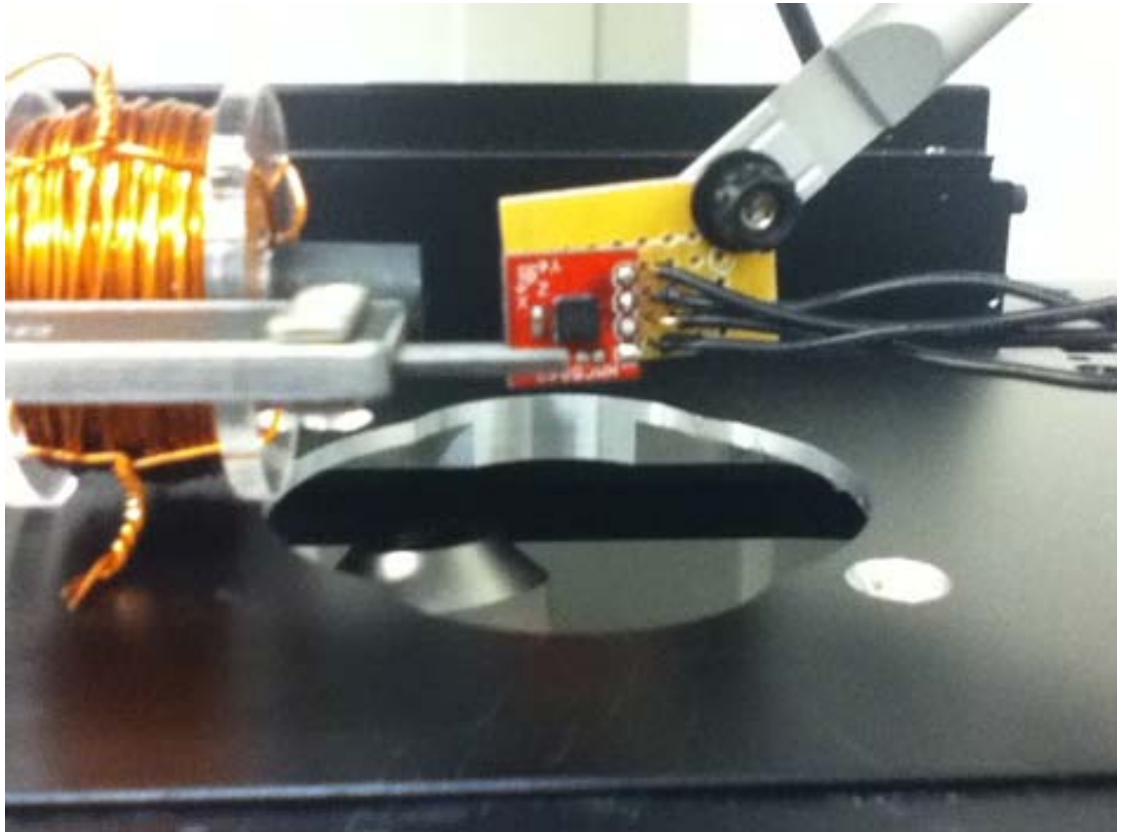
Magnetometer

- Magnetometer was needed to measure field components in FEM model
- Previous work used the $6K Metrolab THM1176 system
- We constructed an adequate system using Arduino Duemilanove with a $50 triple axis digital compass: HMC5843 Honeywell

Sources: www.sparkfun.com, www.metrolab.com

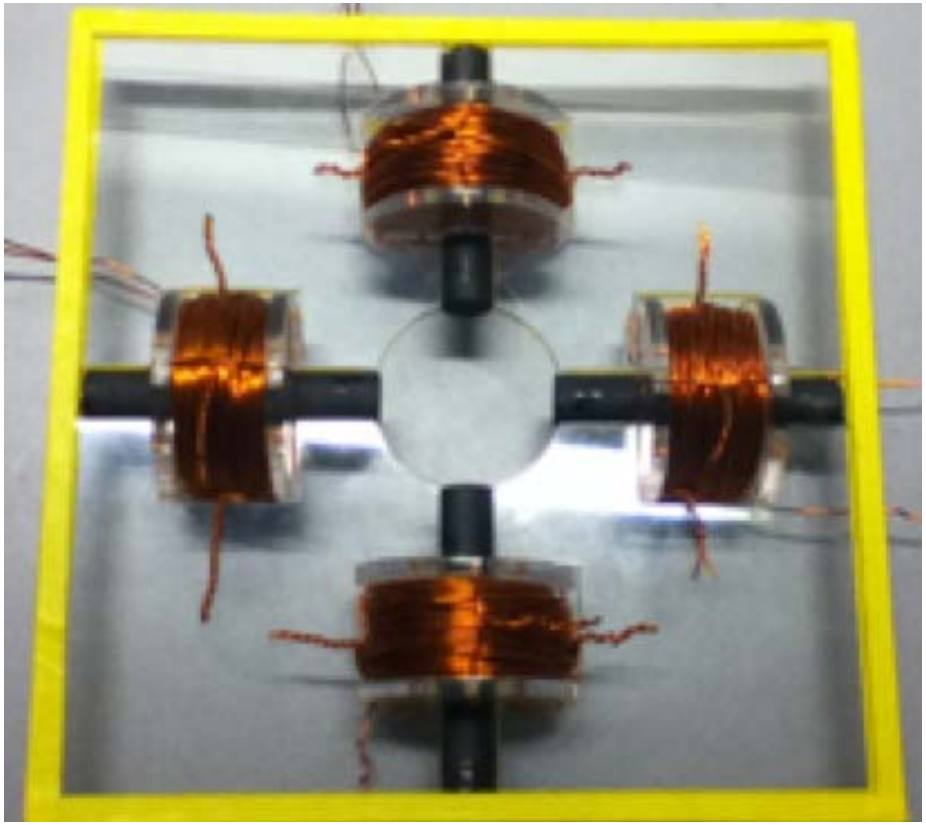
Experimental Setup

- Micromanipulator was used to step through design space



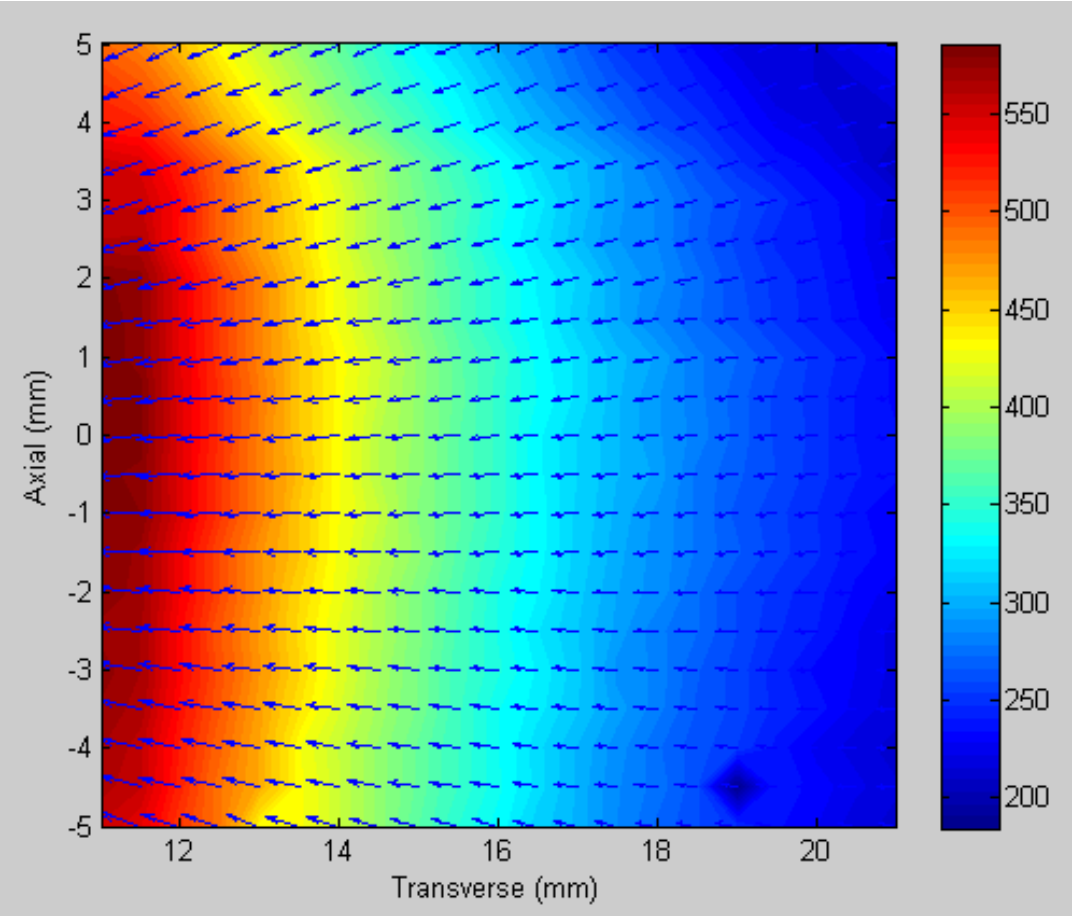
Experimental Setup

- Coils: 300 turns, 22 gauge wire
- Ferrite cores: 50.8mm length, 9.5mm diameter



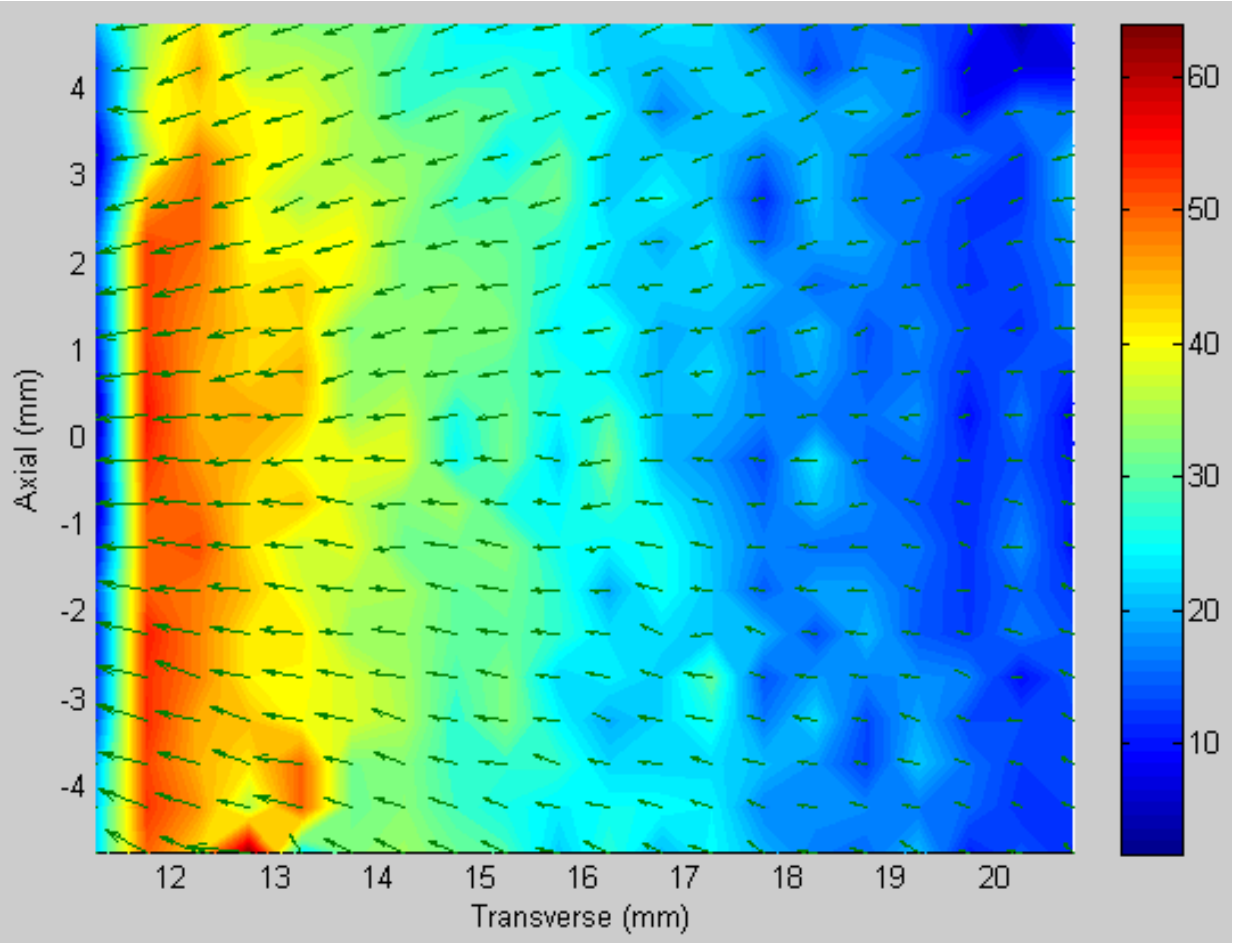
Experimental Model

- Figure shows field when a single coil (11,0) is turned on



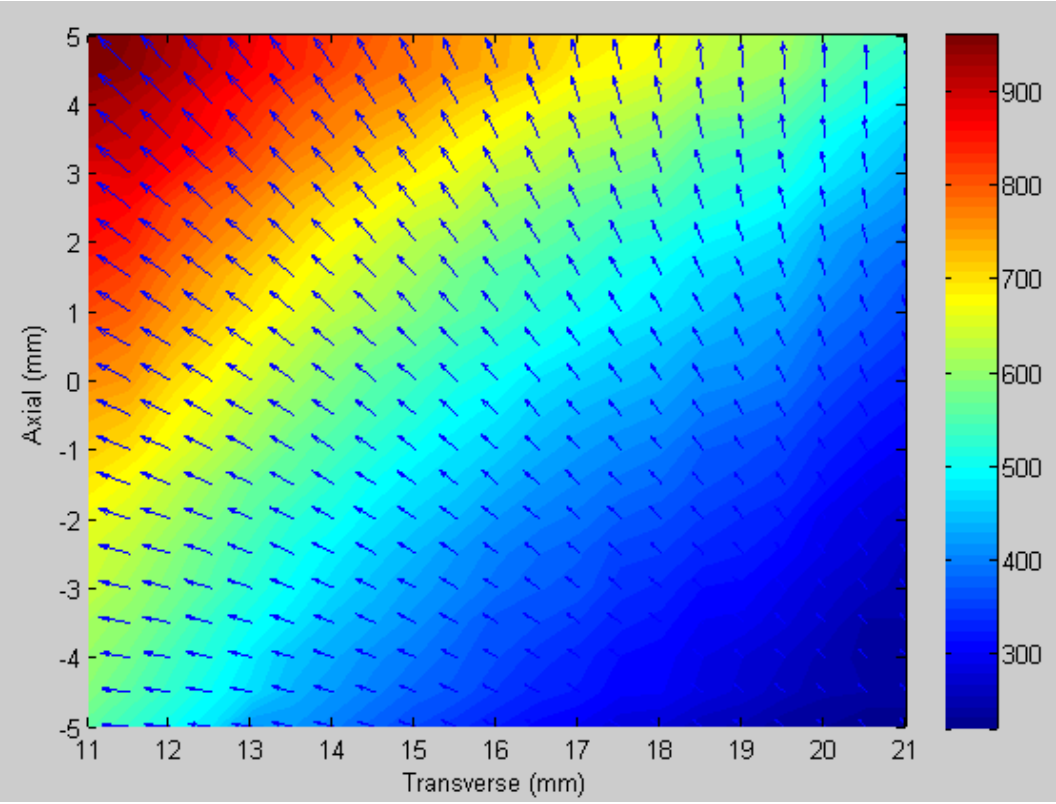
Experimental Model

- Figure shows gradient of field when a single coil (11,0) is turned on



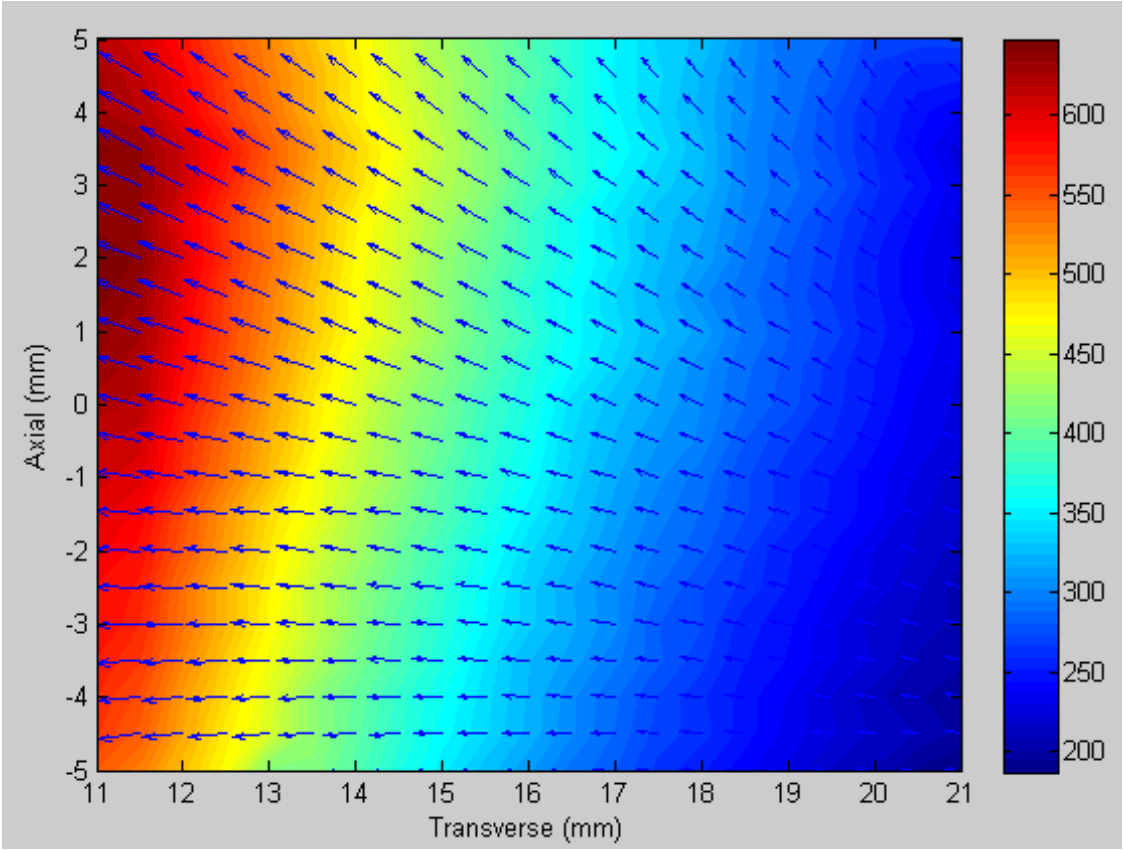
Model Implementation

- Fields superimpose linearly in design space
- Figure indicates field when 2 coils are turned on (11,0) and (16,5), both at 100%



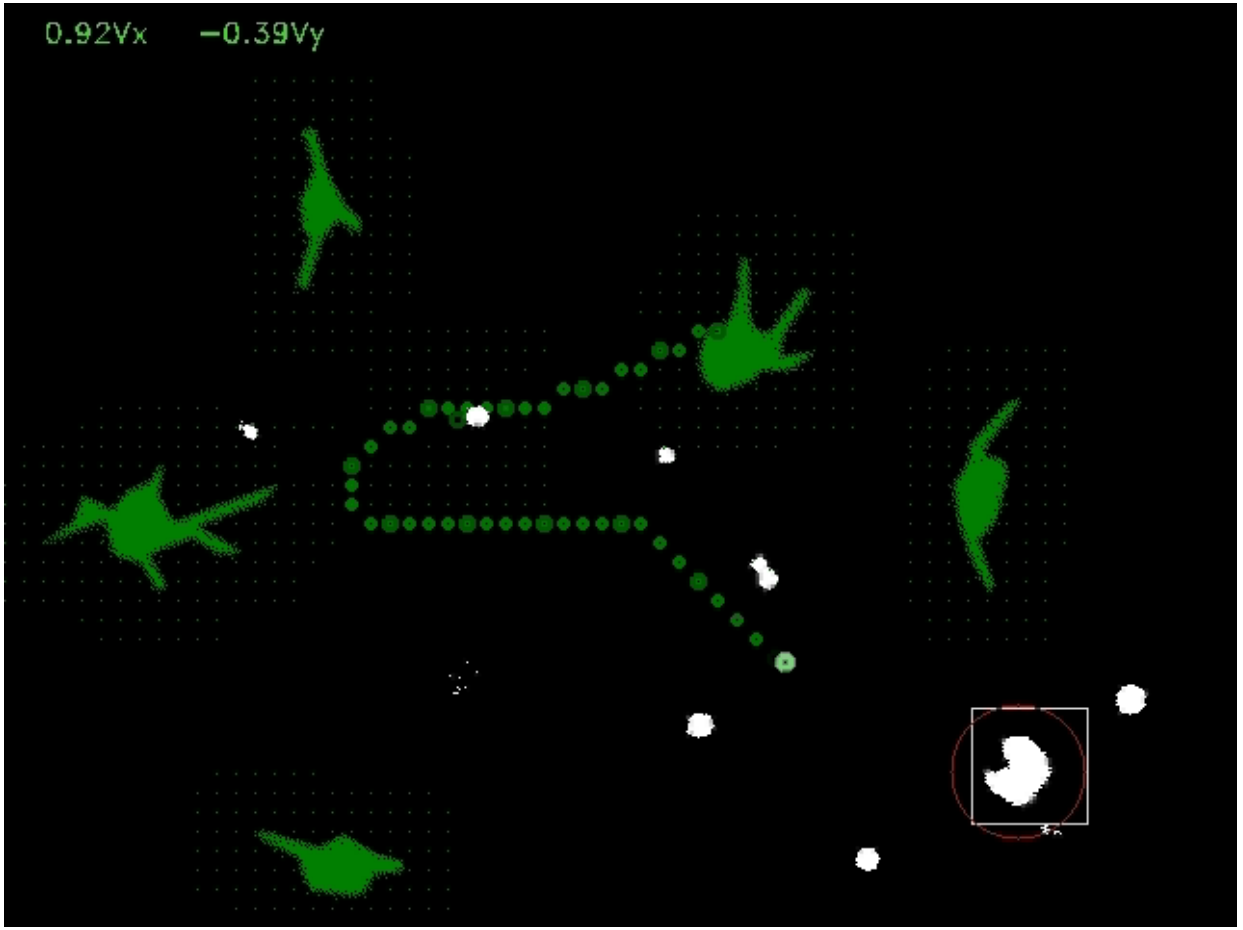
Model Implementation

- Figure indicates field when 2 coils are turned on (11,0) at 100%, (16,5) at 30%
- Qualitative tests confirmed these predictions



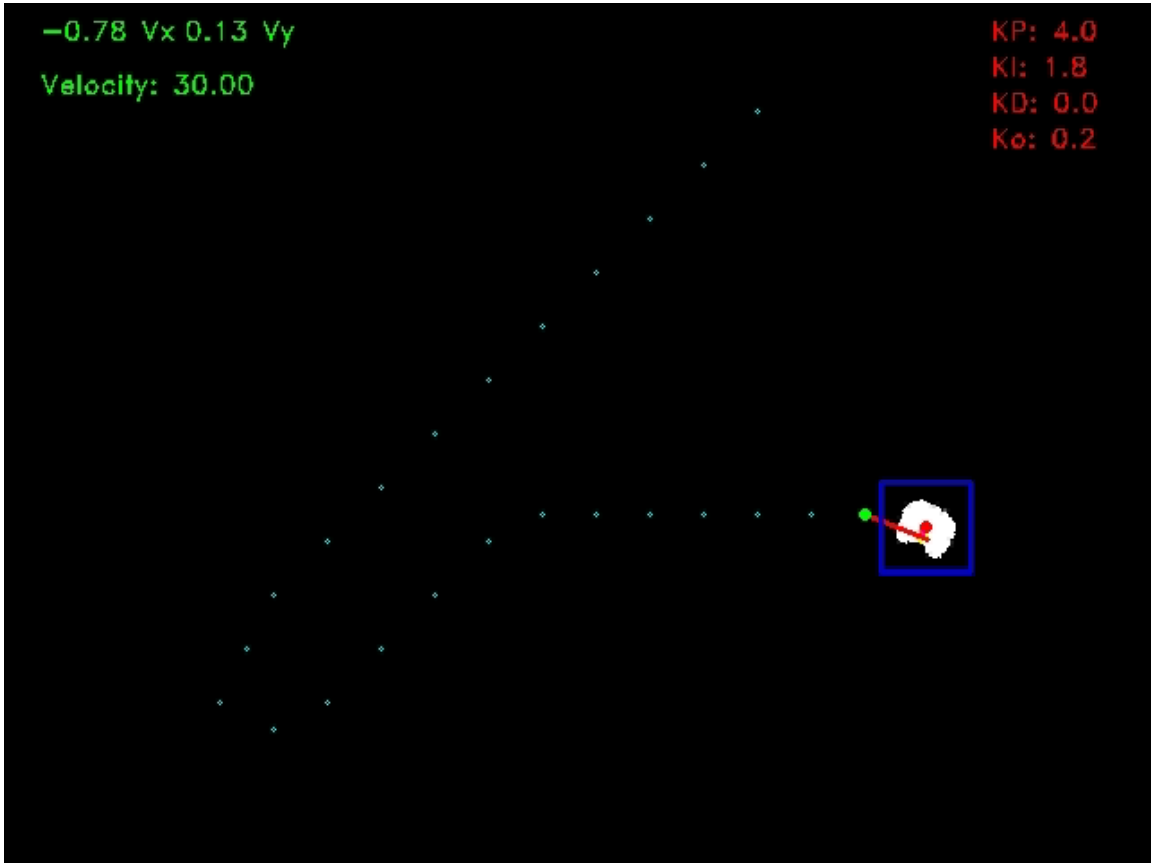
Future Work

- Trajectory: Path finding integrated with field topography model will reduce noise in control



Future Work

- Inverted model will take the parameters of initial and final position, initial velocity and desired final velocity and will provide field topography that satisfies these parameters



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