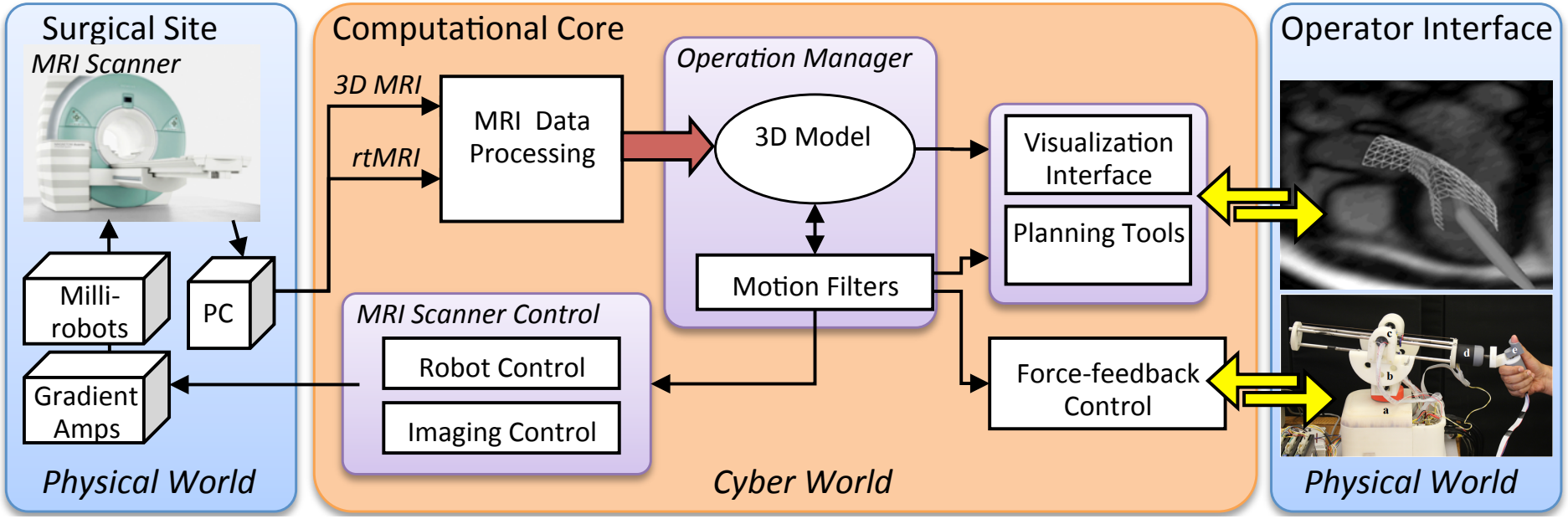
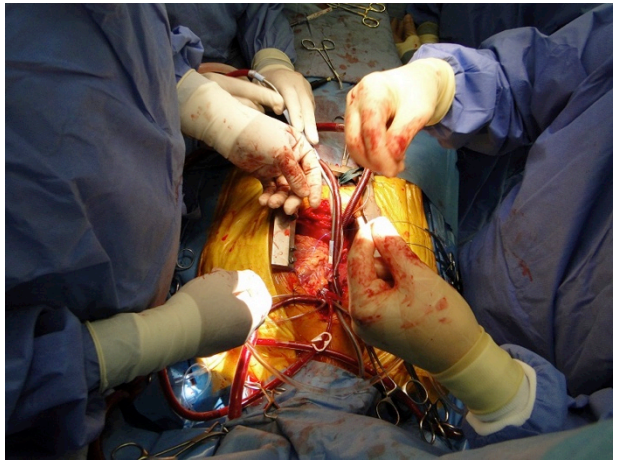
Seventh Annual
Cyber-Physical Systems Principal Investigators' Meeting
Arlington, VA | October 31 – November 1, 2016

CPS: Synergy: Collaborative Research: MRI Powered & Guided Tetherless Effectors for Localized Therapeutic Interventions, *Jan 1, 2017—Dec 31, 2019*

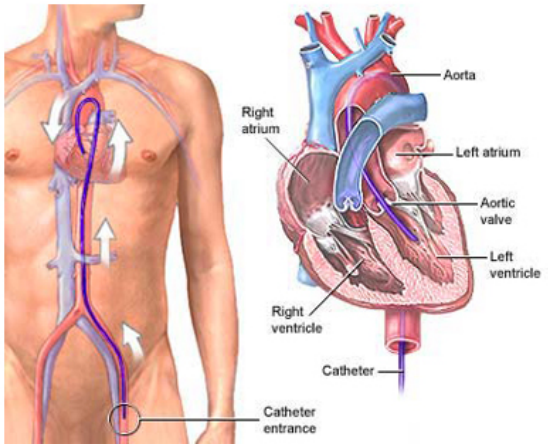


PIs:
- Aaron Becker, PhD: *Robotic Swarm Control Lab*, ECE, U. of Houston
- Dipan Shah, MD: *Cardiovascular MRI*, Houston Methodist DeBakey Heart & Vascular Center
- Nikolaos Tsekos, PhD: *Medical Robotics Lab*, CS, U. of Houston

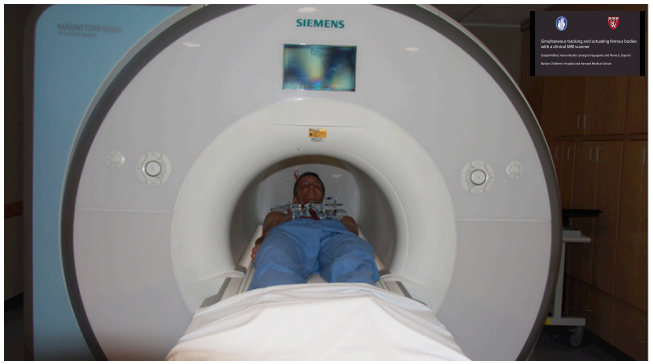
Surgeons need *access* and *sensing*



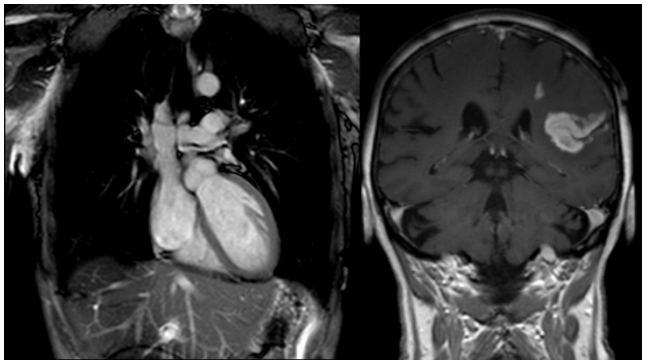
Traditional Surgery

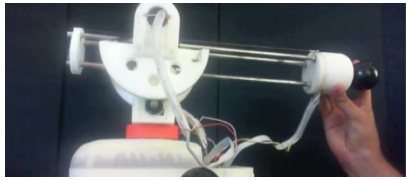


Minimally Invasive Surgery



Goal: Non-Invasive Surgery



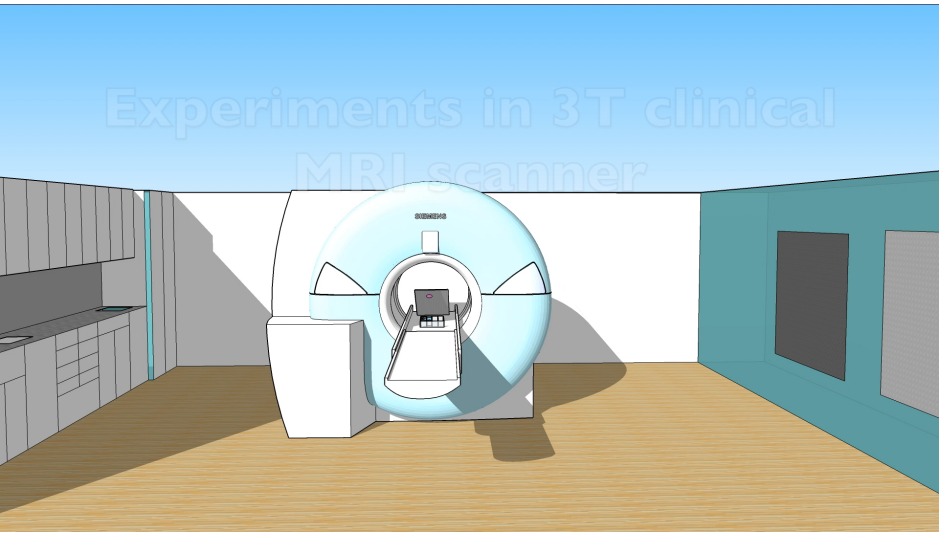


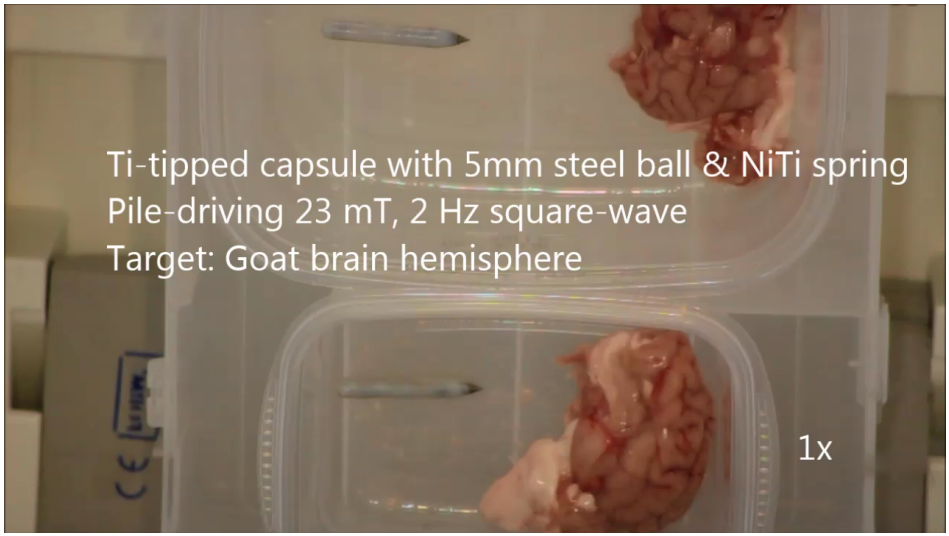
Immersive 3D Sight and Touch

Concept

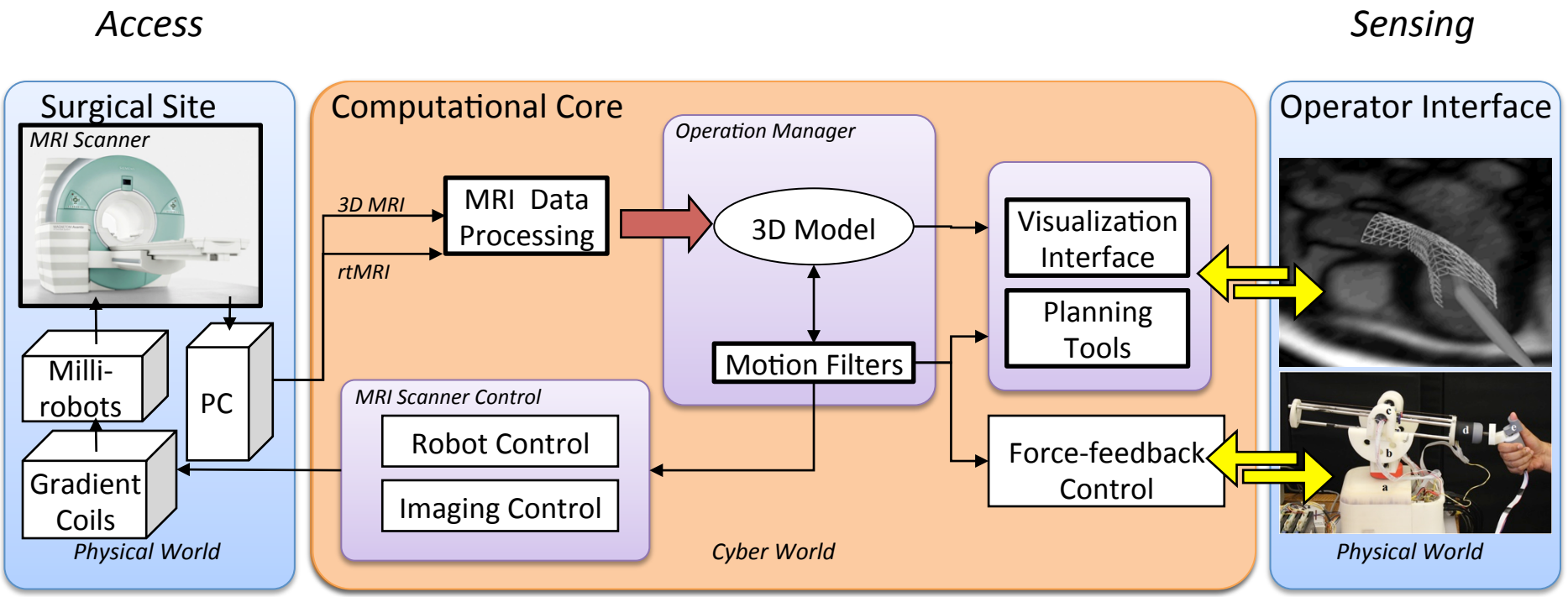
Develop novel CPS: untethered milli-robots powered, imaged, and controlled by magnetic fields of a clinical MRI scanner for therapeutic interventions inside human body

- localized targeted therapy
- minimally invasive surgery
- implanting milli-scale sensors/devices



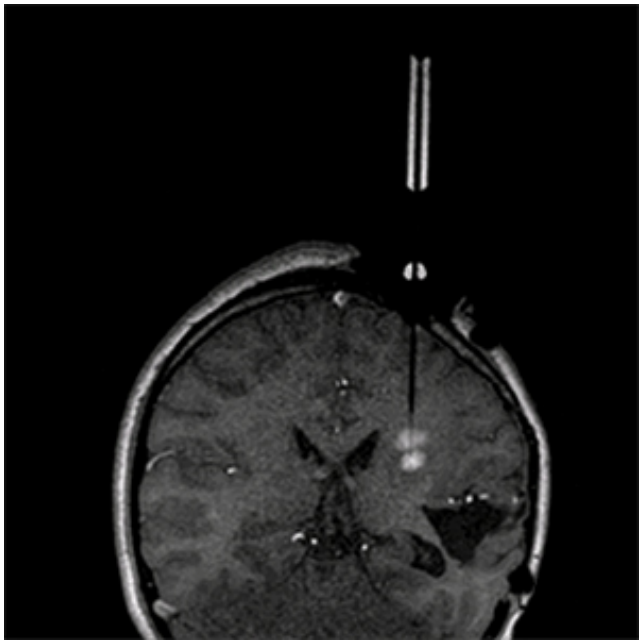


A CPS


Access
Sensing
Surgical Site
MRI Scanner
Milli-robots
PC
Gradient Coils
Physical World
Computational Core
Operation Manager
3D MRI
rtMRI
MRI Data Processing
3D Model
Motion Filters
MRI Scanner Control
Robot Control
Imaging Control
Cyber World
Visualization Interface
Planning Tools
Force-feedback Control
Operator Interface
Physical World

What & why

Patient remains in MRI scanner while surgeon operates



- Real-time MRI feed for interactive maneuvering
- Procedure monitoring enables optimal delivery of therapy (e.g. localized biopsy or delivery of tissue, STEM cells, or drug)
- No X-ray radiation (vs. fluoroscopy & CT)
- Superb contrast and image quality (vs. fluoroscopy & ultrasound)
- Over 5,000 MRI scanners in US

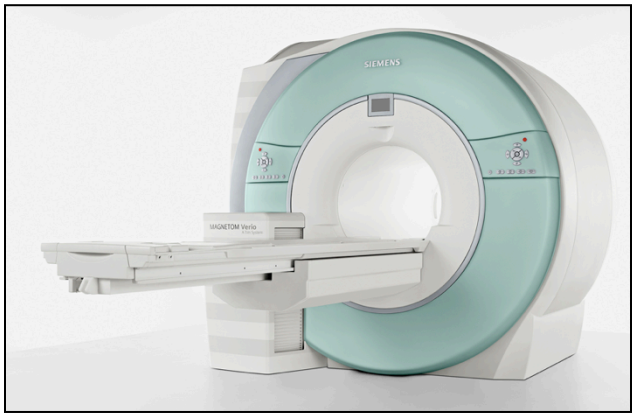
Single-modality, single-session approach

Benefits & Challenges

Using MRI in a Single-Modality Approach

Benefits of MRI

- True 3D
- Plethora of contrast mechanisms
- Inherent coordinate system
- Methods for tracking tools
- On-the-fly adjustment of imaging parameters (plane, orientation, etc.)
- No ionizing radiation

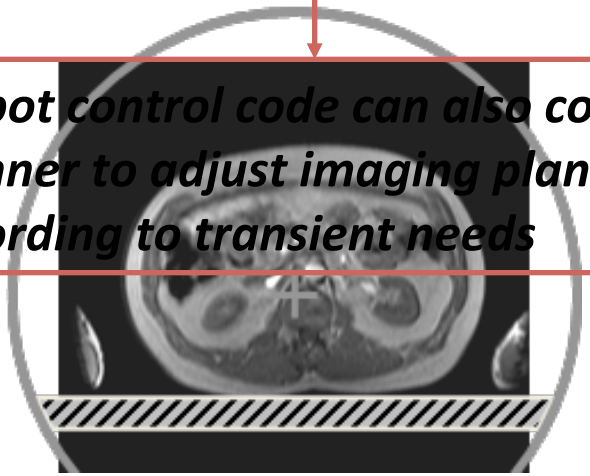


C

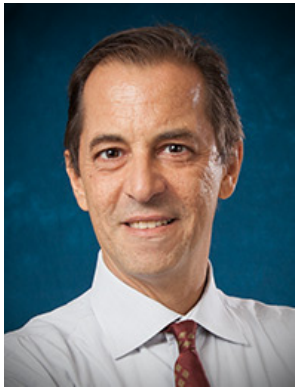
Images and robot share same coordinate system!

- Strong permanent magnetic fields
- Rapidly changing magnetic gradients
- Limited space in the MR scanner
- Slow acquisition speed (≈20 Hz)

Robot control code can also control scanner to adjust imaging planes according to transient needs



Three Team Synergy



ELECTRICAL ENGINEERING
Aaron Becker, PhD

- MRI-powered robots
- Robots & control
- Dynamics & kinematics
- Mechatronics

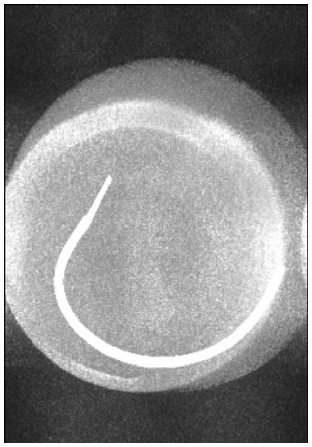
CARDIOVASCULAR MRI
Dipan Shah, MD

- Robot design specs
- MRI sequence specs
- Man-in-the-loop control
- Experimental studies
- Metrics/compliance

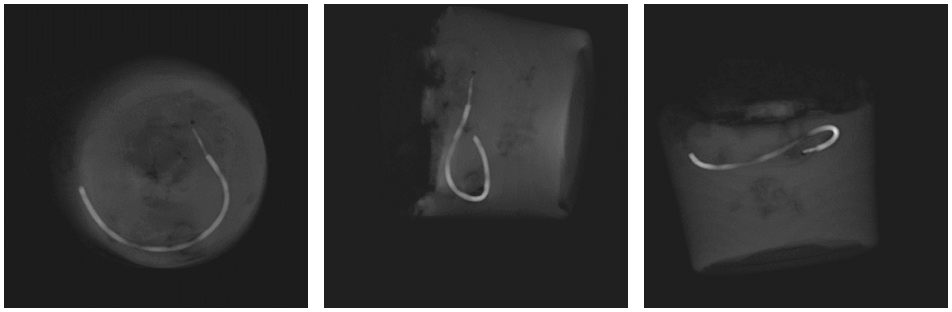
COMPUTER SCIENCE
Nikolaos V. Tsekos, PhD

- Computational core
- MRI methods
- On-the-fly MRI control
- MRI-based real-time paths and corridors
- Augmented reality
- Man-in-the-loop control

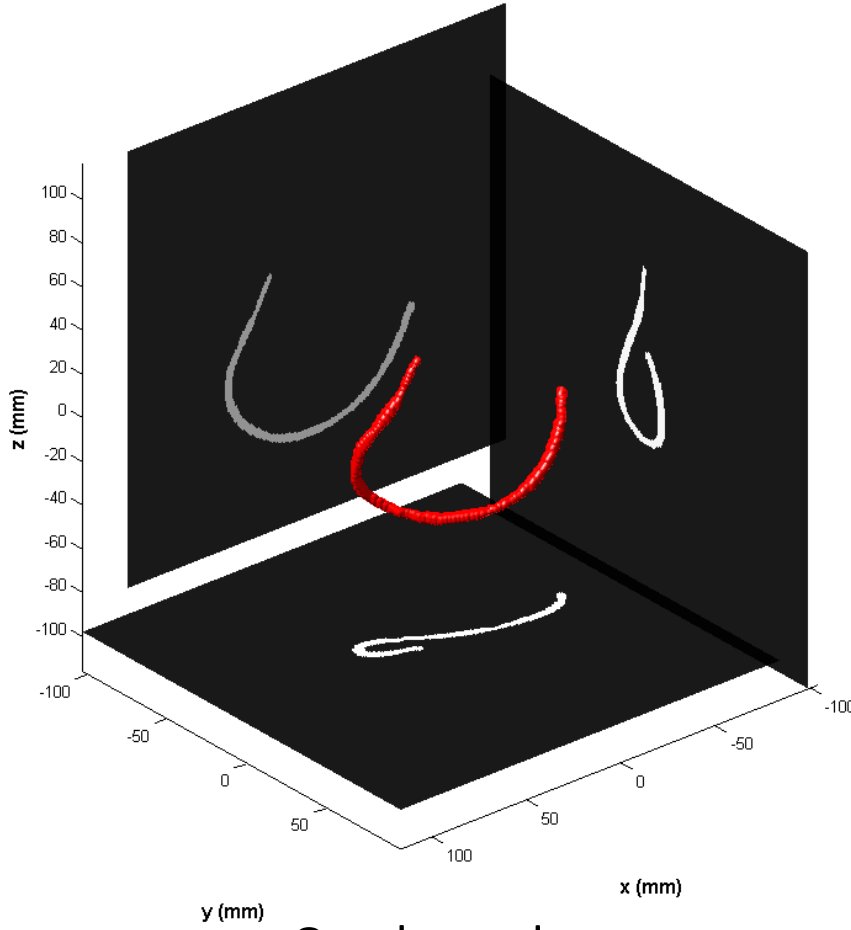
Ultrafast 3D MRI of Tubular Structures



Traditional MIP multislice
(128 slices, 420 s)

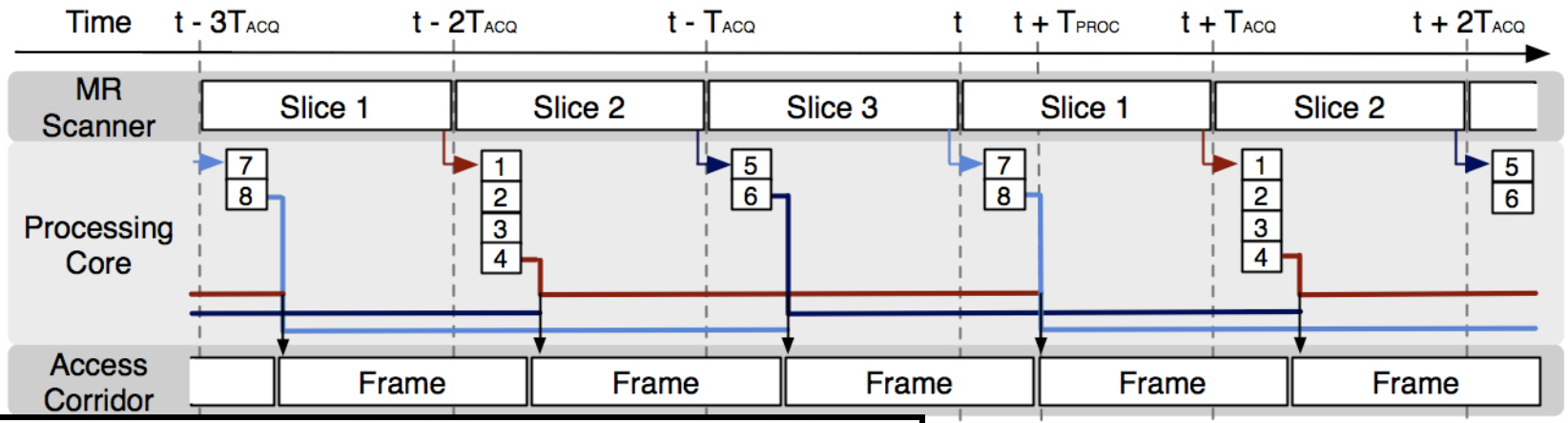


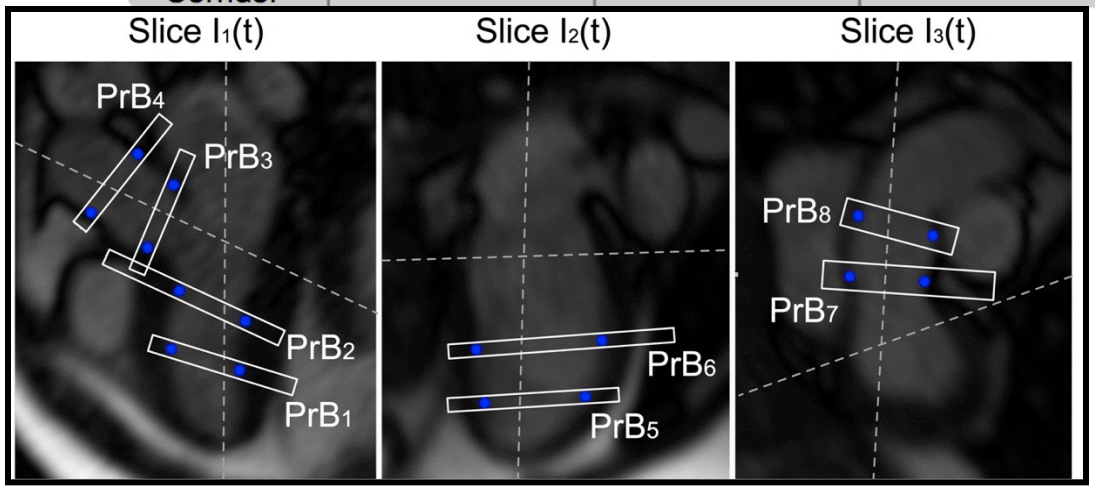
Three MRI volume projections are back-projected (660 msec)

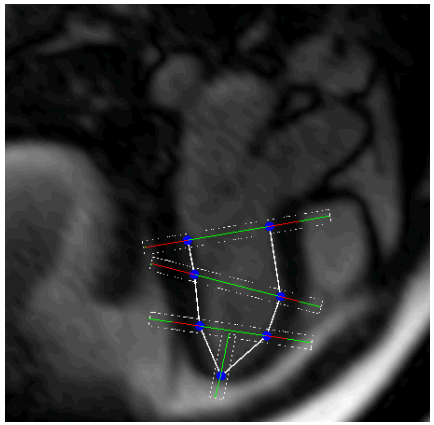


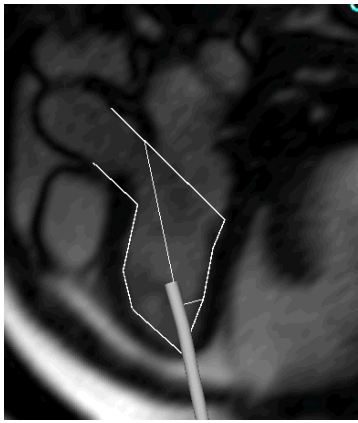
Overlapped
0.66 s vs 420 s

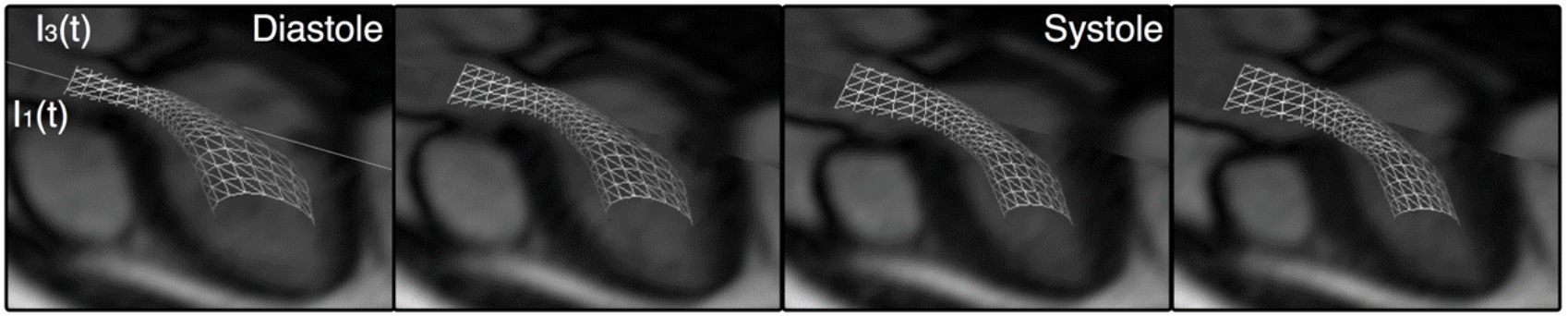
Real-time Image Guidance



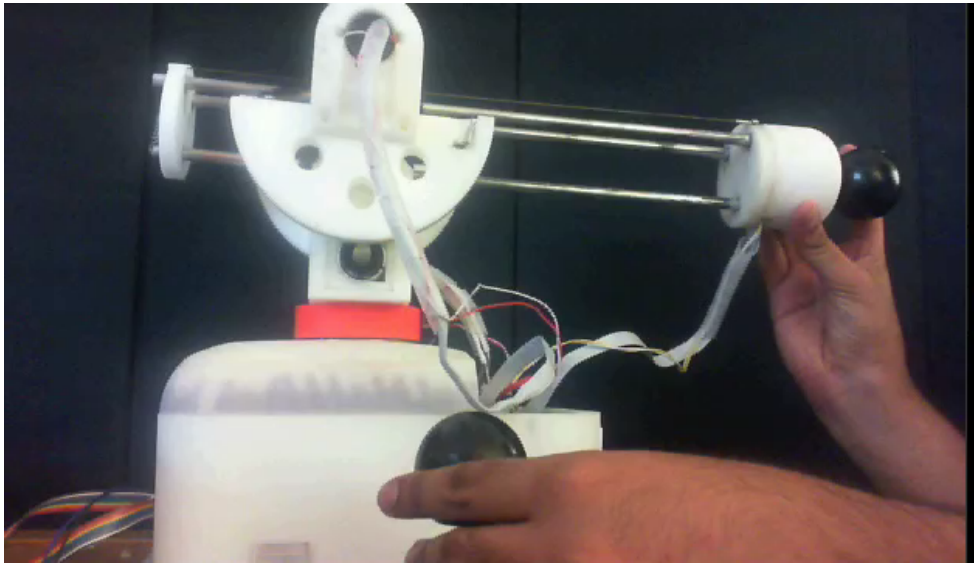




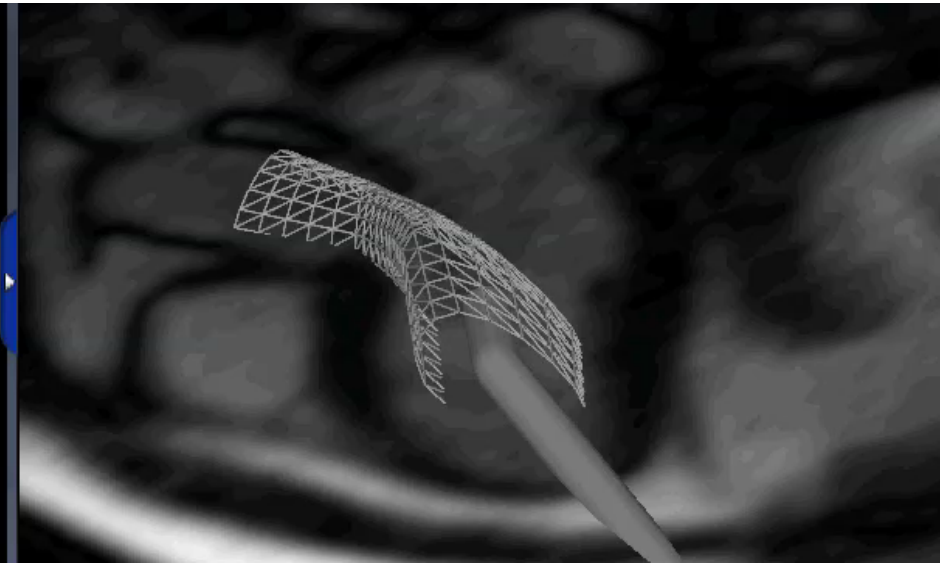




Real-time MRI to Human-Machine Interfacing



Force-Feedback Interface
(5 DoF, developed in-house)

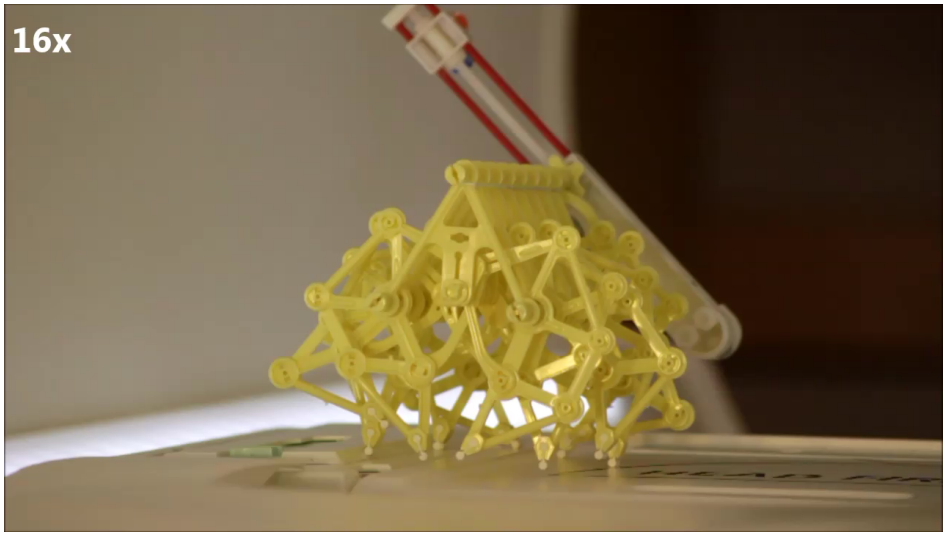


Visualization Interface
(High Definition LCD)

Our robots powered, imaged, & controlled by MRI

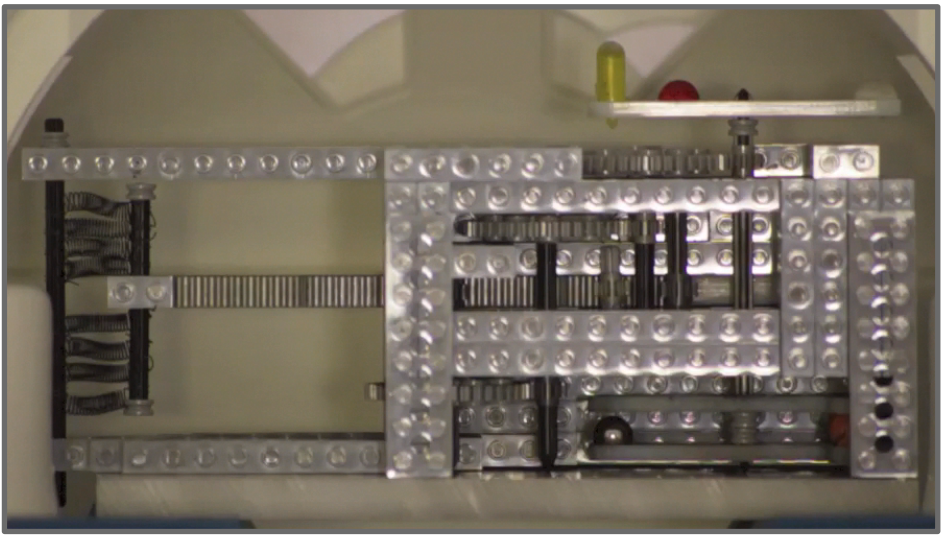
Tetherless biopsy

Tetherless walker

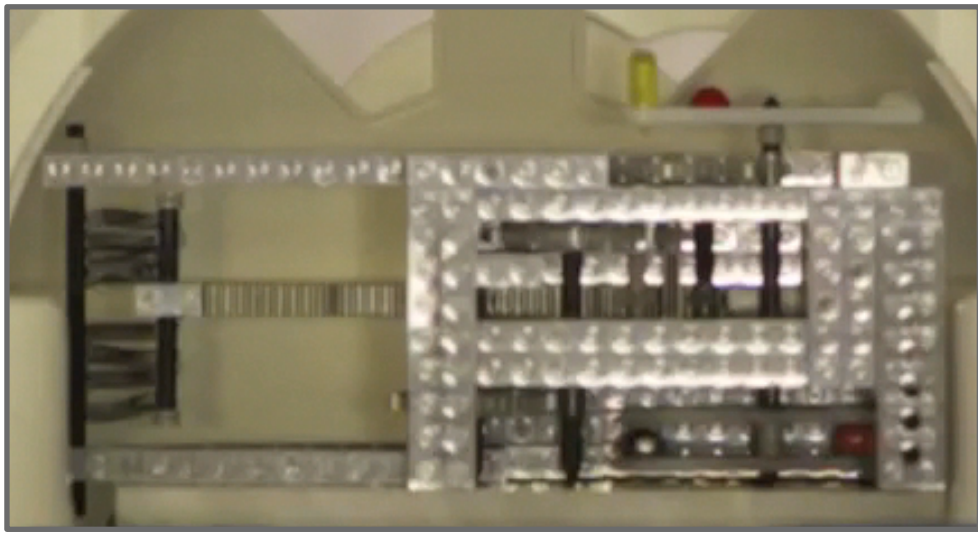


Our robots powered, imaged, & controlled by MRI

Open-loop

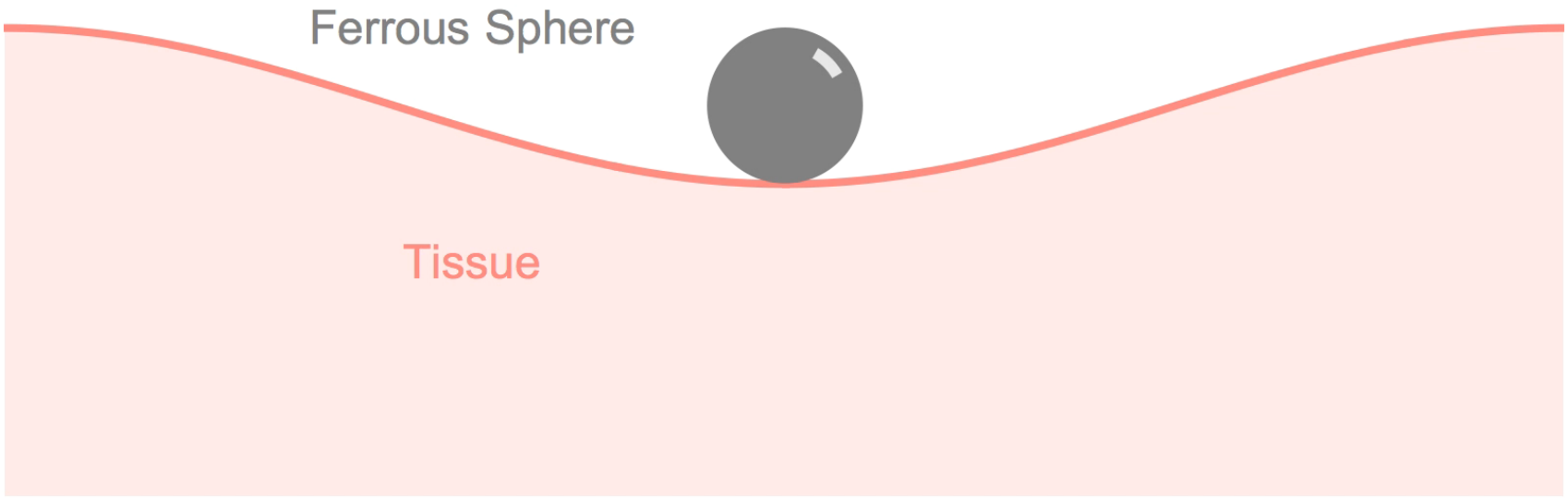


Closed-loop



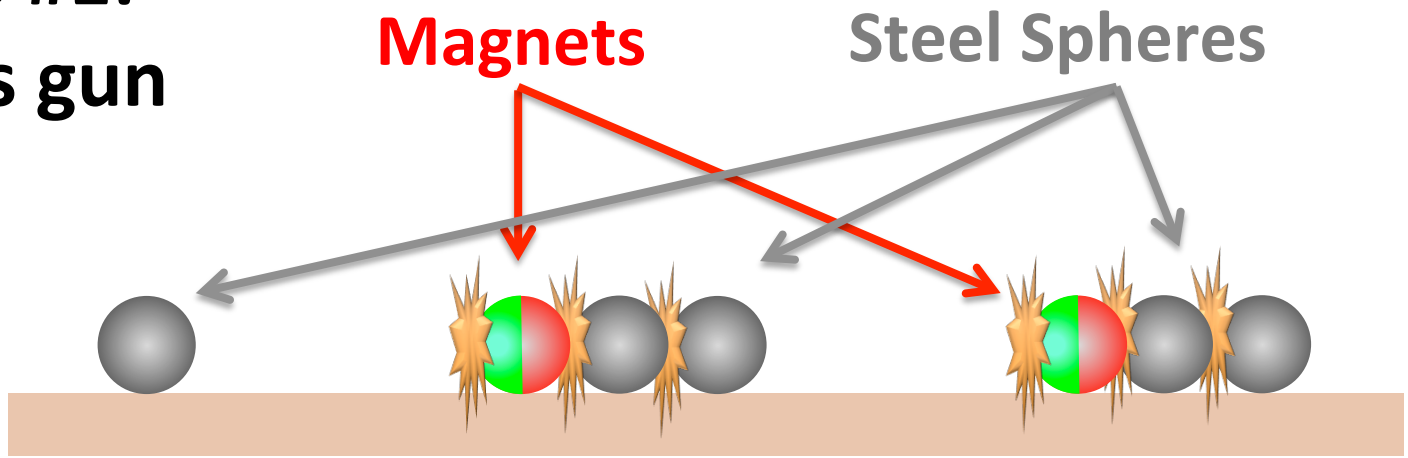
Can achieve clinically relevant forces through closed-loop and gear ratios

Problem: forces inside an MRI



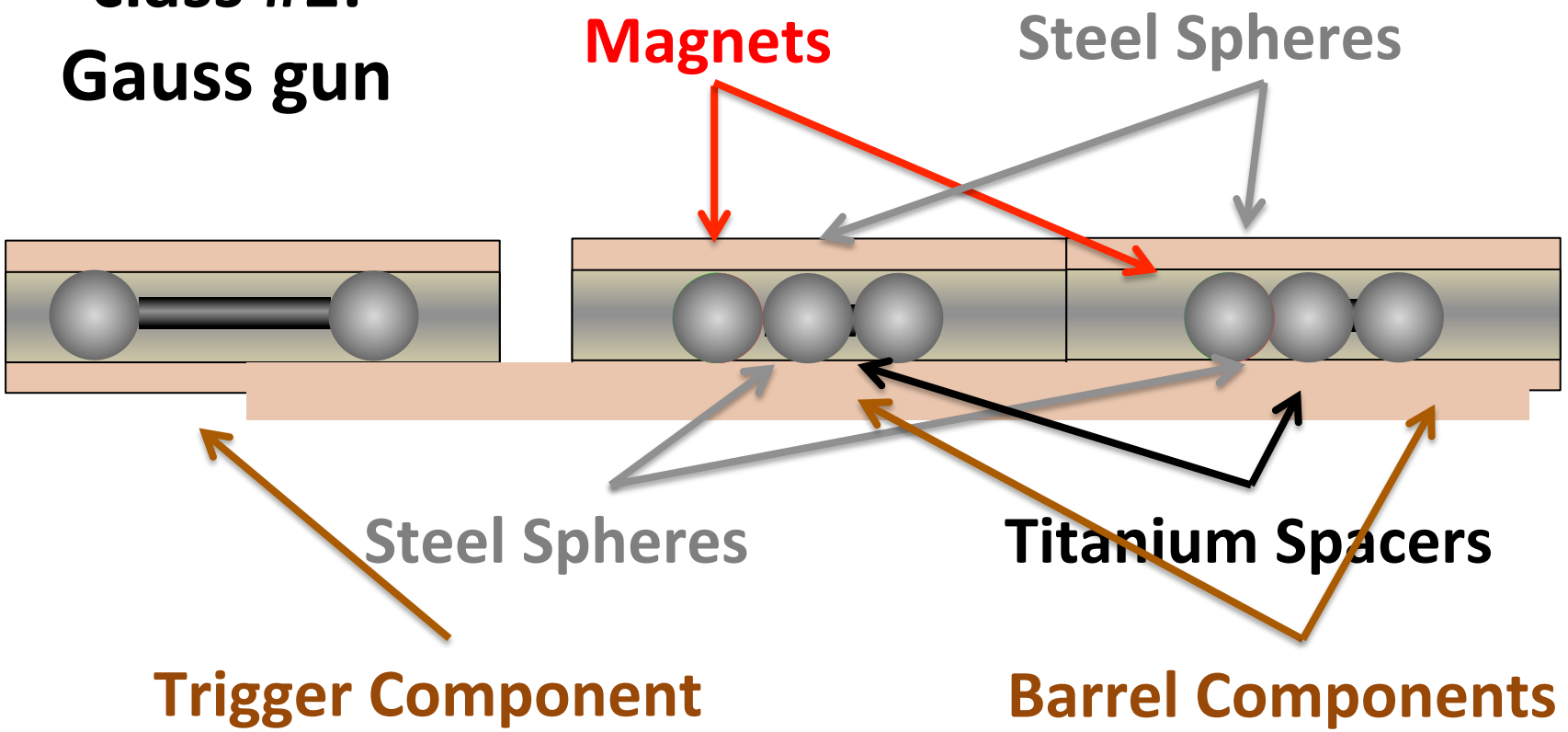
Design class #1: Gauss gun

Gauss Gun Operation



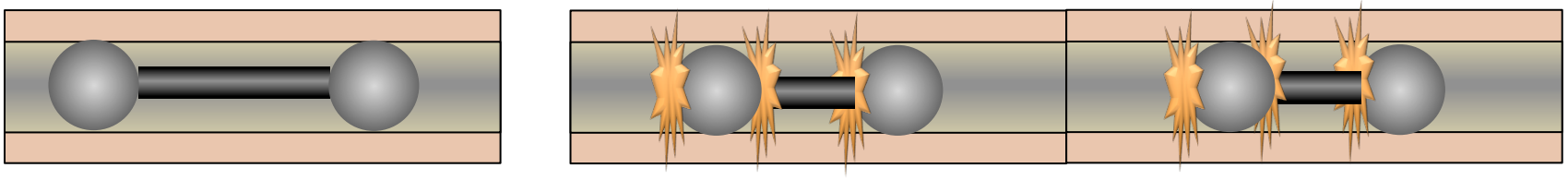
Design class #1: Gauss gun

Converting to MRI

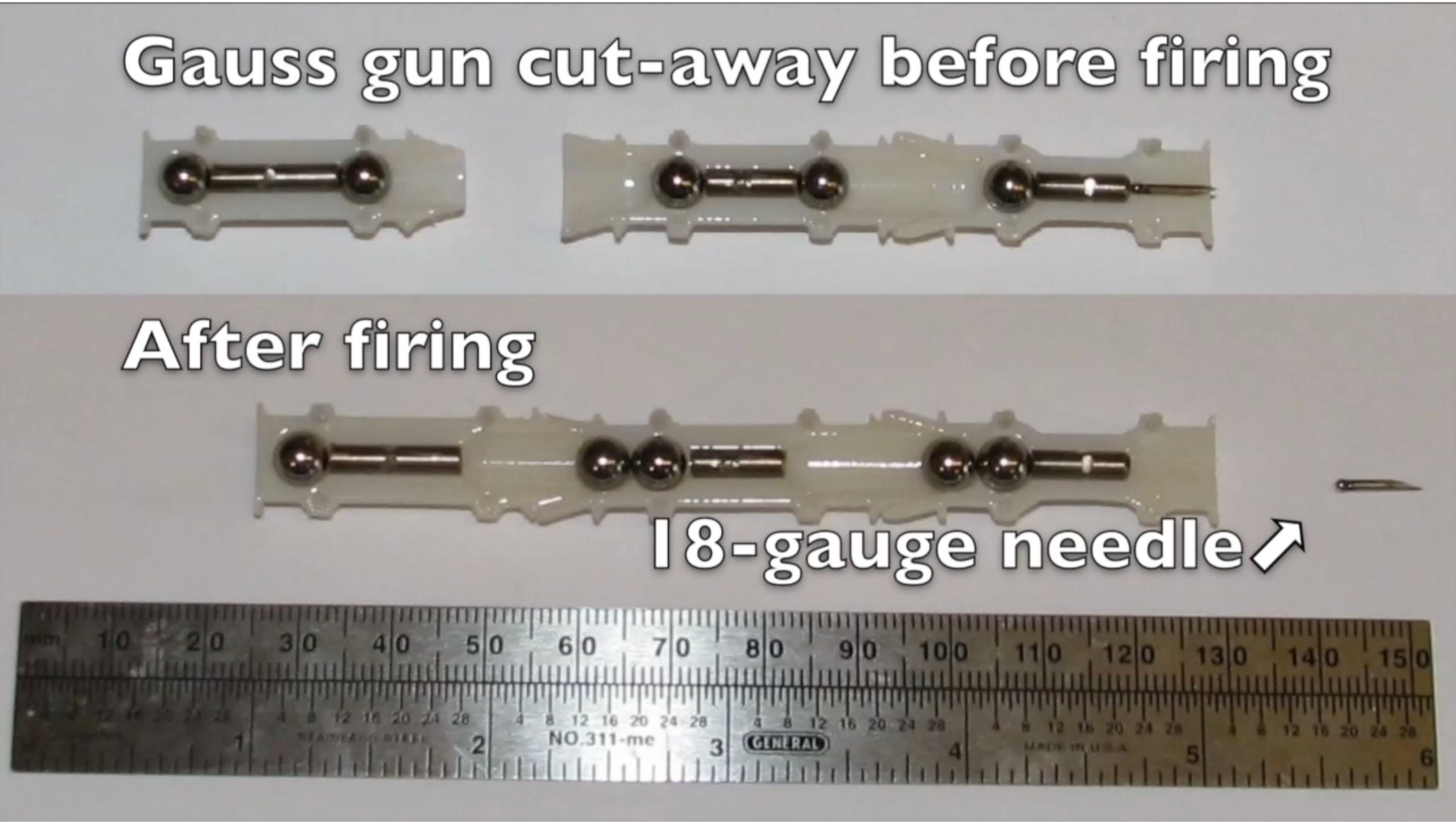


Design class #1: Gauss gun

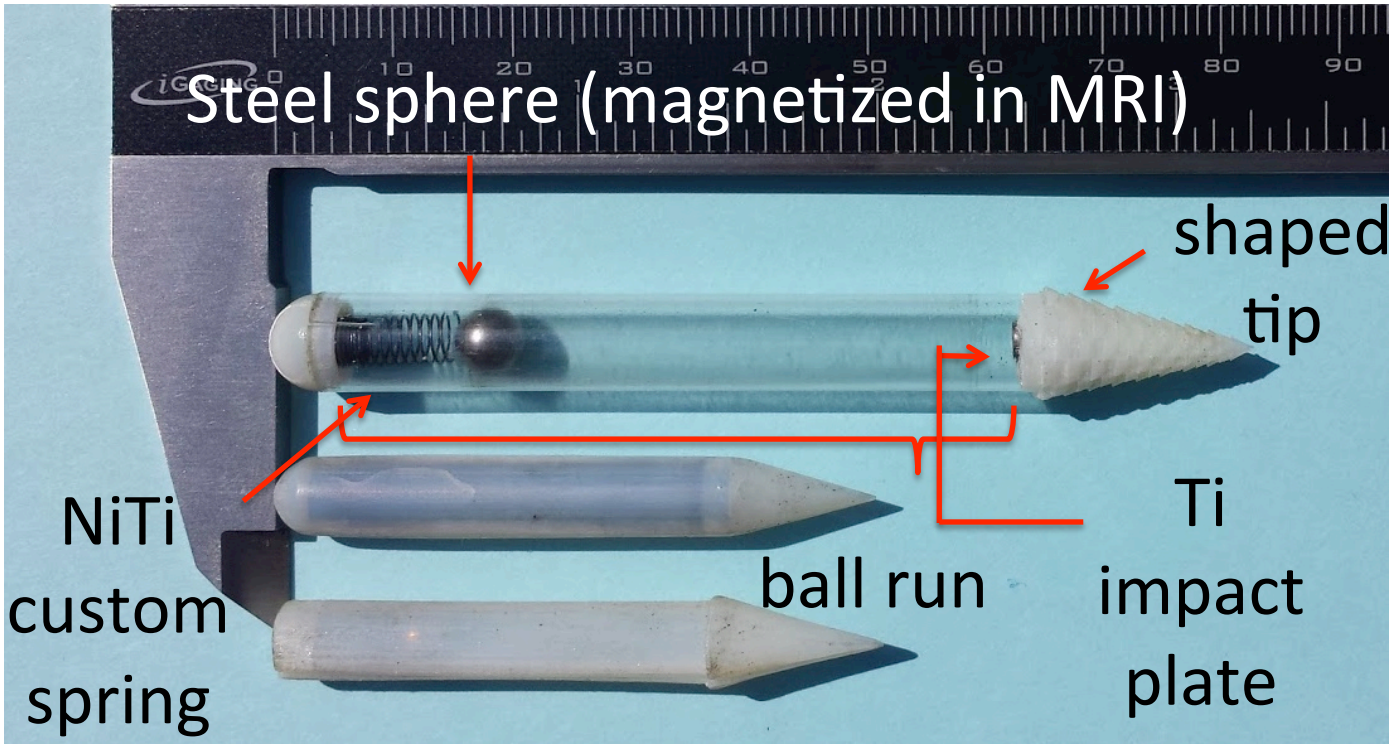
Firing in MRI



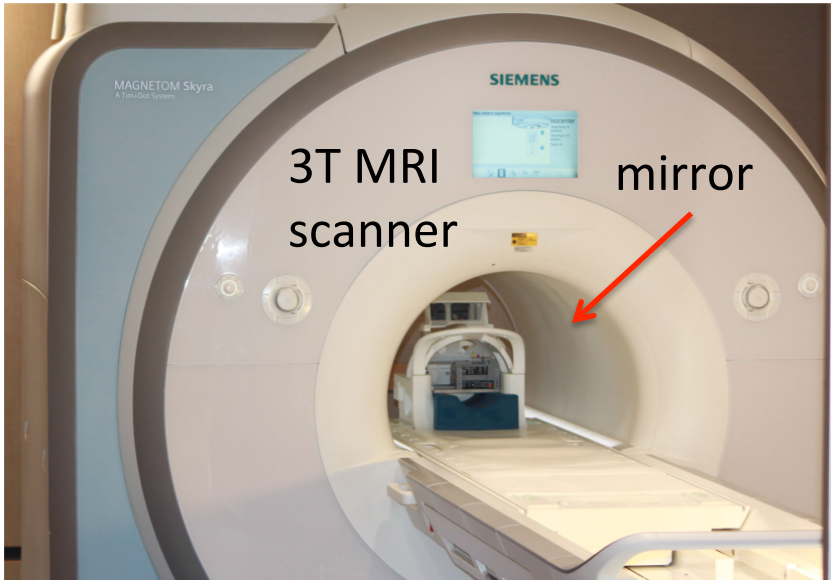
Gauss Gun

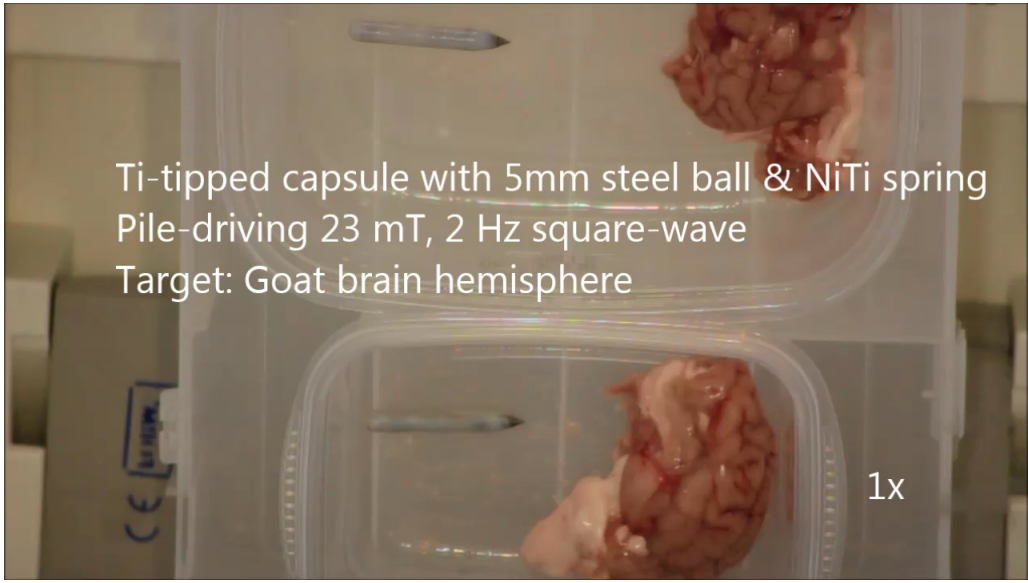

Gauss gun cut-away before firing
After firing
18-gauge needle
NO.311-me
GENERAL

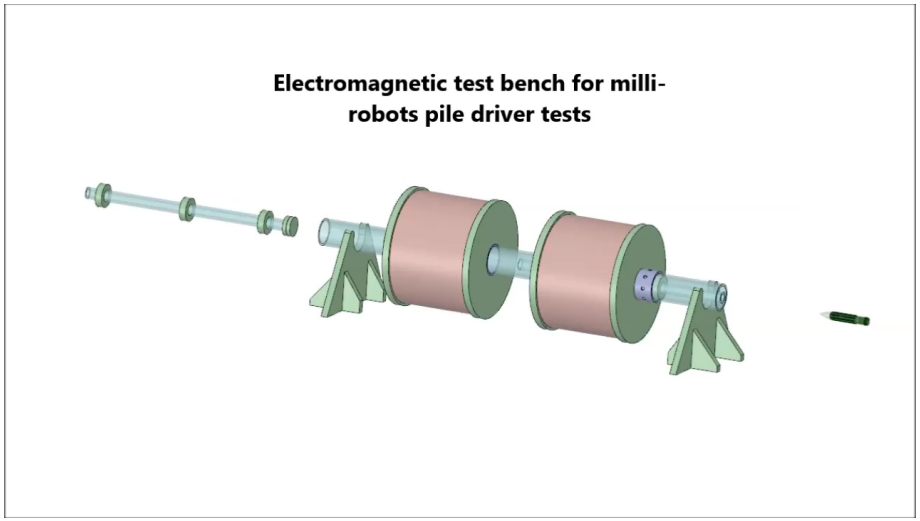
Design class #2: Pile-driver



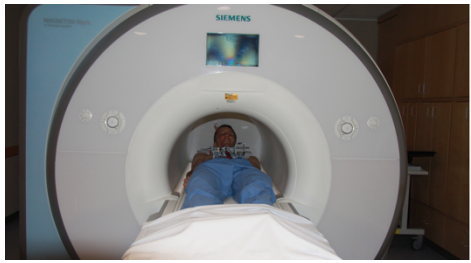
Current Tests of Pile-Driver





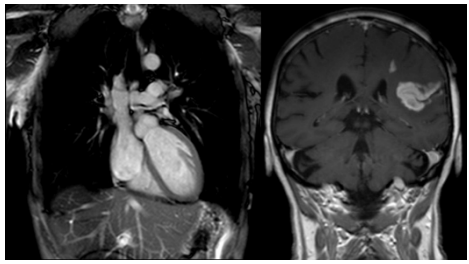


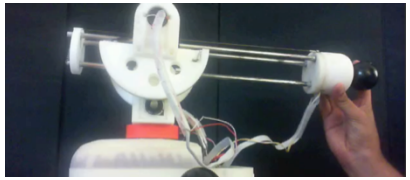
Broader Impacts



Transform minimally invasive interventions

- Real-time image guidance in 3D
- Tetherless delivery of targeted therapies
- Improve patient outcomes
  - faster recovery
  - fewer side effects
  - cost-effectiveness
- Clinical partnership in teaching hospital





Toolset for multi-agent control

- Foundation for medical therapies and surgical interventions
- Citizen science, multi-robot manipulation game, SwarmControl.net

Goal: Non-Invasive Surgery

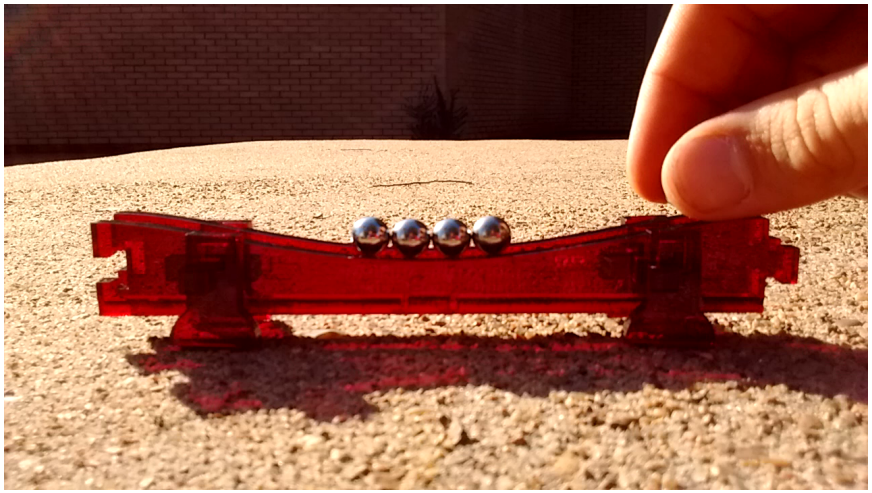
Immersive 3D Sight and Touch

Outreach

Small memento for you

Design: thingiverse.com/RobotSwarmControl

Instructions: https://youtu.be/IWAIx6-hRZI



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UNIVERSITY of HOUSTON

HOUSTON Methodist LEADING MEDICINE

Challenge:

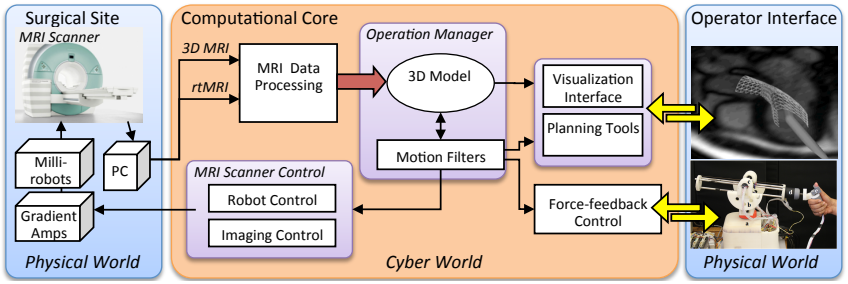
•Perform tetherless micro-surgery inside human body using unmodified MRI scanners

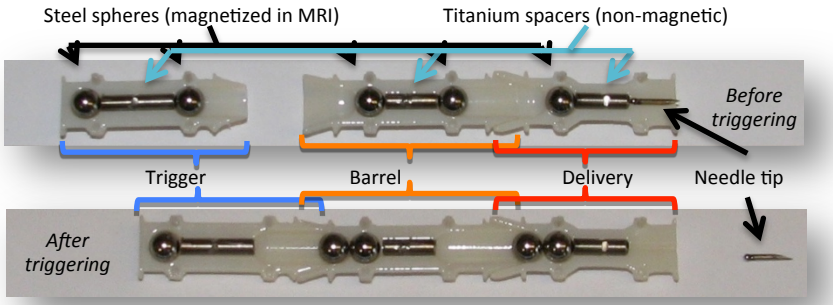
Solution:

MRI Gauss gun: stores magnetic potential energy, chain reaction releases energy when robots self-assemble

MRI pile-driver: converts kinetic energy into impulses to tunnel through tissue

Interactive MRI control: 3D operator immersion to world inside body (touch & sight)





Scientific Impact:

•Adaptive and Intelligent sensor-control (MRI)

•Sensor is also actuator: MRI wirelessly pushes millimeter-scale robots through blood vessels & heart chambers

•Immersive, real-time, interactive, man-in-the-loop control (for MRI operator)

Broader Impact:

•Transform minimally invasive surgery for localized therapy delivery (stem cells/chemo)

•Clinical partnership in teaching hospital

•Multi-agent control toolset

•Citizen-science, multi-robot manipulation game, *SwarmControl.net*

CPS 1646566 and 1646586

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