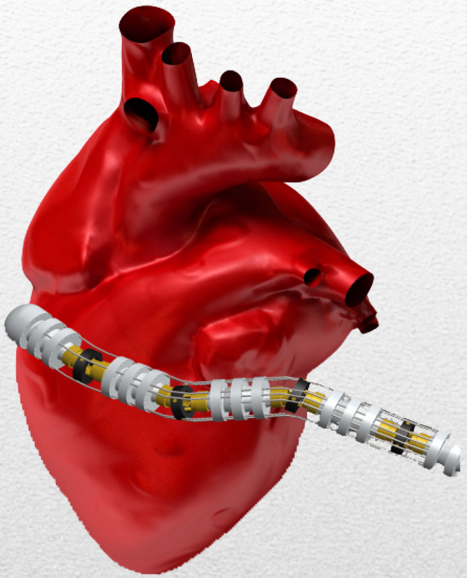
University of Patras
Department of Electrical and Computer Engineering

Design and Experimental Evaluation of SMA-based Tendon-driven Redundant Endoscopic Robotic Surgical Tools



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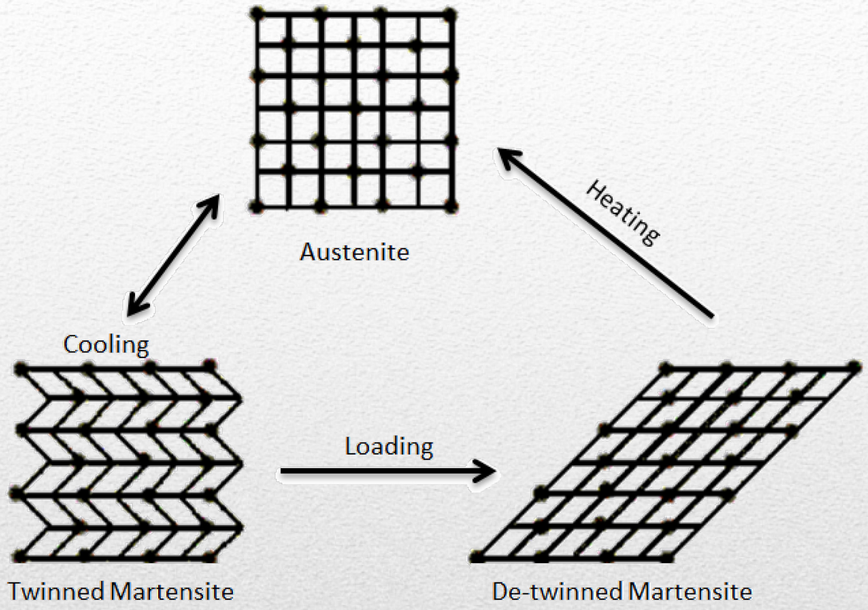
Shape Memory Alloys - SMA

- **SMA** are a group of metals that exhibit two unique properties,
  - Superelasticity and
  - Shape Memory Effect (SME).

- **SME** is the ability to recover to its previously determined dimensional configuration when heated above a certain transition temperature.

- **SMA** can produce large forces during their transformation.

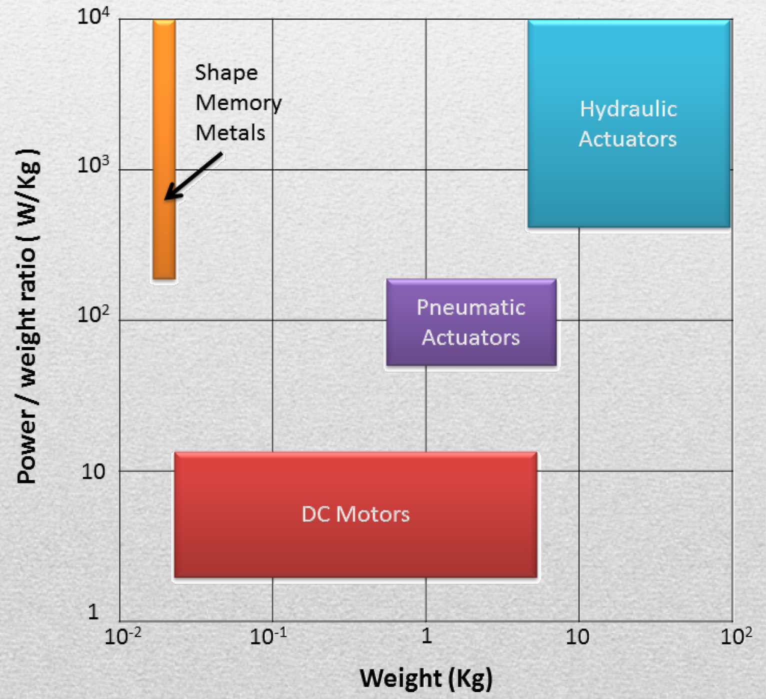
- The most widely used commercial SMA are **NiTi** alloys due to:
  - Greater ductility
  - Corrosion resistance
  - High Biocompatibility



Shape Memory Alloys

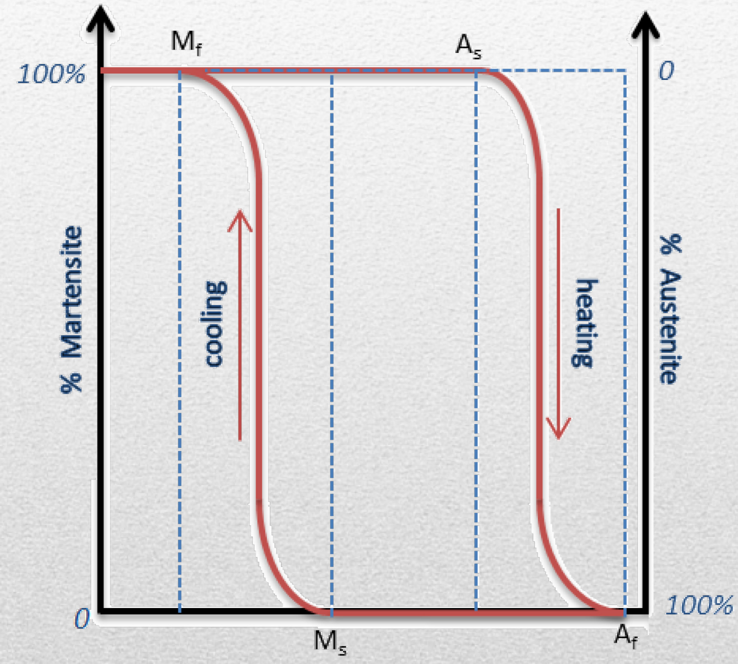
➢ **Advantages of SMA actuators**

- Compact, lightweight with high power/mass ratio and energy density
- Ease of actuation and low voltage requirement
- Clean, silent and spark free operation
- Long actuation life
- (>1.000.000 operation cycles)
- High biocompatibility (MRI compatibility)
- Excellent corrosion resistance
- Direct-driven



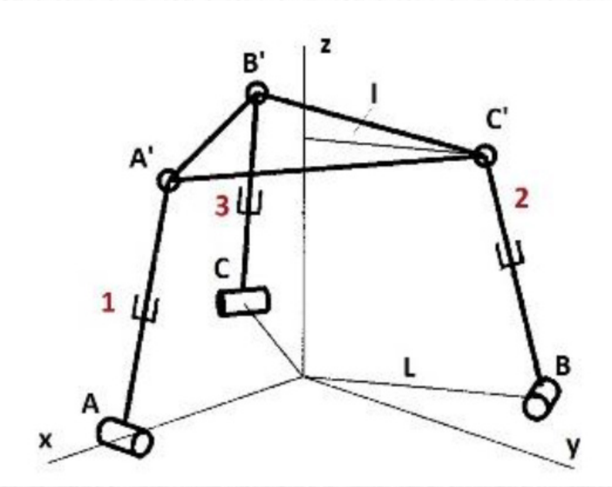
Shape Memory Alloys

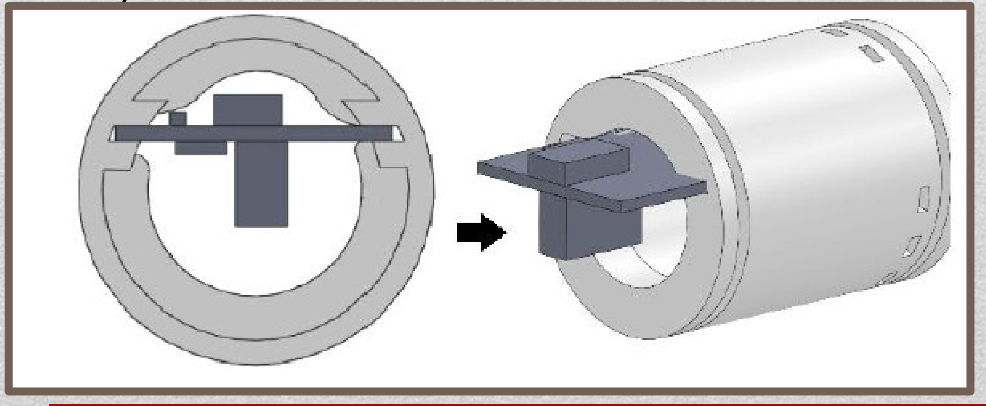
- **Limitations of SMA actuators**
  - Low displacement levels (3 – 4%)
  - Nonlinear Phenomena - Hysteresis
  - Control difficulties
  - Low power efficiency
  - Low operating frequency

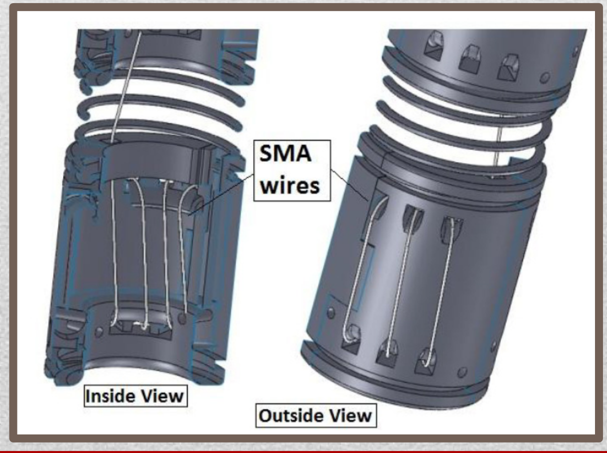


Prototype with embedded actuators

- Macroscopically serial robot
- 3 SMAs per 120° as prismatic actuators (they only pull, not push)-STEWART platform
- A spring replaces the spherical and rotational joints
- 8 modules were used for the tool (24 DOF)
- The SMAs are wrapped around the link wall
- Embedded custom made electronics
- Binary actuation







Prototype with embedded actuators

Data transmission using I2C protocol

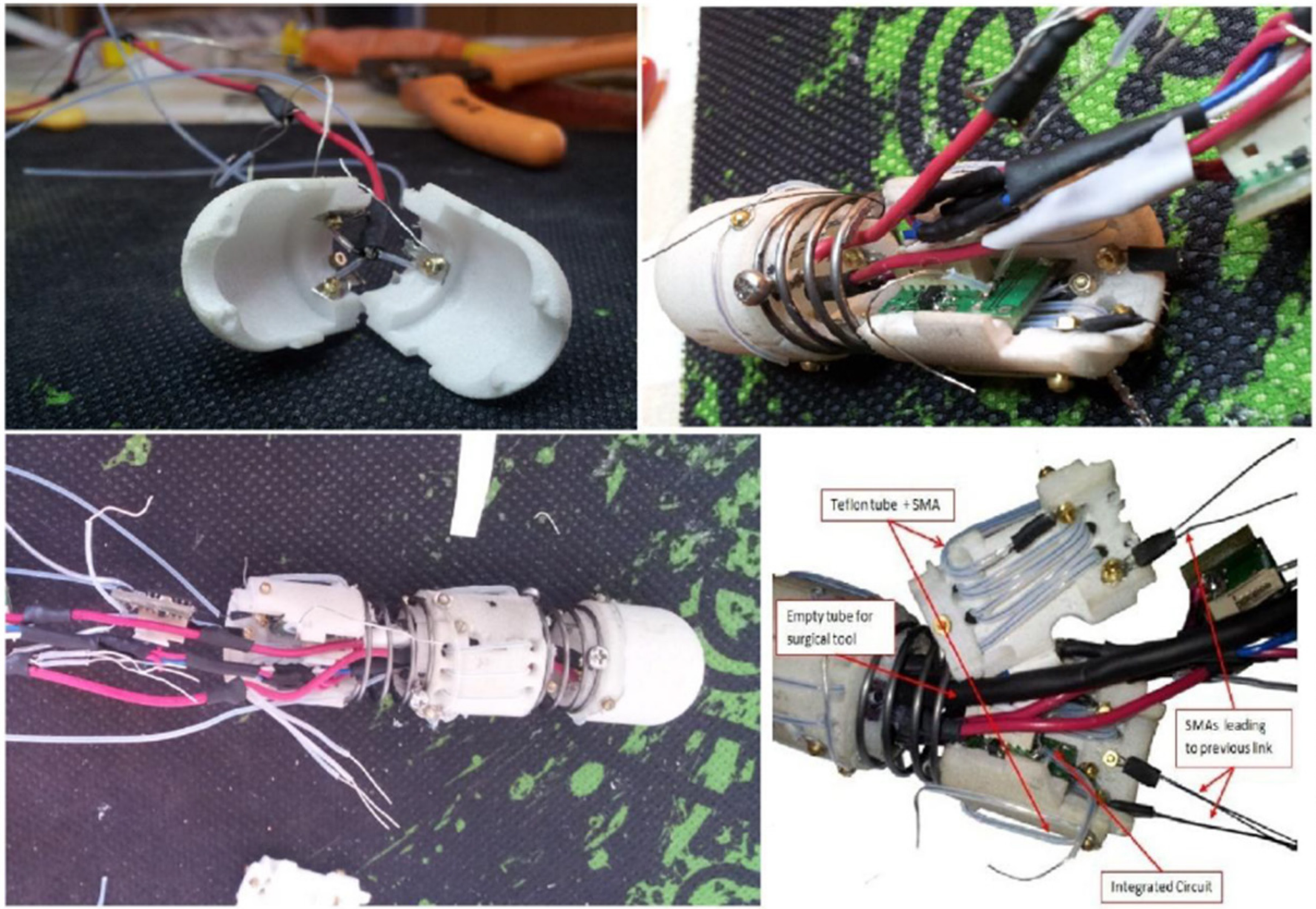
Binary robot → open loop control

Baud rate=4800 bit/sec

Power transmission through 1 cable

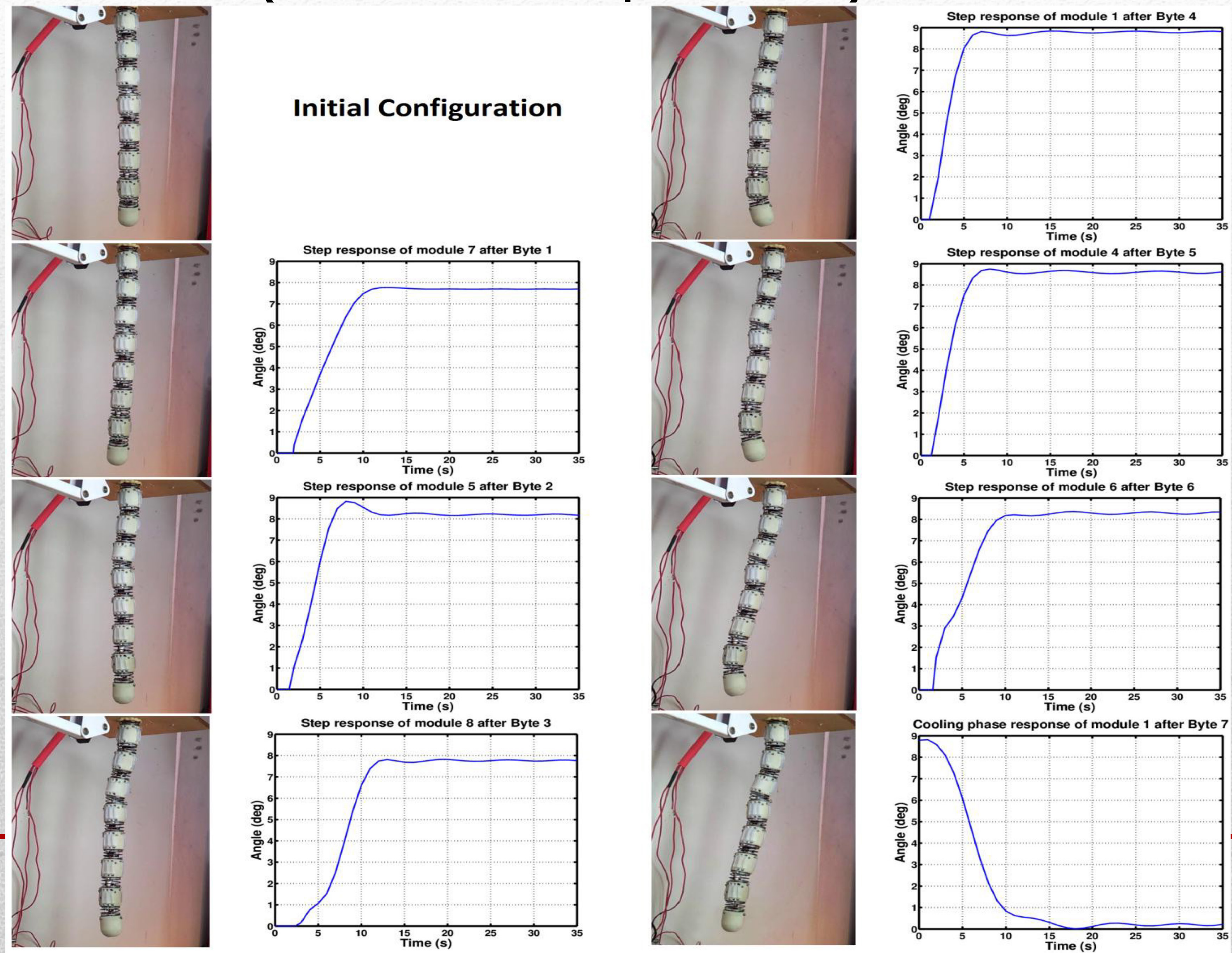
I^2C frequency=100kHz

PWM frequency=1kHz



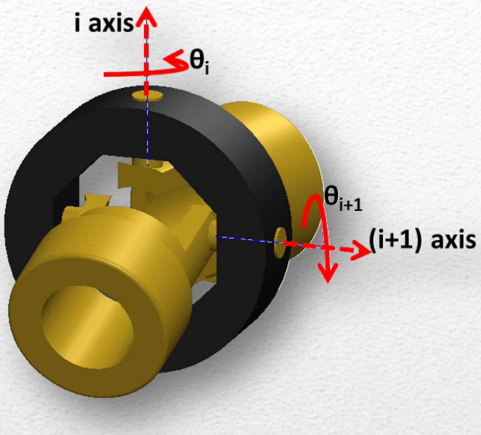
Prototype with embedded actuators

- Total length: **250 mm** Total weight: **80 g** Bending curvature: **90° degrees**
- Diameter: **20 mm (can be reduced up to 10 mm)**

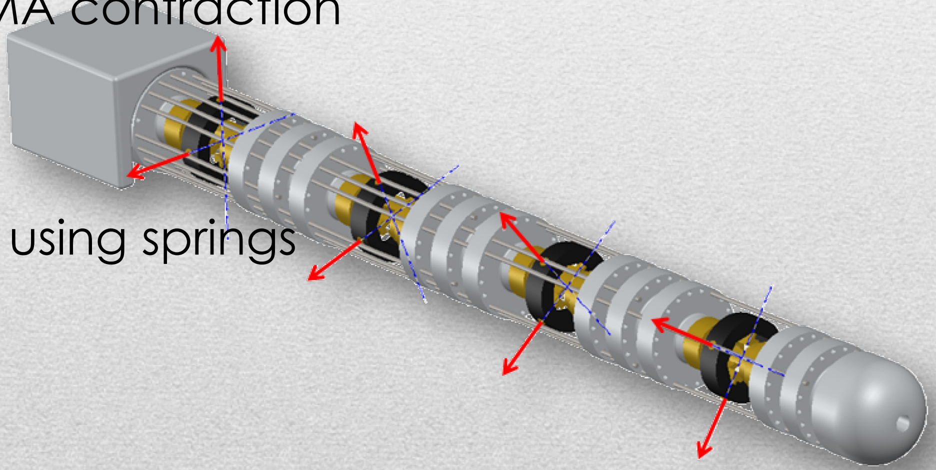


MRI-oriented prototype

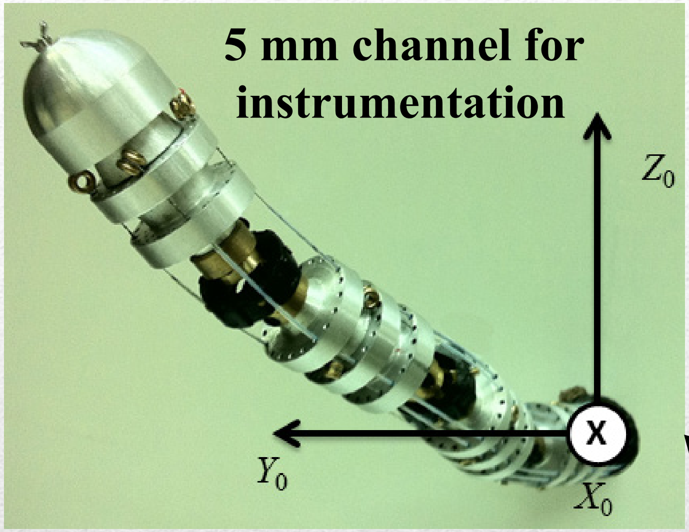
Manipulator Configuration

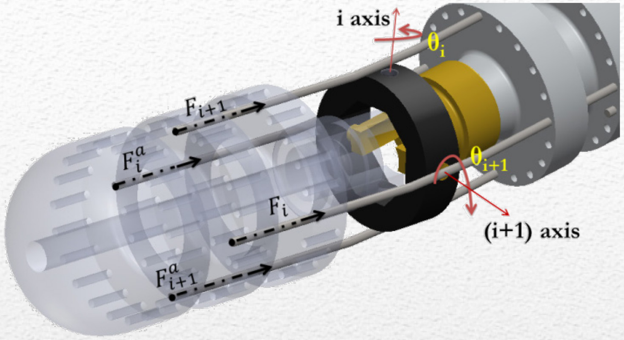


- SMA tendon-driven actuation system
- 8 independent rotational DOF implemented using universal/lateral joints
- All DOF are actively controlled via SMA contraction
- Continuous actuation
- Reverse bias forces for cyclic motion using springs
- Total length of 201 mm
- Diameter of 18 mm
- Total weight 150 gr

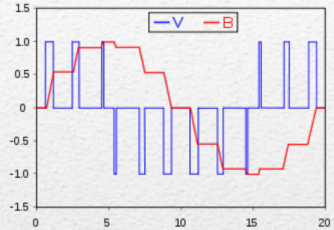


Actuation Mechanism





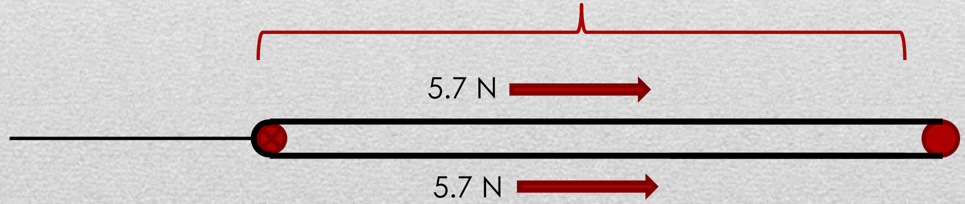
PWM signal



12 V DC

ARM 32-bit Cortex™ - M3

- NiTi alloys (Flexinol) diameter 0.2 mm
- Maximum Force 5.7 N per tendon
- Strain 4%
- Cooling Time 2.7 sec
- Current < 500 mA
- Dual housing Teflon tubes for improved cooling and internal insulation



Inverse Kinematics - Feedback

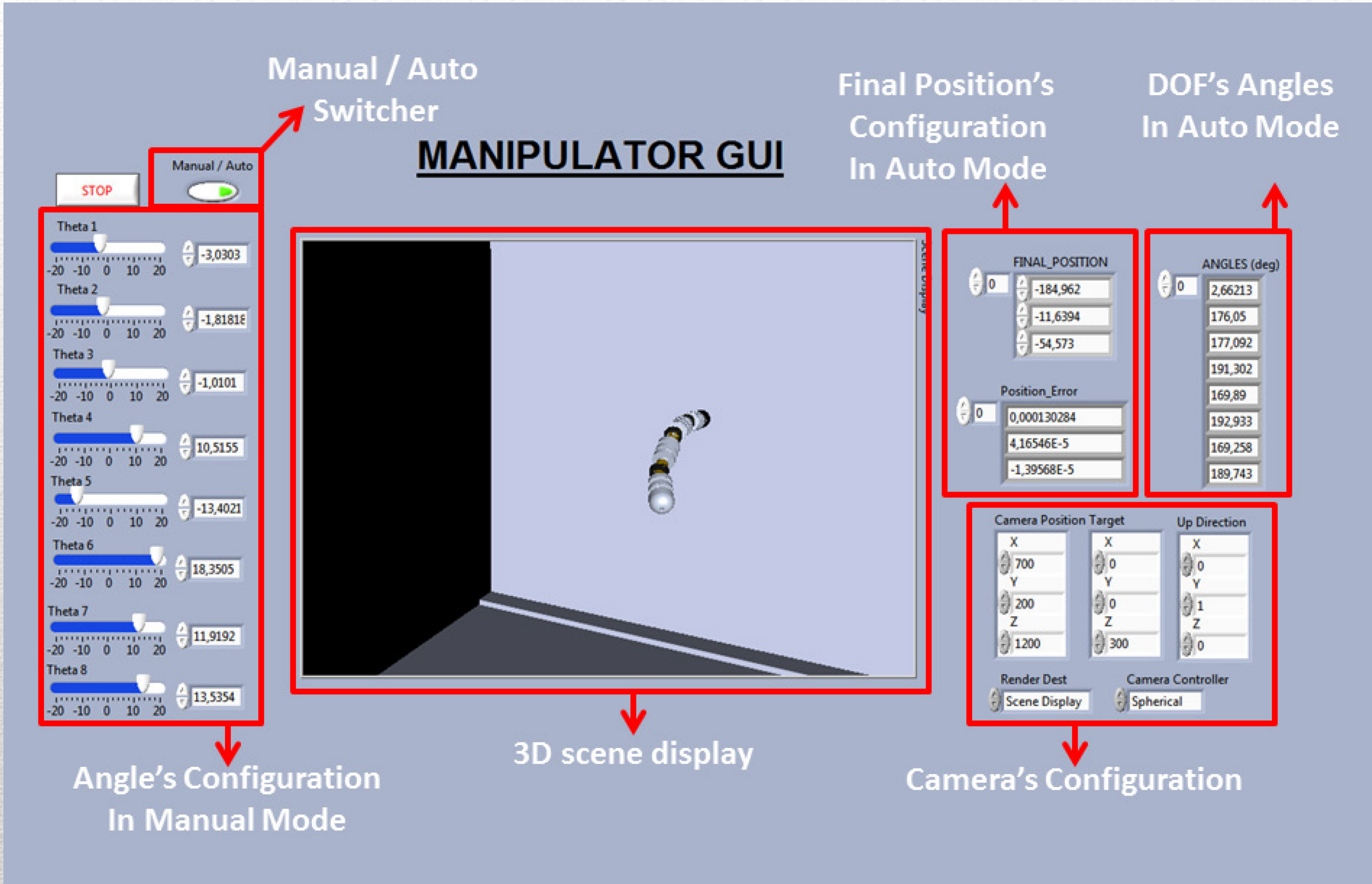
- Dual feedback from actuator resistance measurement and 3D CCD Vision system

A)The actuator's stroke is derived by measuring its resistance with the μC's 12-bit ADC.

B)The vision system is fixed and tracks a tip marker and solves an optimization problem (Sequential Quadratic Programming method) taking into account the dynamics.

- Data are fused using fuzzy logic.
- Real-time acquisition for A (<2ms) and 40 ms latency for B.

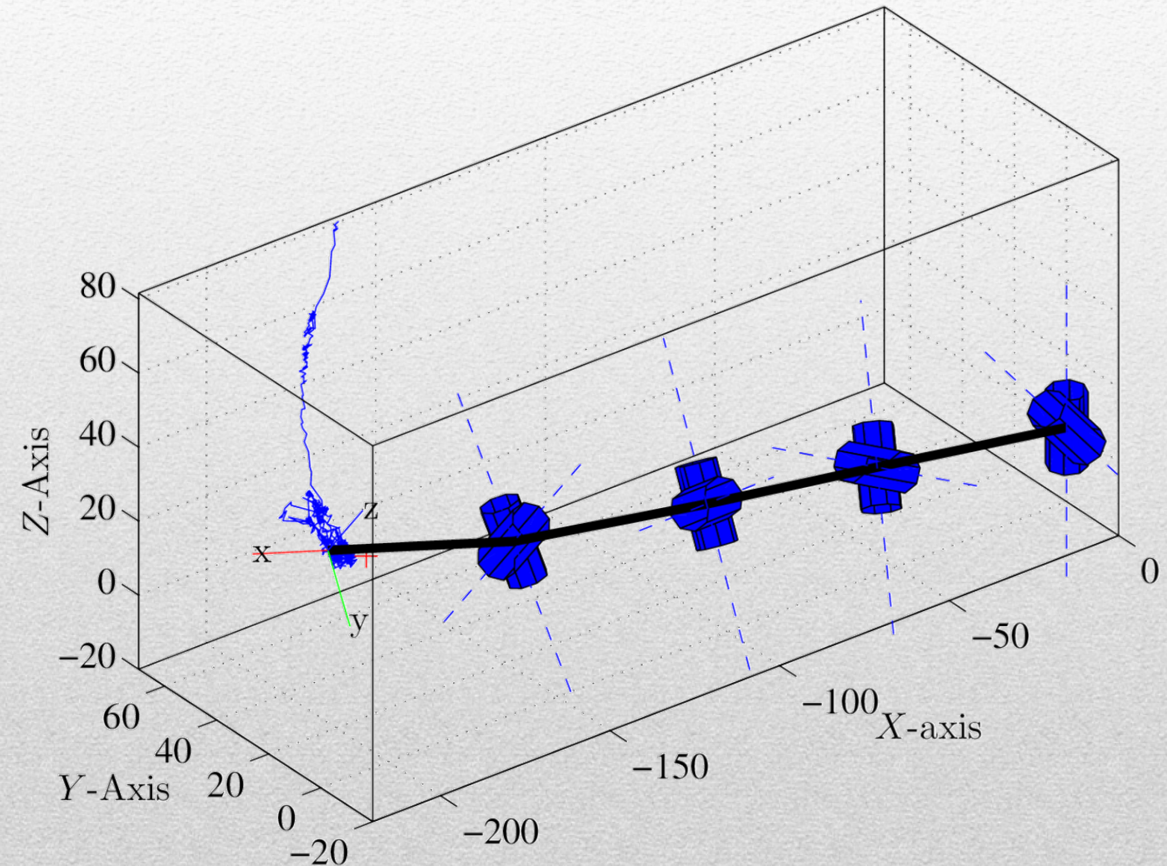
Graphical User Interface in Labview



Experimental Results

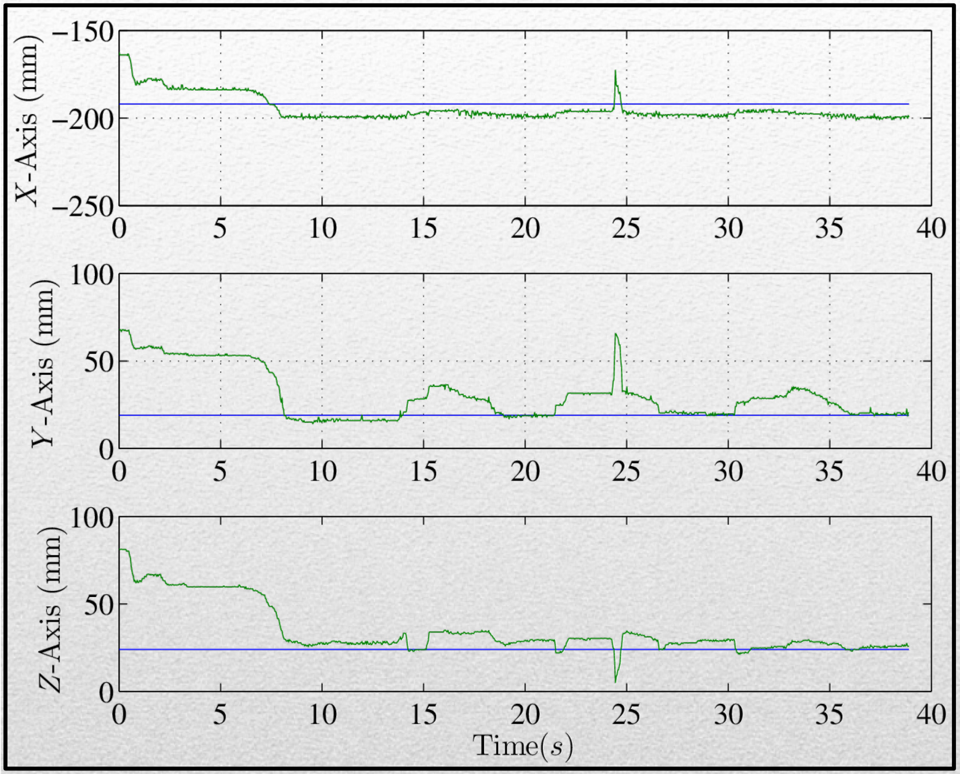
Experimental MIS-tool end-effector 3D-response

- 3D-trajectory from $[p_x, p_y, p_z]$ = [−162, 68, 81] mm to [−192, 19, 24] mm with 3 mm steady state error
- Over 5N force without flexing and over 10N with flexing

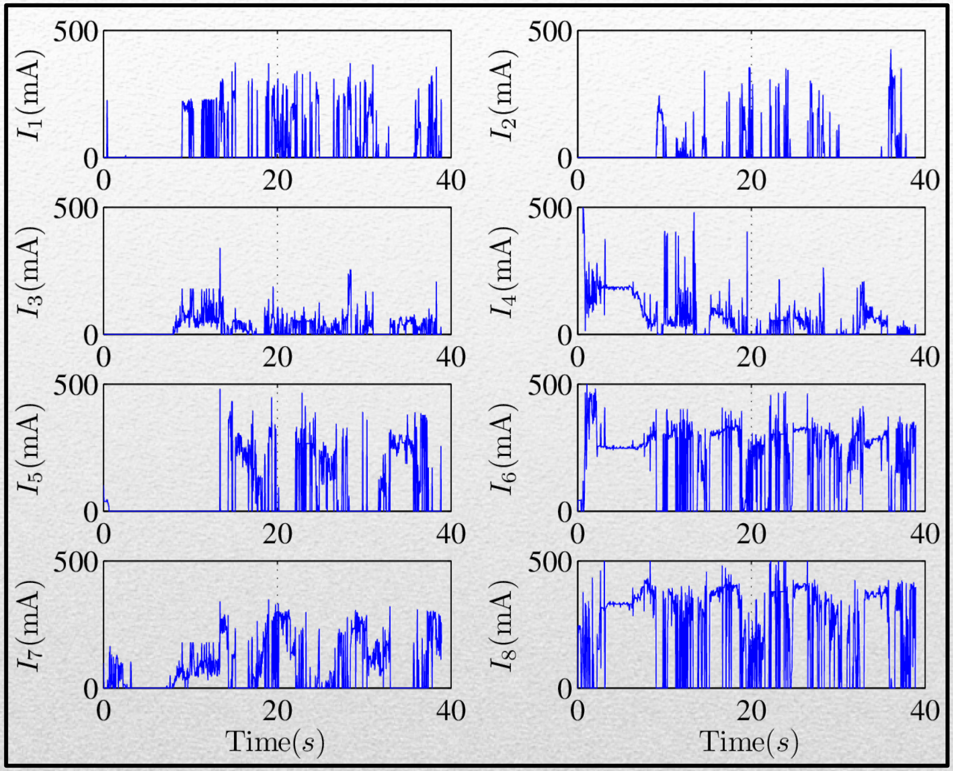


Experimental Results

XYZ Coordinates



SMA-supplied currents



- Maximum Heat Dissipation of 19.6 J/m^3
- Maximum Temperature increase of 10^oC at 5 mm distance from the actuator.

Conclusions

- SMA-based tendon driven actuation for surgical instrumentation is feasible.
- The tools featuring this kind of actuation can also be extremely miniature.
- Advanced control techniques are necessary to achieve fast response:
  - FEA analysis.
  - Preisah modeling of hysteresis.
  - Overcurrent during actuation.

  Etc.
- Cooling is not an issue if many small diameter actuators are used in a ribbon configuration.
- Quaternary alloys (Ni-Ti-Cu-Pu/Pe) expected to be commercialized within the next 3 years.

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Questions ?