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Speaker: Sohrab Eslami

Design and Manufacturing of Embedded Air-Muscles for a Magnetic Resonance Imaging Compatible Prostate Cancer Binary Manipulator

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1- Binary Manipulation

- This paper presents an embedded pneumatic actuator to improve resolution, size, joints hysteresis of an elastically binary manipulator.

- A binary manipulator uses the elastically averaged dielectric elastomer actuator (DEA).

- They used 20 air-muscles with no mechanical joints but lengthen to reach the a higher binary resolution.

Left: MRI control room. Right: Manipulator and patient on MRI table.
2- Proposed Design

The current air-muscle generally implemented is called McKibbens but are highly nonlinear and requires attaching to the frame that causes friction.

The proposed air-muscles are composed of a radially reinforced membrane with molded ribs that limit radial expansion to favor lengthening under pressure.

Pressure inside the air-muscle is kept constant using a 2L reservoir at the entrance of the pneumatic circuit.

A room-temperature vulcanized (RTV) silicone elastomer is chosen for its slow viscoelastic response and small relaxation.

Manufacturing process takes about 6h.
3- Design Models

Manipulator model computes workspace size and resolution and overall stiffness using air-muscle stress-strain characteristic as an input.

\[ F_{P_{\text{max}}} \approx P_{\text{max}} \pi r^2 \]
\[ k = \frac{EA}{L} = \frac{2E \pi r t}{L} \]

\[ \sigma_{11} = 2\left( \lambda_1^2 - \frac{1}{\lambda_1} \right) \frac{\partial W}{\partial h_1} = 2\left( \lambda_1^2 - \frac{1}{\lambda_1} \right) \]
\[ \times \left( C_1 + 2C_2 \left( \lambda_1^2 + \frac{2}{\lambda_1} - 3 \right) + 3C_3 \left( \lambda_1^2 + \frac{2}{\lambda_1} - 3 \right)^2 \right) \]
4- Results

Left: Predicted workspace (needle tip positions) of the manipulator using 12 nonembedded air-muscles.
Right: Predicted workspace of the manipulator using 20 embedded air-muscles. Dotted line: Required workspace. Full line: Healthy prostate
4- Results (continued)

Elastically averaged effect (gray arrow) of the actuation of one air-muscle (black) on end-effector

\[ \Delta X \approx \sum u_k d_k \]

Validation of the manipulator model (20 random targets)

Manipulator during MRI gel insertions
Insertion tests in ballistic gel

MR images are acquired with a multislice gradient echo sequence with the following parameters:
TR/TE = 50/4.58 ms,
number of averages = 4,
FOV = (280 x 280) mm²,
slice thickness = 3 mm,
matrix size = 256 mm x 128 mm,
reconstructed to 512 mm x 512 mm.
5- Conclusions and Outreach

This paper presents the design, manufacturing of embedded air-muscles for an MRI-compatible manipulator for prostate cancer and treatment.

Considered 4 types of air-muscle design models: geometrical design, FEA, 1D model, experimental model.

Workspace, stiffness and precision of the binary manipulator are evaluated.

Under 1.5T MRI, the MR compatibility of the system was tested.