Multi-material Additive Manufacturing of Polymer Robotic Structures for Interventional Radiology

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Medical Context

Image-guided Surgery

Image for Guidance

- **Imaging devices are more and more used for guidance** during interventions in surgery and radiology
- **Image-guided surgery** can offer a better pathology management

Interventional Radiology

- **Interventional radiology**: use of imaging devices such as CT or MRI scanners for surgical tool guidance
- **Percutaneous procedures**: use of needles for biopsy or local treatment

Several Issues

- With CT or CBCT scanner, **X-Ray exposition** is a major issue for the radiologist
- MRI scanners offer long and narrow bores, with **reduced access** to the patient
- **Needle insertion accuracy** is difficult to maintain: 3D control from 2D images is challenging with lack of **dexterity** & ergonomy

Several Issues

- **Very long learning curve**
- **Radiologist experience critical** for the **task success**
- **Training cost** is significant
- **Robotic assistance** can be helpful

Assistance with Robotics

Perfint, Robio EX System

- Needle positioning device for CT-guided procedures
- **Limitations:**
  - **Bulky** system
  - **Manual needle insertion** which means X-Ray exposition if per op imaging is being used
  - **No compensation** of patient and organ movements

Assistance with Robotics

iSYS, iSYS 1

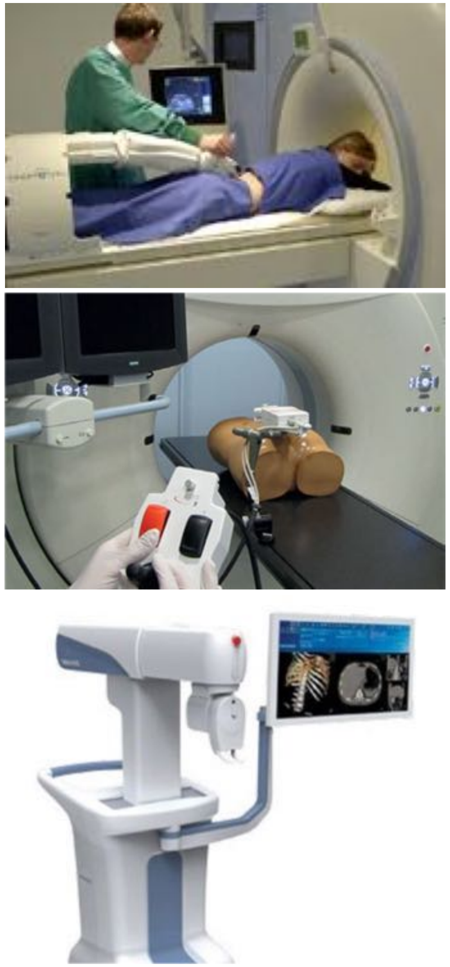
- Remote manipulation for needle path guidance
- **Limitations**:
  - **Manual insertion**
  - **Not MRI compatible**
  - Table mounted: **no compensation** of patient and organ motions

Assistance with Robotics

Innomedic, Innomotion

- MRI compatible system for needle positioning
- **Limitations**:
  - Table mounted system, **no compensation** of patient and organ motions
  - **Cumbersome** system

Assistance with Robotics



- Need for robotic solutions:
  - **To control needle kinematics** in the challenging environment of MR, CT, CBCT imaging devices
  - To **actuate** motions, with sufficient safety and **without degradation of image quality**
  - **Compact** enough for patient-mounted approaches

Motivations for MMAM

3D Printing to Improve Solutions

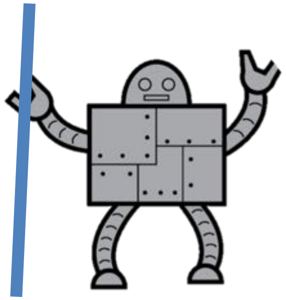
Requirements

Compatibility (MRI)

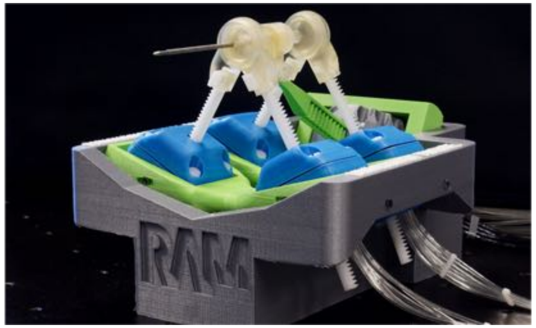
Compactness and
light weight

Advantages of 3D Printing

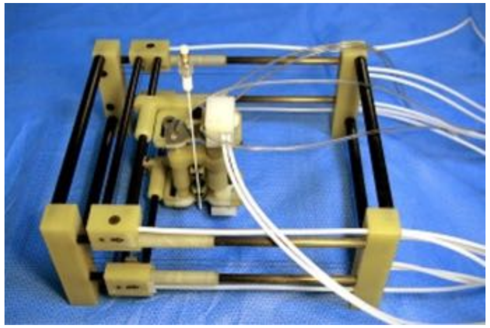
Use of polymer
materials



Reduction of the
number of
assemblies



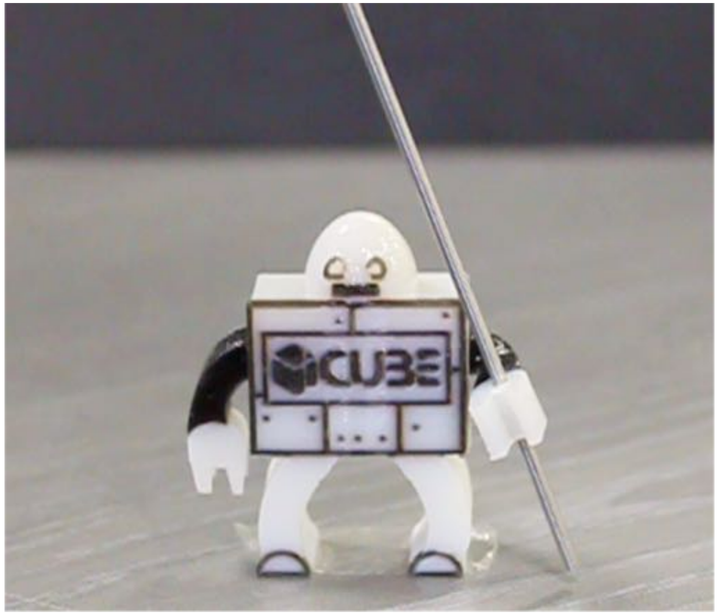
[Stormram 3, U. Twente]



[LPR, U. Grenoble-Alpes]

[Robopsy, MIT]

Interest of MMAM



- Freedom of shape at no cost
- Freedom in the choice of materials within a part
- Flexible parts to obtain movements

Performances of Interest

Geometrical accuracy

- Minimum feature size: 1mm
- Accuracy: 0.1mm
- Flatness < 0,1mm
- Angular errors < 0,1°

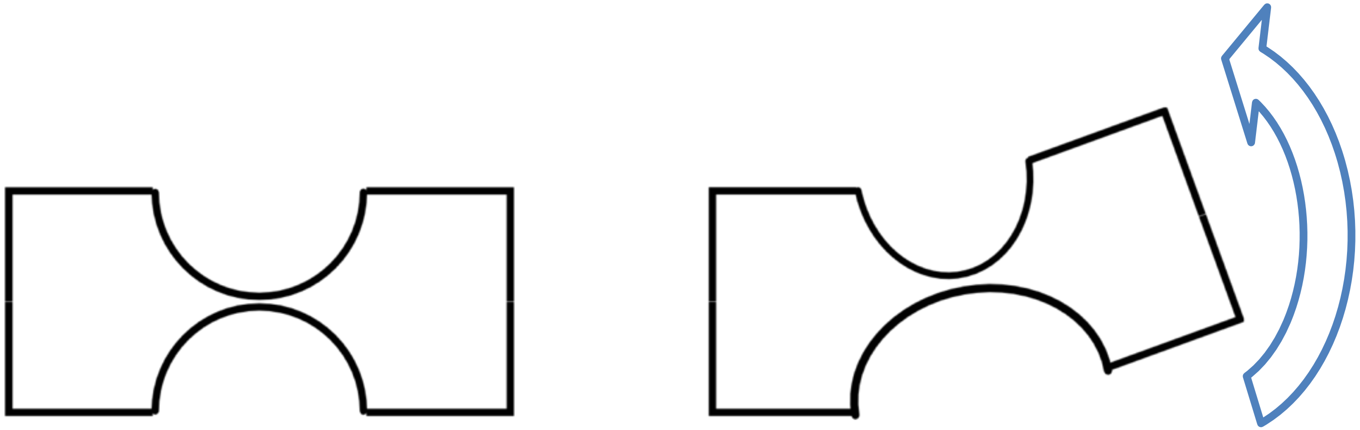
Material behavior

- One elastic material (E = 1800 MPa)
- One soft material (E = 1 MPa), hyper-elastic and incompressible, >60% strain
- Resistance of material interfaces
- Gamma sterilization can be applied to both materials

MMAM for Robot Architectures

Revolute joint based on MMAM

Well-known design: notch-type compliant joint

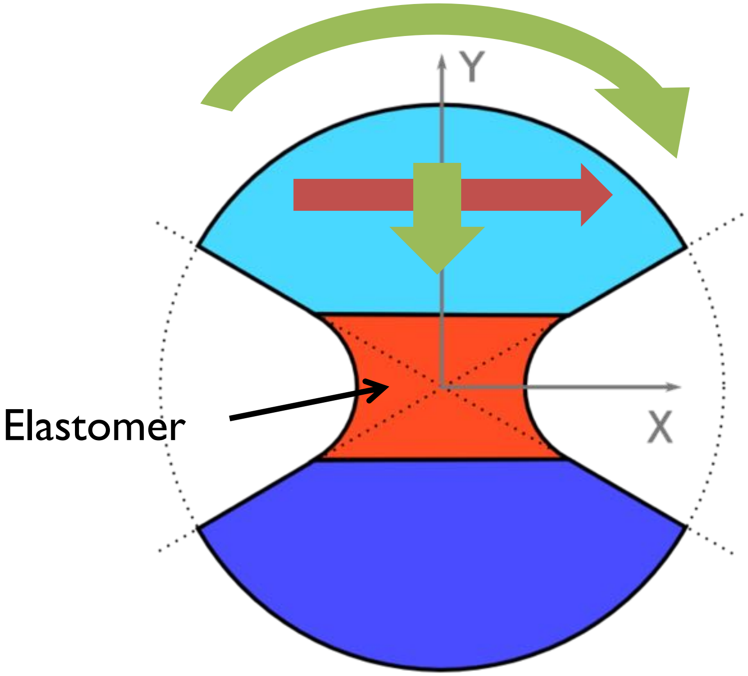


Properties:

- 🟢 High compactness
- 🔴 Large range of motion
- 🔴 Low rotational stiffness
- 🟢 High accuracy

Revolute joint based on MMAM

Freedom in material selection: elastomer at the center of the joint



Remark:

- High stiffness along negative Y because material incompressibility

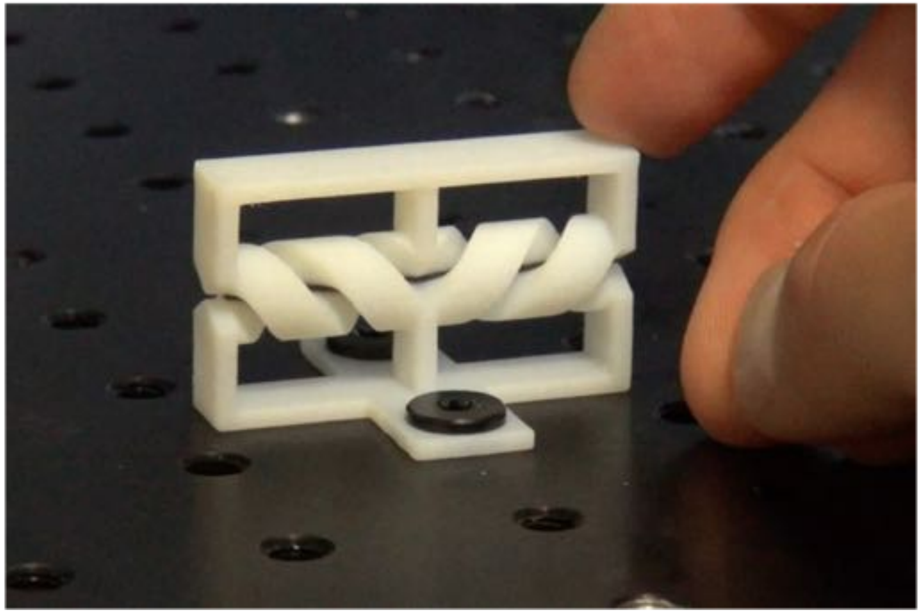
Properties:

- 🟢 High compactness
- 🟢 Large range of motion
- 🟢 Low rotational stiffness
- 🔴 High accuracy

Revolute joint based on MMAM

Freedom of shape of MMAM:

- Helical sweep to place sections with different orientations in parallel
- Two helices with opposite pitches to get symmetrical behavior



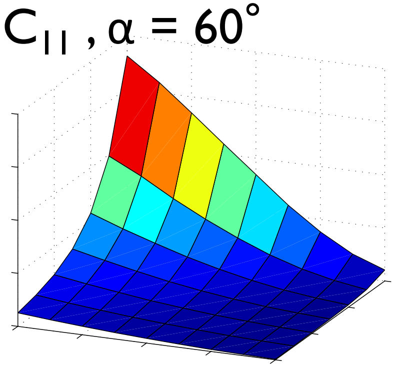
Properties:

- High compactness
- Large range of motion
- Low rotational stiffness
- High accuracy

A standardized component

Numerical and experimental studies

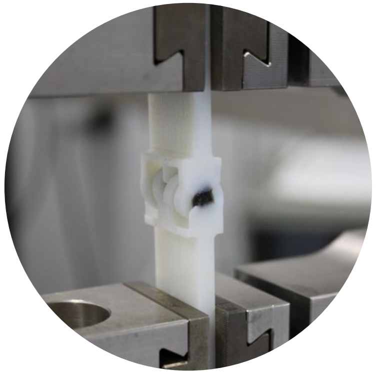
- FEA to explore the performances of all possible geometries
- Experimental measurement of the stiffness matrix and the range of motion
- Setup of a design method to ensure the performances of the joints taking into account the process impact



Design Charts

Results: an « off the shelf » component

- With a design method to select the geometry
- With a design method to ensure that the actual performances match those requirements
- With adequate performances for single-use or limited number of uses in a device (hundreds of cycles)



Kinematic architectures

Needle manipulation with compact compliant architectures

- A spherical architecture with Remote Center of Motion as a single part (RCM accuracy: 0.4 mm, 80°cone workspace)

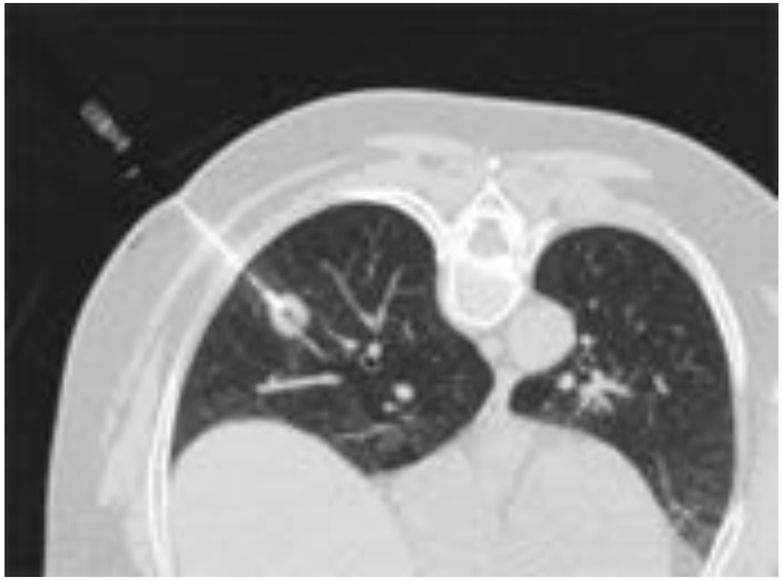
Kinematic architectures

Needle manipulation with compact compliant architectures

- A spherical architecture with Remote Center of Motion as a single part (RCM accuracy: 0.4 mm, 80°cone workspace)
- Serial or parallel architectures can be designed as compact systems

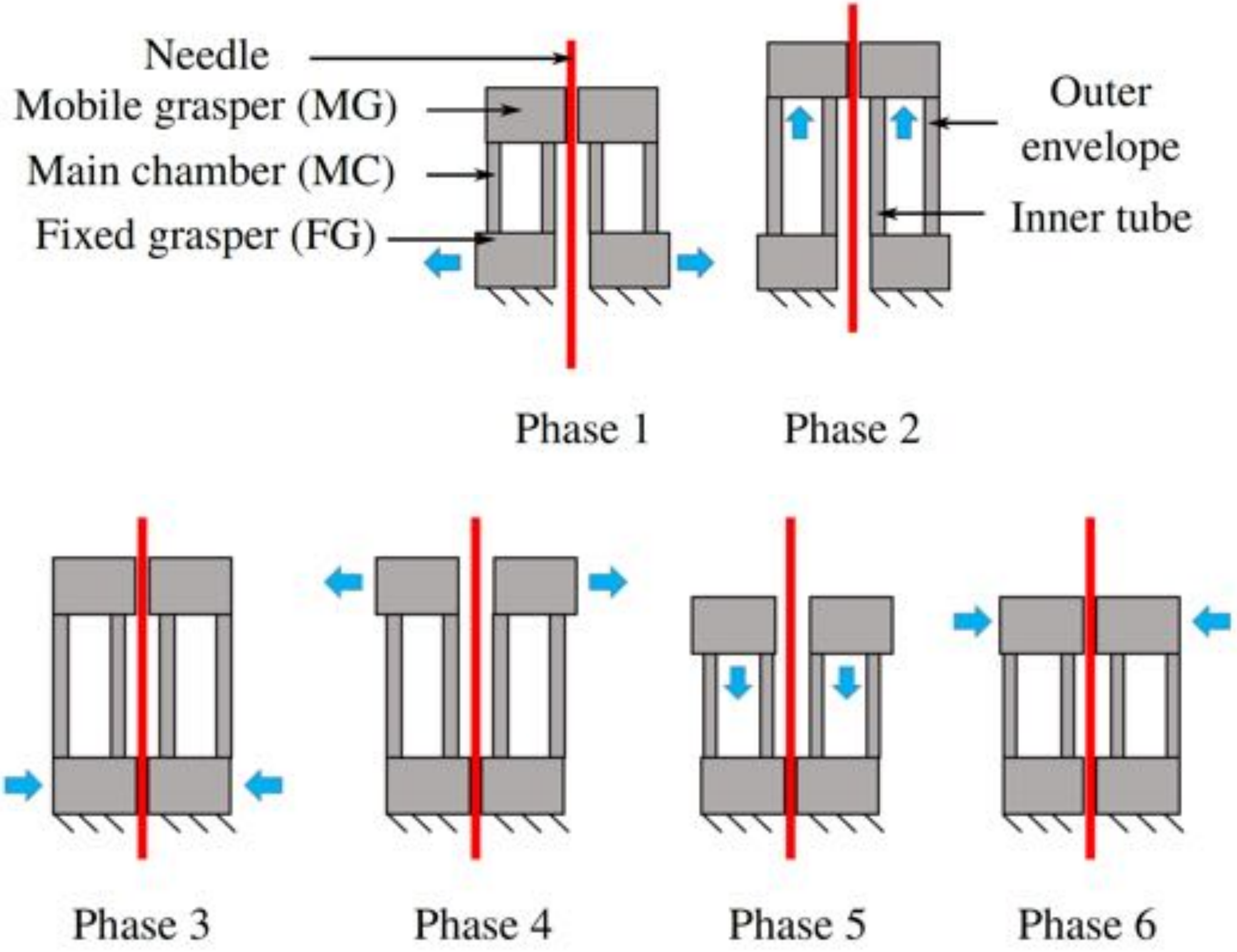
MMAM for Actuation

Main Requirements for a Needle Driver

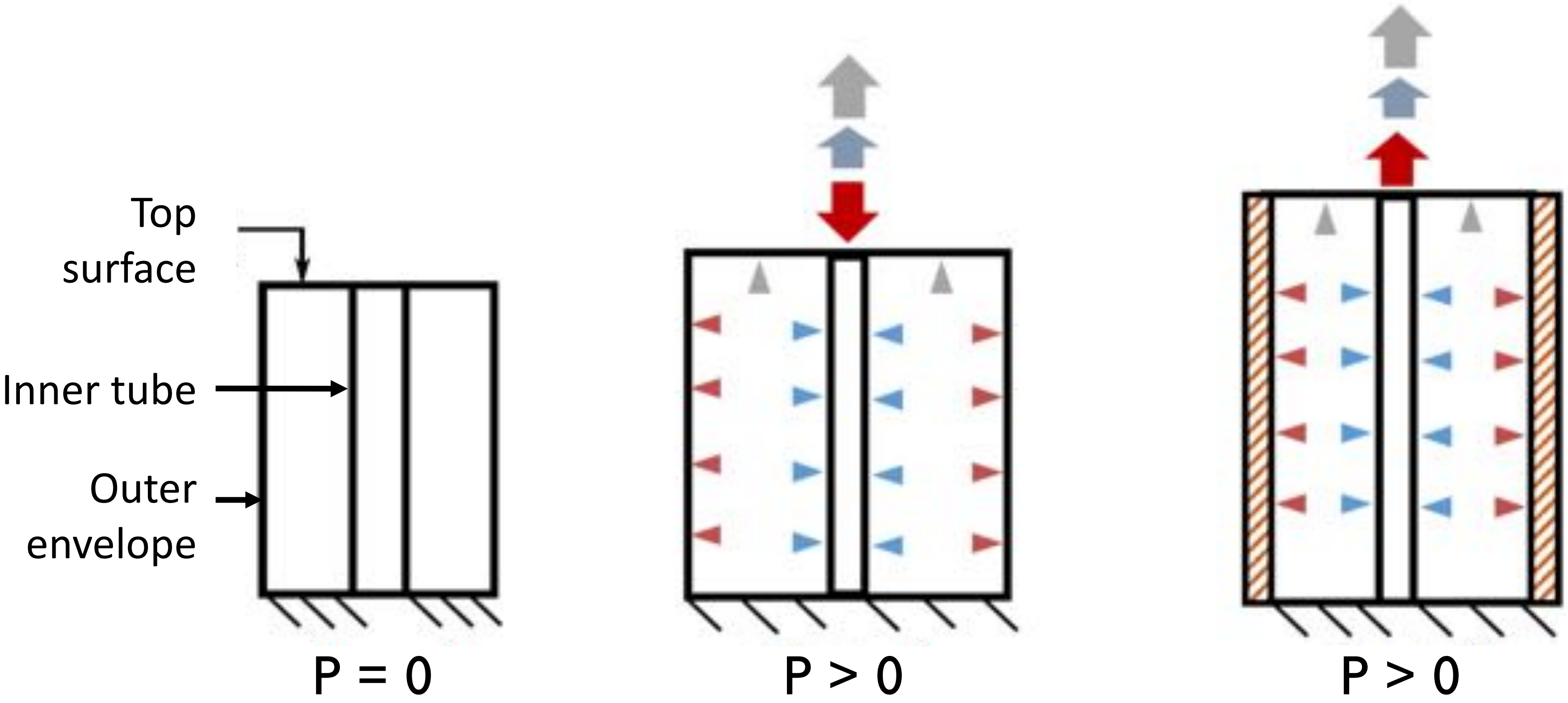


- Insertion force: 2 N
- Velocity: 1mm/s
- Lateral stiffness g.t. needle lateral stiffness
- Diameter and length l.t. 30 mm
- Compatible with X-ray and MRI

Inchworm Kinematics



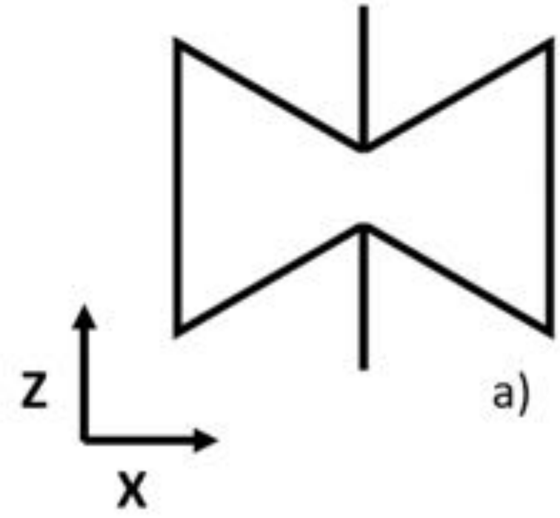
Use of metamaterial



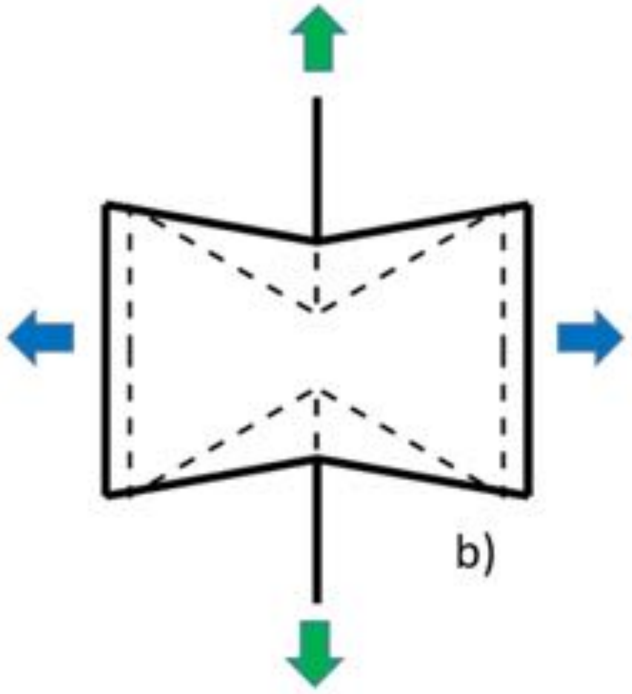
Conventional material
Positive Poisson ratio
→ **Axial contraction**

Metamaterial
Negative Poisson ratio
→ **Increased axial displacement**

Auxetic material

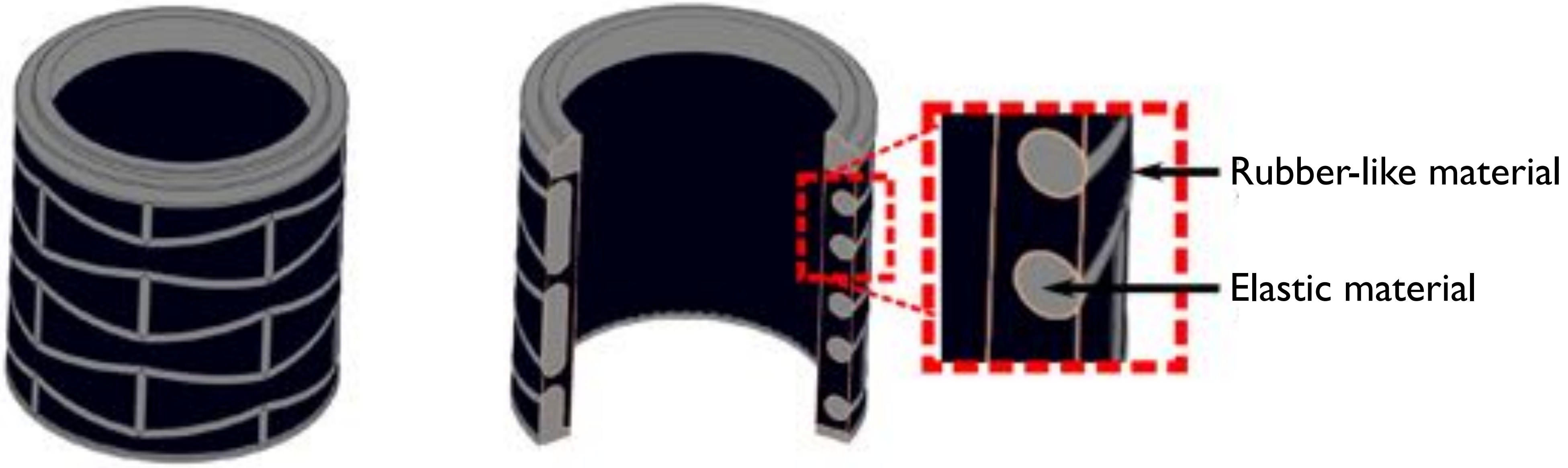


Inverted honeycomb with no load



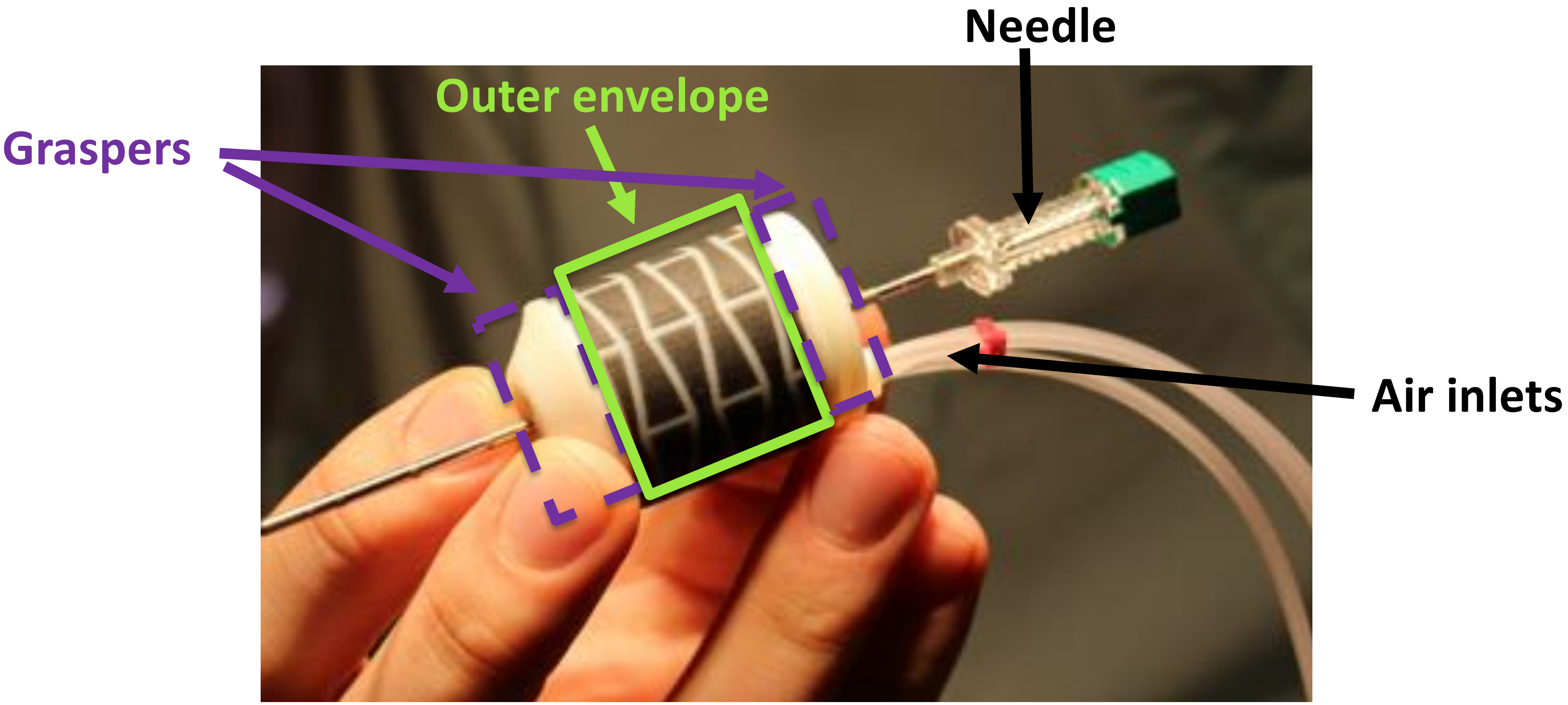
Displacement along X implies displacement along Z → negative Poisson ratio

Design of the outer envelope using MMAM

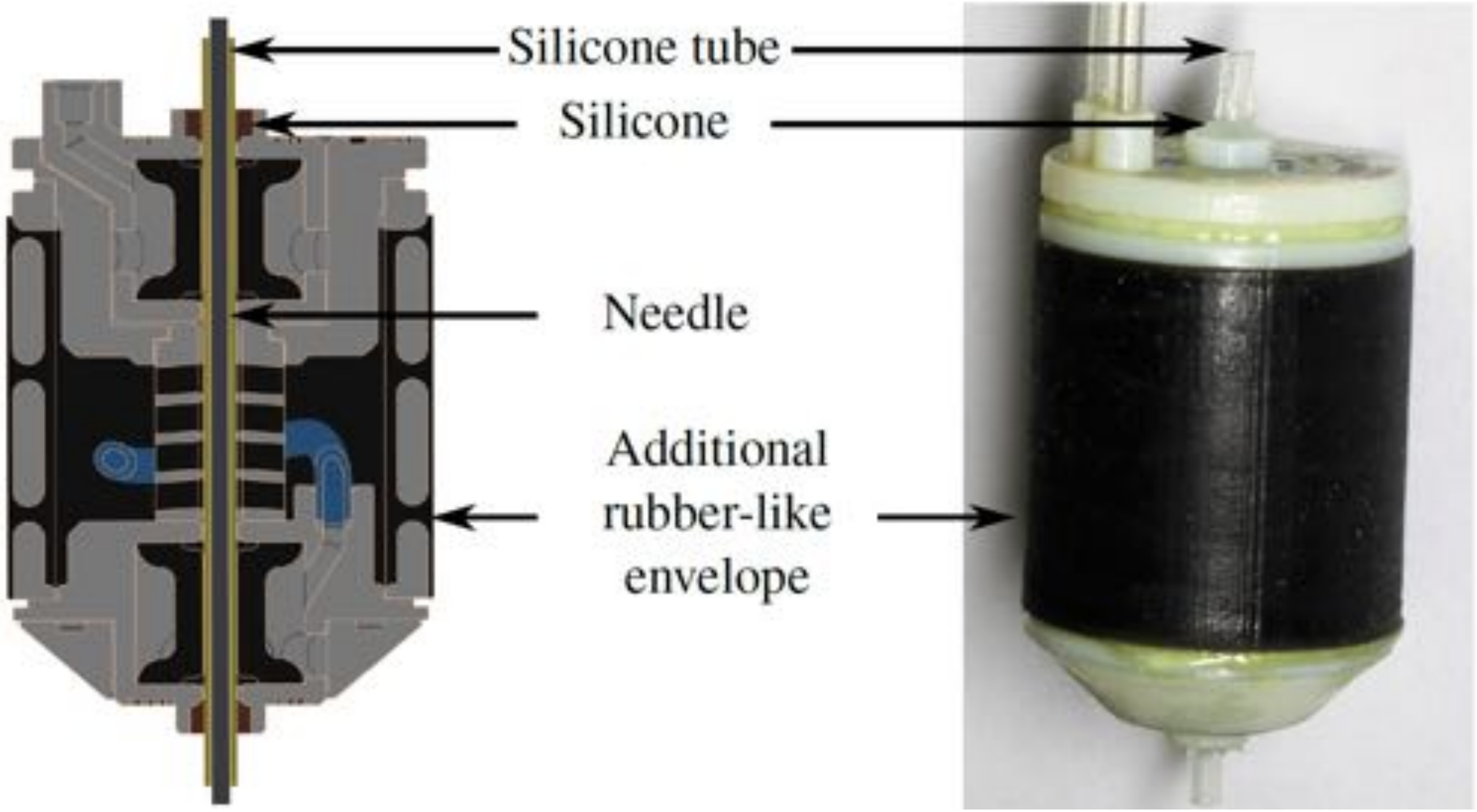


- Elastic material used:
  - **To get the auxetic behavior**
  - **To ensure driver stiffness**
- Rubber-like material used for **hermetic chamber**

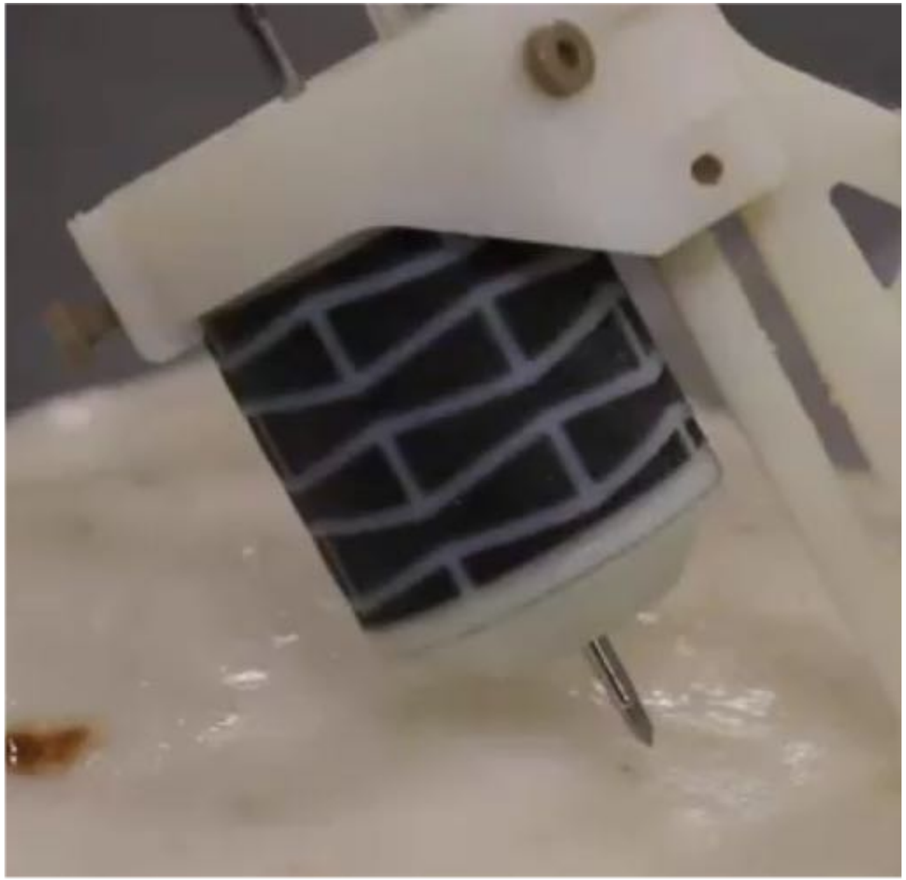
Implementation



Implementation



Insertion Characteristics



- Step size around 0.5 mm
- No load velocity: 0.65 mm/s
- During insertion in biomechanical phantom: 0.4 mm/s

Integration and Medical Impact

Robotic Assistance

Targeted procedures

- Biopsies on liver, lung, kidney

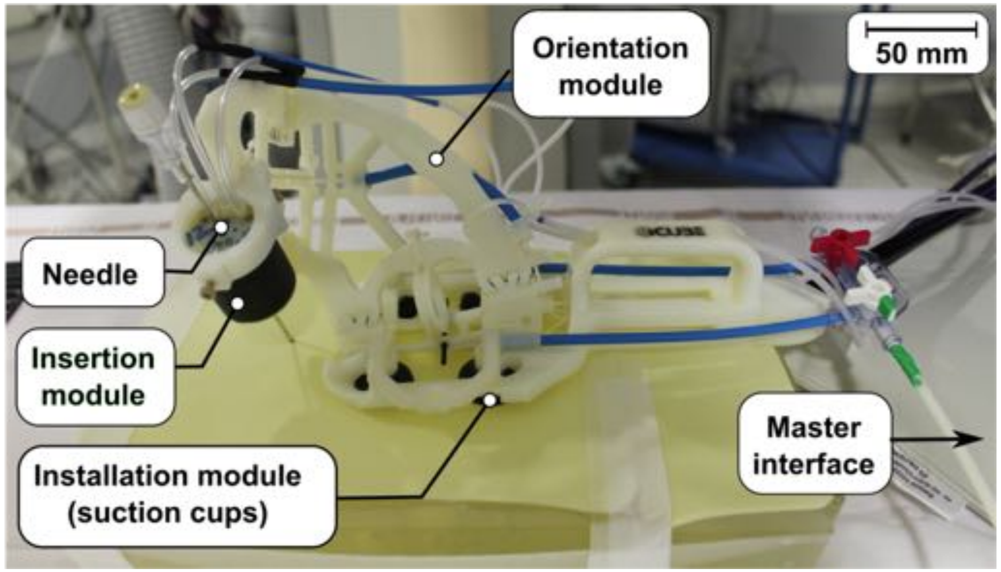
Approach

- To rely on dedicated assistance software now being integrated in medical imagers
- Not to use robot registration, but direct control by the radiologist

Method for determination of specifications & workflow

- Observation of procedures in France & Germany (> 35h in MRI, CT)
- Identification of required functionalities and associated workflow
- Validation with the radiologists

Assessment in CBCT

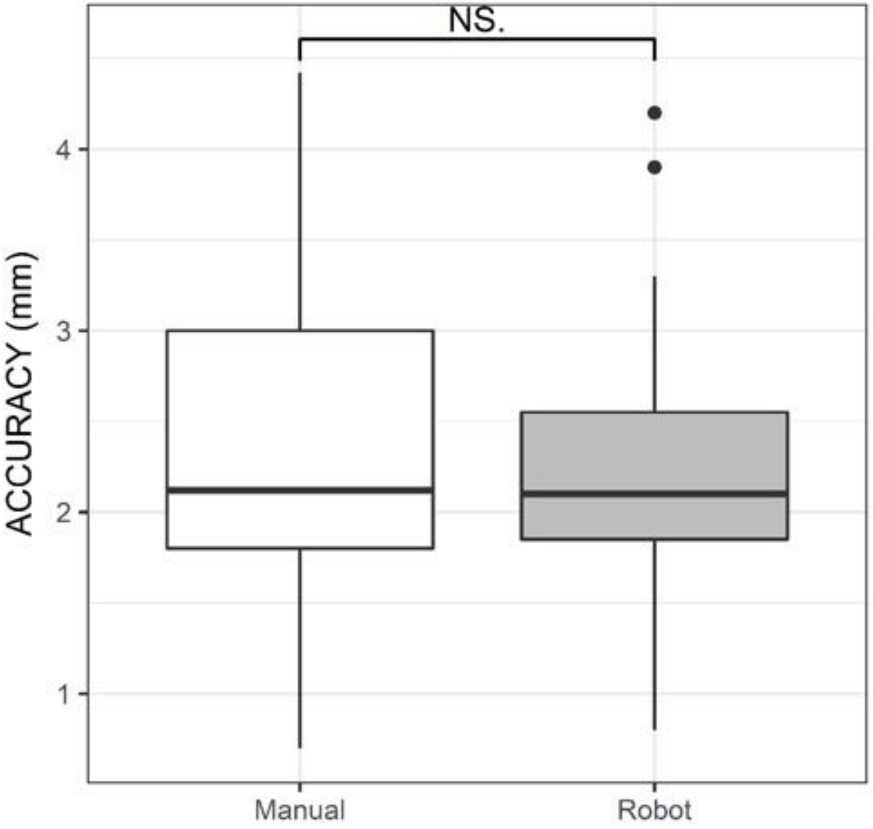


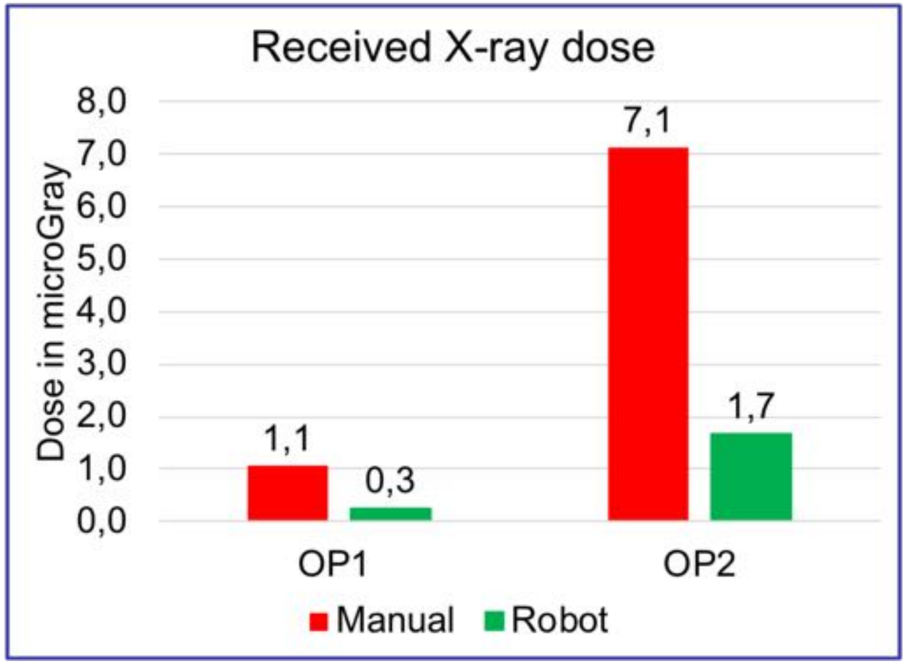
- Remote control of orientation and insertion
- Manual adjustment of insertion point
- Phantom to simulate skin and tissue stiffness with embedded targets

Assessment in CBCT

- 2 operators with no experience of robot
- 17 manual, 16 robot-assisted insertions
- Measurement of accuracy and X-ray exposition with dosimeters on operator hands

Evaluation


NS.
ACCURACY (mm)
1
2
3
4
Manual
Robot


Received X-ray dose
Dose in microGray
8,0
7,0
6,0
5,0
4,0
3,0
2,0
1,0
0,0
1,1
0,3
7,1
1,7
OP1
OP2
Manual
Robot

Conclusions & Perspectives

Conclusions

- Design based on MMAM can open possibilities for **robot architectures, actuation and also sensing.**
- **Fluidic actuation** of interest in combination **with MMAM**. Hydraulic solutions under investigation.
- Integration of **active materials**, and fabrication of **micro-structures** of interest for news designs of sensors or actuators

Acknowledgement

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Thank you for your attention

INVESTISSEMENTS D'AVENIR

robotex

CAMI
COMPUTER ASSISTED
MEDICAL INTERVENTIONS

interreg

Dépasser les frontières :
projet après projet
Der Oberrhein wächst zusammen,
mit jedem Projekt

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