Conceptual Design of a Soft Robot for Applications in Magnetic Resonance Imaging

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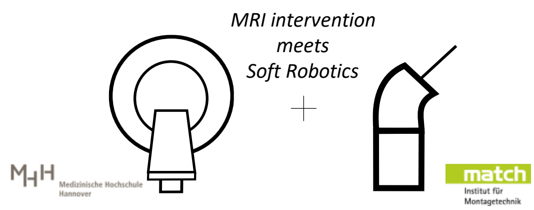
Introduction

One of the main issues of interventions with magnetic resonance imaging (MRI) is the limited working space and the resulting non-ergonomic working position of the interventionalist. For this reason, robotics is gaining interest, but due to the MRI compatibility traditional robots, made of metal and driven electronically do not offer a sufficient solution.

Soft material robots without electrical components and driven by pneumatic pressure, could solve this problem. Additional advantages are the flexibility, biocompatibility and a lower risk in human-robot interactions [1].

In cooperation with the Hannover Medical School (MHH), an MRI soft robot is designed to be used in **percutaneous tumour ablation**. Based on the use case of a liver tumour, a concept for the safe positioning and insertion of an applicator was created. Percutaneous tumour ablation is a minimally invasive image-guided diagnostic and therapeutic procedure for the treatment of tumours. The tumour cells can be killed with the help of a local temperature change through a probe [2].

In this project MRI robotics will be augmented with a flexible and compliant robotic concept with potential for case-unspecific use. This involves easy replacement and length adjustment of a soft robot. Therefore, a list with requirements for an MRI compatible soft robot was created. During the procedure, the robot must be able to absorb accidental impacts without performing any significant movement while providing a certain elasticity.



Method

Important requirements for an MRI-safe soft robot are:

- Compatibility standard ASTM F2503-20 and prevention of electromagnetic interference or image artifacts.
- The ability to hold the puncturing needle and its own weight without yielding to the weight in the operating state.
- The ability to achieve a certain rigidity in order to bring the medical instrument to the desired location and keep it stable and secure.
- An attachment to the couch or in the bore of the MRI.

Based on the requirements the first developed actuator concept is the MRTCyloneRob (MRT Cylindric Silicone Robot):

- Not designed as one rigid body, but in the form of several cylinders
- Overall length of 98 mm with three cylinders, each with a semi-circular shaped air channel and a central cavity for granular jamming (Fig. 1)

The second concept is an adoption of the well-known STIFF-FLOP robot [3]:

- The diameter was increased from 25 mm to 27 mm and the air channels were moved slightly further away from the center (Fig. 2).

Experimental Protocol: A finite element analysis was used to investigate the resistance to gravity, the maximum pressure and the achievable bending of the soft robotic concepts. The actuators were tested in an experimental setup with six OptiTrack cameras for position tracking. The pressure was increased in steps of 5000 Pa while the deflection of the actuators tip was measured.

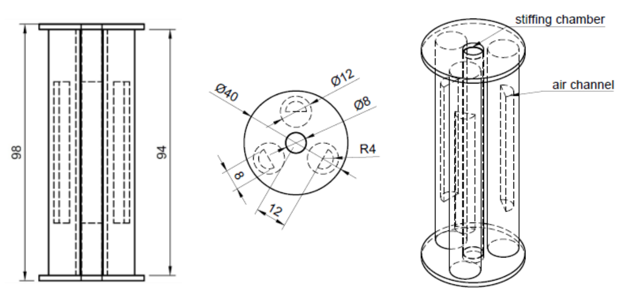


Figure 1 – Construction drawing of MRTCyloneRob

Results

MRTCyloneRob*:* The total deflection and bending achieved during multiple tests at 0.9 bar is on average 29.67 mm and 16.76 °. The deflection curve shows an asymptotic behavior (Fig. 3).

STIFF-FLOP: The deflection achieved during multiple tests at 0.8 bar is on average 12.91 mm. This equals an angle of 14.79 °. The deflection curve shows a linear behavior (Fig. 4).

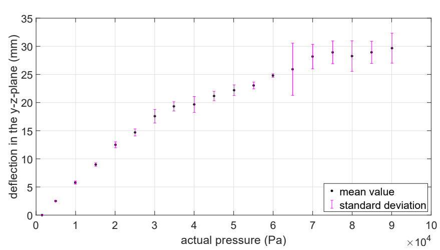


Figure 3 – Deflection of the MRTCyloneRob under pressure

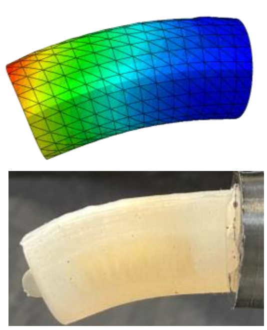


Figure 2 - Simulation and experimental results of one STIFF-FLOP module

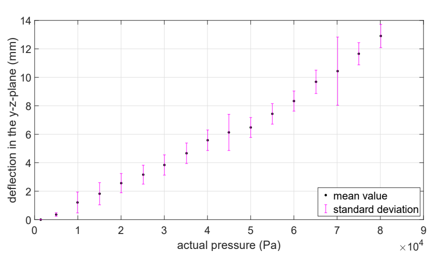


Figure 4 – Deflection of STIFF-FLOP under pressure

Discussion

The promising results presented in this poster show potential for the proposed usage as actuators for applications in an MRI intervention like the percutaneous tumour ablation. The used materials do not interfere with the MRI and therefore do not affect the imaging process. The achieved bending is sufficient for a multi-segment soft robot like the concept shown in Fig. 5.

Outlook:

- Optimizing the dimensions of the actuators (this concerns the diameter and the length).
- In this way, modularity will be simplified, and fewer actuators are needed to reach the target range.
- Evaluating the stiffness with different experiments including the medical diagnostic and ablation needles.

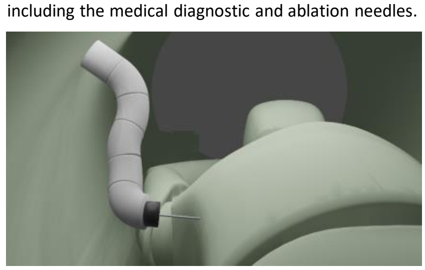


Figure 5 – Schematic representation of a soft robot in an MRI application

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