Supporting information

Design and evaluation of a pneumatic actuation unit for a wasp-inspired self-propelled needle

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# Arduino code to control Arduino board in phantom and MRI experiments

**S1\_Software\_Arduino.ino** contains the Arduino program code for the phantom and MRI experiments in this study. This code can be run in the Arduino IDE (Integrated Development Environment) software by uploading it to the Arduino Uno board. The Arduino IDE software can be downloaded on the Arduino website: <https://www.arduino.cc/en/software>.

# Phantom experiment protocol

The experimental procedure for each measurement inside the gelatin phantoms was executed in the following sequence of eight steps:

1. Set the correct stroke length for the Pneumatic Ovipositor Needle based on the target setting.
2. Attach the actuation unit of the Pneumatic Ovipositor Needle to the table while horizontally aligning the needle with the cart.
3. Place a new gelatin phantom on the cart.
4. Manually insert the needle approximately 35 mm into the gelatin.
5. Open the valves of the pressure regulator to set the output system (gauge) pressure () to 0.5 bar.
6. Start the data acquisition to measure the cart position.
7. Start the Arduino code to actuate the needle for thirty cycles.
8. Close the valves of the pressure regulator to set the output system (gauge) pressure () to 0.0 bar.

# MATLAB software to run the phantom experiment data analysis

Running the analysis file **S3\_SlipPneumaticOvipositorNeedle.m** requires the supplementary raw data set of the phantom experiment (i.e., **S4 Data**). Therefore, in the MATLAB code you need to replace 'C:\path\your\data\folder\' with the actual path to your downloaded **S4\_Data.zip** folder.

# Raw data set of the phantom experiment

The **S4\_Data.zip** file contains the raw data sets of the phantom experiment. **Table S4-1** shows the individual data sets.

**Table S4-1.** Excel worksheets containing individual measurements. The following information is reported: the experiment condition, the folder, the subfolder, and the name of the individual measurement worksheet.

|  |  |  |  |
| --- | --- | --- | --- |
| Condition | Folder | Subfolder | Individual measurements worksheets names |
| S2-I05 | stroke experiments | 2mm | 2mm, 2mm\_2, 2mm\_3, 2mm\_4, 2mm\_5, 2mm\_6, 2mm\_7, 2mm\_8, 2mm\_9, 2mm\_10 |
| S4-I05 | stroke experiments | 4mm | 4mm\_1, 4mm\_2, 4mm\_3, 4mm\_4, 4mm\_5, 4mm\_6, 4mm\_7, 4mm\_8, 4mm\_9, 4mm\_10 |
| S4-I03 | speed experiments | i01 | 01\_1, 01\_2, 01\_3, 01\_4, 01\_5, 01\_6, 01\_7, 01\_8, 01\_9, 01\_10 |
| S4-I01 | speed experiments | i03 | 03\_1, 03\_2, 03\_3, 03\_4, 03\_5, 03\_6, 03\_7, 03\_8, 03\_9, 03\_10 |

# Phantom experiment video

**S5\_VideoPhantom.mp4** contains a video of the actuation unit and needle tip in the gelatin phantom for Condition S4-I01.

# Magnetic resonance parameters

This appendix contains the Magnetic Resonance (MR) parameters set for the Magnetic Resonance Imaging (MRI) experiment in this study. **Table S6-1** shows the MR parameters set for the 3D gradient-echo acquisition of the *ex vivo* porcine liver experiment.

**Table S6-1.** MR parameters for MRI experiment in *ex vivo* porcine liver tissue.

|  |  |
| --- | --- |
| Sequence | 3D gradient echo |
| k-space trajectory | Pseudo-radial (ky/kz) |
| Repetition time (TR) | 6.0 ms |
| Echo time (TE) | 2.8 ms |
| Flip angle | 20 degrees |
| Field of view (mm) | 80 x 60 x 25 mm3 |
| Matrix size | 192 x 128 x 48 |
| Total acquisition time | 3 min |
| Reconstructed temporal resolution (dynamic images) | 7.2 s |

# MRI experiment protocol

The experimental procedure for the measurement inside the *ex vivo* porcine liver tissue was executed in the following sequence of nine steps:

1. Place the tissue box on the wheels on an RF base plate inside the RF coil.
2. Manually insert the needle through an insertion hole in the tissue box over 63.5 mm in the agar and liver tissue.
3. Attach the actuation unit of the Pneumatic Ovipositor Needle to the semi-cylindrical tube while horizontally aligning the needle with the tissue box’s insertion hole.
4. To ensure visualization of the needle, slide the experimental setup on the semi-cylindrical tube into the MRI bore.
5. Connect the control unit to the actuation unit of the Pneumatic Ovipositor Needle using air hoses.
6. Open the valves of the nitrogen gas cylinder and its pressure-reducing valve to set the output system (gauge) pressure () to 3.0 bar.
7. To image the needle position with respect to the liver tissue and the tissue box, perform a 3D gradient echo acquisition continuously for 3 minutes.
8. After 1 minute of 3D gradient echo acquisition of the start position of the needle, start the Arduino code to actuate the needle for thirty cycles, which corresponds to a theoretical distance travelled of 120 mm for the set stroke length of 4 mm.
9. Close the valves of the nitrogen gas cylinder and its pressure-reducing valve to set the output system (gauge) pressure () to 0.0 bar.

# MRI experiment video

**S8\_VideoMRI.mp4** contains the dynamic MRI video of the experiment in *ex vivo* porcine liver tissue.