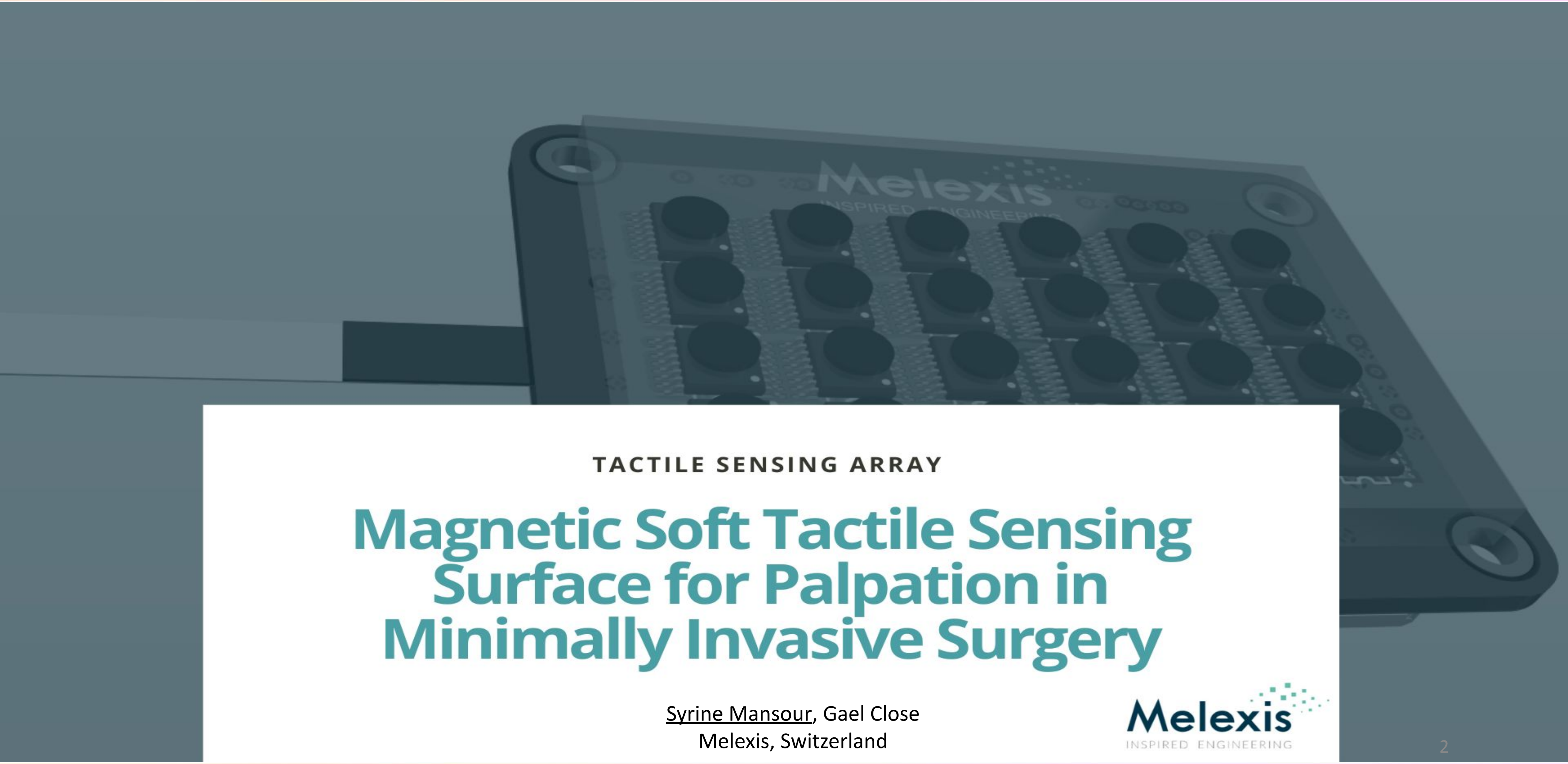
EMSA 22
MADRID



TACTILE SENSING ARRAY

Magnetic Soft Tactile Sensing Surface for Palpation in Minimally Invasive Surgery

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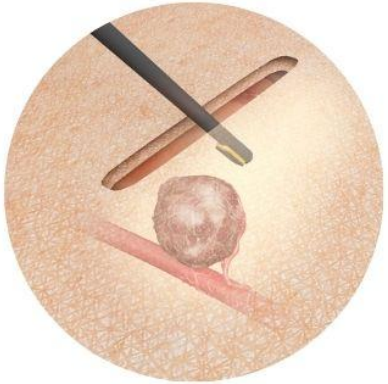
Melexis, Switzerland

Melexis
INSPIRED ENGINEERING

Motivation

Device



Implementation

Minimally Invasive Surgery (MIS)

- Surgical procedures e.g. Laparoscopy, Endoscopy
- Instruments inserted through small incisions or body orifices

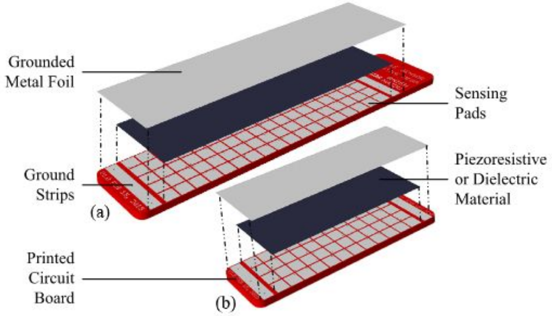
✔ Less tissue damage, less post-operative trauma

✘ Indirect contact with tissues: loss of the sense of touch

Challenge: Reliably localize malignant tumors through palpation in MIS

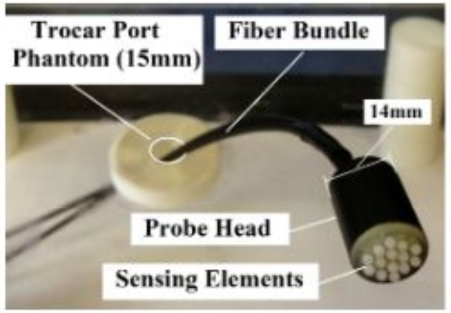
Tactile sensing in MIS

Capacitive:
Change of electrical capacitance of the dielectric medium separating electrodes
- Needs humidity calibration [3]
- Sensitive to electromagnetic noise [3]



CAD of a capacitive tactile sensor for MIS [1]

Optical:
Light transmission through an optical fiber to a detector
- Bulky
- High power consumption [3]
- High cost [3]



Prototype of an optical tactile sensor for MIS [2]

[1]:A. S. Naidu, R. V. Patel and M. D. Naish, "Low-Cost Disposable Tactile Sensors for Palpation in Minimally Invasive Surgery," in IEEE/ASME Transactions on Mechatronics, vol. 22, no. 1, pp. 127-137, Feb. 2017, doi: 10.1109/TMECH.2016.2623743.
[2]: H. Xie, H. Liu, L. D. Seneviratne and K. Althoefer, "An Optical Tactile Array Probe Head for Tissue Palpation During Minimally Invasive Surgery," in IEEE Sensors Journal, vol. 14, no. 9, pp. 3283-3291, Sept. 2014, doi: 10.1109/JSEN.2014.2328182.
[3]: Othman Wael, Lai Zhi-Han A., Abril Carlos, Barajas-Gamboa Juan S., Corcelles Ricard, Kroh Matthew, Qasaimeh Mohammad A., “Tactile Sensing for Minimally Invasive Surgery: Conventional Methods and Potential Emerging Tactile Technologies” , Frontiers in Robotics and AI vol 8, 2022

Device: Palpaxis

Magnetic:
Change in magnetic field detected by the Hall effect

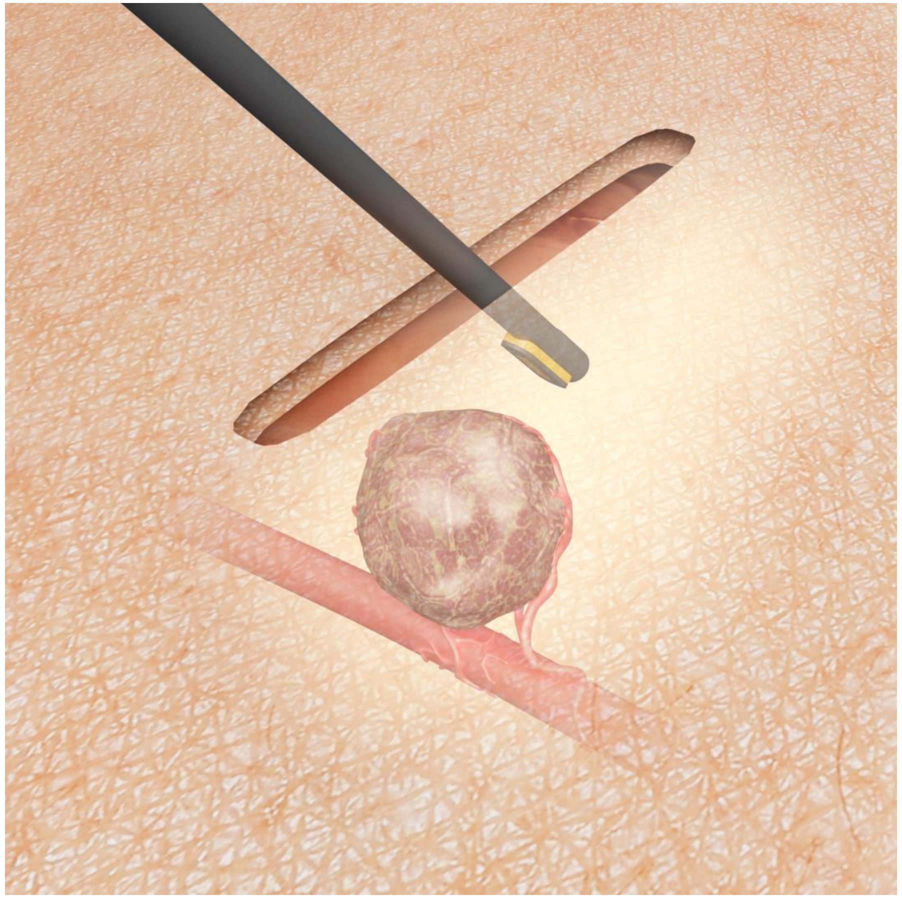
- 3D detection
- Magnetic stray field immunity




Soft	Safe	Robust	Mapping
High compliance	Biocompatible elastomer	Magnetic stray field immunity	Area investigation

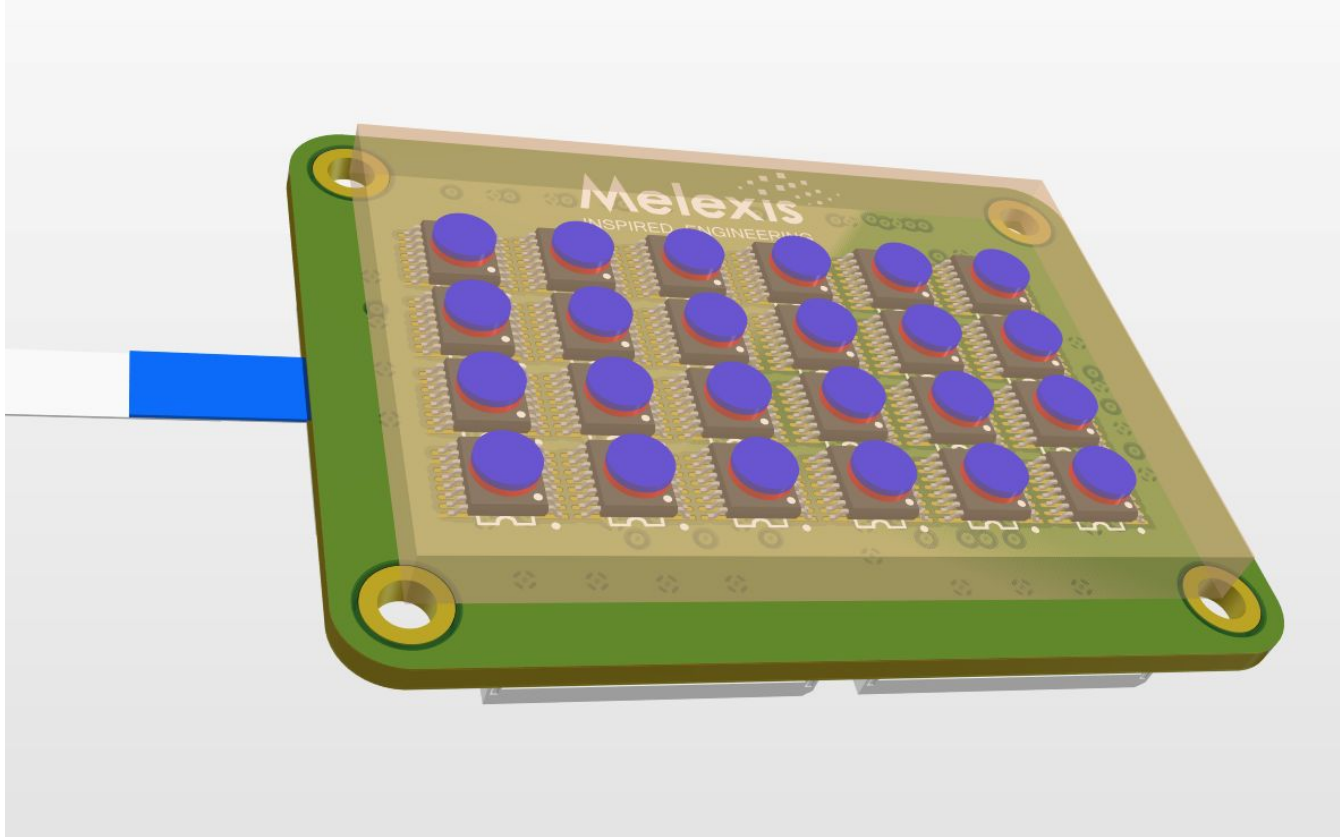
Device: Palpaxis

Palpaxis mounted on a Minimally Invasive Surgical instrument



Palpation in Minimally Invasive Surgery

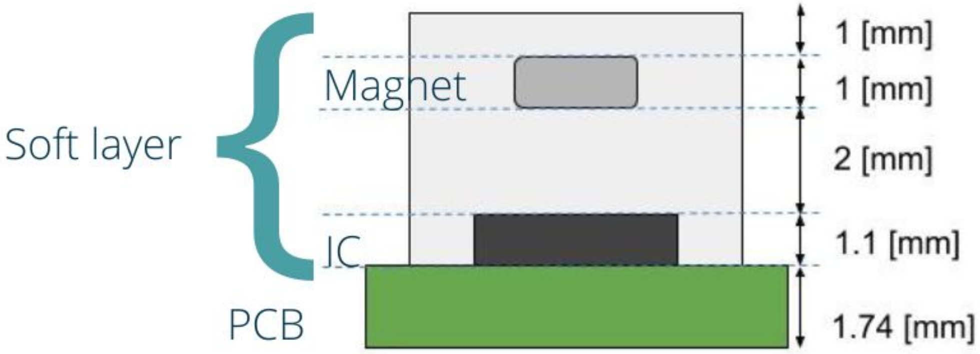
Device: Palpaxis



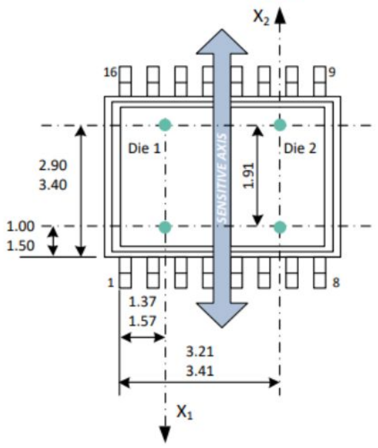
Architecture of Palpaxis, the tactile sensing surface

- Layer architecture
- Surface of 45[mm] x 25[mm] for 24 taxels
- Physical pitch 7.56 [mm]

Design parameters



Integrated circuit Tri-axis technology



SENSING SPOTS - HALL PLATES

MLX90377 Dual-Die Dual-Disk

Multiple pixels since die has 2 sensing spots, each surrounded by HE [4]

PACKAGE

The two adjacent dies are packaged inside a TSSOP16 with independent output pins

Width×Length×Height [mm]: 5.0×6.4×1.0

Material

Viscoelastic, Hardness: 30 shore A

Fit for short invasive operations with limited contact duration (less than 24h), Biocompatibility: ISO10993

[4]: N. Dupré, Y. Bidaux, O. Dubrulle and G. F. Close, "A Stray-Field-Immune Magnetic Displacement Sensor With 1% Accuracy," in IEEE Sensors Journal, vol. 20, no. 19, pp. 11405-11411, 1 Oct.1, 2020, doi: 10.1109/JSEN.2020.2998289.

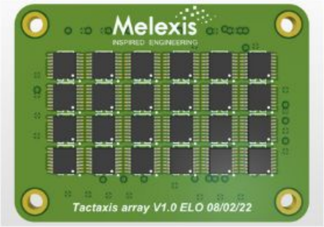
Prototyping
Step 1

LAYOUT

Array of 6 x 4 chips

Vertical spacing: 3 [mm]

Horizontal spacing; 1 [mm]



CHIP SOLDERING

Soldering paste applied through the stencil

Post curing in IR IC Heater (7min, reaches 250)

CAPACITANCES - CONNECTORS

Soldering paste was applied with a syringe above the pins

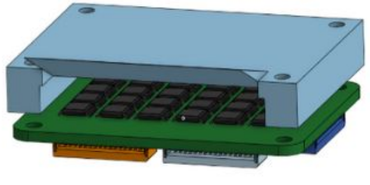
Element placement with tweezers

Post curing at high temperature

MOLD

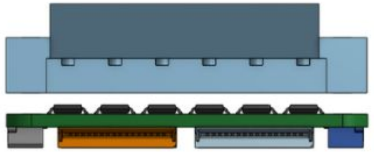
Tightly fixed with screws directly above the sensor

Silicone casting directly on chips: better adherence



RIDGES

Inspired from the human skin, texture of the epiderm



NEODYMIUM MAGNETS

Shape: Disk

Material: NdFeB

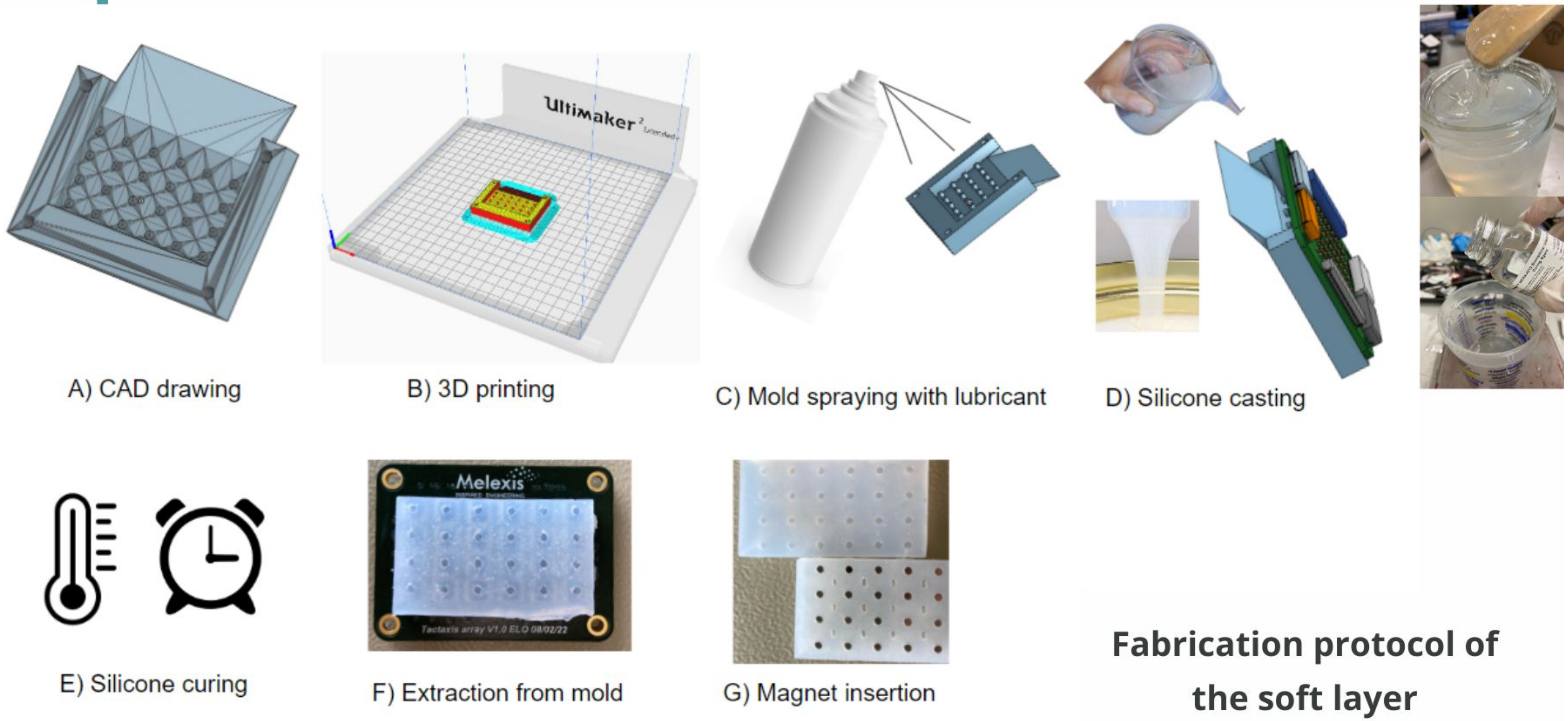
Diameter: 2 [mm], Height: 1 [mm]

Br (Residual magnetism) : 1.37 - 1.42 [T]

Direction of magnetisation: axial

Position: centered above each chip

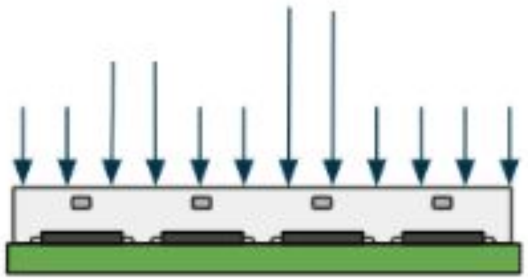
Prototyping
Step 2



Fabrication protocol of the soft layer

Working principle

Mechanical load → Compression of soft layer → Magnet(s) displacements → Variations in magnetic fields → Transduction via Hall effect → Conversion to digital data by on-chip electronics → Differential processing for stray field immunity → Output: contrast mapping



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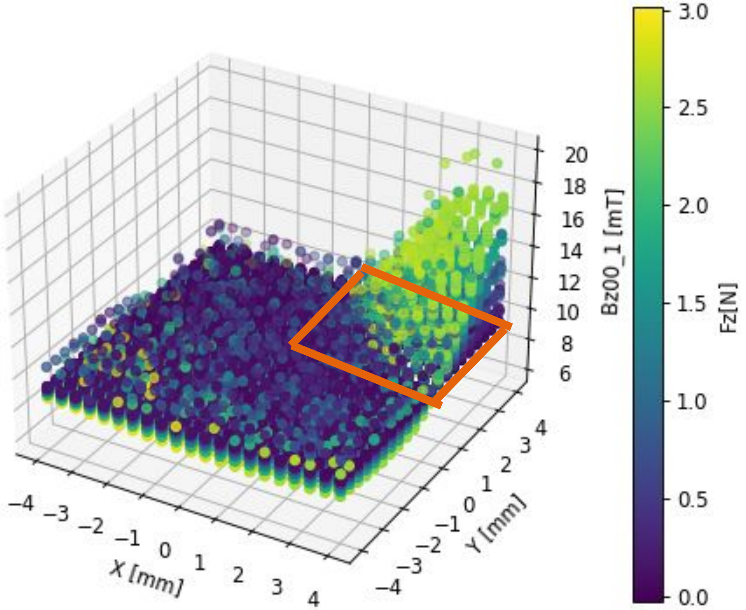

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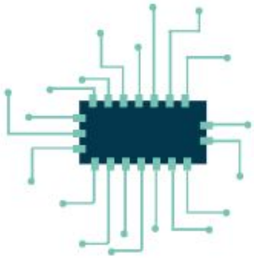

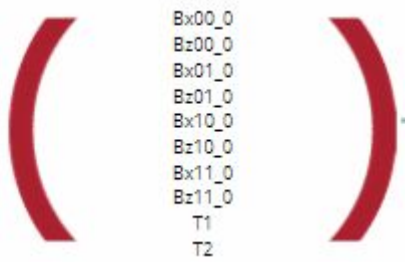

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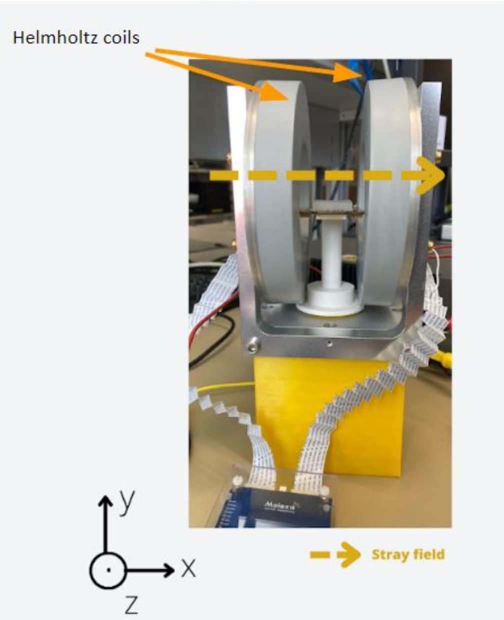
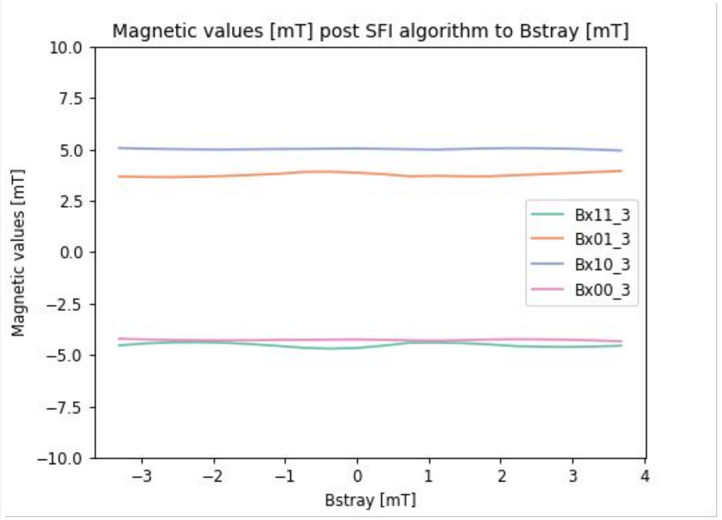


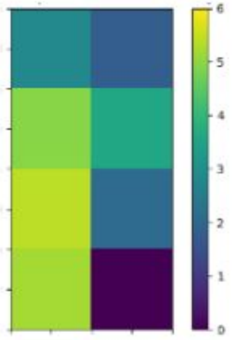
Experimental setup for Bstray



Mechanical rest under variant magnetic stray field
-> Sensor is stray field immune

Working principle

Mechanical load → Compression of soft layer → Magnet(s) displacements → Variations in magnetic fields → Transduction via Hall effect → Conversion to digital data by on-chip electronics → Differential processing for stray field immunity → Output: contrast mapping

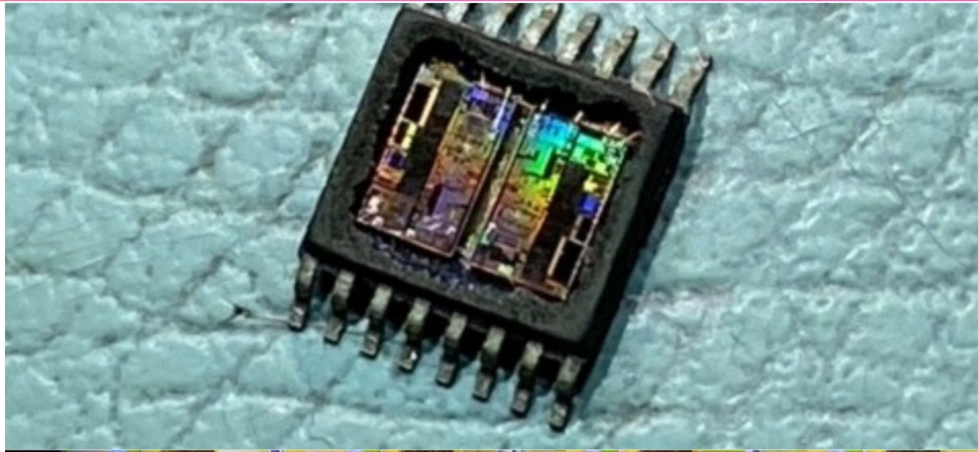


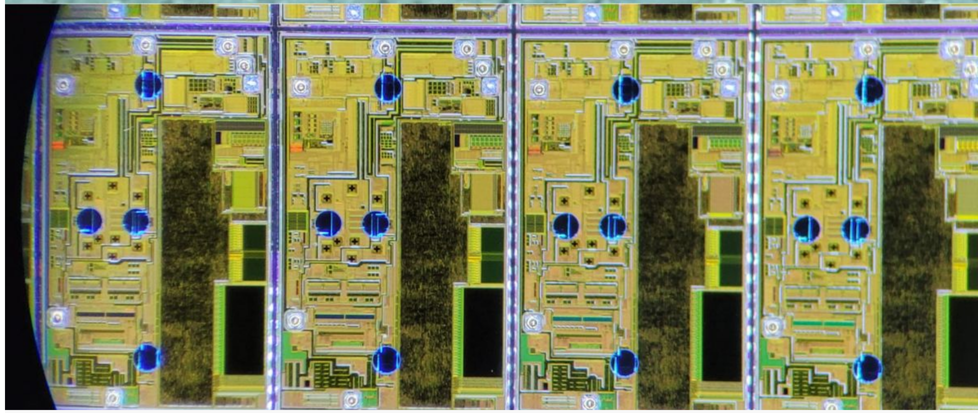
Hardware optimization

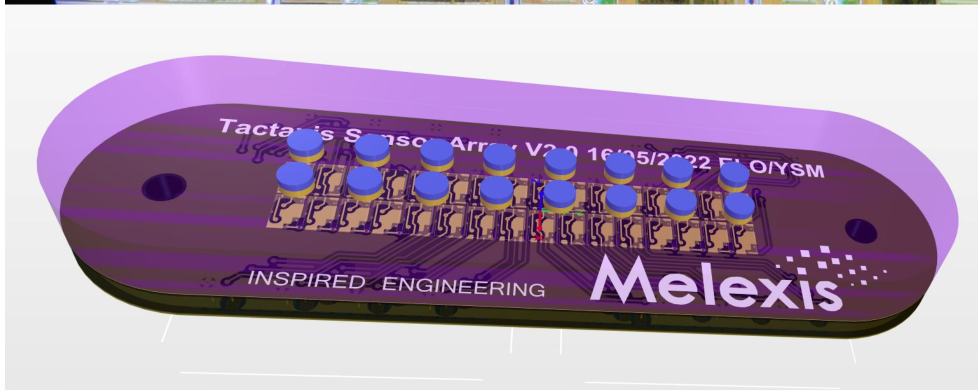
Dimensional constraint -> miniaturized version

Chip-on-board

- Strip of 31[mm] x 6.5[mm] for 16 taxels
- Physical pitch: 3.30[mm]
- Elongated shape to fit on a trocar
- Enhance spatial resolution
- Bare dies
- Flip chip assembly

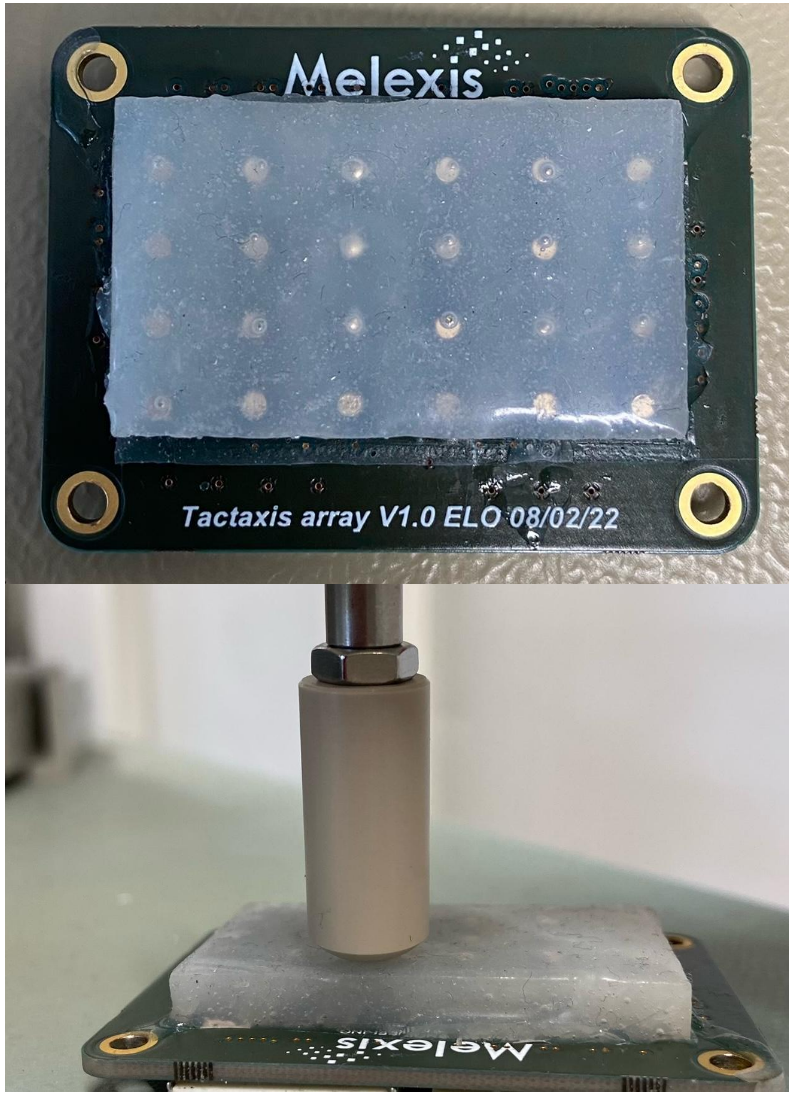






Recapitulation of characteristics

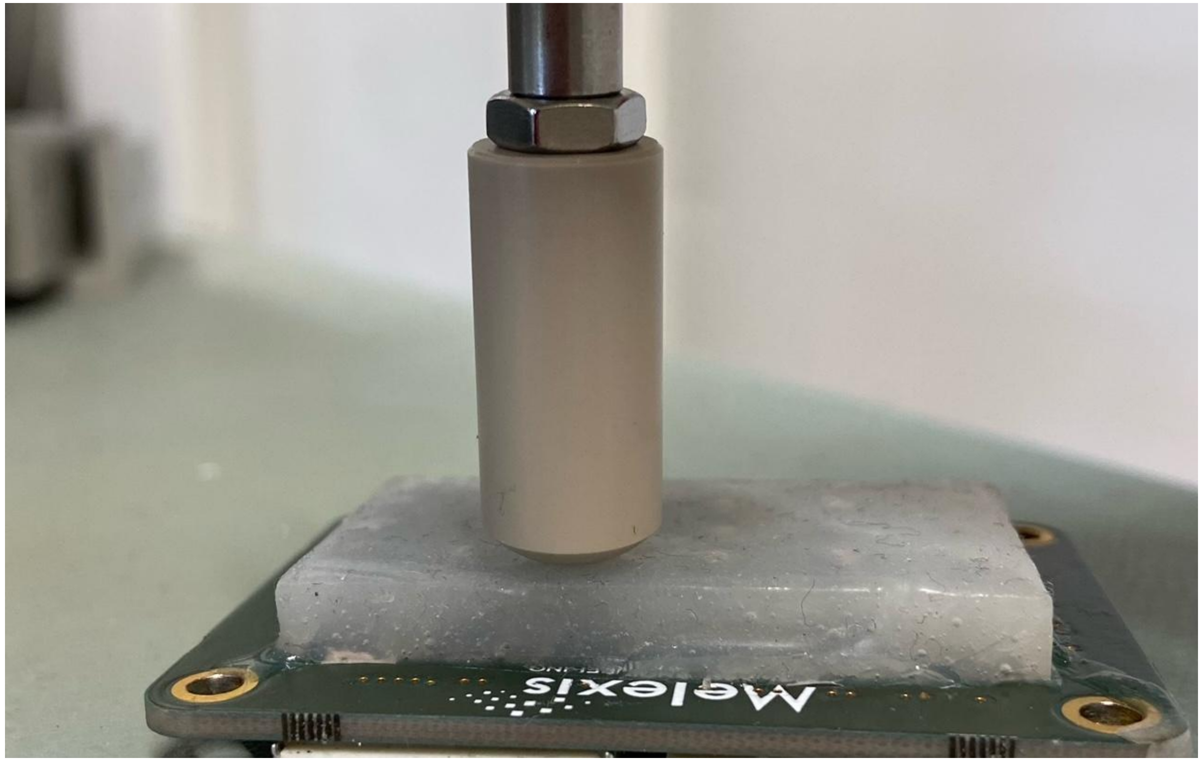
Parameter	Value
Resolution	Weight of a peanut, around 0.3 [mN]
Maximum sensed Normal Force	6 [N]
Top layer	High compliance Biocompatibility Weak tissue slippage

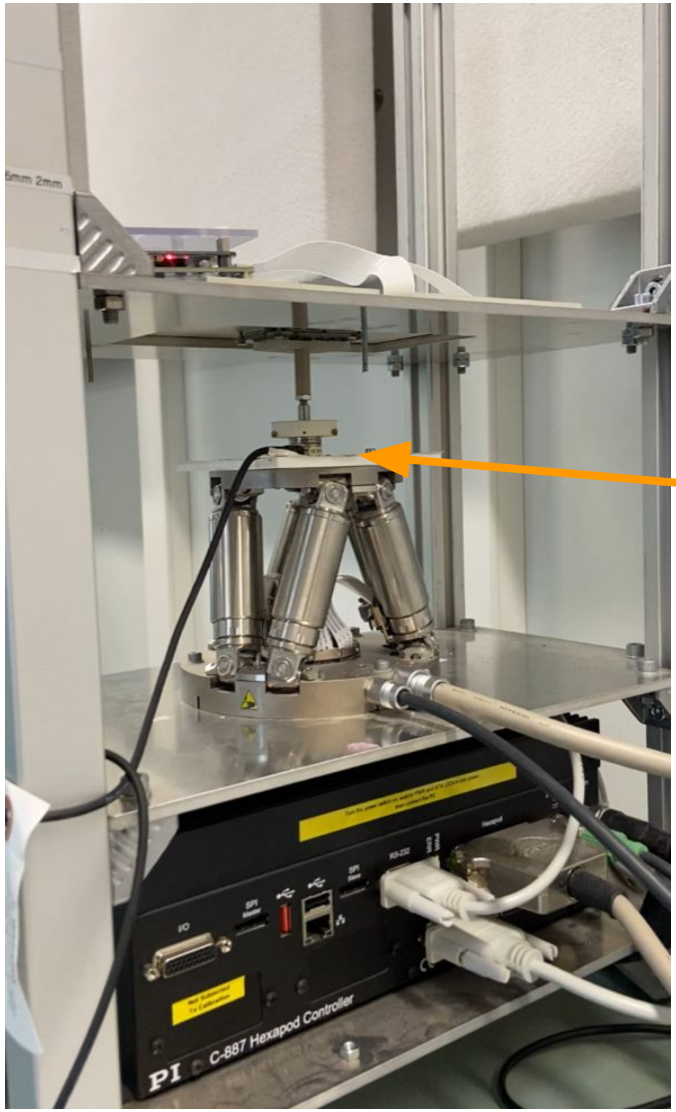


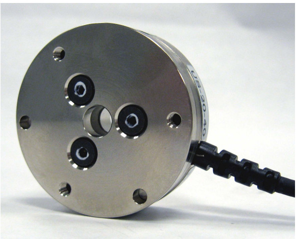
Thank you for your attention!
Questions?

Appendix

Experimental setup for indentation and force calibration

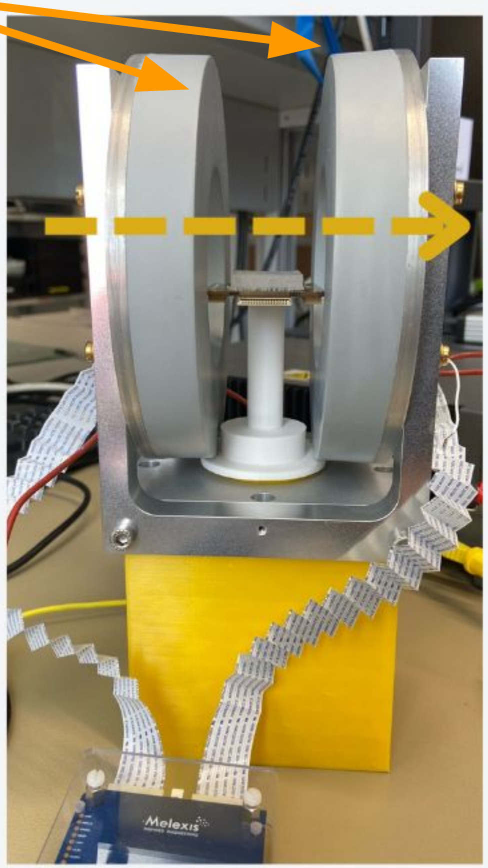




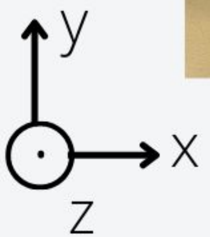


Magnetic stray field

Helmholtz coils



Stray field



SOURCE

Natural: from non-man-made objects, e.g., the Earth’s magnetic field

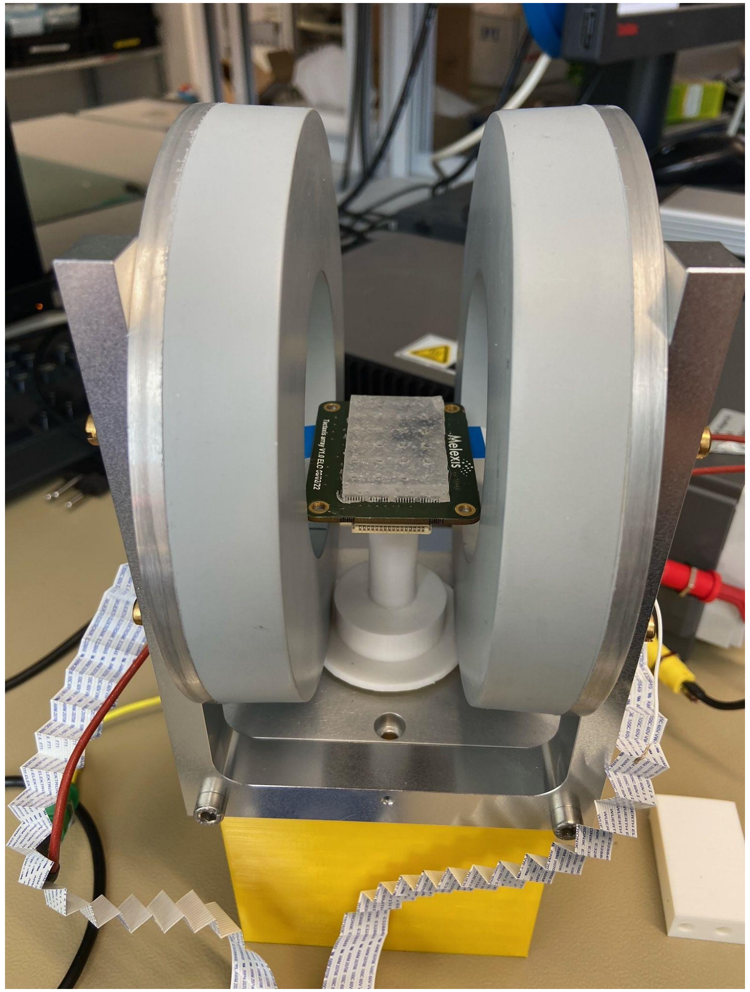
Environmental: from nearby man-made objects (neighboring electronics)

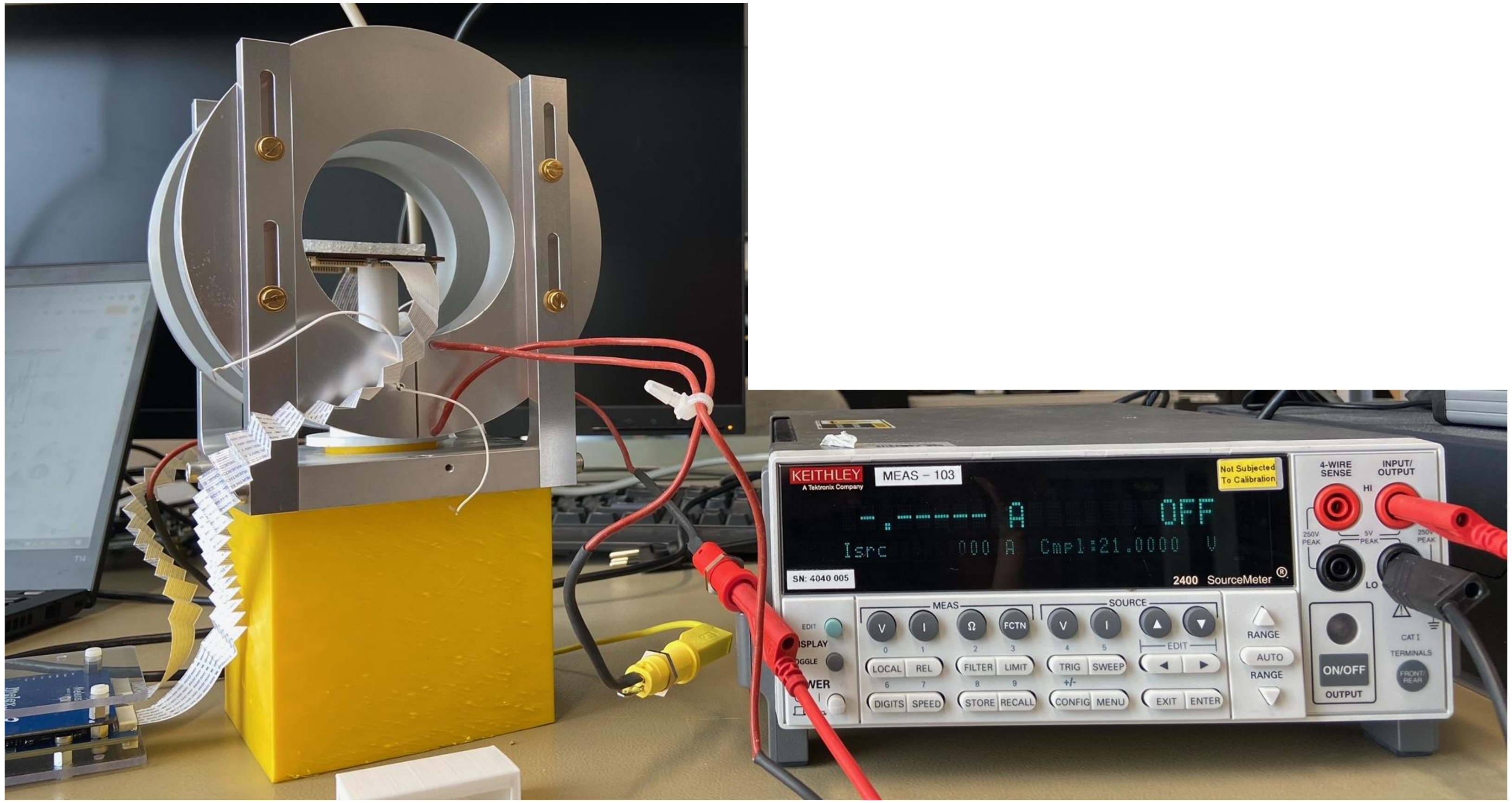
SF IMMUNITY ALGORITHM

Differential measurement

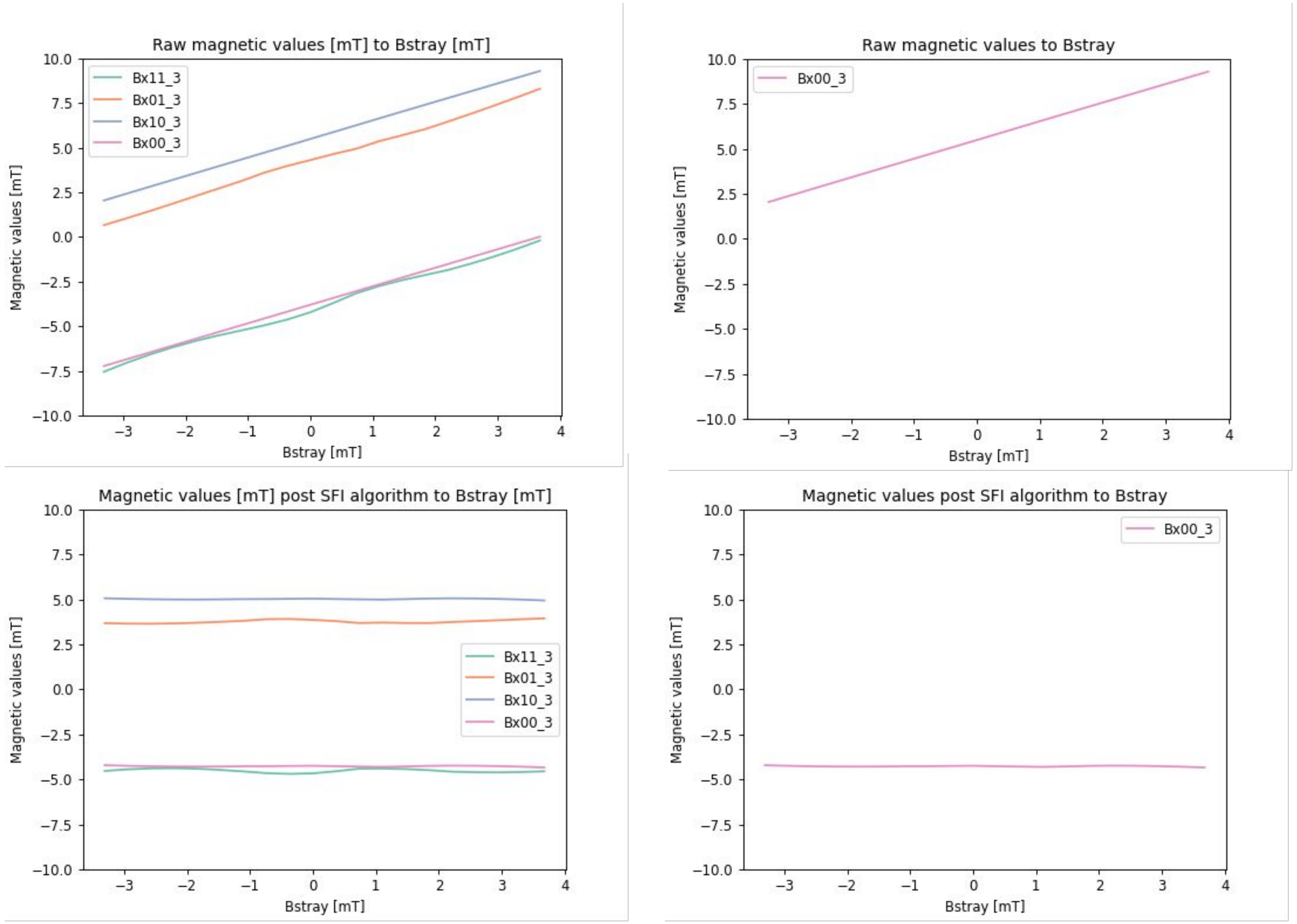
Relative variations of magnetic signal readout

Experimental setup for stray field effect



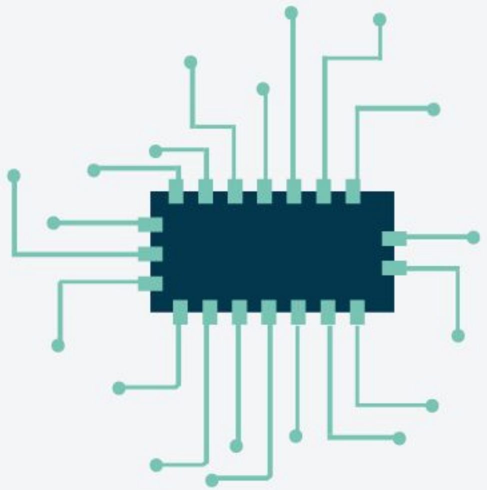


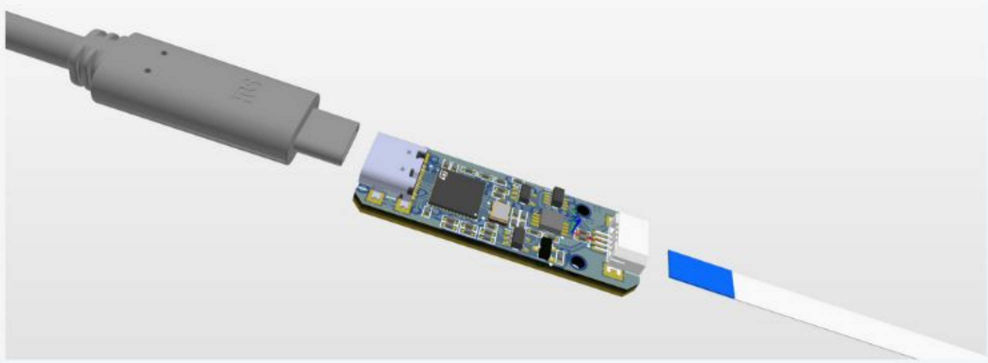
Stray field immunity

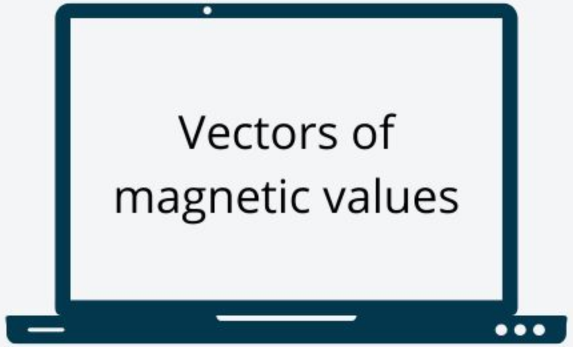


Data acquisition

Chip ⟷ MelexIO ⟷ Computer





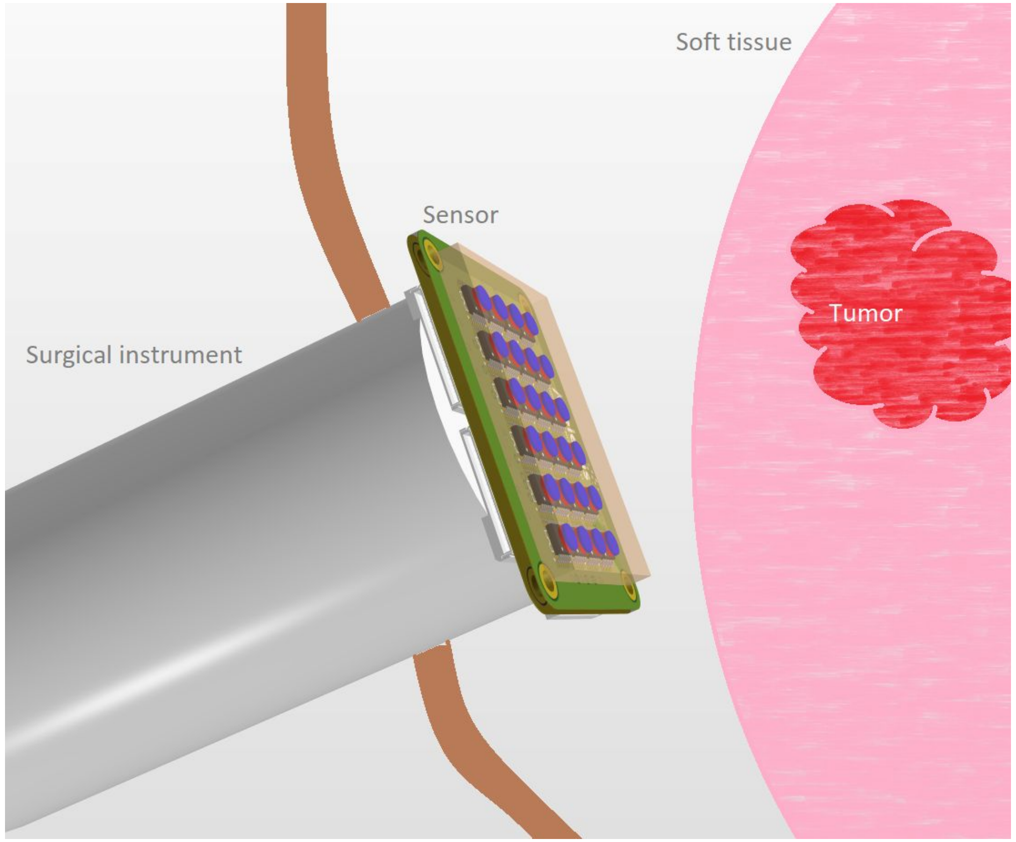


$$\begin{pmatrix} Bx00\_0 \\ Bz00\_0 \\ Bx01\_0 \\ Bz01\_0 \\ Bx10\_0 \\ Bz10\_0 \\ Bx11\_0 \\ Bz11\_0 \\ T1 \\ T2 \end{pmatrix}$$

Recapitulation of characteristics

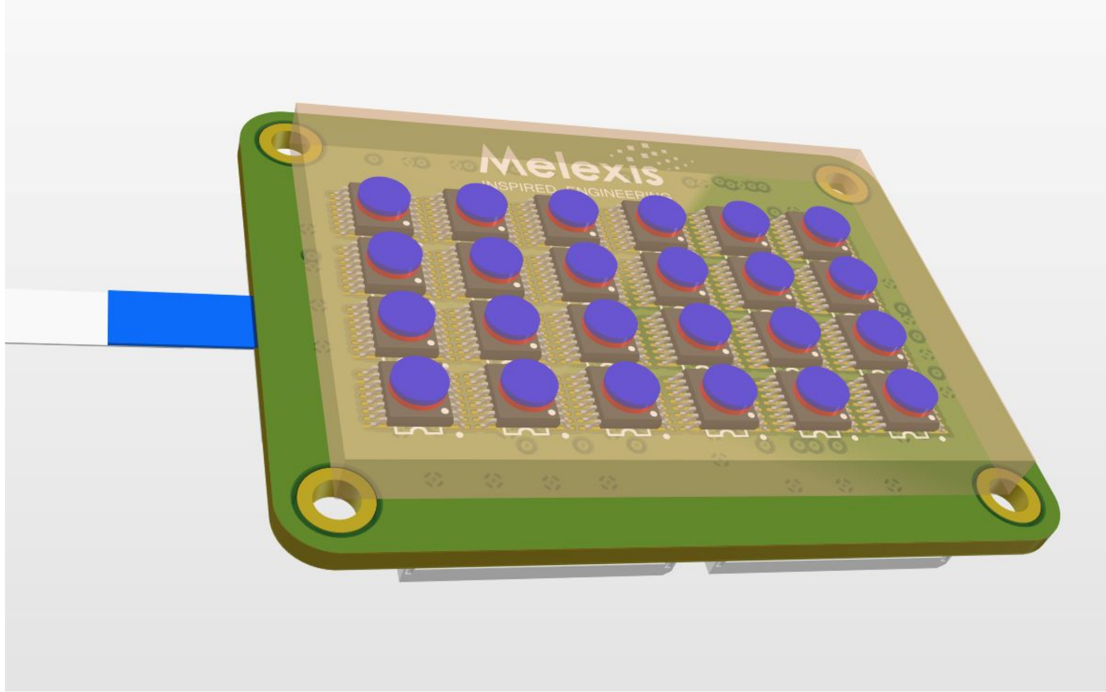
Parameter	Value
Number of taxels	16 taxels / 24 taxels (depending on hardware model)
Physical pitch (center-to-center distance of chips)	3.30[mm] / 7.56[mm]
Spatial resolution	Lower than pitch: machine learning model
Scan rate	>= 100[ms] per acquisition
Resolution	Weight of a peanut, around 0.4 [mN]
Maximum sensed Normal Force	6 [N]
Top layer	High compliance - Biocompatibility - Weak tissue slippage

Device: Palpaxis



Goal is to perform palpation in minimally invasive surgery

Surface of 45[mm] x 25[mm] for 24 taxels
Physical pitch 7.56 [mm]



Architecture of the device