3D PRINTED SENSOR INSPIRED BY TRICHOID SENSILLA OF INSECTS, EARLY STUDIES OF THE MECHANICAL STRUCTURE

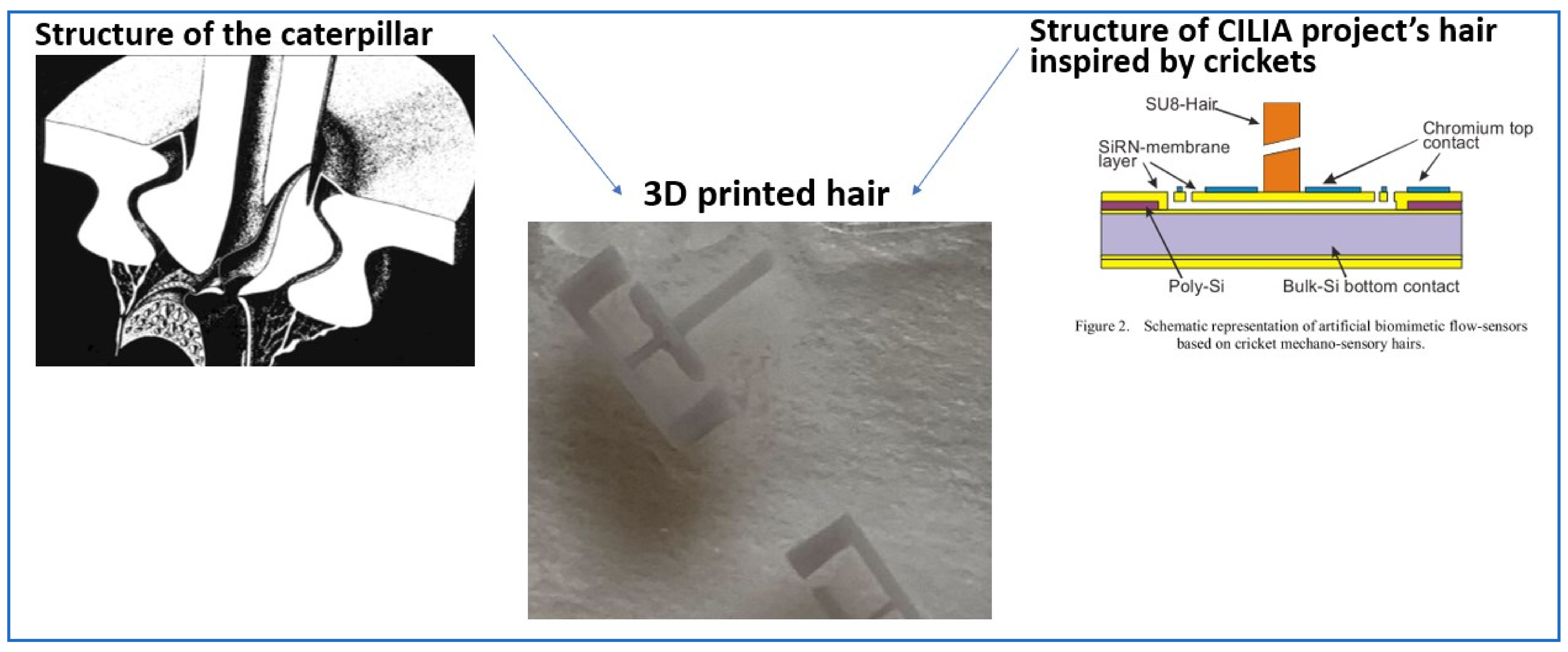
AUTHORS: Samuele Martinelli, James F.C. Windmill & Andrew Reid

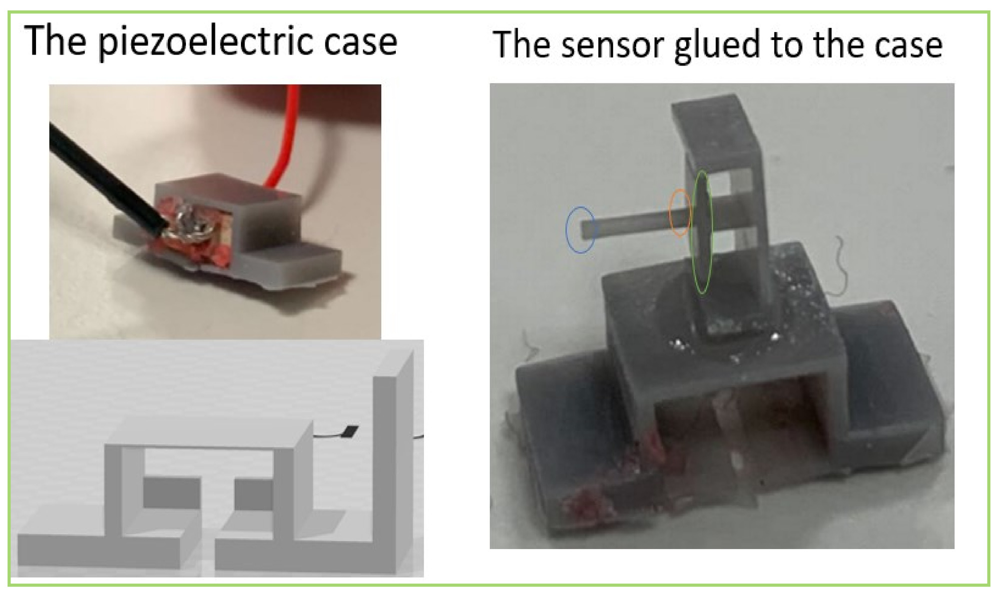
University of Strathclyde Engineering

INTRODUCTION

Nature has, for the longest time, inspired mankind in the development of new technologies. In the past few decades, thanks to thorough biological studies on insects we have come to better understand how their different sensory systems work. A fascinating sensing mechanism is the hair-like structure, often called trichoid sensilla or trichobothria, which are mainly used to sense low frequency, near field, sound and air vibrations [1]. Nevertheless, some iterations of this sensing mechanism are used as touch sensors, and it is believed that from this structure stem other sensilla that sense odour, temperature, and acceleration, as well as gyroscope-like mechanisms [2].

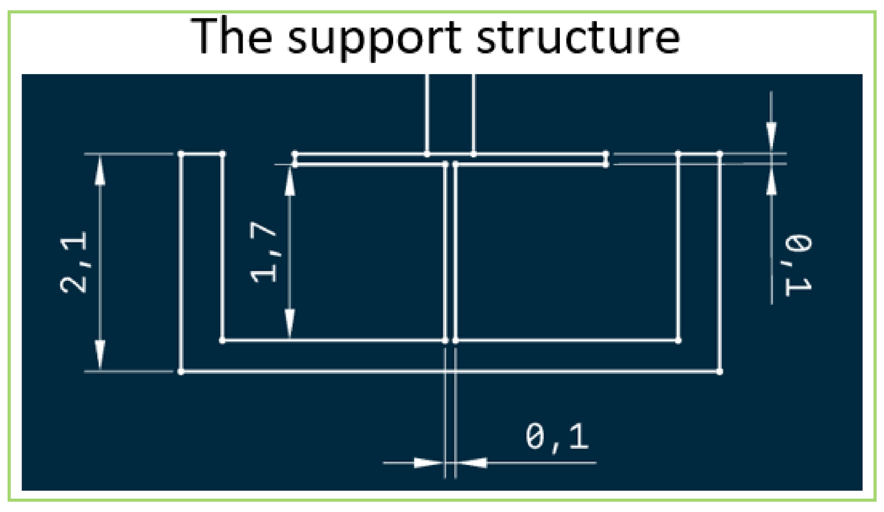
This project will use 3D printing techniques to create a sensor inspired by the trichoid sensilla of insects (mainly the hinged structure of the caterpillar *B. Brassicae* [3], and the cerci of crickets previously studied by the EU CILIA project [4]). This would provide sensing of low frequency sounds at different frequencies based on small variations of the structure (e.g., different diameter or hair length). This can sense frequency specific sounds with great accuracy and, used together in array structures, measurement of the frequency component of a sound without the need for a computationally expensive Fast Fourier Transforms (FFT).





METHODOLOGY

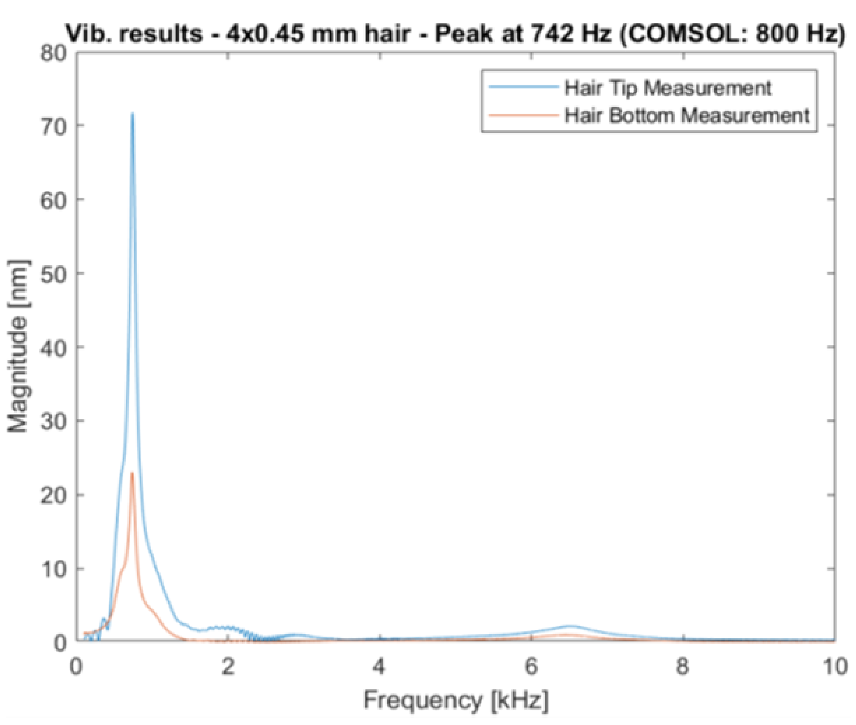
The sensors are printed by using an Asiga MAX X27 3D printer. In order to test the sensors' mechanical response the sensor was glued on a structure containing a piezoelectric chip (Thor Labs TA0505D024W). The vibration was then measured using a 3D-Laser Doppler Vibrometer (Polytec MSA-100). Measurements were taking at the tip and bottom of the hair and the sensing plate. COMSOL was used for simulation.

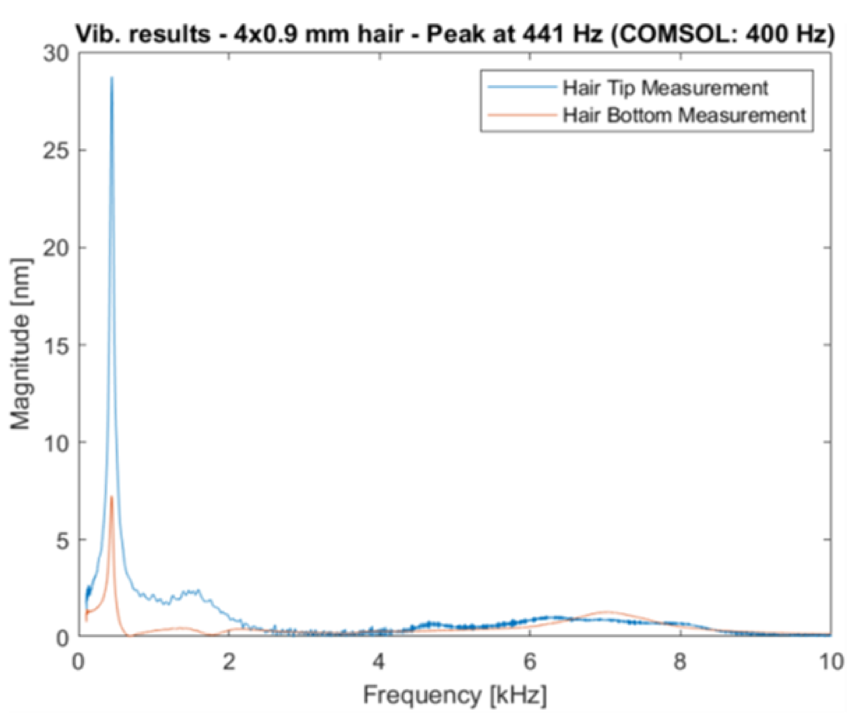


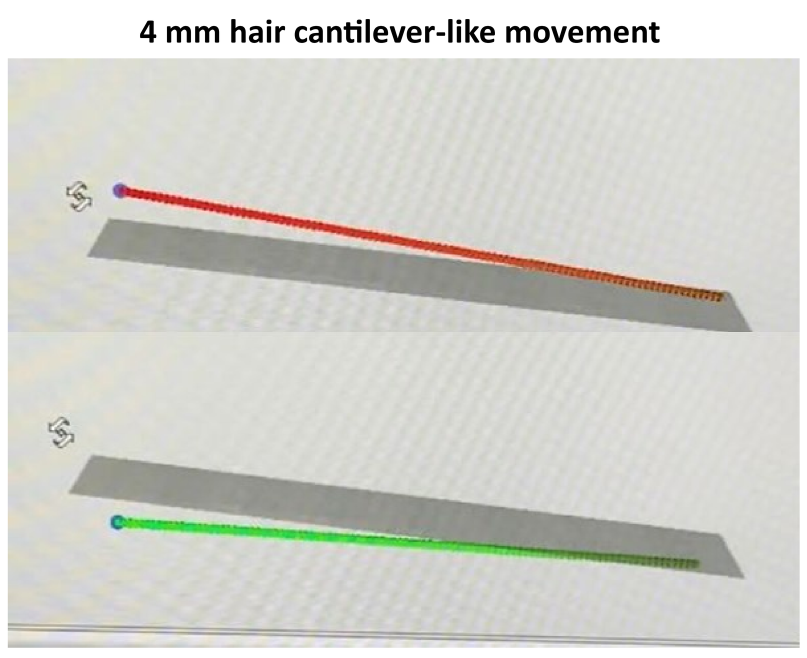
The tested hairs have four lengths (4, 3, 2 and 1 mm) and two diameters (0.90 and 0.45 mm). The T-like support structure represents the sensing component of the sensor, the vertical part is 1.7 mm tall and 0.1 mm thin. The horizontal part (which would be a capacitive plate in future) is 0.1 mm thin and has a surface of 2x3 mm.

RESULTS

- The best results were obtained with the two 4 mm long hair as their resonant frequency was a very distinguishable peak and the movement of the hair was cantilever like (what is needed for proper movement of the supporting plate). The resonant frequencies were close to the ones in COMSOL.
- The 3 mm hair had confusing results as its peaks for both diameters were around the same frequencies. The results did not agree with COMSOL whatsoever, and their movement was not cantilever like.
- For the 2 mm hair the movement was similar to the 3 mm one but with a better frequency response as it was a clearer peak, which was different from the COMSOL evaluation by only 100 Hz.
- The 1 mm hair had mainly noisy movement and no clear frequency response. The hair might be too short.







Hair	Vibrometer	COMSOL
3x0.45 mm	1227 Hz	1000 Hz
3x0.90 mm	1086 Hz	600 Hz
2x0.45 mm	1211 Hz	1300 Hz
2x0.90 mm	906 Hz	800 Hz

FUTURE WORK

The obtained results are promising but they need to be validated with experiments in the acoustic domain. This will be followed by making the base of the sensor capacitive in order to get an electrical output from the displacement of the hair. Other materials and structures need to be studied to get the best response.

ACKNOWLEDGMENTS

I would like to thank for the support during my PhD the University of Strathclyde, my supervisor Prof Windmill, and Dr Reid for his invaluable help. I would like to thank DSTL for funding this project.

References:

[1] A. Reissland and P. Görner, "Trichobothria," in *Neurobiology of Arachnids*, F. G. Barth Ed. Berlin, Heidelberg: Springer Berlin Heidelberg, 1985, pp. 138-161.

[2] T. A. Keil, "Functional morphology of insect mechanoreceptors," *Microscopy Research and Technique,* vol. 39, no. 6, pp. 506-531, 1997, doi: 10.1002/(SICI)1097-0029(19971215)39:6<506::AID-JEMT5>3.0.CO;2-B.

[3] H. Markl and J. Tautz, "The sensitivity of hair receptors in caterpillars of Barathra brassicae L. (lepidoptera, noctuidae) to particle movement in a sound field," *Journal of Comparative Physiology,* vol. 99, no. 1, pp. 79-87, 1975-03-01 1975, doi: 10.1007/bf01464713.

[4] G. Krijnen, T. Lammerink, R. Wiegerink, and J. Casas, "Cricket Inspired Flow-Sensor Arrays," in *2007 IEEE Sensors*, 2007-01-01 2007: IEEE, doi: 10.1109/icsens.2007.4388455.