PalpAid: Multimodal Pneumatic Tactile Sensor for Tissue Palpation

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Introduction

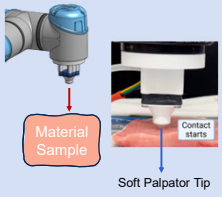
- In surgical oncology, understanding tactile properties of tissues is vital in determining tumor margins.
- Robot-assisted surgery diminishes surgeons' sense of touch. Vision alone is not enough.

No Tactile Feedback → Force-only sensing is limiting.

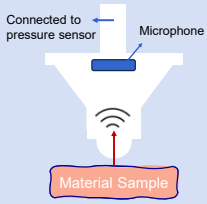
Source: https://www.unitymedcenter.com/hospital/davinci-surgical-system.html

Working Principle

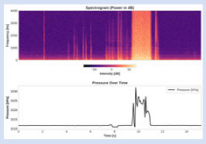
Leveraging rich acoustic signal and pressure differential data from how different materials respond to contact via palpation



Palpation motion controlled by UR3 robotic manipulator

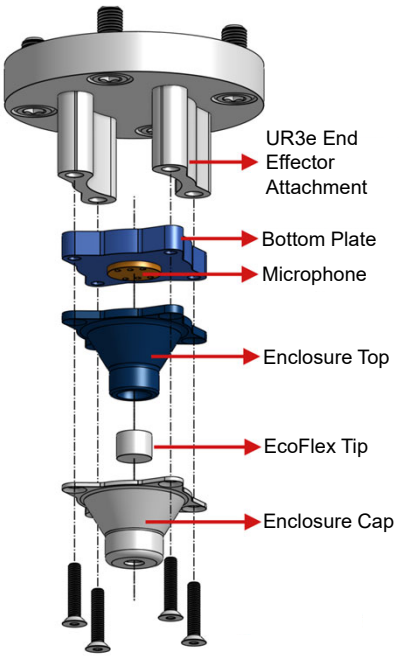


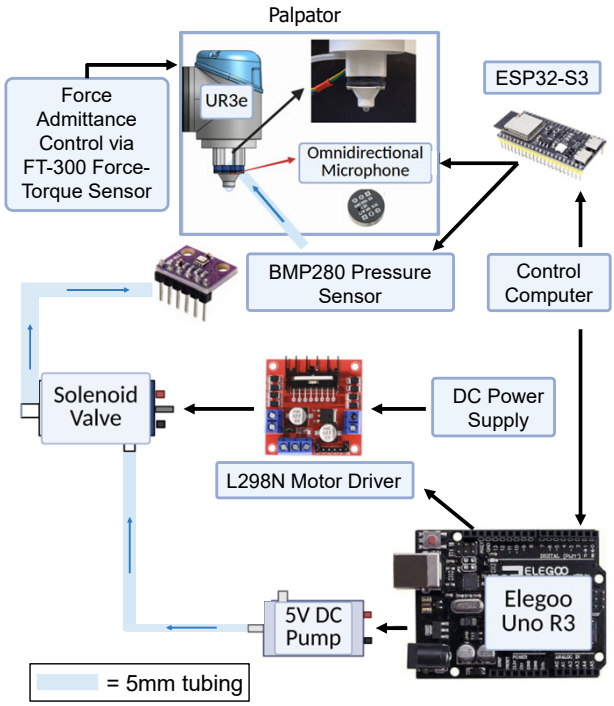
Air inside the sensor cavity act as a sound transmission medium



Pressure changes detect contact events. Each material produces unique acoustic signatures, enabling classification via supervised machine learning algorithms.

System Overview





Data Acquisition
Synchronized pressure and acoustic sensing during palpation

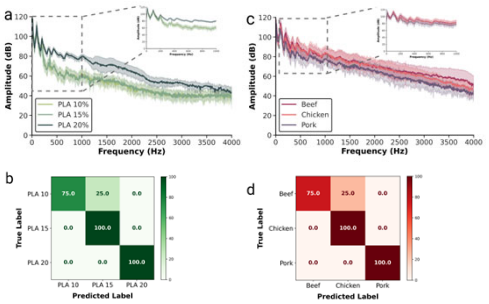
Contact Event Detection
Pressure peak detection isolates contact intervals

Feature Extraction
MFCC features computed for each segmented audio

Classification
Support Vector Machine used for material and tissue classification

Results

Below are the experimental results on hard PLA of varying infill densities and soft animal tissues (bovine, chicken, and porcine)



a) PLA palpation frequency distribution with emphasis on 0–1000 Hz range;
b) Hard material classification result;
c) Soft-tissue palpation frequency distribution with emphasis on 0–1000 Hz range;
d) Soft material classification result.

Key Takeaways

- Interchangeable tip, simple design, and low-cost fabrication enable scalable and rapid integration in clinical settings.
- Distinct acoustic signatures were observed across different materials.
- Multimodal sensing framework allows differentiation of material types.
- Robust performance in both hard and soft materials.

Conclusion

PalpAid offers a low-cost, modular alternative to expensive vision-based tactile sensors.

- **Multimodal Sensing:** Achieves biocompatible material classification at a fraction of the cost.
- **Interchangeable Design:** Features a swappable palpator for versatile, modular applications.
- **Clinical Roadmap:** Future work focuses on sensitivity characterization and acoustic signal processing.

Further Information

Please scan the QR code or email devi.yuliarti@duke.edu

https://raprakashvi.github.io/palpaid/

Toward restoring tactile perception in robot-assisted surgery