Force-Sensing Drills for Surgery

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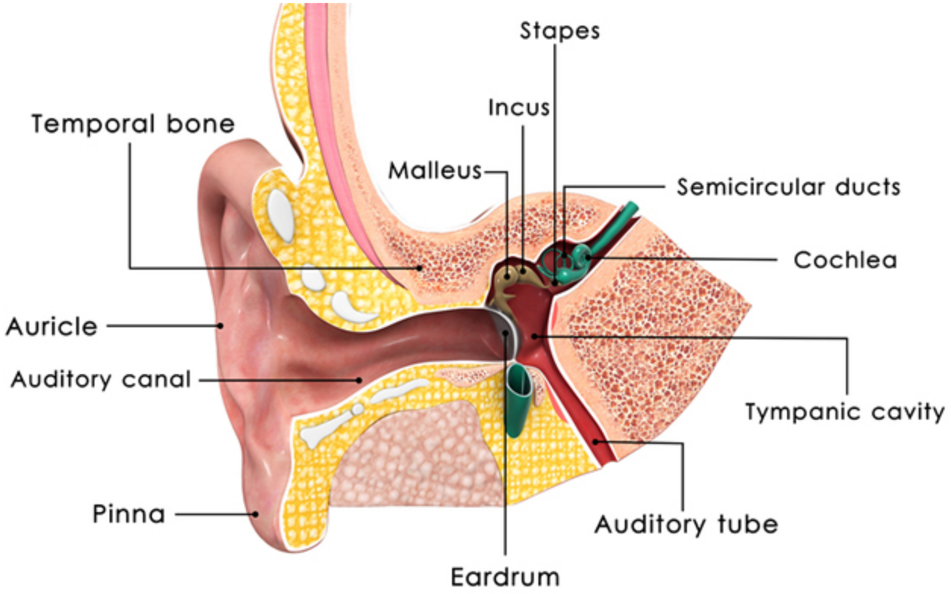
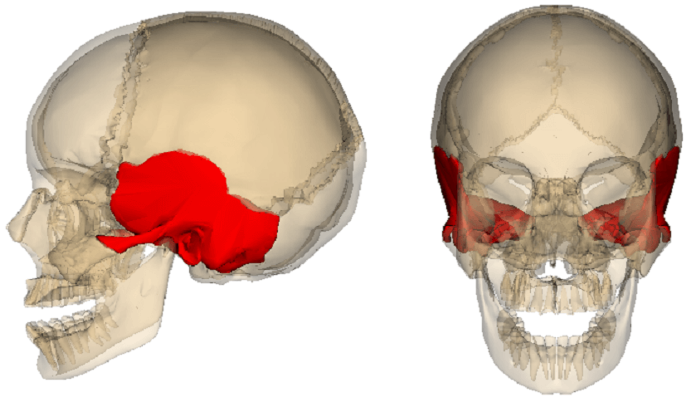
Why do we want to sense drilling forces?

- Bone drilling is required for many surgical procedures
- For inner/middle ear + skull base surgery, surgeons drill through temporal bone.
  - This requires high precision and accuracy from the surgeon.
- The anatomy in this region (veins, arteries, nerves, brain tissue, spinal cord) is very sensitive.
- Force sensing enables force feedback, virtual fixturing, and improved guidance, which can decrease surgeon error.
- A force sensing instrument can be used to train and evaluate surgeons.





Force Sensing with Pneumatics (Gaudeni et al. 2020) [1]

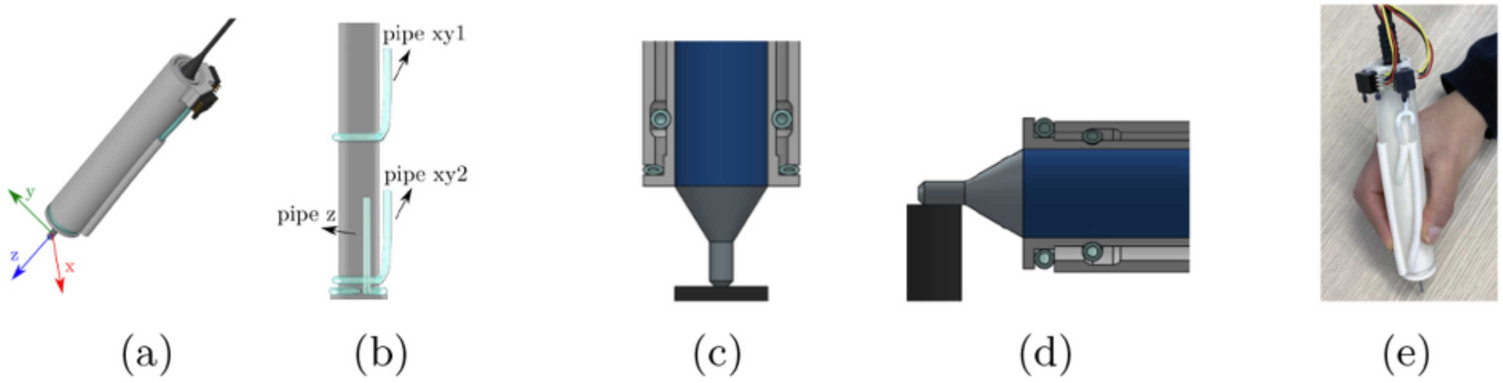


Fig. 1. The developed sensing system: (a) CAD model; (b) attachment of pipes to the inner shell; (c)(d) details of the sensing mechanism measuring perpendicular and tangential forces, respectively; (e) a user holding a surgical drill enriched with the sensing cover. Outer soft silicone pipes are covered by rigid housings to prevent the surgeon from touching them and affecting the measurements.

Handheld Surgical Drill With Integrated Thrust Force Recognition (Hessinger et al 2013) [2]

- Custom-designed deformation element fitted with strain gauges
- Tested with plywood and polystyrene specimen
- This paper is questionable

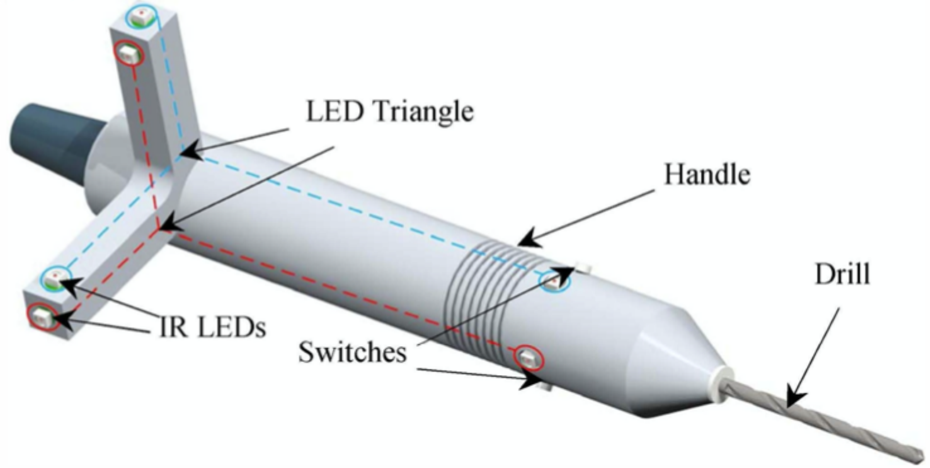


Fig 1. Design of the handheld drill device

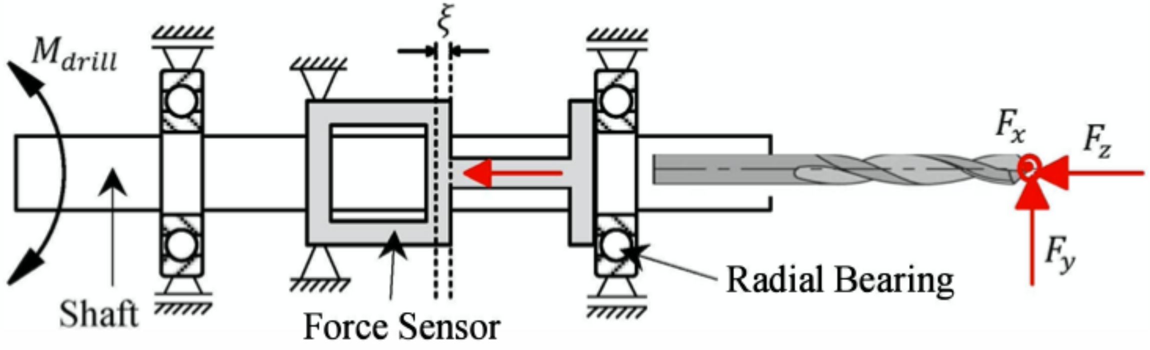


Fig 2. Mechanical structure with force sensor integration

Drilling instrument with force sensing using ATI Nano 43 and dVRK (Sang et al 2017) [3]

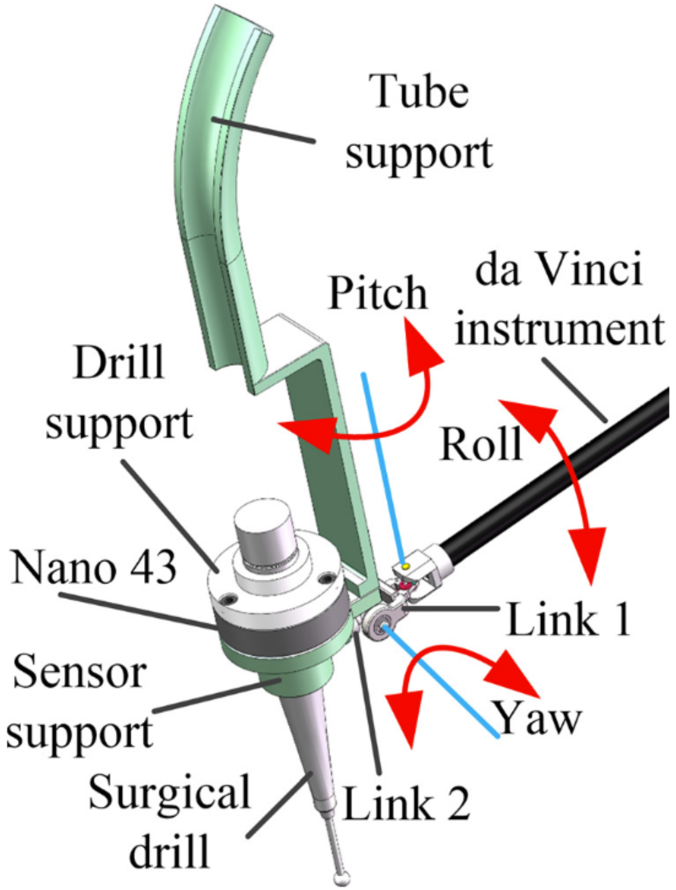


Fig. 1 The 3DOF tendon-driven surgical instrument

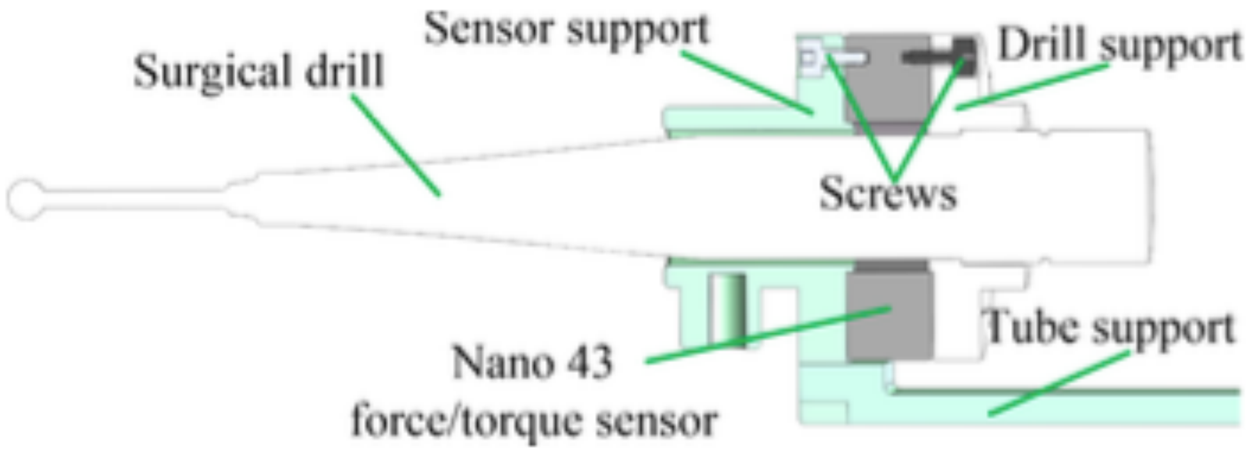


Fig. 3 The interface design of the surgical drill with F/T sensor

Drilling instrument with force sensing using ATI Nano 43 and dVRK (Sang et al 2017) [3]

- Verified position transformations by comparing desired and actual positions of drill tip
- Verified force transformations by sensing tool tip forces and applying joint torques
- To provide force feedback, a body wrench is applied at the tool control point
    - Use inverse body Jacobian to determine joint torques

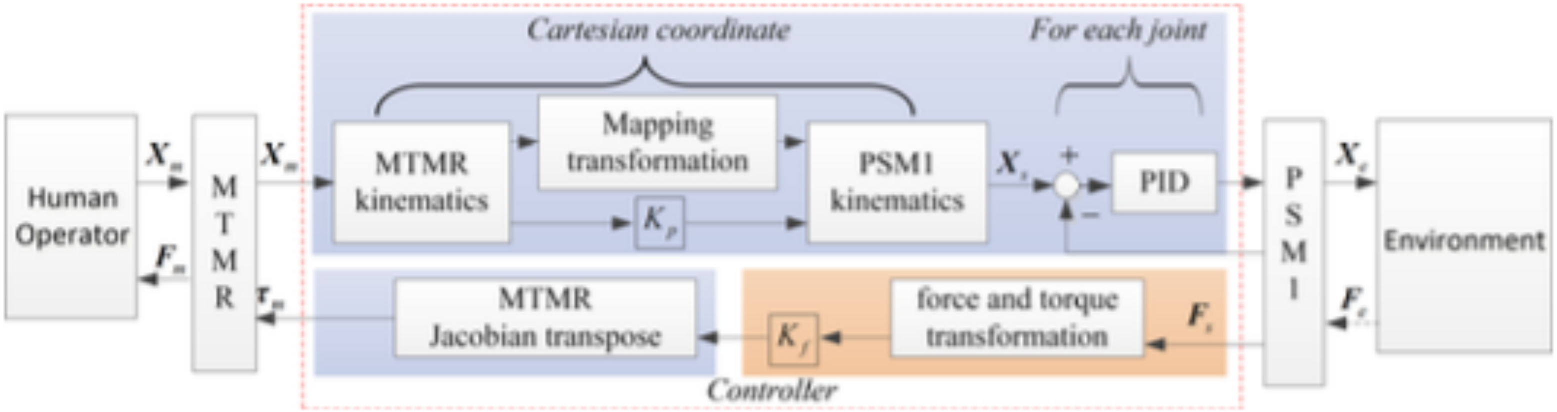
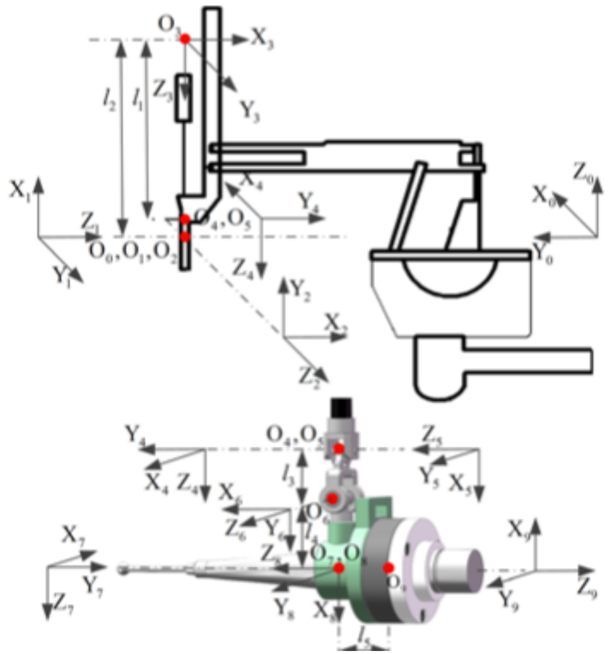


Fig. 7 The master–slave motion and force feedback control structure



$$^{MTMR_{tcp}}\mathbf{W}_{PSM1_{tcp}} = (\mathbf{J}_b^T)^+ \boldsymbol{\tau}$$

$$\begin{bmatrix} \mathbf{F}_S \\ \boldsymbol{\tau}_S \end{bmatrix} = \begin{bmatrix} \mathbf{F}_E \\ \boldsymbol{\tau}_E \end{bmatrix} + \begin{bmatrix} \mathbf{F}_G \\ \boldsymbol{\tau}_G \end{bmatrix} + \begin{bmatrix} \mathbf{F}_I \\ \boldsymbol{\tau}_I \end{bmatrix} + \begin{bmatrix} \mathbf{F}_O \\ \boldsymbol{\tau}_O \end{bmatrix}$$

Drilling instrument with force sensing using ATI Nano 43 and dVRK (Sang et al 2017) [3]

- Achieved impressive trajectory tracking and force sensing.

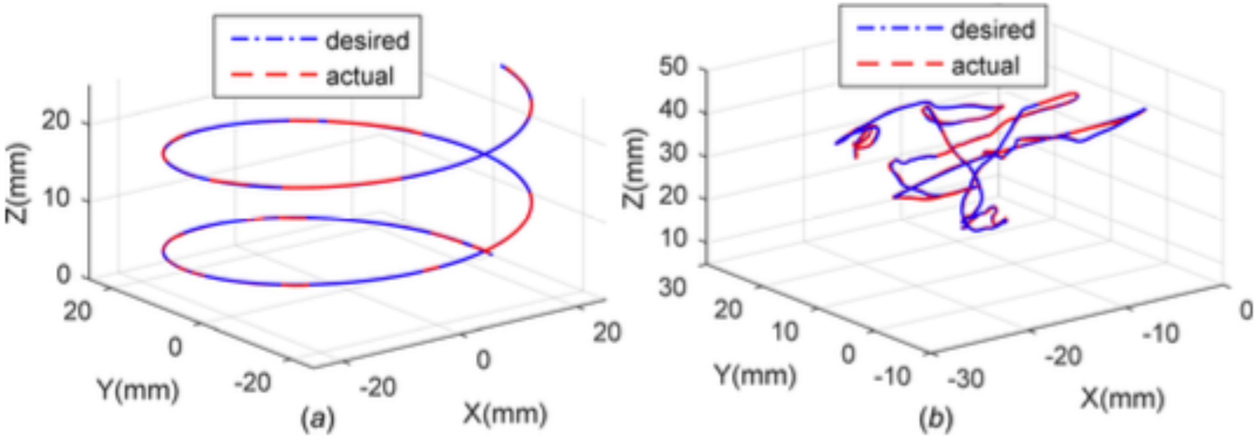


Fig. 8 The trajectory tracking responses under two modes: (*a*) command mode and (*b*) master–slave mode

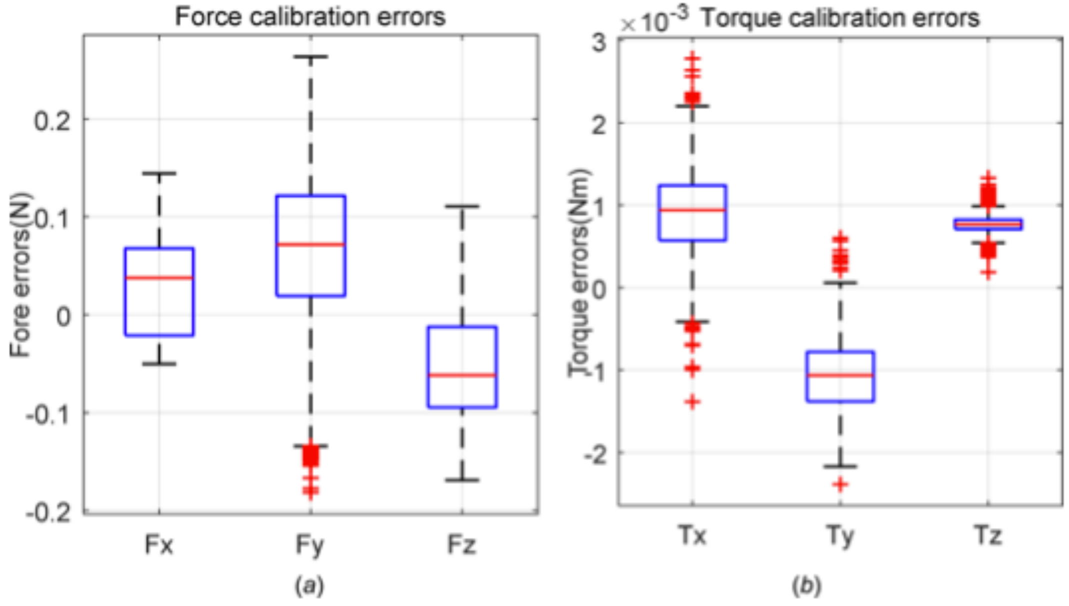


Fig. 10 The calibration errors: (*a*) force errors and (*b*) torque errors

Reading List

[1] T. B. C Gaudeni, GM Achilli, M Mandala, D Prattichizzo, "Instrumenting Hand-Held Surgical Drills with a Pneumatic Sensing Cover for Haptic Feedback," Cham, 2020: Springer International Publishing, in Haptics: Science, Technology, Applications, pp. 398-406.

[2] J. H. M Hessinger, PP Pott, R Werthschutzky "Handheld Surgical Drill With Integrated Thrust Force Recognition," presented at the IEEE International Conference on E-Health and Bioengineering, Grigore T Papa University a/Medicine and Pharmacy, Iasi, Romania, November 21-23,2013, 2013.

[3] R. M. H Sang, E Wilson, H Fooladi, D Preciado, K Cleary, "A New Surgical Drill Instrument With Force Sensing and Force Feedback for Robotically Assisted Otologic Surgery," *Journal of Medical Devices,* vol. 11, September 2017.