Low-cost 3-axis soft tactile sensors for the human-friendly robot Vizzy

Seminar Critical Review
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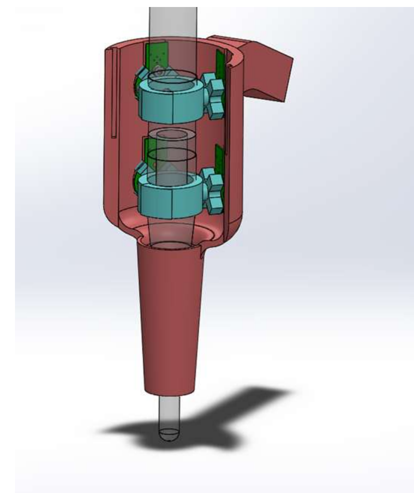
GALEN ROBOTICS

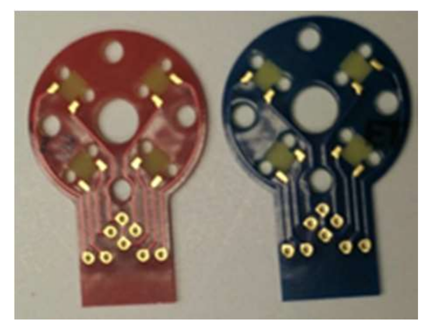
Project Background (Group 15)

- **Galen Robot:** Hand-over-hand cooperatively controlled surgical robotic system used for head and neck microsurgery.
- Currently Galen system can detect tool-to-robot forces but for some applications it is also useful to control/detect tool-to-tissue forces
- Our group is working on developing a force sensing drill for skull base surgery.
  - Force readings could be used for better control of Galen
  - Applications: Visual feedback, safety limits, surgical skill evaluation, unbiased comparison of surgical techniques

Paper Selected: Low-cost 3-axis soft tactile sensors for the human-friendly robot Vizzy

- Conference paper sent to our group by Professor Taylor
- Current design uses strain gauge force sensors developed by the BLAM lab
- Challenges: sensors are large, drill to sleeve contact difficult to construct
- Paper describes a potential alternative
  - Hall effect force sensor design





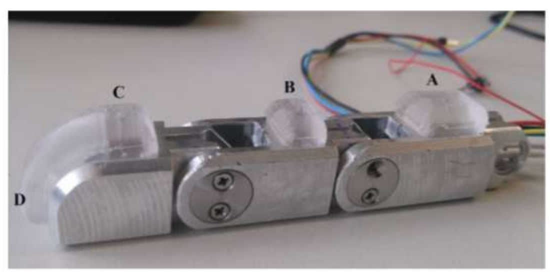
Citation: T. Paulino et al., "Low-cost 3-axis soft tactile sensors for the human-friendly robot Vizzy," 2017 IEEE International Conference on Robotics and Automation (ICRA), Singapore, 2017, pp. 966-971.

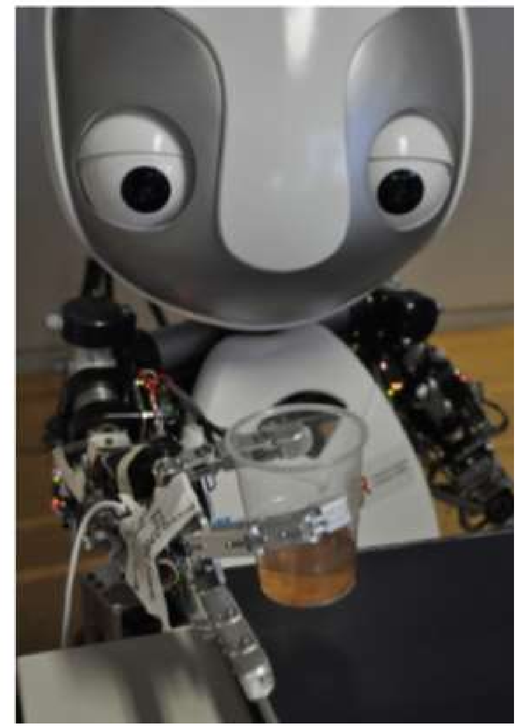
Problem Summary

- Need for tactile sensing to ensure safe interaction between robot and environment
- Desired Sensor features:
  - Soft contact surface
  - Ability to measure complete force vector (normal and shear forces) with high sensitivity, low hysteresis, and good repeatability
  - Size, weight, complexity constraints
- Although more companies have been commercializing tactile sensors, price is still relatively high and specifications are inadequate for specific applications

Key Result

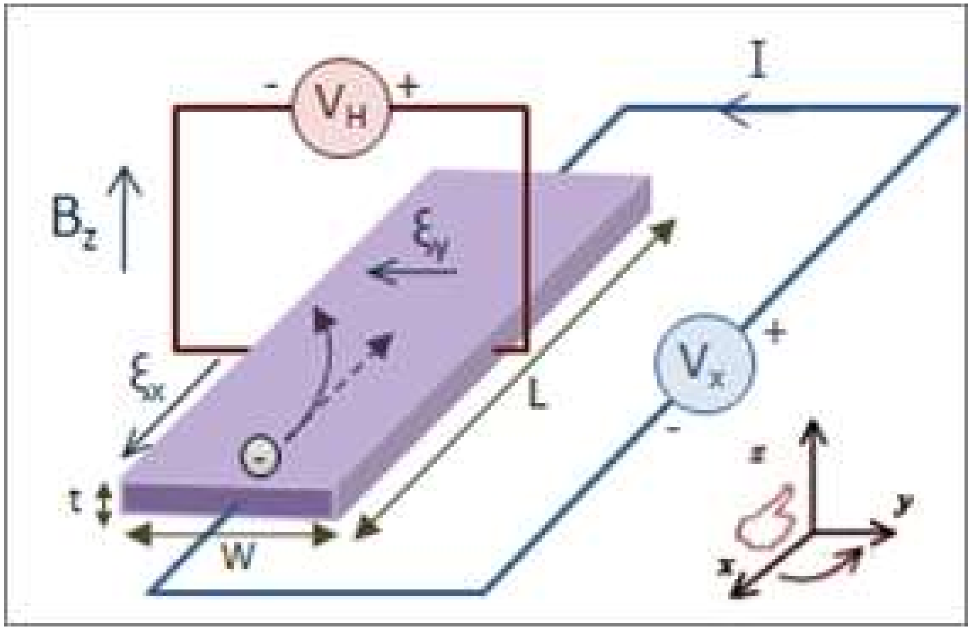
- Paper presents design, development, and characterization of a 3-axis tactile sensor
- Three main contributions
  - Novel solution for 3-axis soft tactile sensing, with state of the art performance
  - Detailed description on how the sensor can be fabricated at low cost without specific technical expertise
  - Demonstrated real-world use of the sensor





Background: Hall effect

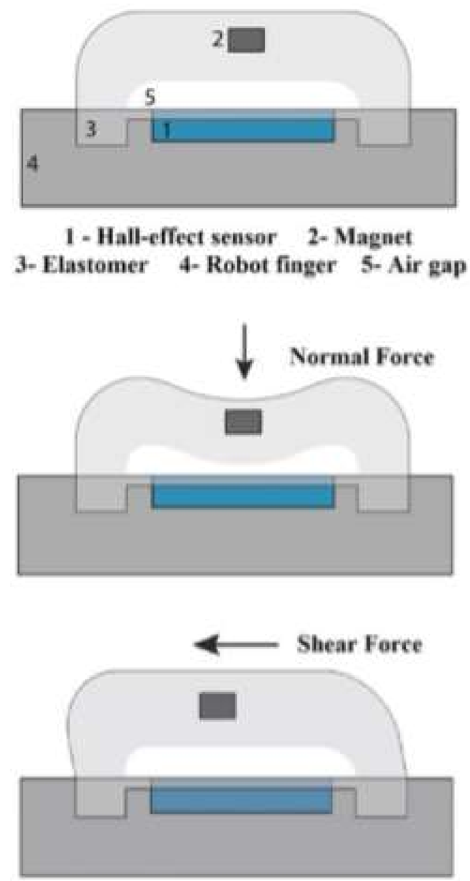
- Current flowing through slab
- Presence of the magnetic field: charged particles experience Lorentz force
  - Buildup of charge on one side of the slab creates electric field
- Hall voltage: potential difference across the slab
  - Outputted by Hall effect sensor



https://en.wikipedia.org/wiki/Hall_effect

Technical Approach: Sensor Design and Working Principle

- Sensor consists of soft elastomer with permanent magnet inside and Hall effect sensor below
- Hall effect sensor that was used is 3-axis sensor
  - Can detect magnetic field variations caused by the application of both normal (Z) and Shear (X, Y) forces
- Air gap to improve sensitivity [1]
- Initial prototype outlined in a 2013 paper but no characterization or real-world experimentation reported [2]

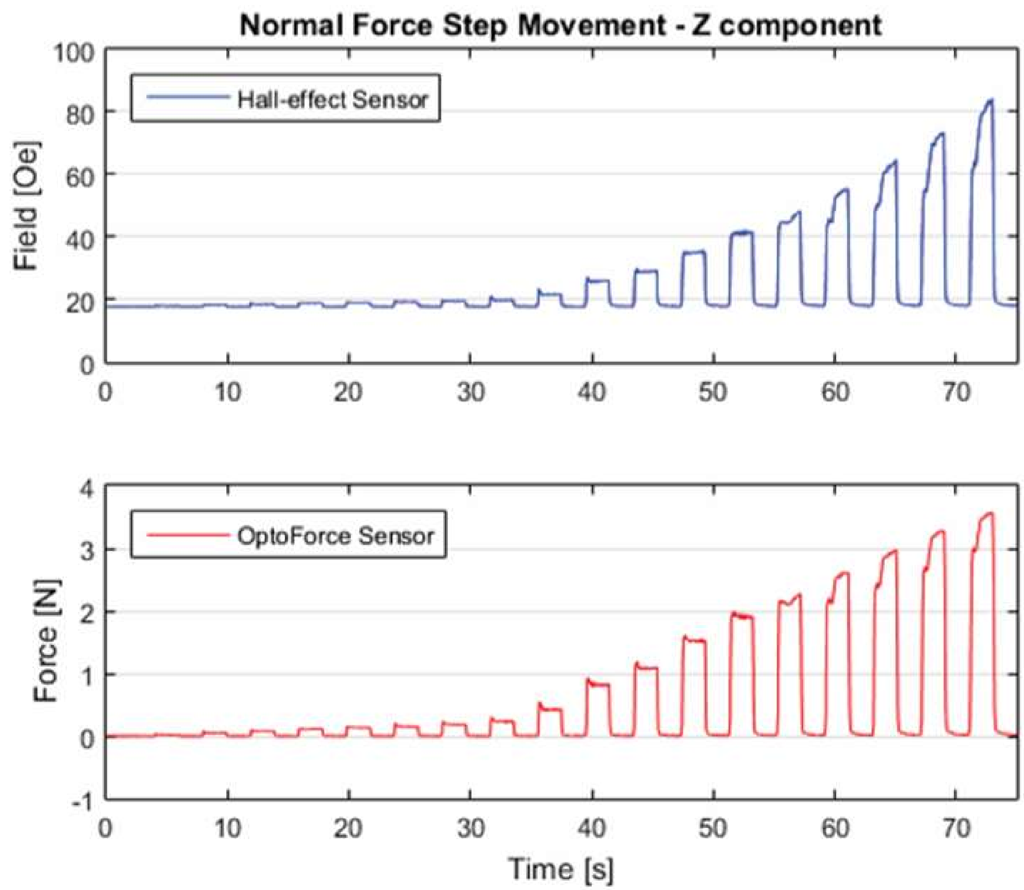


Sensor Components

- Hall effect sensor: Melexis MLX90393 magnetic node
  - 3 x 3 mm
  - 16-bit output proportional to magnetic flux density along X, Y, Z axes [3]
- Flexible PCB used to bend to fit Vizzy finger geometry
- Elastomer made out of Polydimethylsiloxane (PDMS)
  - Widely used silicon-based polymer
  - Shaped using 3D printed molds (CAD files freely available)
- Permanent magnet: neodymium disk magnet with 1mm diameter and 1mm height with grade N45 was used
- Data from sensors acquired with Arduino through I2C protocol
  - Requires four wires per sensor

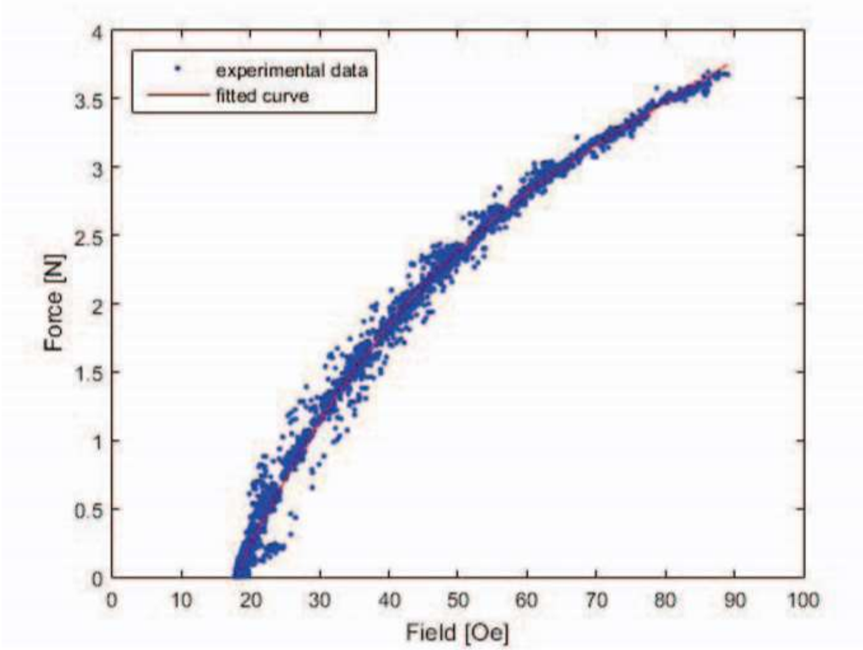
Calibration

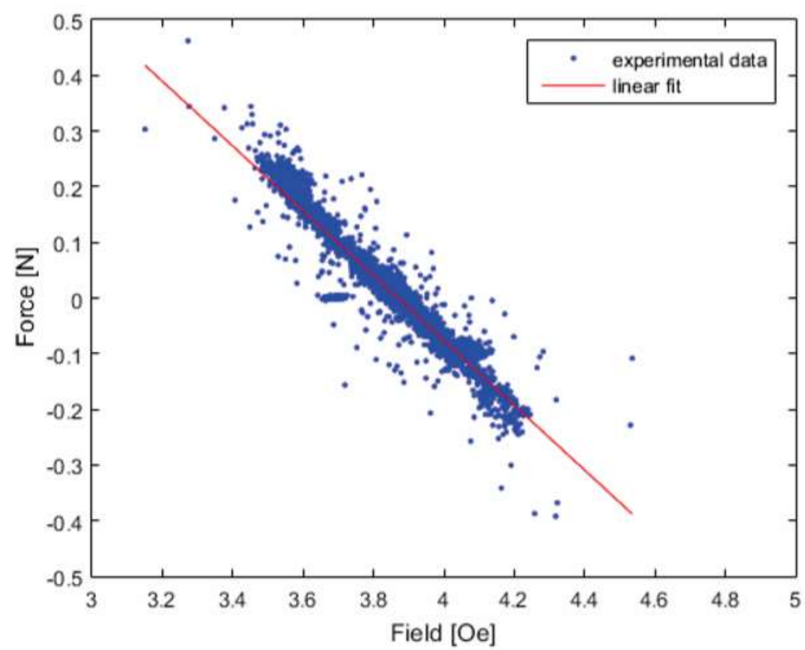
- Reference sensor: OptoForce optical force sensor
- Increasing force step movement
  - Hall effect force sensor pressed against reference sensor with increasing intensity over three main directions
  - 1N constant normal force during shear force calibration
  - Repeated 10 times for each direction



Calibration

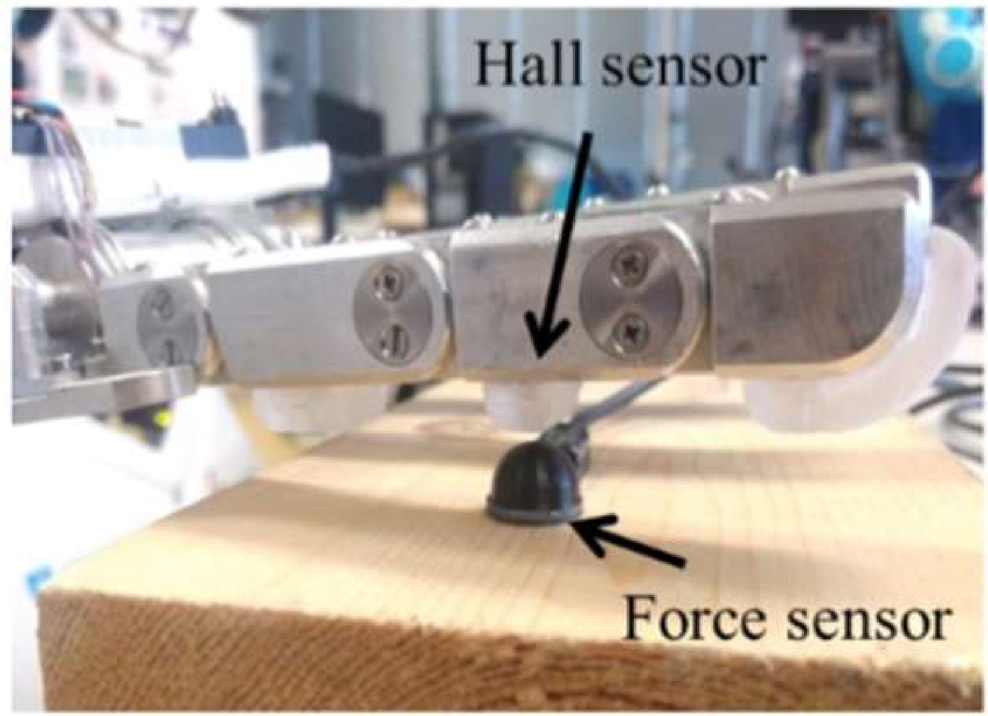
- Quadratic regression performed for Z (normal force) component
- Linear regression for each of the X and Y (shear force) components



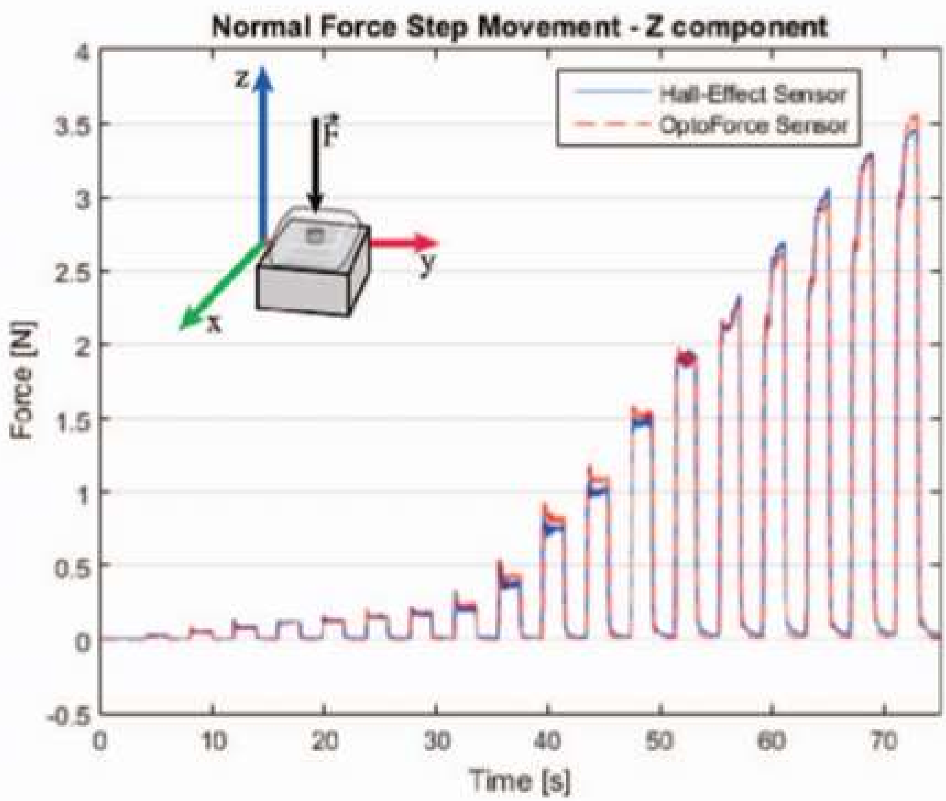


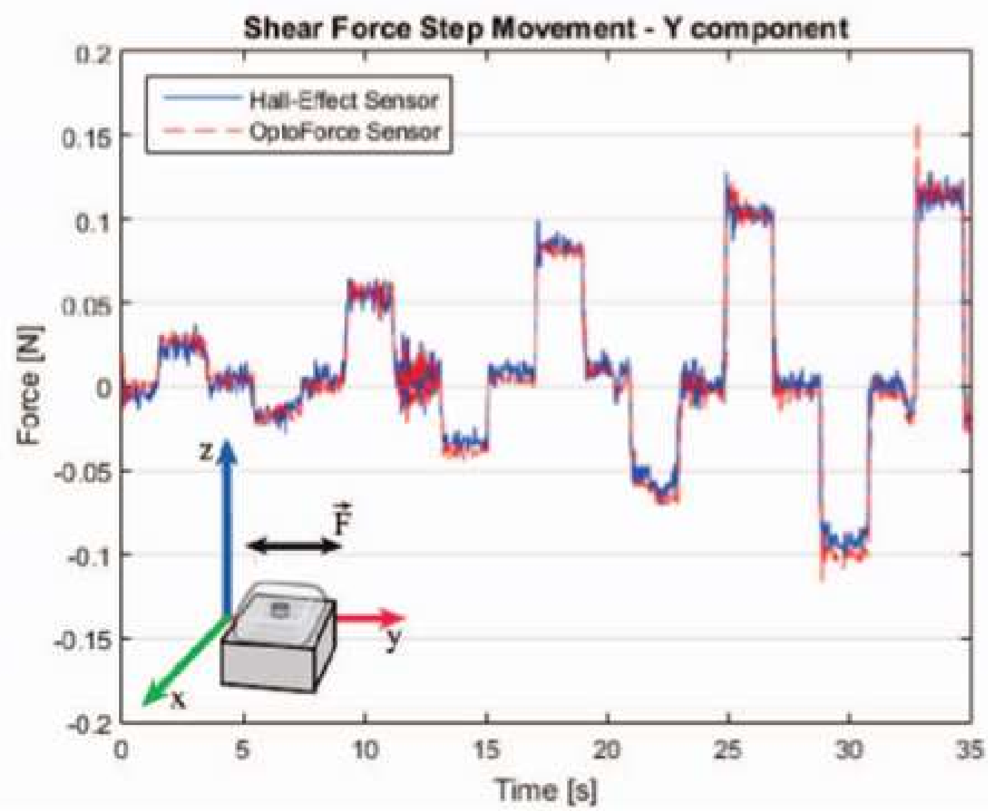
Validation

- Measured calibrated output of one sensor mounted on robot while a finger applied pressure on the reference force sensor.
- Plots were created for both normal and shear force detection (next slide).
- Normalized root-mean-square error computed using *goodnessOfFit()* MATLAB function
  - -Infinity (poor fit) to 1 (perfect fit)
  - Normal force: 0.9123
  - Shear force: 0.7908



Validation Plots

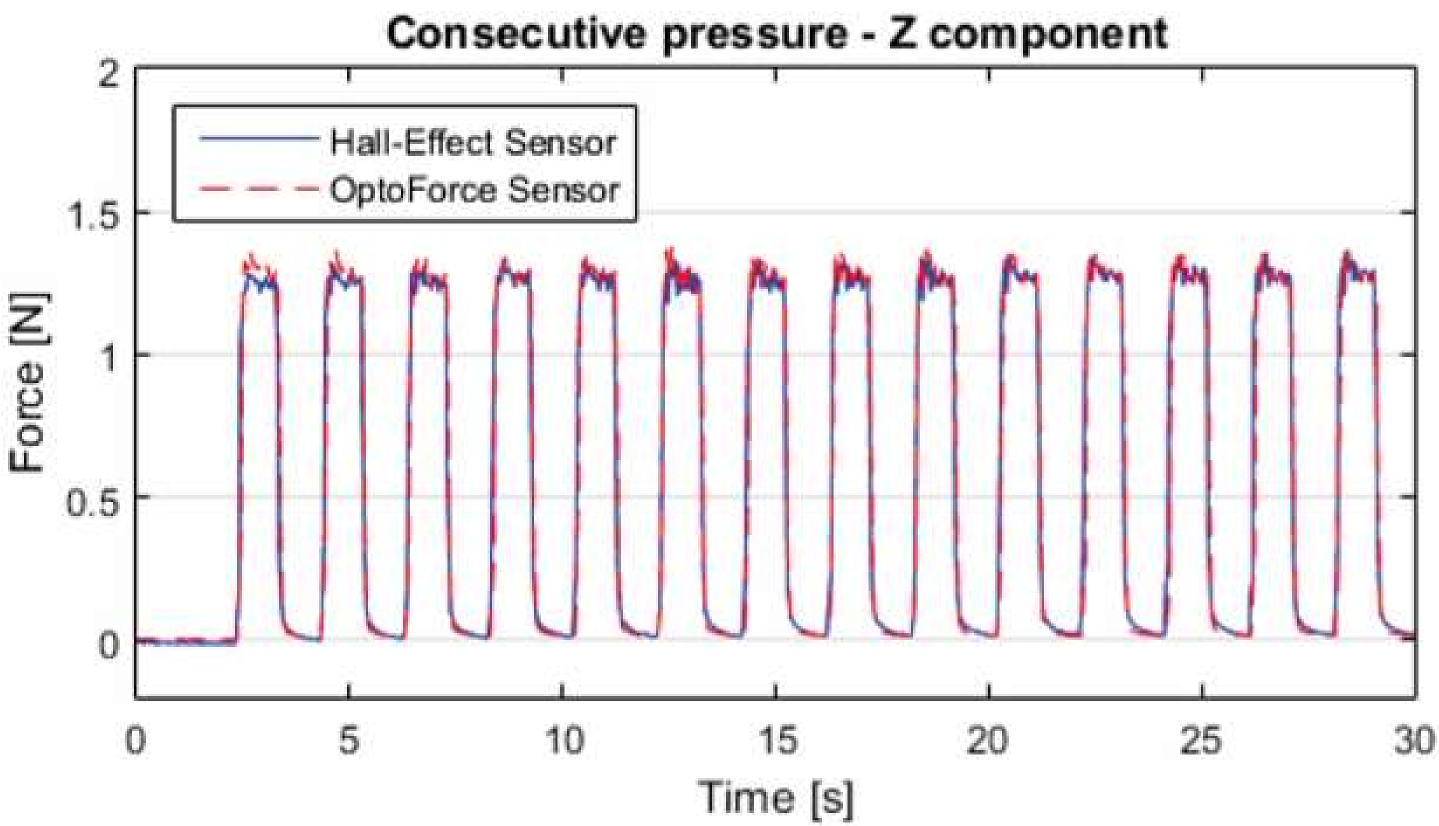




Hysteresis, Sensitivity, Noise

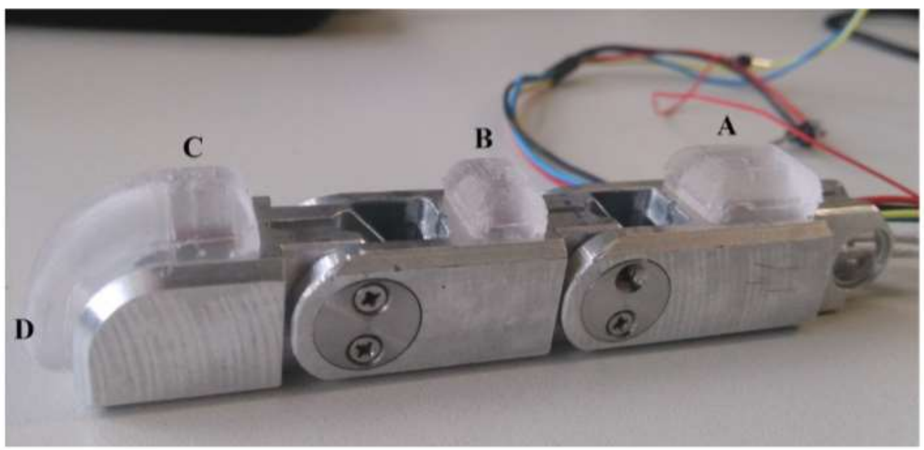
- Limited Hysteresis
  - Robot finger tapped repeatedly on reference sensor while applying consecutive pressures of same intensity
- Minimum force detected
  - Micropositioning system: moved from position right before contact in 4μm increments
  - 7.2mN for normal force – state of the art considering sensors integrated into robot hands
  - less than 20mN for shear force – not an exact measurement due to "limitation of the calibration setup"
- Noise level: ±2.5 mN

Consecutive Force Experiment

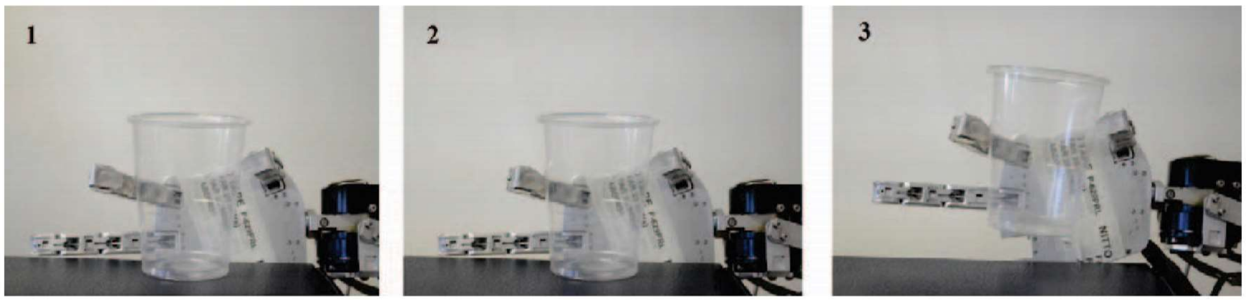


Real-world Experiment

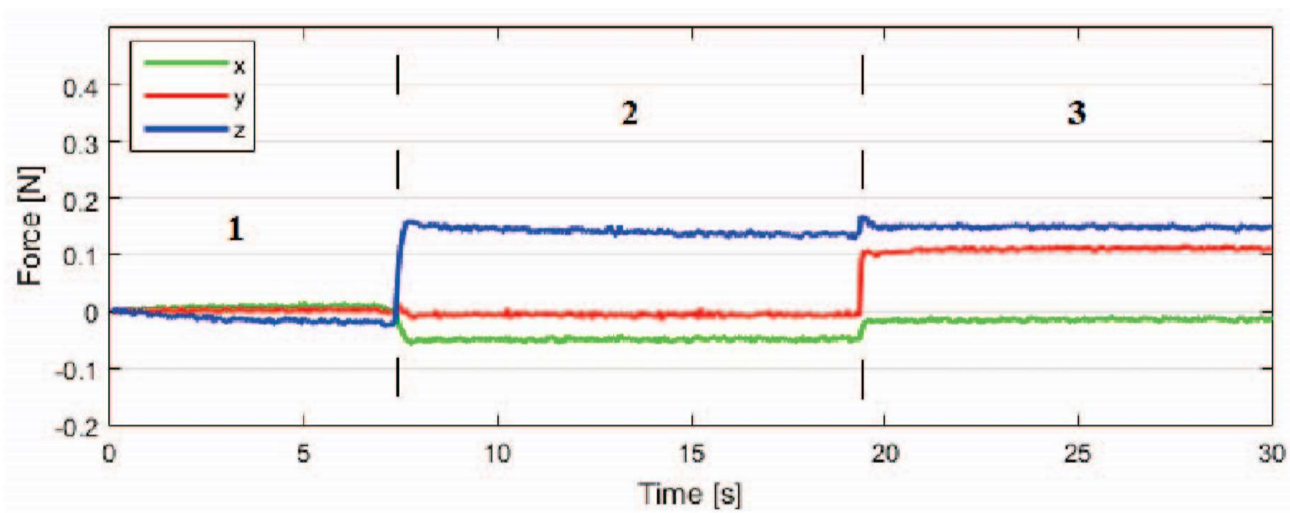
- Experiment in which Vizzy grabbed and lifted a plastic cup
  - Either empty or partially filled with water
- Force values recorded on sensor C in image below
- Increase in Y component (+0.3 N) consistent with increase in weight of cup when filled with water



Vizzy Lifting Empty Cup

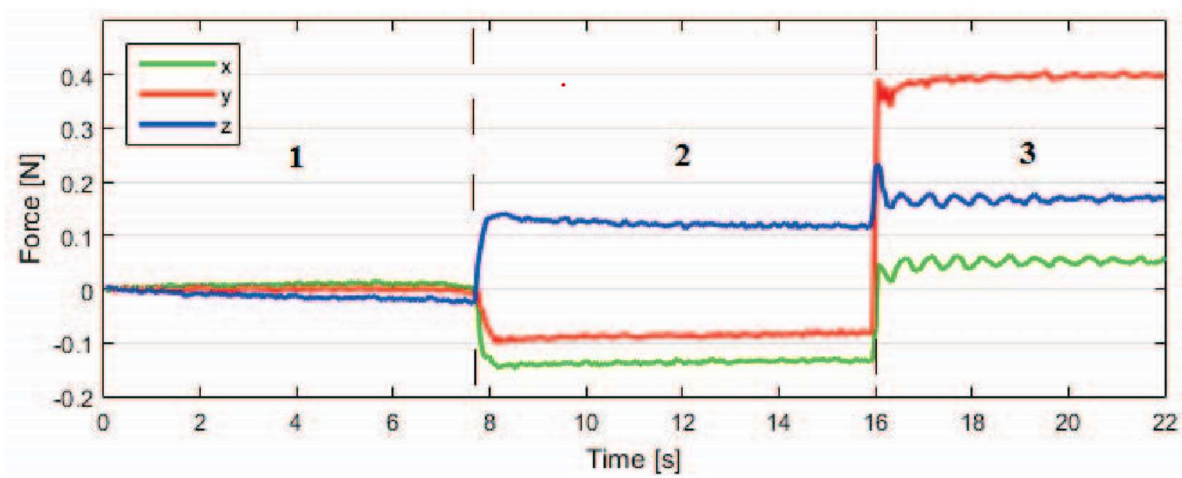


(a) 1 - Before contact 2 - Grabbing cup 3 - Lifting cup.



Vizzy Lifting Partially Filled Cup

(a) 1-Before contact 2-Grabbing cup 3-Lifting cup.



Assessment

- Novel approach to tactile force sensing in robotic applications
- Paper provided detailed process on how to assemble and calibrate the sensors
- Accessible to researchers due to low cost of components and limited expertise necessary

Assessment

Pros

- Paper clearly outlined development and testing steps
- Diagrams were helpful in understanding experiments performed and data collected
- Paper was explicit regarding the components used

Cons

- In our project electrical current is running through drill: could cause magnetic interference with the Hall sensors (interference cases untested in this paper)
- Many grammatical mistakes but did not detract from overall meaning
- Could have done more detailed testing to determine optimal air gap, elastomer material, etc.

Conclusion

- The force sensing method described in this paper could improve our group’s drill design
  - Hall effect sensors much smaller than strain gauge sensors
  - More stable contact between drill sleeve and drill (elastomer/flexure material)
- Next steps:
  - Testing of a wider range of applications
  - Experimenting with different components
  - Magnetoresistive sensor
  - Exploring cases where magnetic interference is possible

References

1. L. Jamone, L. Natale, G. Metta, and G. Sandini, “Highly sensitive soft tactile sensors for an anthropomorphic robotic hand,” IEEE Sensors Journal, vol. 15, no. 8, pp. 4226–4233, 2015.
2. C. Ledermann, S. Wirges, D. Oertel, M. Mende, and H. Woern, “Tactile sensor on a magnetic basis using novel 3d hall sensor - first prototypes and results,” in INES. IEEE, 2013.
3. “Melexis - MLX90393 micropower triaxis R magnetometer datasheet,” https://www.melexis.com/en/product/mlx90393/triaxismicropower-magnetometer.