Skoltech
Skolkovo Institute of Science and Technology

Space and Engineering Systems

High-speed Delta Robot for Automatic Smartphone Disassembling Based on Human Haptics

In Russian: Высокоскоростной дельта-робот для автоматической разборки смартфонов на основе хаптики

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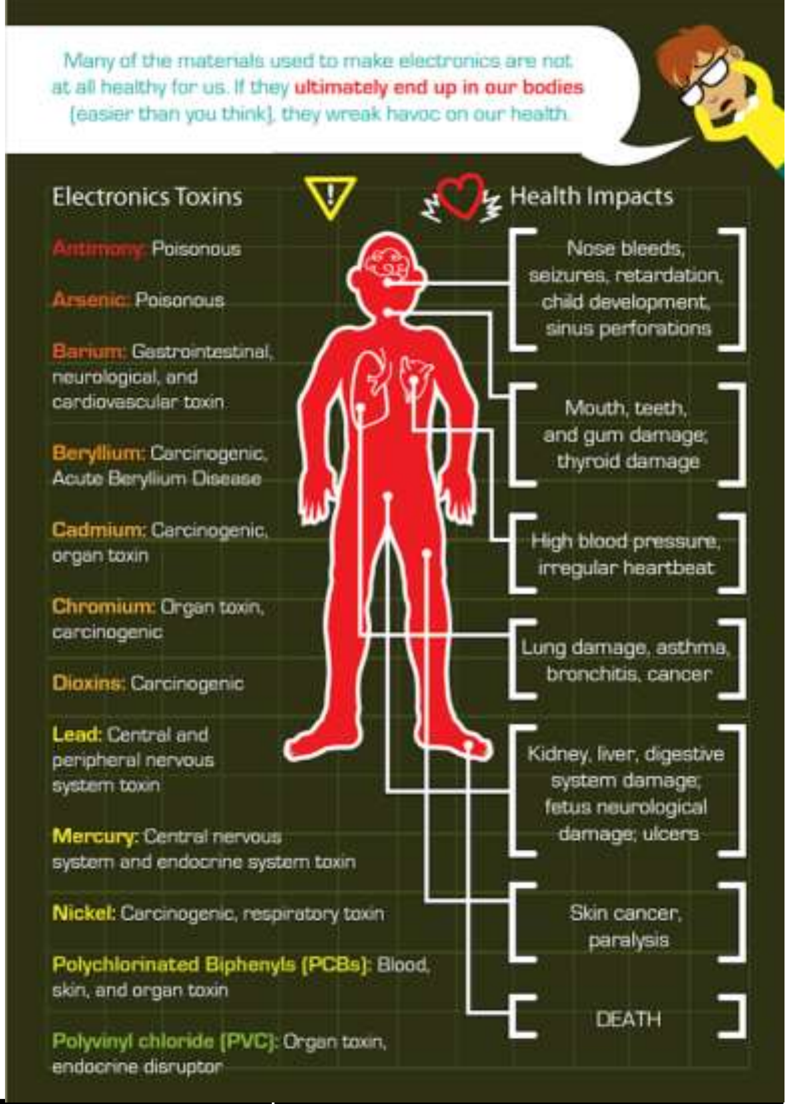
June, 2018

General problem

Global
E-waste
46 Mt
in 2017

Data from United Nations Environment Program

>80% end up in
landfills and incinerators



Product	Total disposed, Mln. units	Trashed	Recycled	Recycling rate
Computers	51.9	31.3	20.6	40%
Mobile	**152**	135	17.4	**11%**

E-waste in the US, 2010, Data collected by EPA

General problem

2016 - Liam only for iPhone 6
2018 – Daisy, 9 versions of iPhone. Has the potential to recover for every 100,000 devices:

Aluminum 1900 Kg
Gold 0.97 Kg
Silver 7.5 Kg
Rare Earth Elements 11 kg
Tungsten 93 Kg

Copper 710 Kg
Platinum 0,10 Kg
Tin 42 Kg
Cobalt 770 Kg
Tantalum 1.8 Kg

Apple recovered 2,204 pounds (1 000 kg) of gold from broken iPhones in 2016.

CNN press

Rujaevich, C., Lessard, J., Chandler, S., Shannon, S., Dahmus, J., Guzzo, R.: Liam - An Innovation Story (2016). URL https://www.apple.com/environment/pdf/Liam_white_paper_Sept2016.pdf

Objective

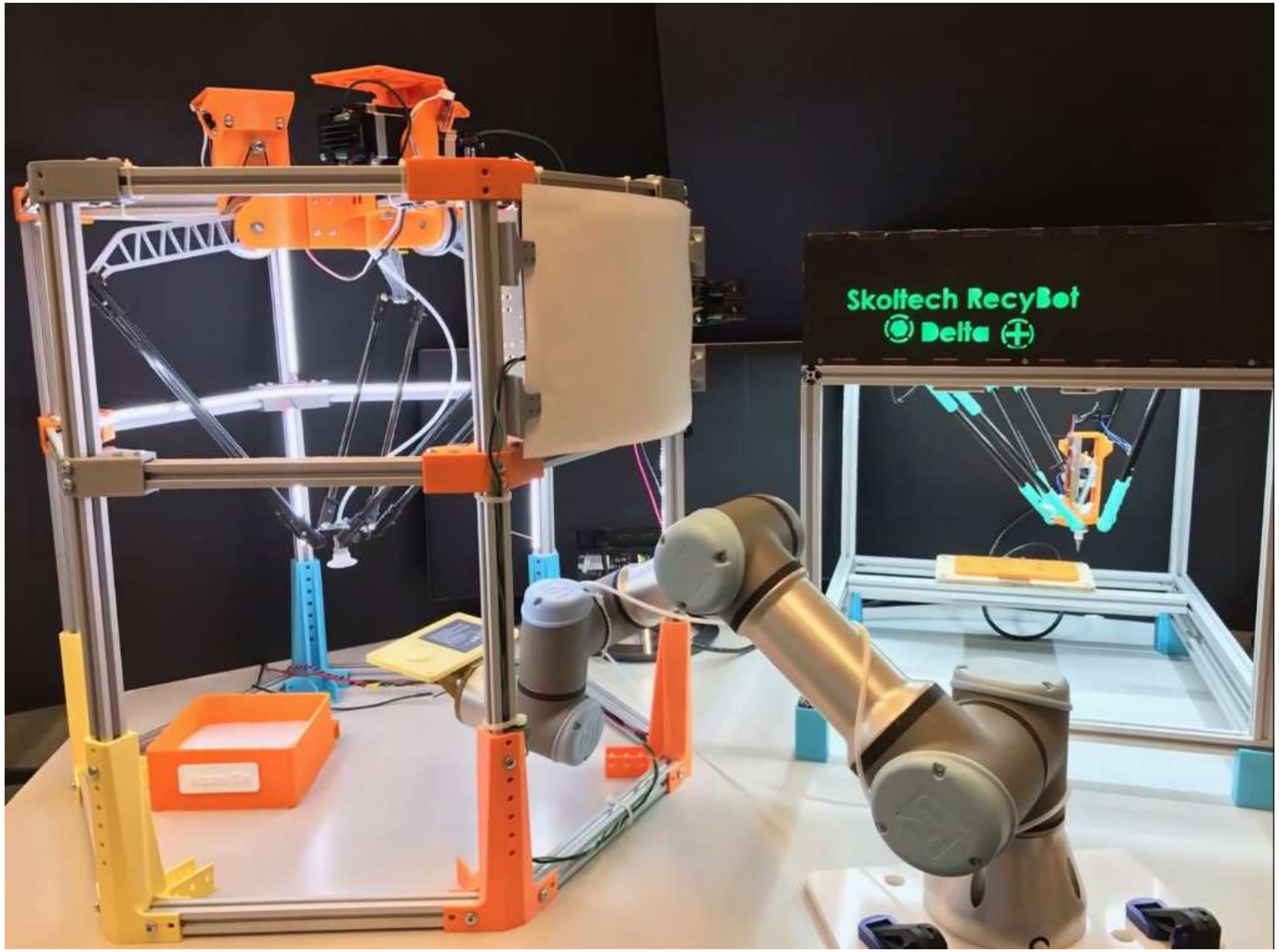
The **RecyBot** project focuses on the development of a universal high-speed intelligent robotic system for electronics recycling. RecyBot consists of several robots, each tailored to perform a specific task, which joined target is to **disassemble smartphones** at the component level and to enable **material recovery**.

The thesis is focused on:

- The developing of the high-speed robot

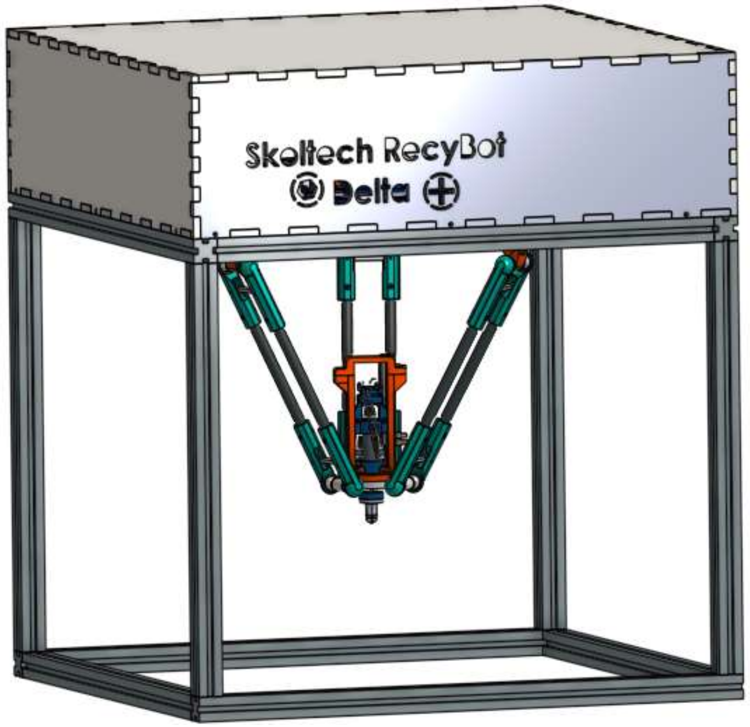
- The study of the human haptics during the screwing and unscrewing operation

- Implementation of the haptic patterns to control system



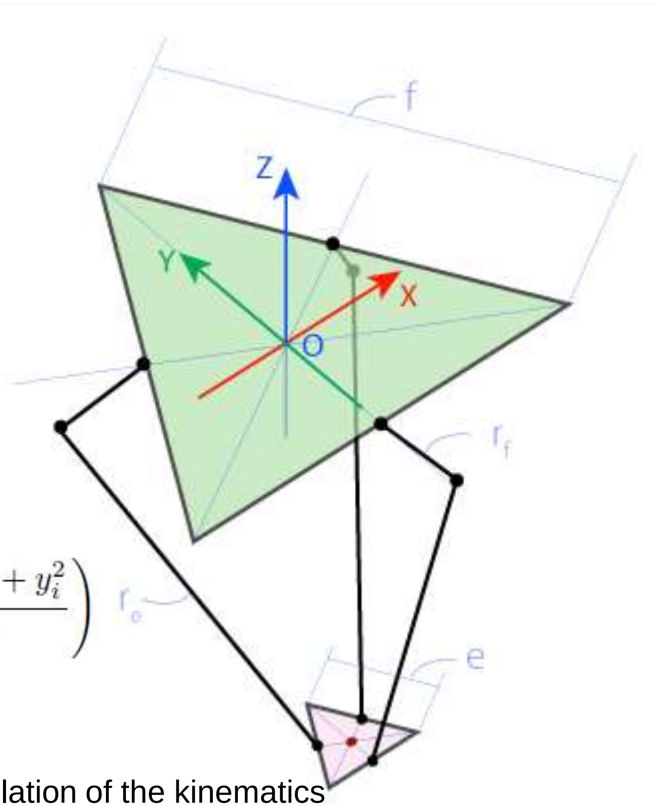
Development of the High-speed Delta Robot

- Design and construction of the delta-robot
- Forward kinematics
- Working space calculation
- End-effector tool for unscrewing with passive compliance

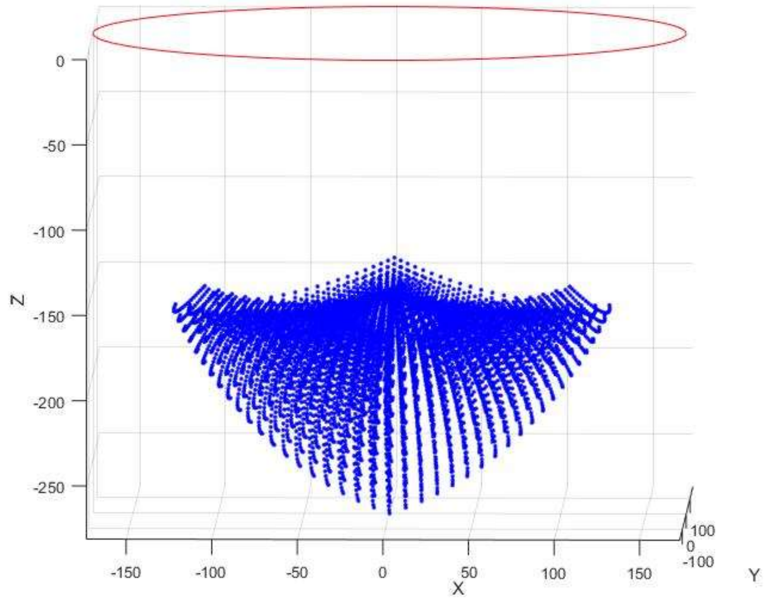


Design of the delta-robot for unscrewing

$$\theta_i = \arccos\left(\frac{-(r_e^2 - z_i^2) + r_f^2 + (x_i + e - f)^2 + y_i^2}{2r_f\sqrt{(x_i + e - f)^2 + y_i^2}}\right) - \arctan\left(\frac{y_i}{x_i + e - f}\right)$$



Calculation of the kinematics



Calculation of the working space

Automatic disassembly

Computer Vision

Mask application

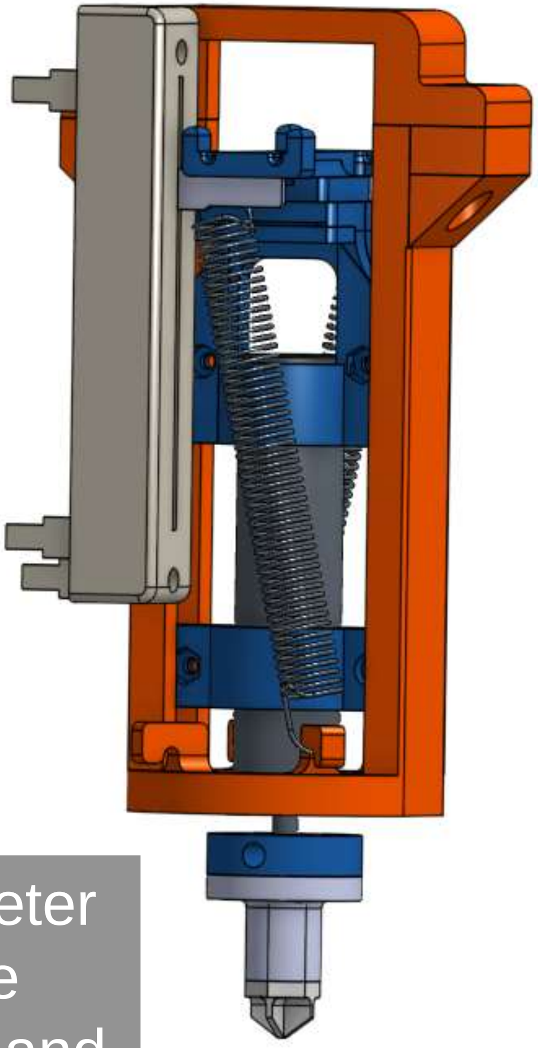
Screws position detection (6 pictures of 32x32 pixels are compared to the area of the dummy phone)

End-effector tool

Design with passive compliance.

Calculation of the torque by current sensor and behavior by potentiometer.

The potentiometer indicates the position, force, and thus unscrewing status.



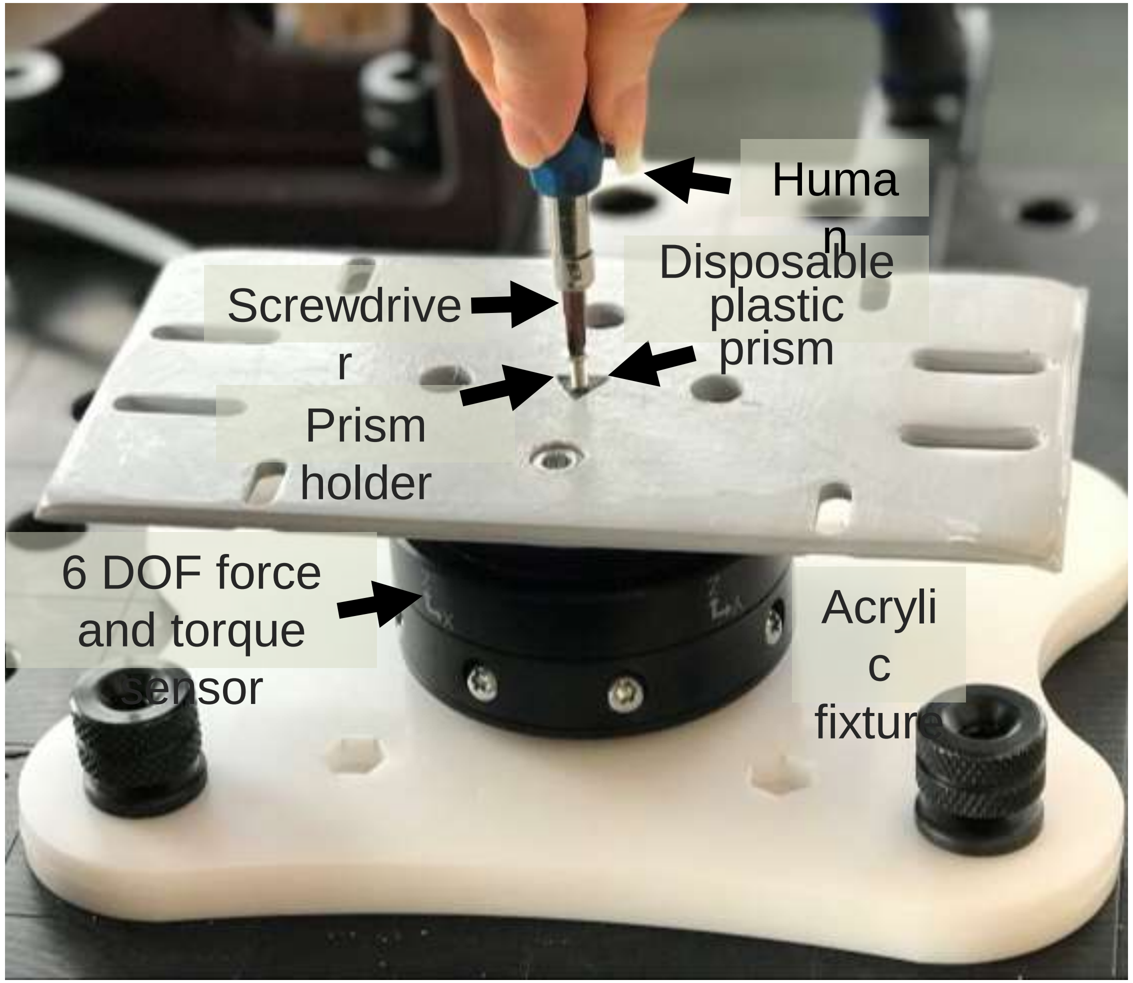
Design of the end-effector tool with passive compliance

Results

Study of Human Haptics of Screwing and Unscrewing Operations

No research on human haptics of screwing and unscrewing done before.

The principal factors to measure and control: the **perpendicular force**, and the **torque** applied about the axis of the screw.

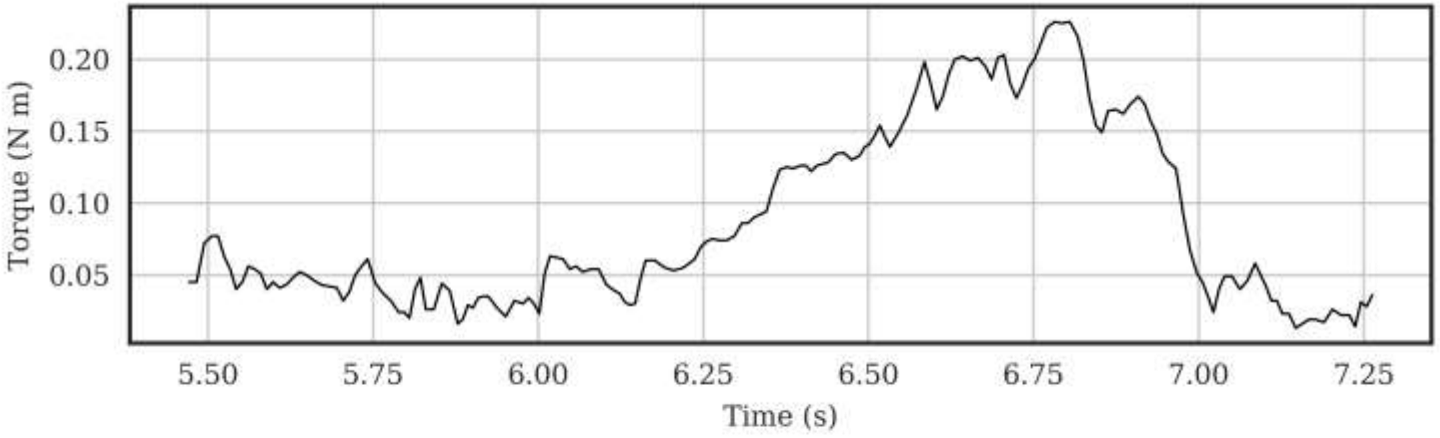


Experiment Setup

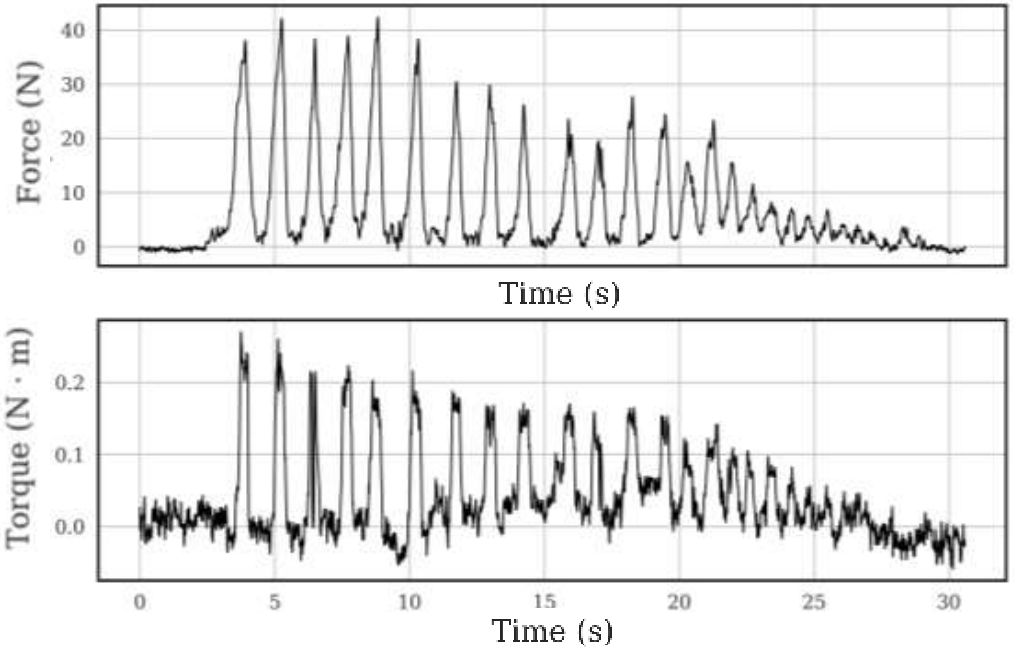
Results

Typical patterns of force along the screw axis and torque during screwing and unscrewing of a Phillips screw from the two types of a disposable prisms.

Screwing in a nut prism

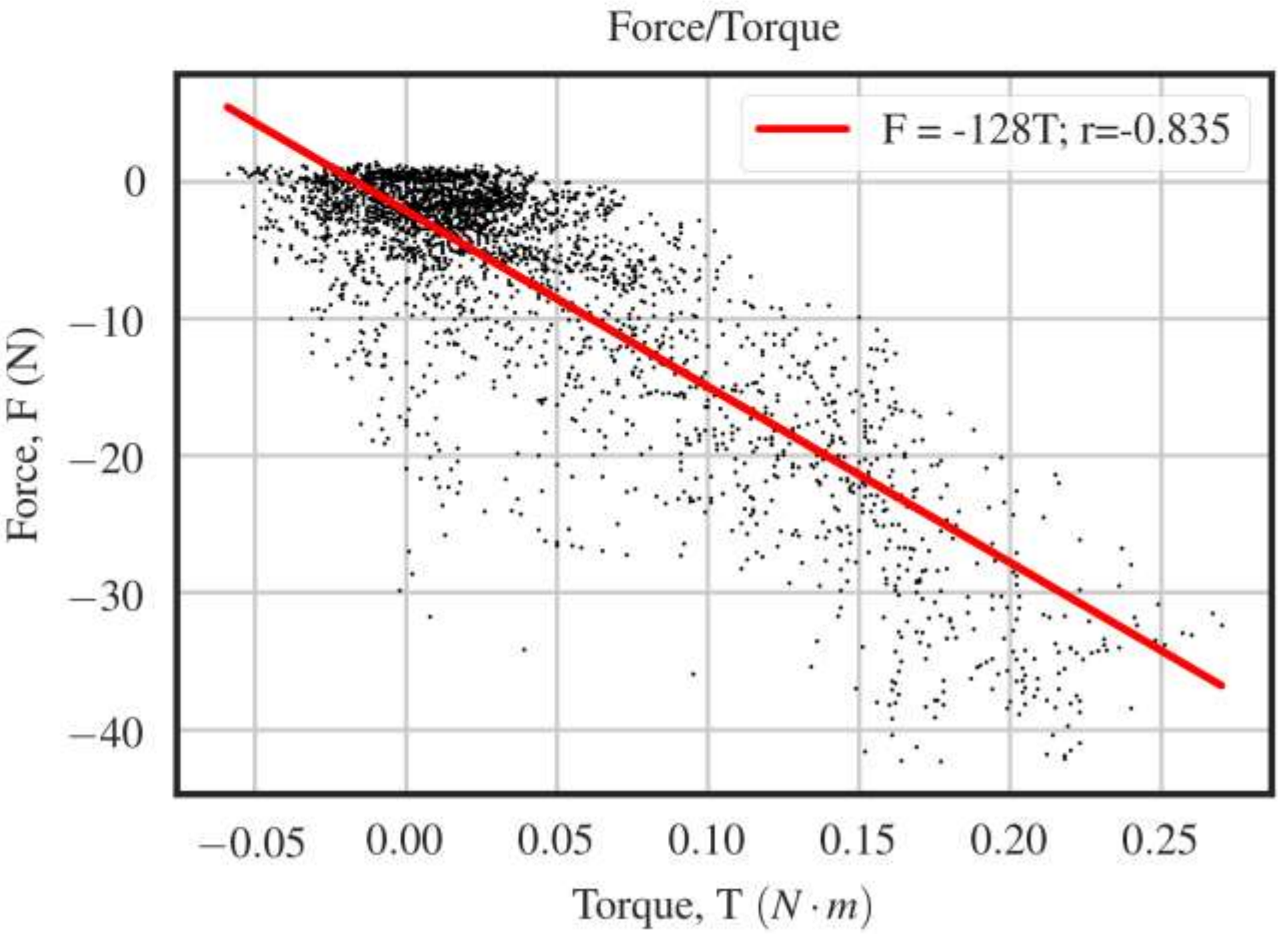


Unscrewing in a hole prism



Screwing oscillatory pattern with the frequency of (1.3 ± 0.4) Hz.

Results



Relationship between force and torque for the time series. Points represent individual measurements and the red line is the least squares approximation.

A correlation between force and torque applied simultaneously is observed.
r = (0.75 ± 0.13)

Results

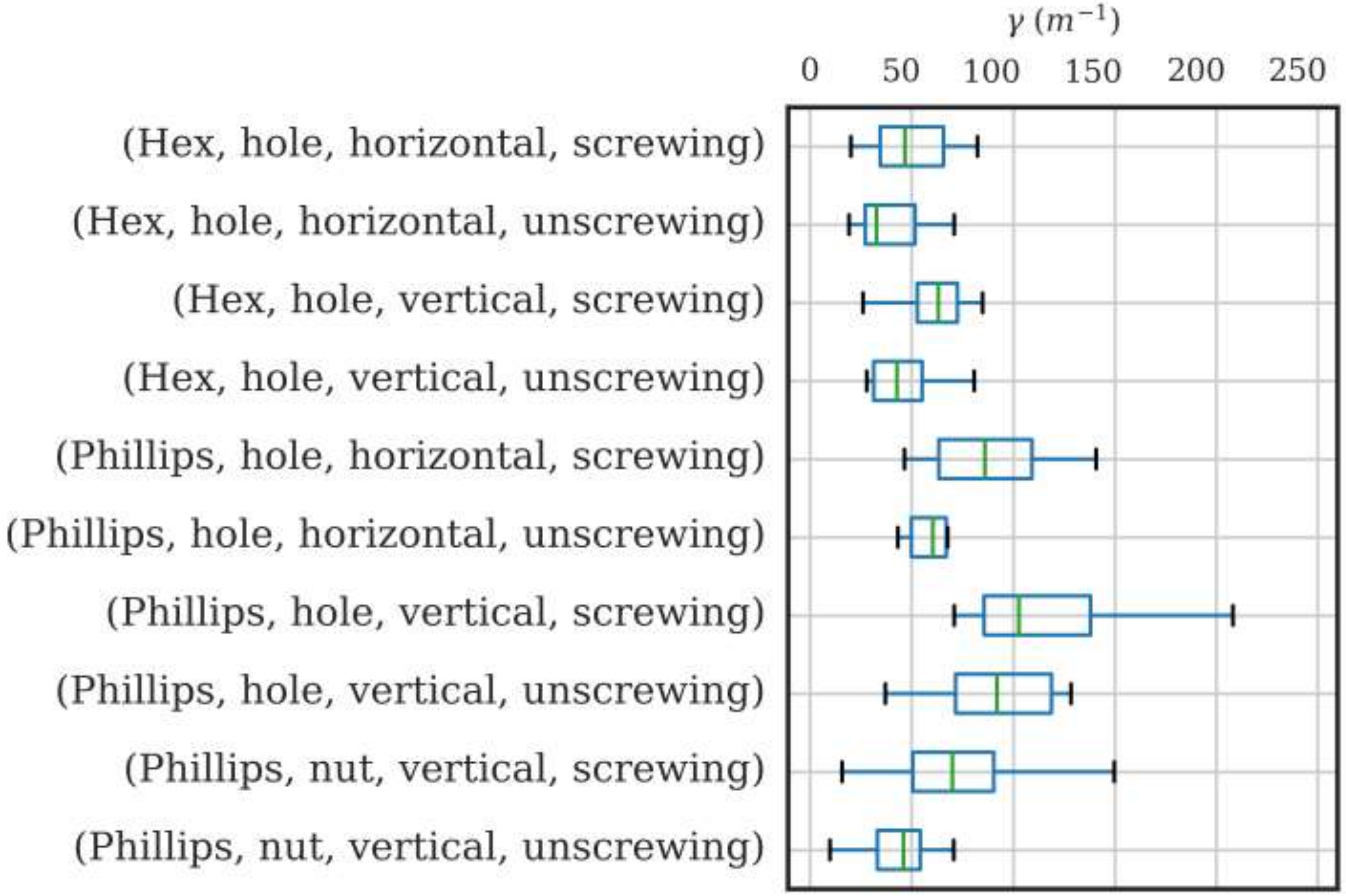
We proposed the radio Force/Torque γ as a characteristic of the screwing and unscrewing operations.

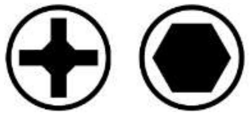
The average γ for unscrew different screws:

Phillips = $(106 \pm 37)m^{-1}$

Hexagonal = $(57 \pm 25)m^{-1}$

- **The axial force applied is principally to avoid the slippage.**



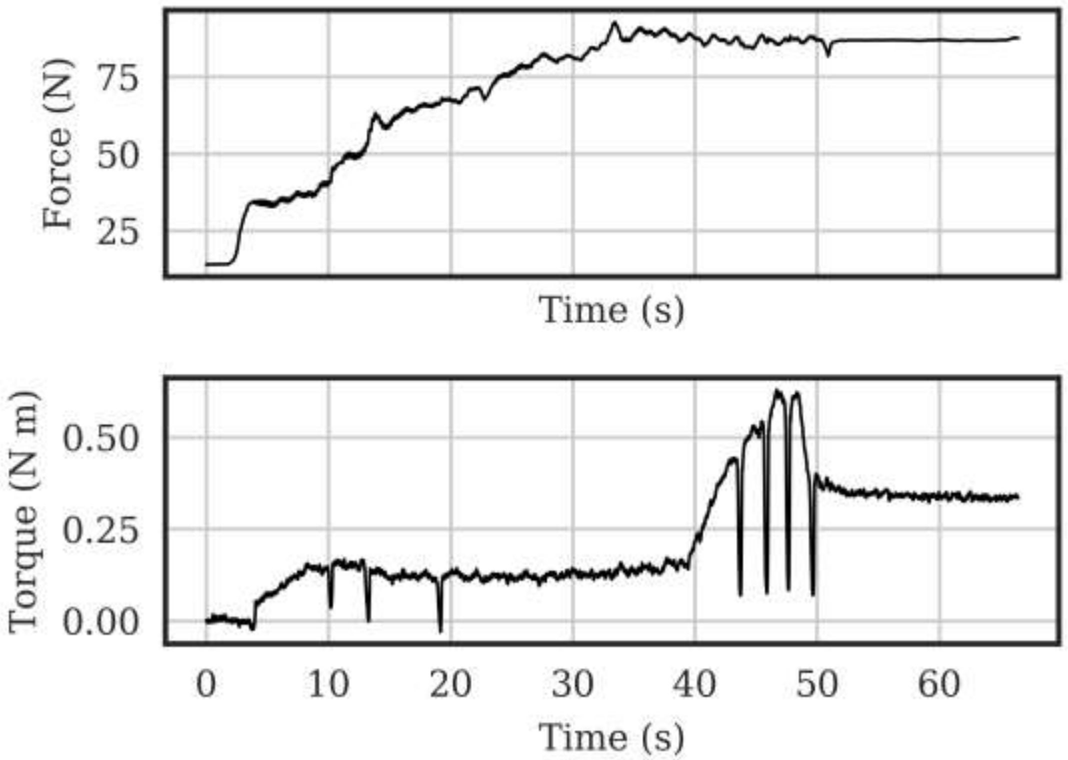


Bar plot of Force/Torque ratio γ (m^{-1}) in different conditions.

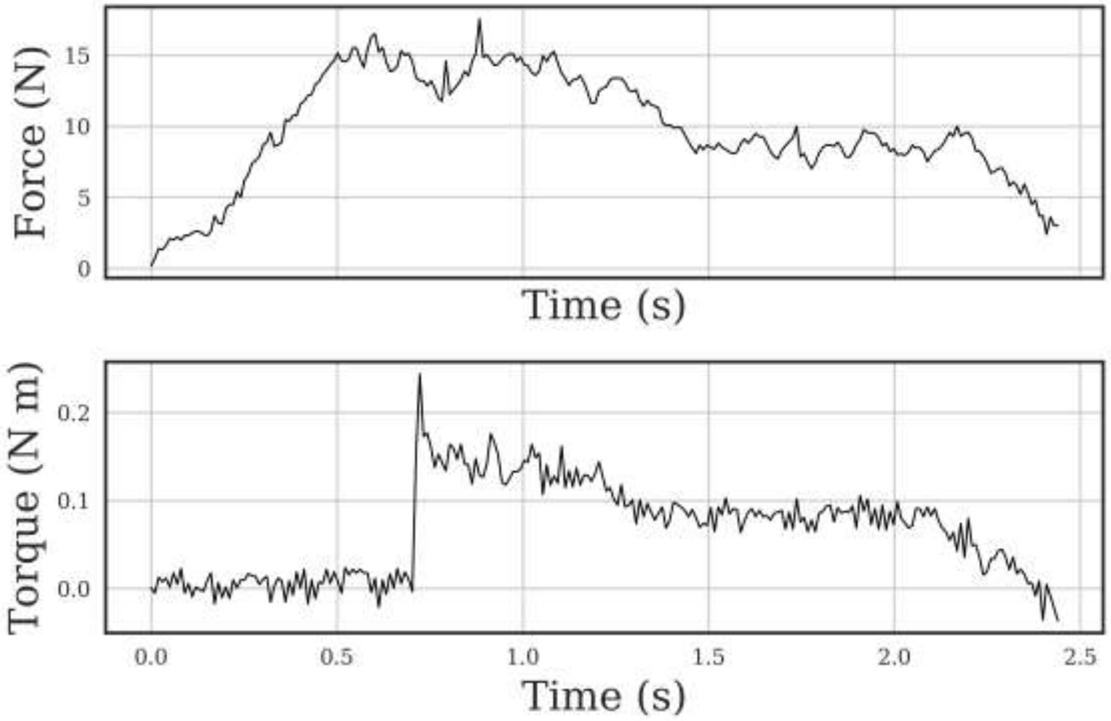
Results

Implementation of the ratio γ in the screwing-unscrewing robot.

Screwing by the robotic system



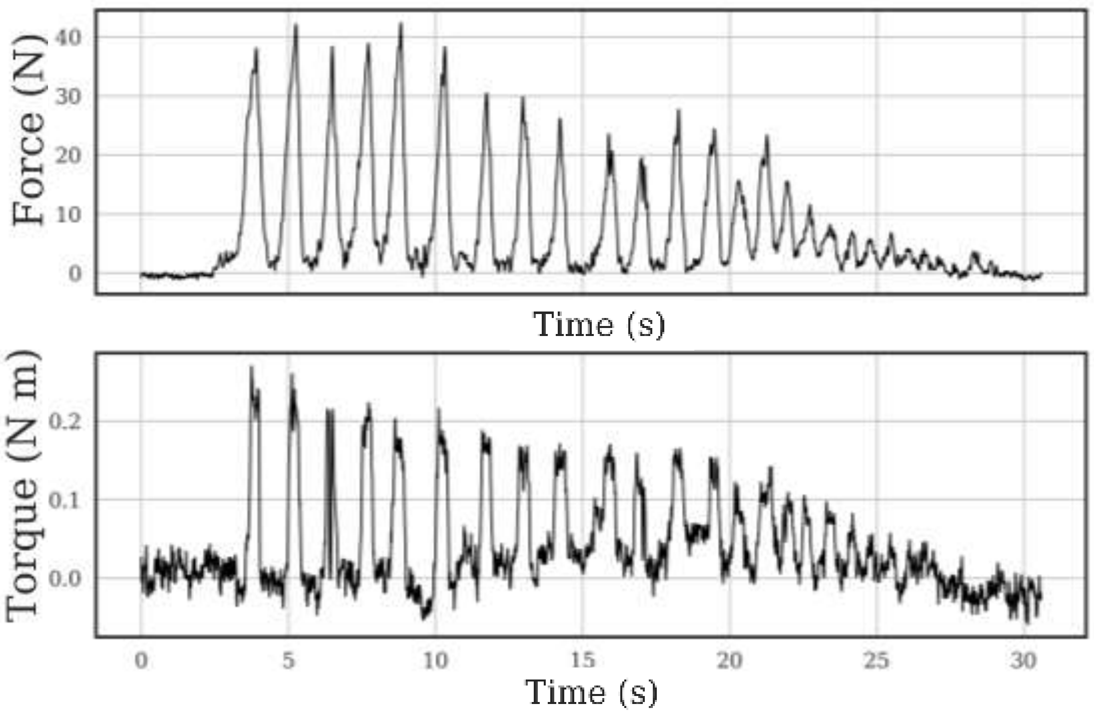
Unscrewing by the robotic system



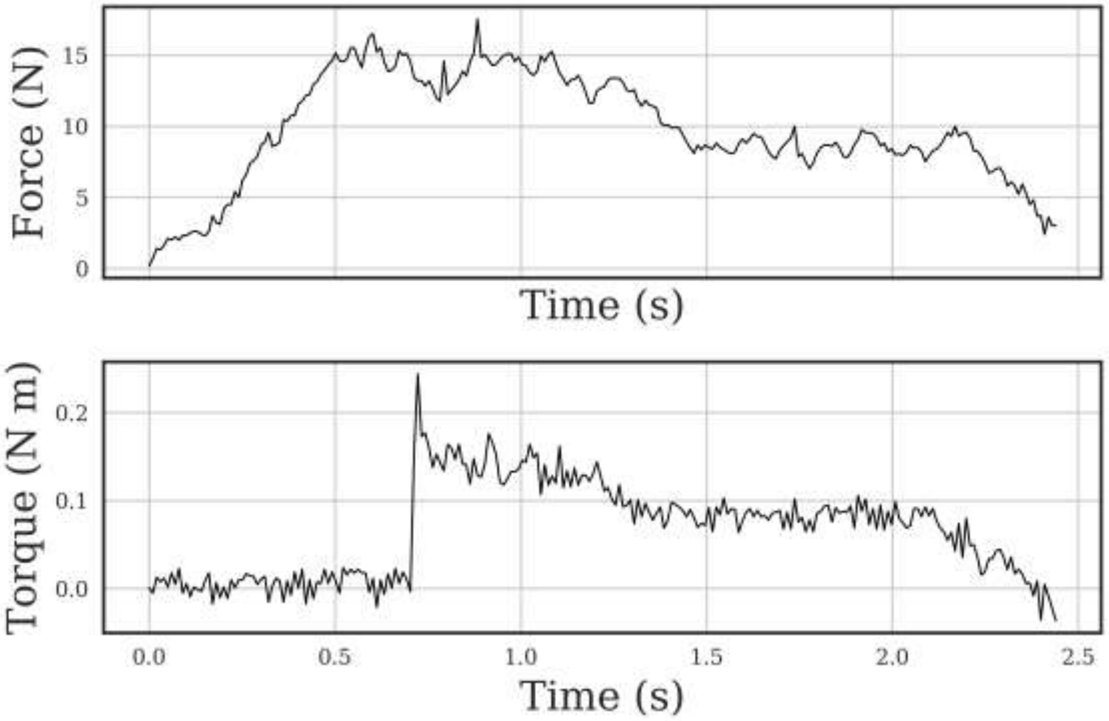
Results

Comparison between the human unscrewing and the unscrewing by the robotic system

Human Unscrewing



Unscrewing by the robotic system



Discussion of results

- Correlation torque and force.
- Find the right ratio γ (Force/Torque) in the exact conditions and implement the force control, based on the torque measurement.
- Learn from human and teach robot.
- Reduce the slippage (cam-out).
- Camera calibration for best results.
- Teleoperation using the haptic patterns.

Publications:

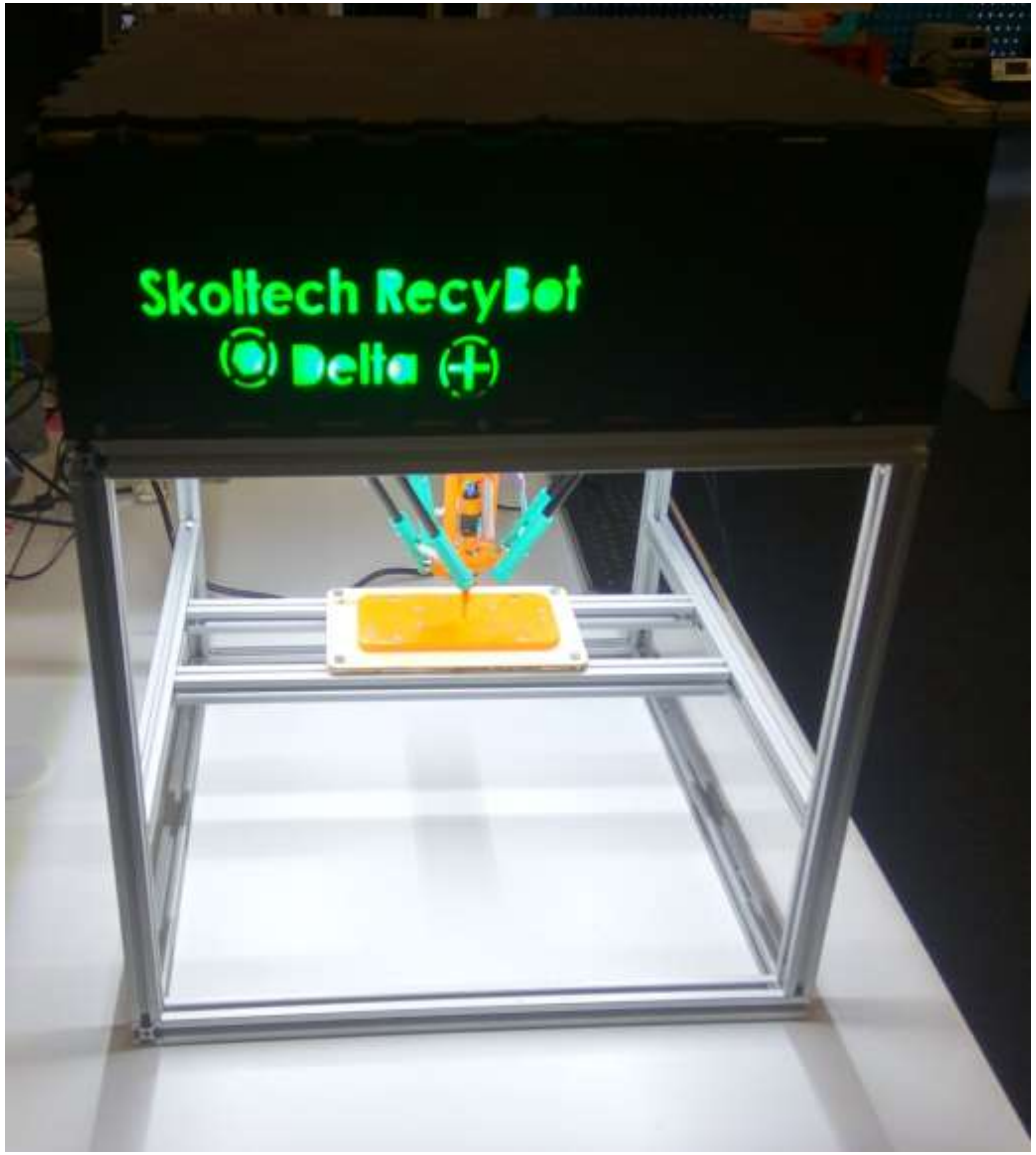
- EuroHaptics, paper publication (June 2018. Pisa, Italy)
- IEEE Haptics Symposium, work in progress (March 2018, San Francisco, USA)
- Paper Submission in the International Conference on Intelligent Robots and Systems (IROS 2018)

- D. Mironov, M. Altamirano, H. Zabihifar, A. Liviniuk, V. Liviniuk, K. Youcef-Toumi, D. Tsetserukou. "Haptics of Screwing and Unscrewing for its Application in Smart Factories for Disassembly," in Proc. Int. Conf. Eurohaptics 2018, Pisa, Italy, June 13-16, 2018. Pag. 85-86 (Acceptance rate 57%), (Scopus and WoS).

- D. Mironov, M. Altamirano, H. Zabihifar, K. Youcef-Toumi, D. Tsetserukou. "Haptics of Screwing and Unscrewing for its Application in Robotics," in *Proc. IEEE Haptics Symposium (Haptics 2018)*, Work in Progress San Francisco, California, March 25-28, 2018. Accepted. (Scopus and WoS).

Conclusions

It is expected that the approach proposed in this thesis can potentially improve the robustness of the unscrewing operation, thus enhancing the automation, and solving the economic and environmental problems.



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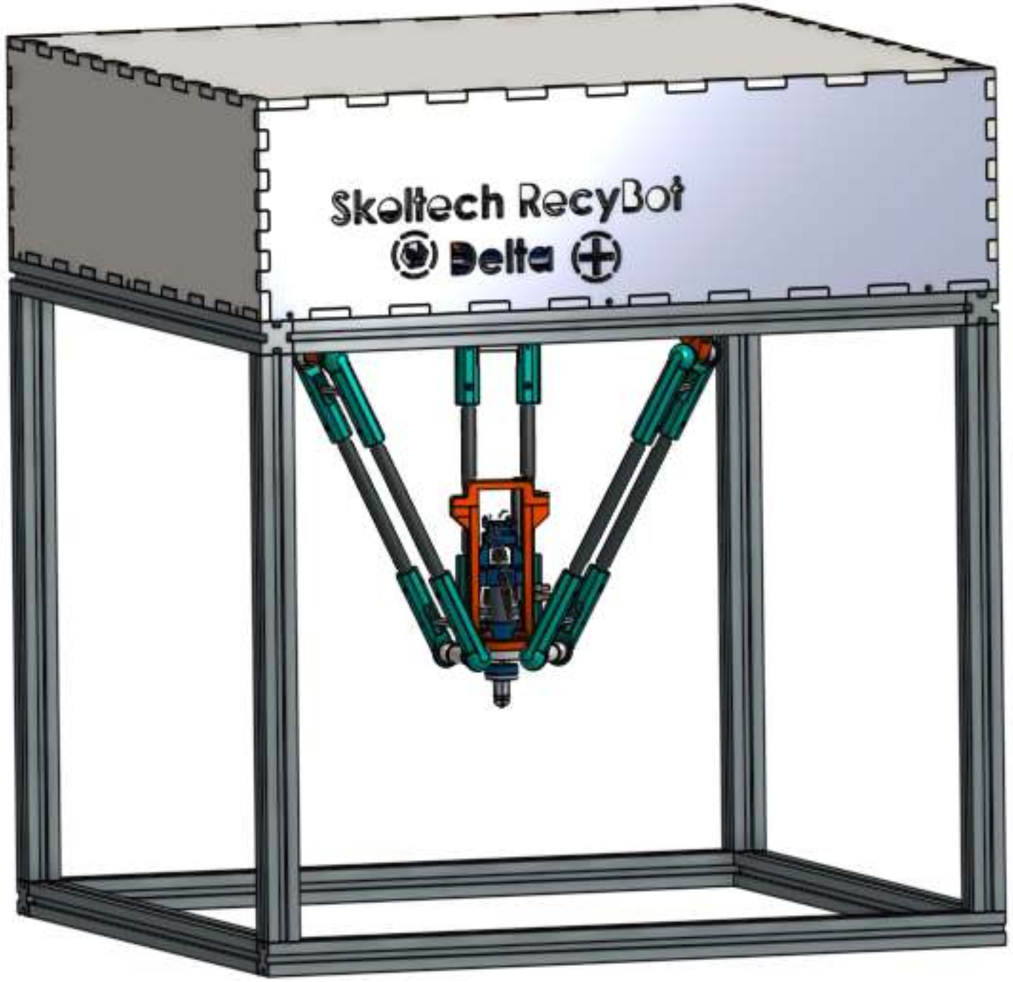
Thank you for your attention

Спасибо за внимание

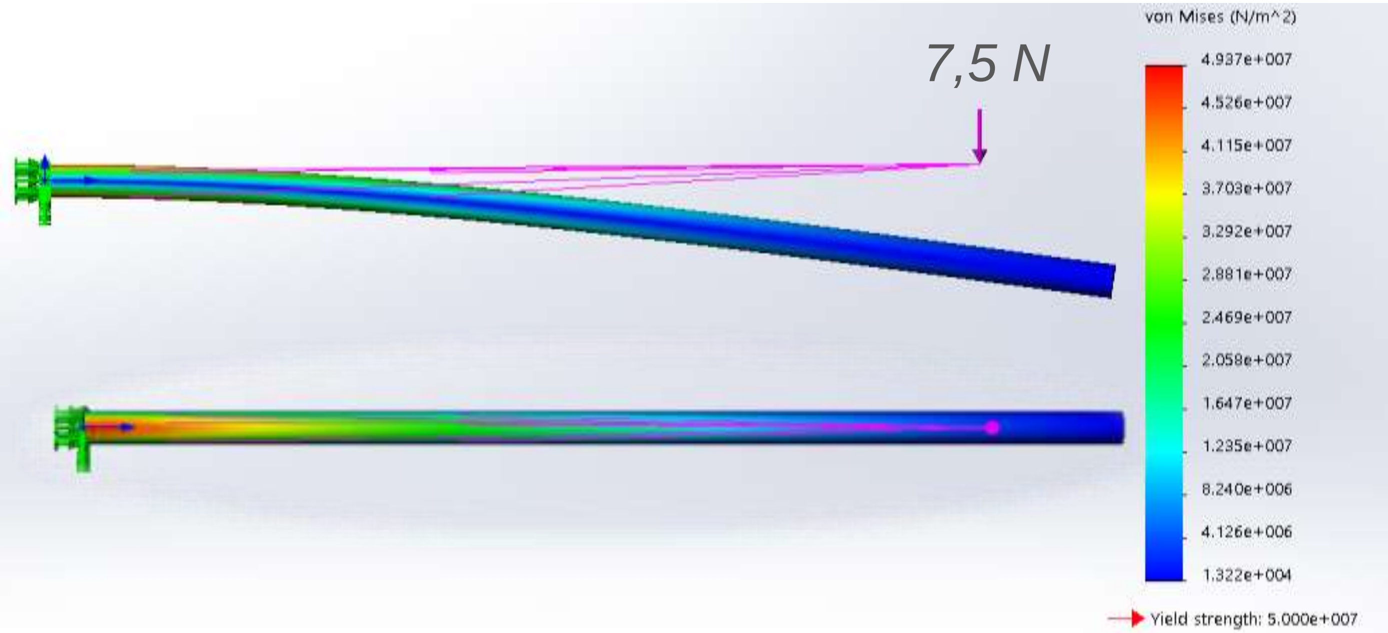
Gracias por su atención

Backup slides

Methods



***Design** a delta robot as a high-speed robot for the implementation of the operation.*



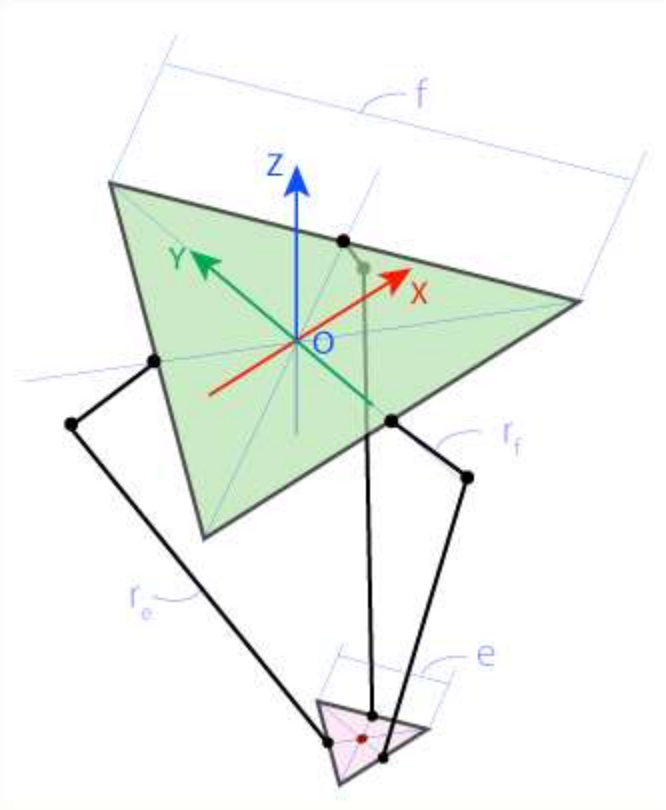
Carbon fiber tube

***Elastic Modulus** 135 Gpa*
***Poisson's Ratio** 0,24 N/A*
***Mass Density** 16 g/cm^3*
***Yield Strength** 50 MPa*

***Factor of Safety** 1,35*

Methods

*Calculation of the **inverse kinematics** of the robot.*

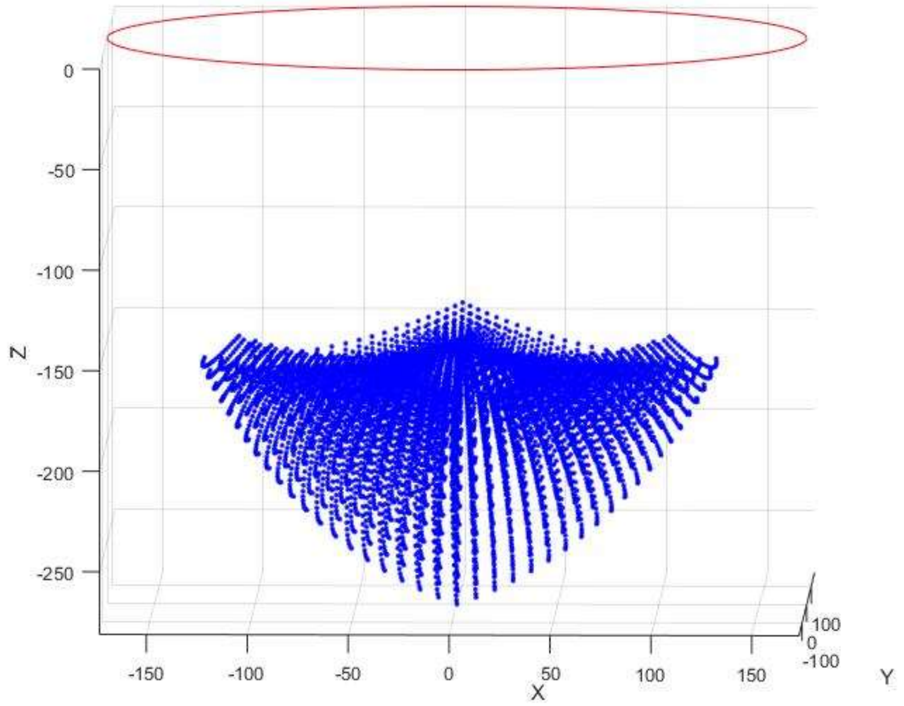


$$\theta_i = \arccos\left(\frac{-(r_e^2 - z_i^2) + r_f^2 + (x_i + e - f)^2 + y_i^2}{2r_f\sqrt{(x_i + e - f)^2 + y_i^2}}\right) - \arctan\left(\frac{y_i}{x_i + e - f}\right)$$

Main geometric parameters:

- *f* = Side of the upper triangle
- *e* = Side of the lower triangle
- *rf* = Length of upper link
- *re* = Length of the parallelogram link

- *f* = 300mm
- *e* = 100mm
- *rf* = 80mm
- *re* = 240mm



Working space ~ 200 x 200 x 50mm

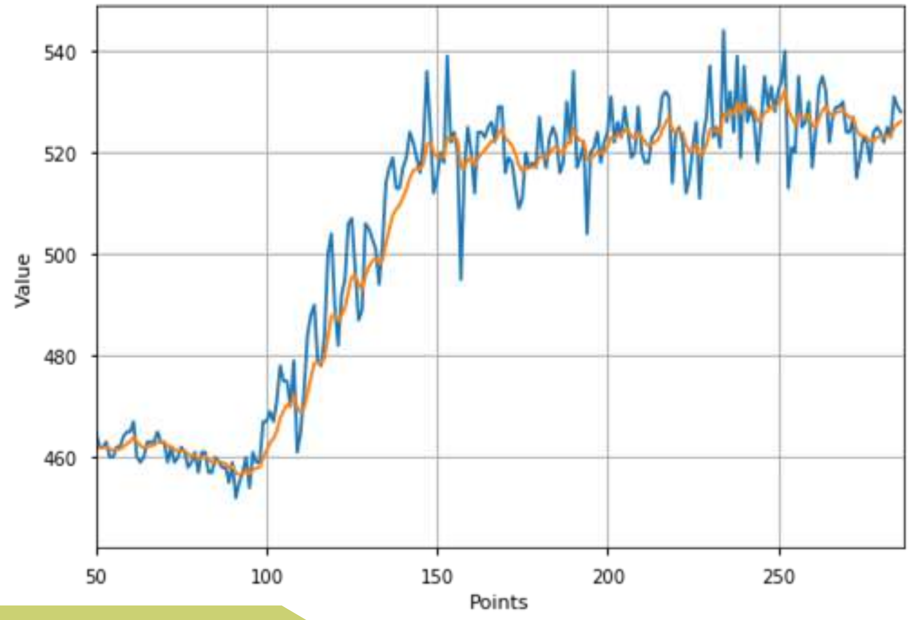
Methods

Compliant end-effector design

Passive unscrewing tool

Metallic springs

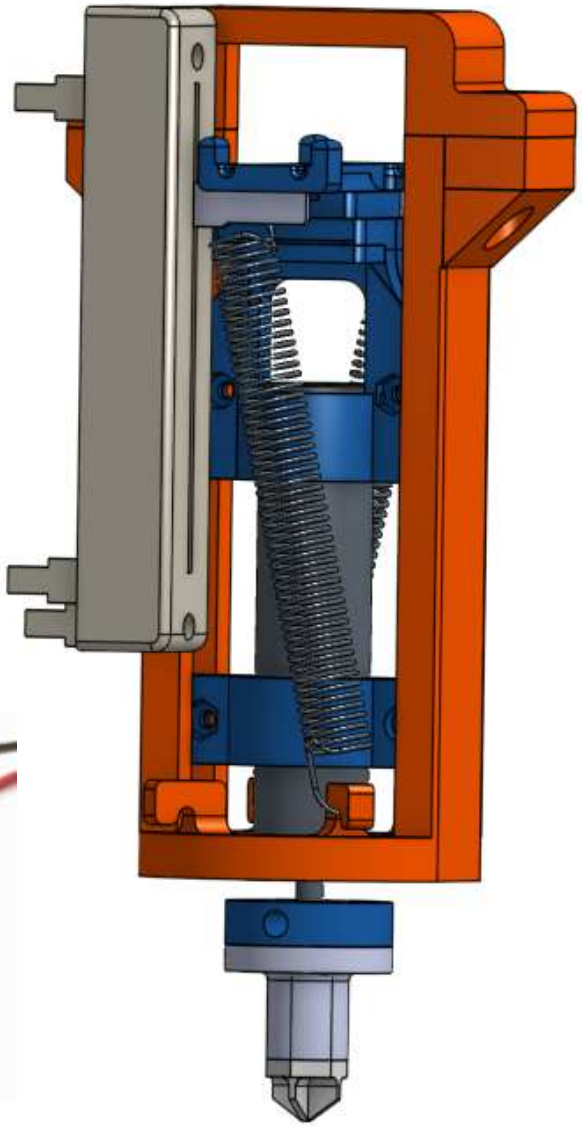
Potentiometer



The potentiometer indicates the position, force, and thus unscrewing status.

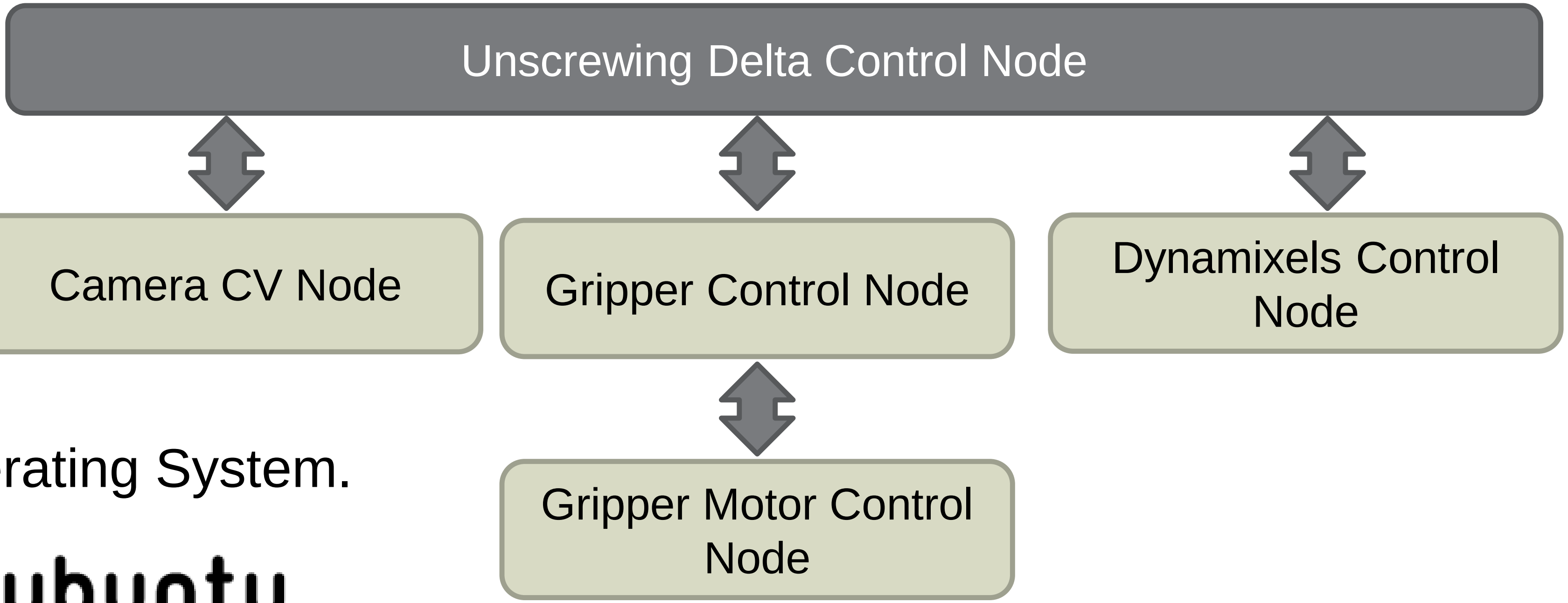
Current Sensor ACS712

Maxon Motor



Methods

*The **system control** of the robot is done by ROS (Robotic Operating System) That enables nodes to locate one another.*



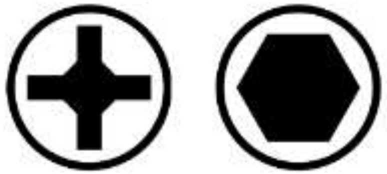
Control in Robot Operating System.

Methods

10 participants: 7 men, 3 women from 22 to 40 years.

6 different conditions, 9 sets of data for each participant.

Rep	Crew type	Position	Base Type	Screw driver type
2	Phillips	Vertical	Triangle hole	Phillips
1	Hexagonal	Vertical	Triangle hole	Hexagonal
3	Phillips	Vertical	Triangle with nut	Phillips
1	Phillips	Vertical	Triangle hole	Phillips bigger
1	Phillips	Horizontal	Triangle hole	Phillips
1	Hexagonal	Horizontal	Triangle hole	Hexagonal



Validation Screwing-unscrewing robot