Improving the viability of unscrewing for automated phone disassembly

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engineering design

Project Context

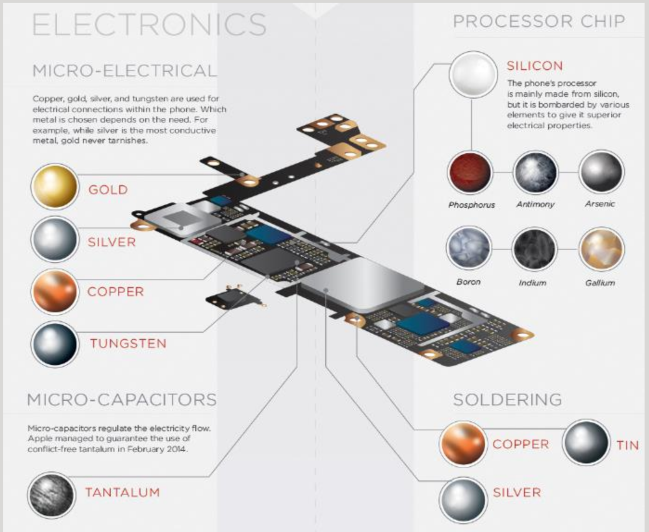
57.4 million tonnes: Estimated amount of e-waste produced globally in 2021 (Greater than the weight of the Great Wall of China) [1].

85 kg : A new smartphone generates 85kg of emissions in the first year of use. 95% of this results from manufacturing processes including shipping and mining [2].

2.5 – 10% : Current reuse percentage for electronics in UK [3].

£370 million : Estimated value of rare–Earth materials found in e-waste in UK landfills alone [3].

Rare-Earth materials found in iPhone 6S [4]:



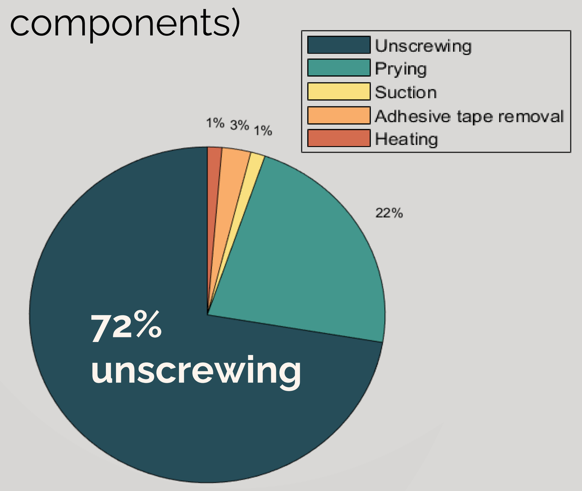
Solution: automated non-destructive disassembly

This helps:

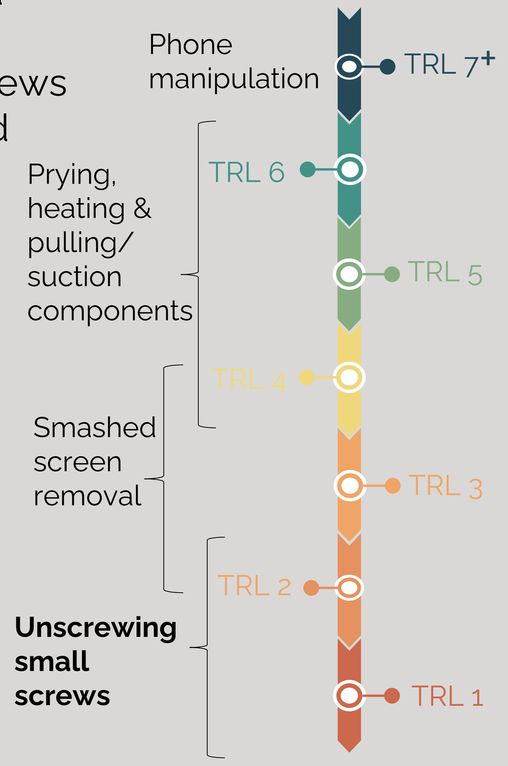
- Reduce health and safety hazards.
- Minimise rare-earth metal losses.
- Reuse working components.

Limiting Process: Unscrewing

No previous work has attempted automated non-destructive disassembly on actual phone screws (due to how small screws are and variability of End-of-Life components)

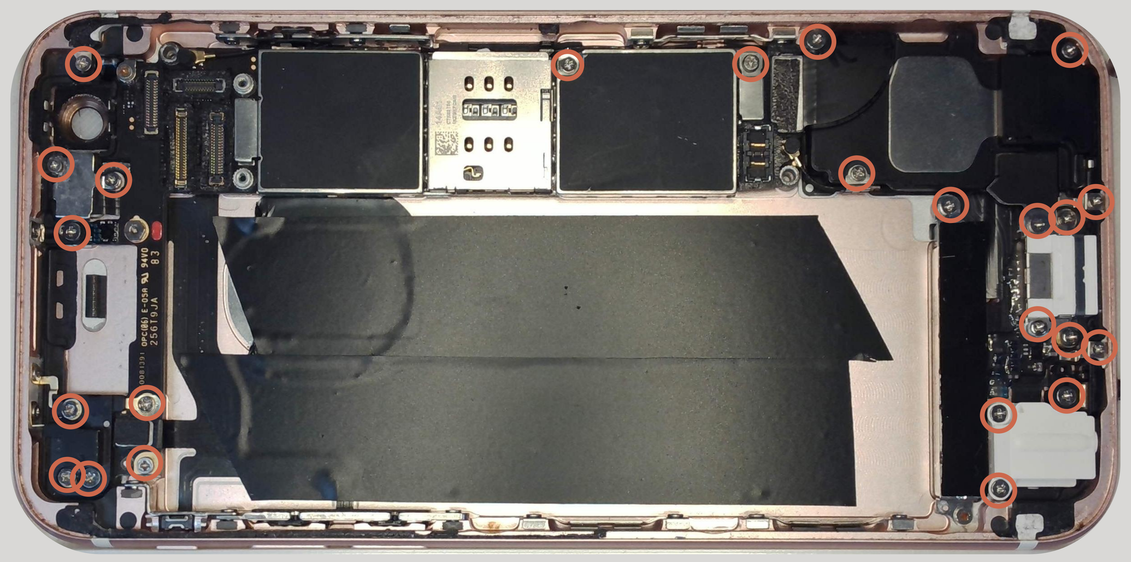


Frequency of disassembly actions for a iPhone 6S:



Project Aims

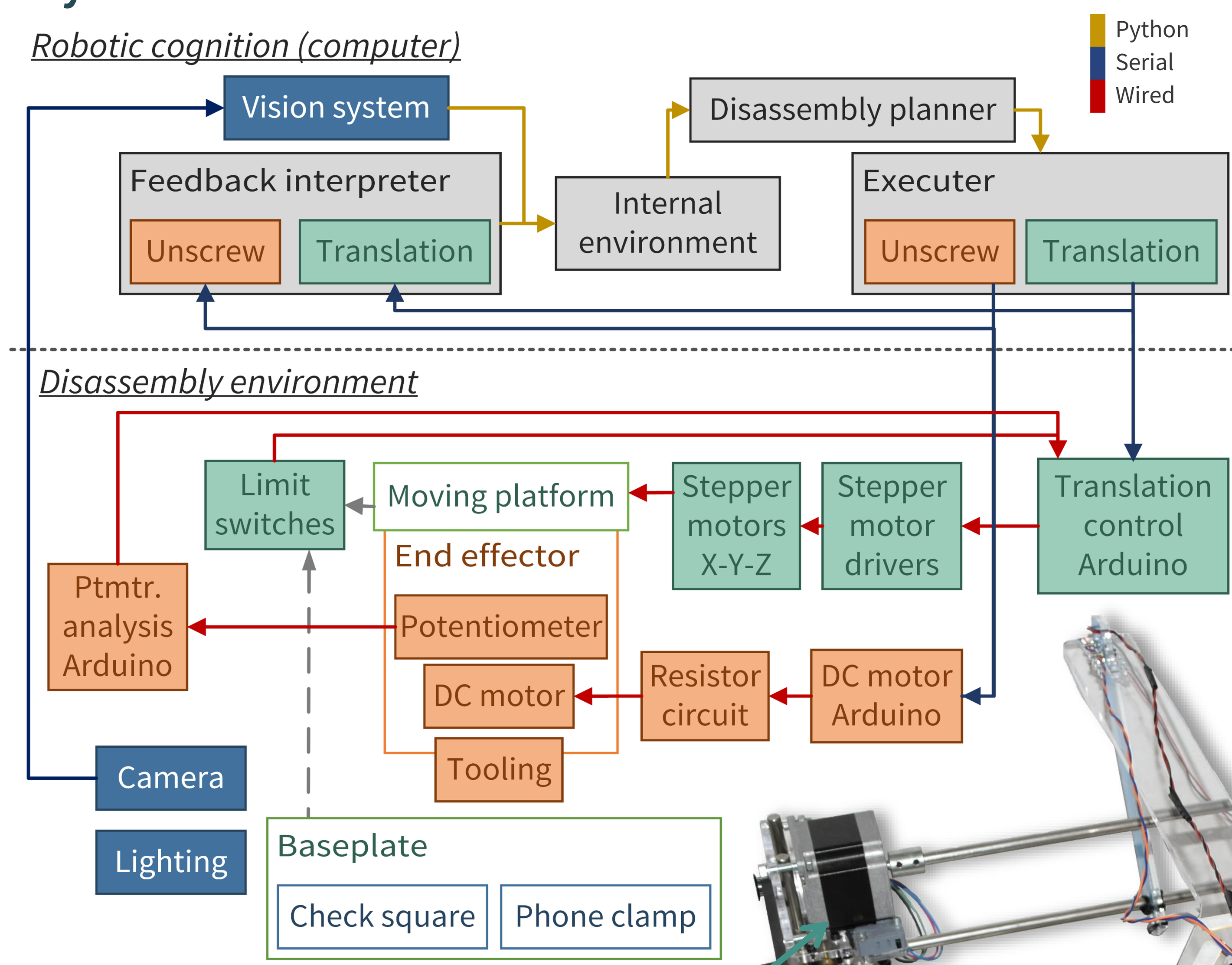
- Improve the TRL of automated unscrewing of smartphone screws without previous knowledge of screw locations
- Build a technology demonstrator of the proposed system
- Optimise subsystems to improve overall success rate



Phone screws are typically 0.8 – 1.5mm diameter

[1] https://weee-forum.org/ws_news/international-e-waste-day-2021/
[2] https://www2.deloitte.com/us/en/insights/industry/technology/technology-media-and-telecom-predictions/2022/environmental-impact-smartphones.html
[3] https://resource.co/article/uk-track-become-europe-s-biggest-e-waste-contributor
[4] https://www.mining.com/web/infographic-the-extraordinary-metals-in-an-iphone-6s/

System Architecture



Gantry

Requirements:

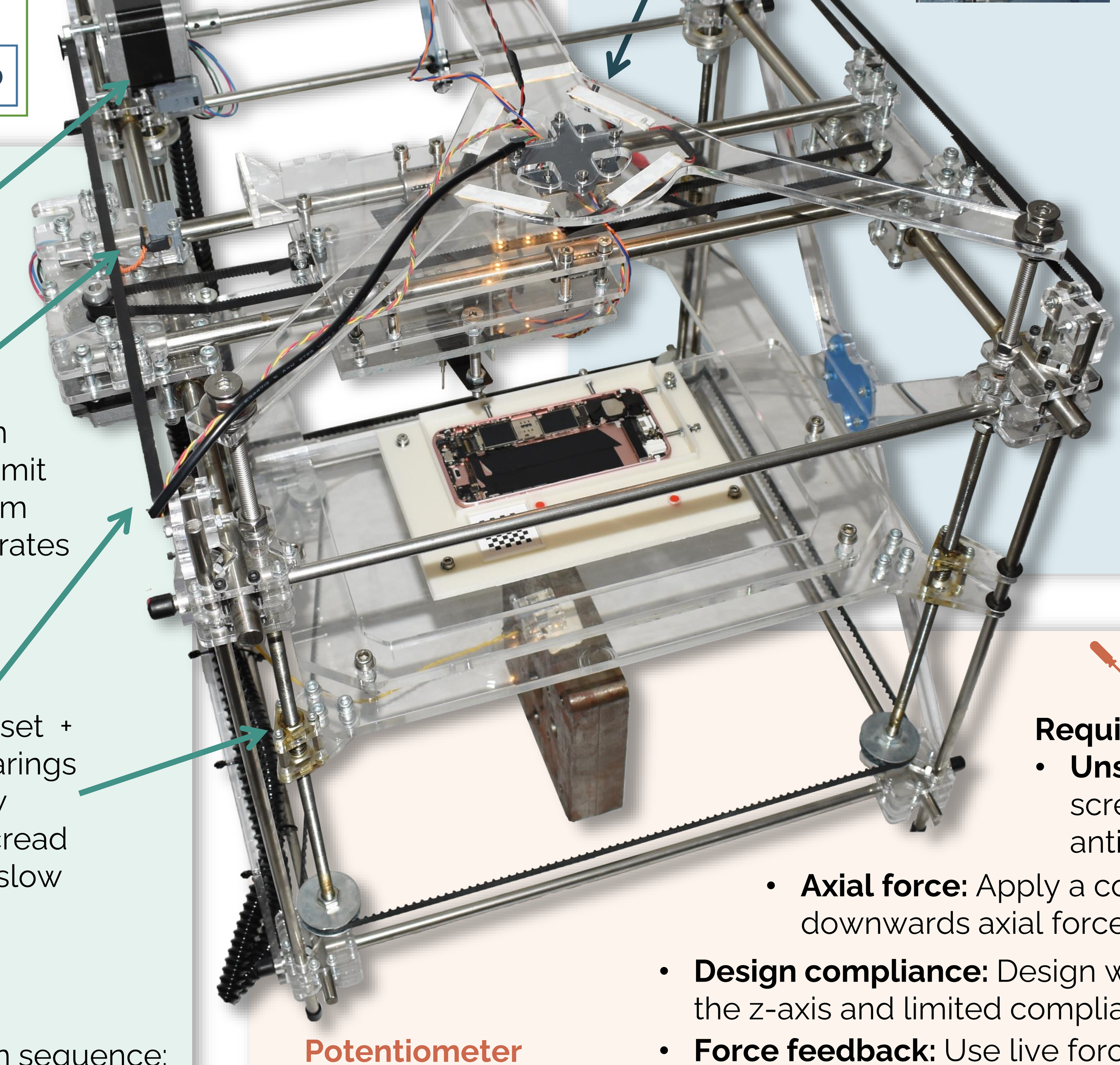
- **Resolution** of <0.1mm
- **Allign** screw head with end effector

Stepper motors with **32 micro step** setting

Overhead end effector platform designed to hit limit switches to datum each axis – calibrates position

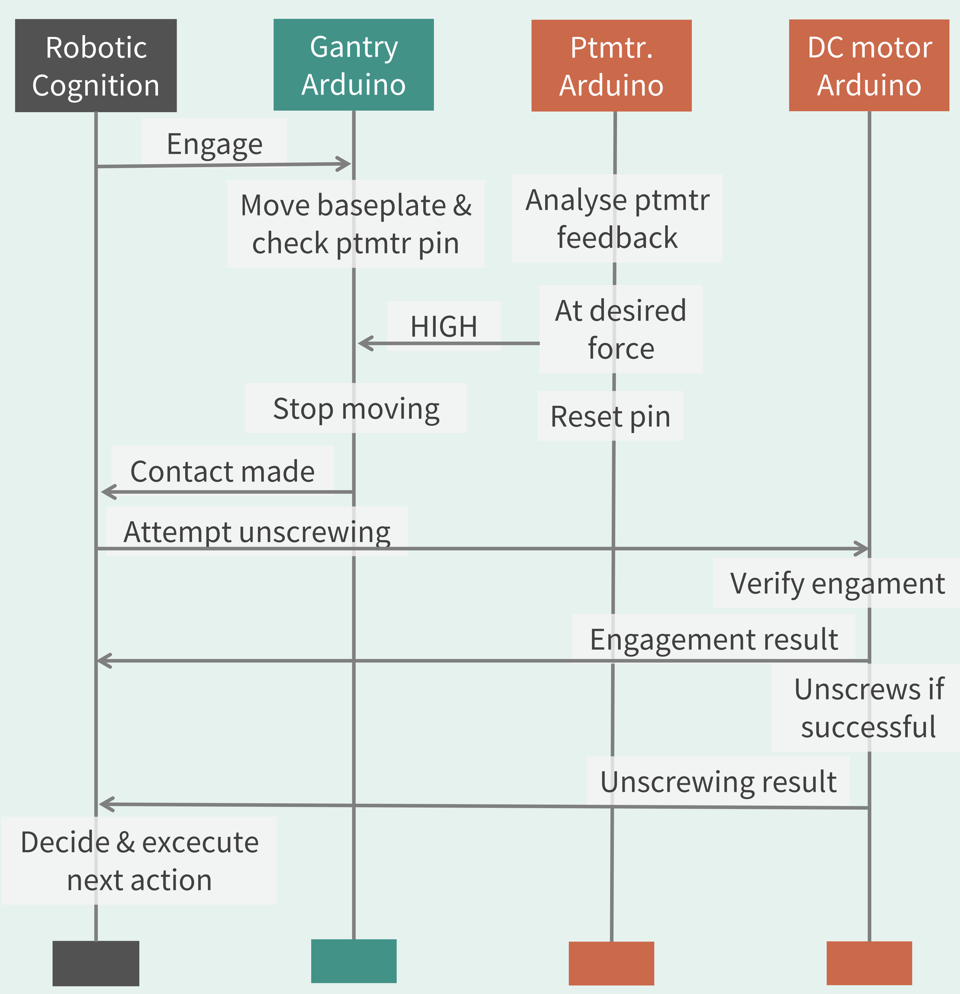
Spiral search algorithm implemented to find missed screws

Belt tension set + platform bearings & lead screw greased -incread precision at slow speeds



System Control

Engagement & unscrewing communication sequence:

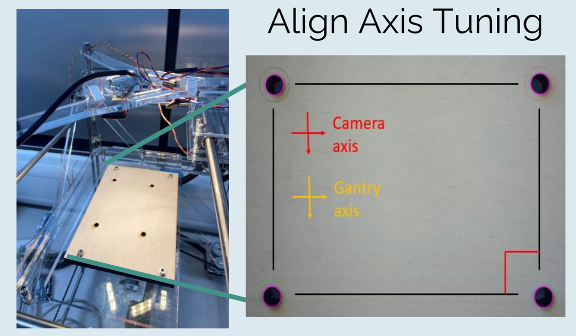


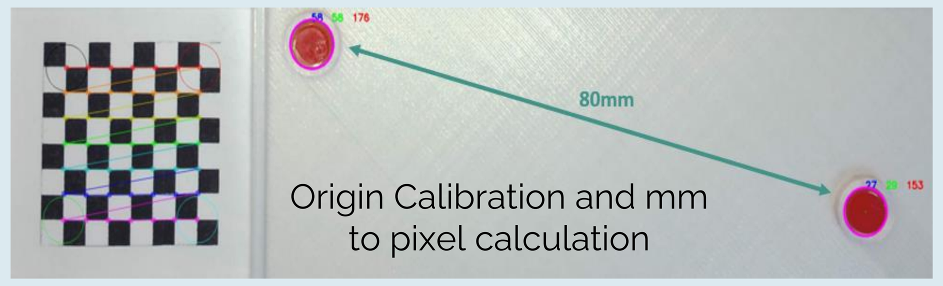
Machine Vision System

Requirements

- **Accuracy:** Find the pixel center of the screw to +/- 1/5th screw diameter.
- **Repeatability:** Show the same screws to the same accuracy every time with the same image.
- **Resolution:** The pixel to mm ratio shall be <0.1mm.
- **False negatives:** Max 1/5 screws missed
- **1 False positive** per 5 screws

Align Axis Tuning

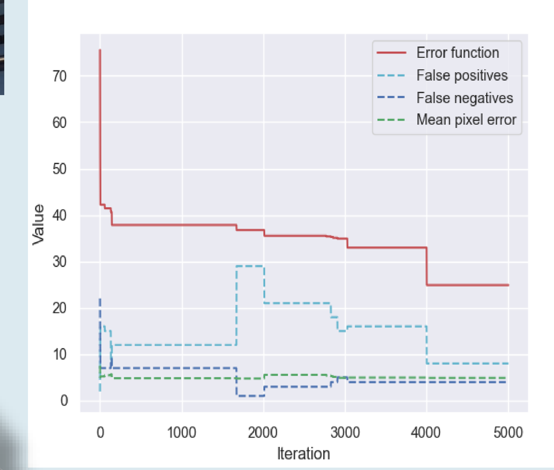




Origin Calibration and mm to pixel calculation

5MP Camera + LED Light Ring

Automated **Hough Circle** Parameter Tuning



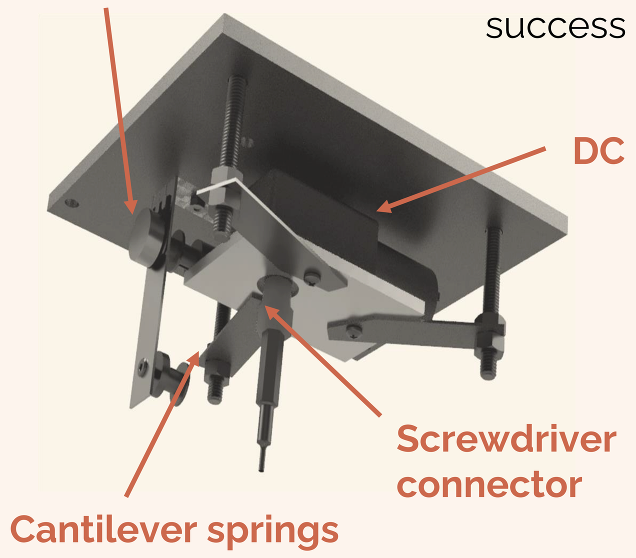
Output

- Screw location from origin (mm)
- Tuning of an array to map gantry origin to vision origin was required

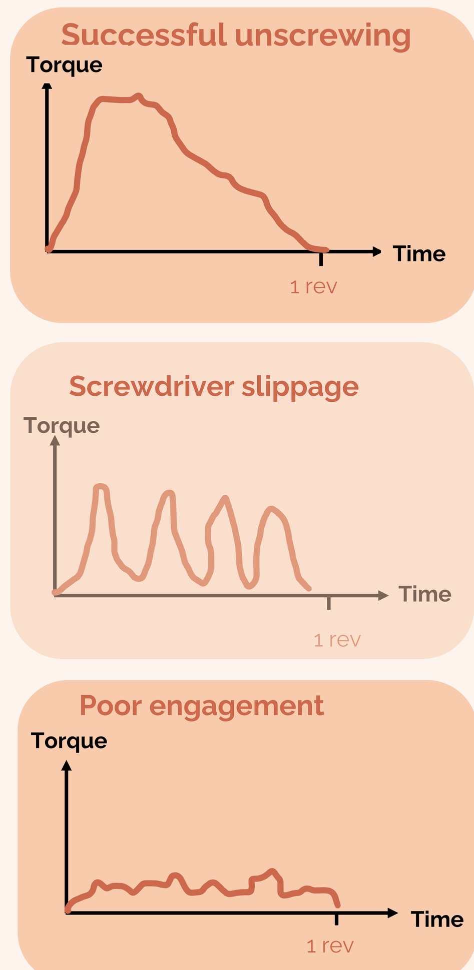
End Effector

Requirements

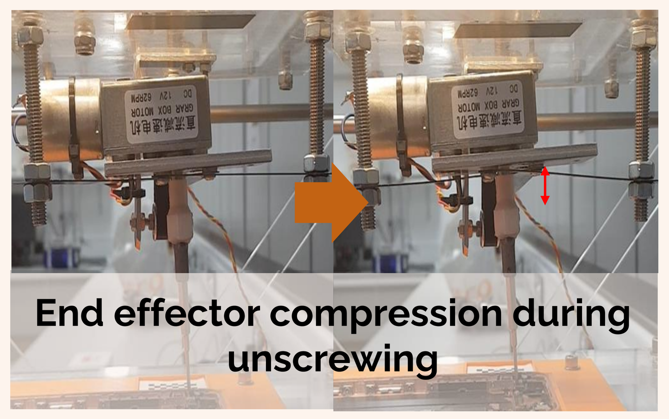
- **Unscrew:** Engage with the screwhead an apply a controlled anticlockwise rotation to unscrew.
- **Axial force:** Apply a controlled, consistent downwards axial force during operation.
- **Design compliance:** Design with significant compliance in the z-axis and limited compliance in x/y-axis.
- **Force feedback:** Use live force measurements to feedback success of operations



Predicted graphs of torque vs DC motor revolutions for unscrewing scenarios



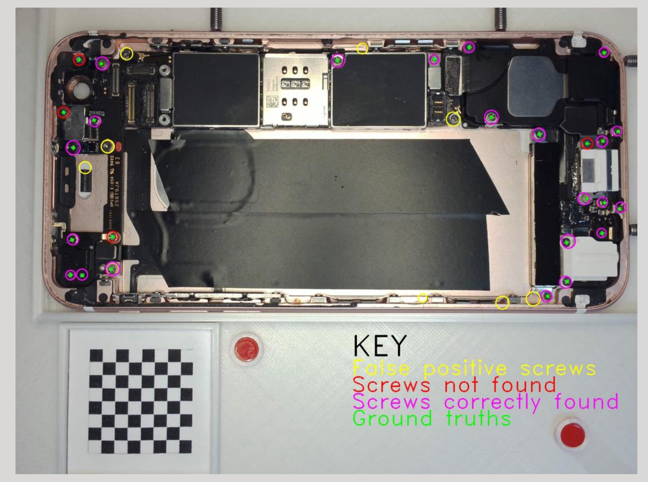
1. Cantilever spring compresses upwards
2. Potentiometer belt moves downwards an equal amount



Testing & Verification

The main challenge to improve the success rate was achieving the positional accuracy of aligning the tooling with the screw.

Machine Vision System



0.057 mm/pixel resolution

Pixel accuracy: **mean error 4.90 pixels**

mm accuracy: aprx. 0.5mm

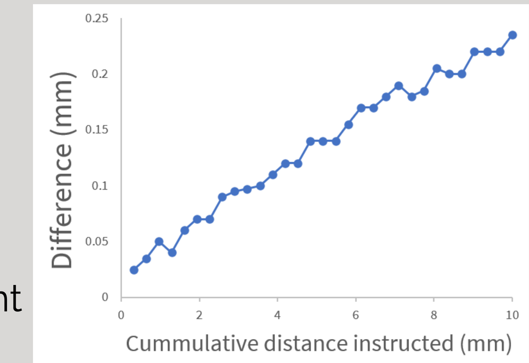
False +'s: 8 for every 22 correct screws

False –'s: 4 for every 22 correct screws

Gantry

< 0.01 mm precision

Motor steps/ mm calibrated using dial gauge for **98.31 % accuracy** in translation - preliminary system testing indicated this error is insignificant to engagement success



Business Case

Further R&D projects required to improve TRL to level 9 for commercialization. Fully automated phone disassembly will achieve:

- **Social:** Many smartphone users can now recycle their phones knowing the maximum material is extracted
- **Economical:** Extracted material is money not wasted in landfill
- **Environmental**: Less natural resources wasted and helps solve the growing electronic waste problem, and move towards a circular economy for phones

Conclusions

- Improved the TRL level of automated unscrewing of smartphone screws from TRL 1 to 3
- With more time and money it is possible to automate unscrewing smartphone screws of 0.8-1.5mm diameter
- Produced the first ever automated smartphone unscrewing machine non-specific to the type of phone

Future Work

Vision System

- Development of edge detection to identify cross shape – requires better camera and will improve false positives and false negatives
- Development of neural network approach to work in parallel with current Hough Circle algorithm approach – improve overall accuracy
- Improve pixel to mm conversion – main error source

End Effector

- Using a torque sensor instead of inferring torque from current will improve unscrewing characterisation.
- Addition of rotary encoder – allows angular position of the end effector to be measured and controlled.
- Further design iterations of cantilever required to stabilise end effector, to reduce variability of position

Translation & Control

- Access to higher resolution measurement instrumentation required to improve steps/mm + gantry & vision system datum offset calibration
- Higher power motors or gearing down pulley system needed to improve repeatability at higher speeds required for cost effective operation