Directed Energy Research Centre

Everybody Is A Maker:
Rapid Mechanical Prototyping Using Laser Cutters

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TII Online Seminar - 18.04.2021

Technology Innovation Institute

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About Me

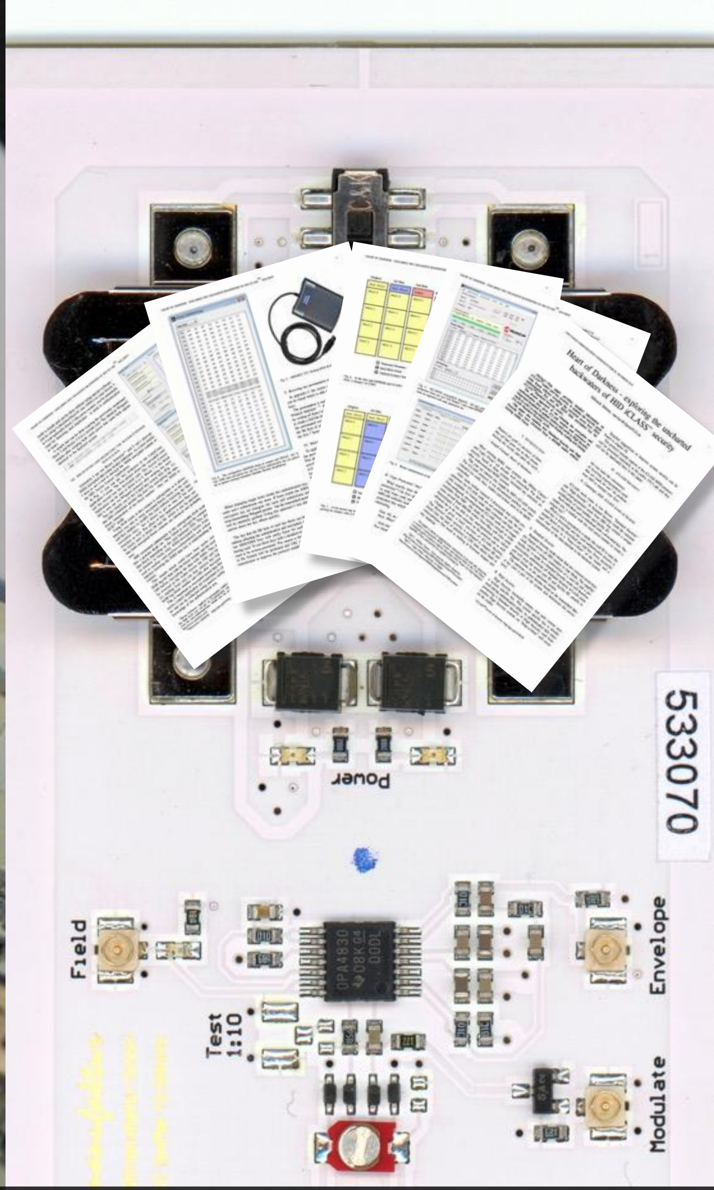
My Open Software & Hardware Projects

Shared fun is more fun

I created a wide range of open hardware designs and software tools around RF(ID)/BLE security research and electronic art projects. You can find a more information on my public work at meriac.com

OpenPCD RFID Project

Created first open hardware RFID Reader, Sniffer and Emulator Projects for 13.56 MHz RFID system & designed Hardware for first MiFare RFID Hacks.



Hacked HID iClass Security

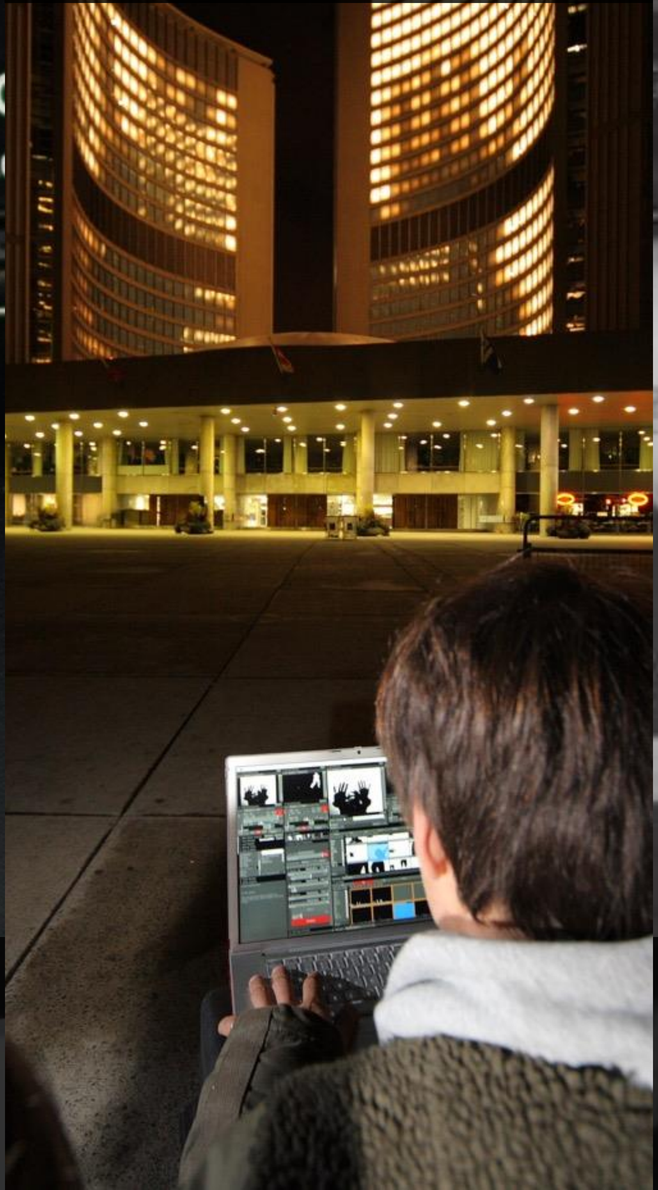
Published “Heart of Darkness” security paper & created open 13.56 MHz RFID Sniffer design for iClass security analysis

OpenBeacon.org

Realtime 2.4 GHz Localization & Human Interaction Analysis – see SocioPatterns.org for academic publications based on our system.

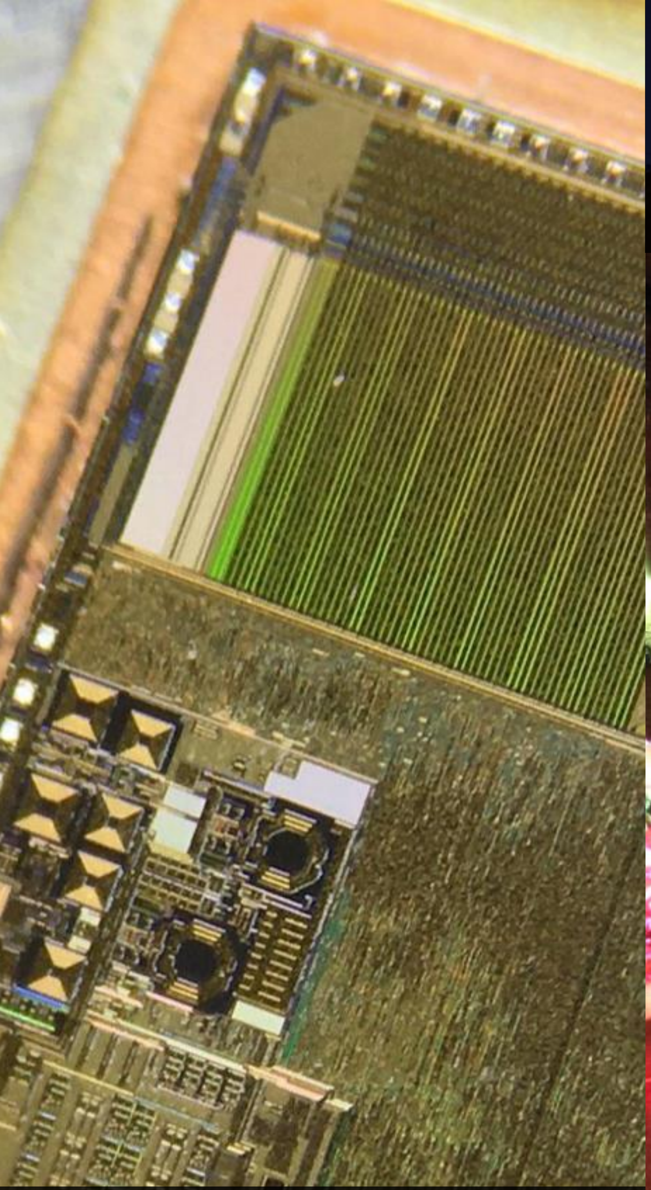
Blinkenlights Stereoscope

Designed and deployed 960x realtime Wireless Halogen Dimmers for the Blinkenligts Stereoscope Project around Toronto City Hall: Turning both towers into live, interactive displays.



Xbox Linux Team

Part of the team hacking the first trusted computing platform for consumers.
See “Hacking The Xbox” by Andrew “bunnie” Huang for more information.



Microchip Security

Reverse engineering and researching safer chip de-capping methods for making hardware attacks more accessible to private security researchers.

Blinkenstick

Designed low cost & high resolution light painting Hardware using LPD8806 RGB LED strips and the RaspBerry PI for realtime rendering.

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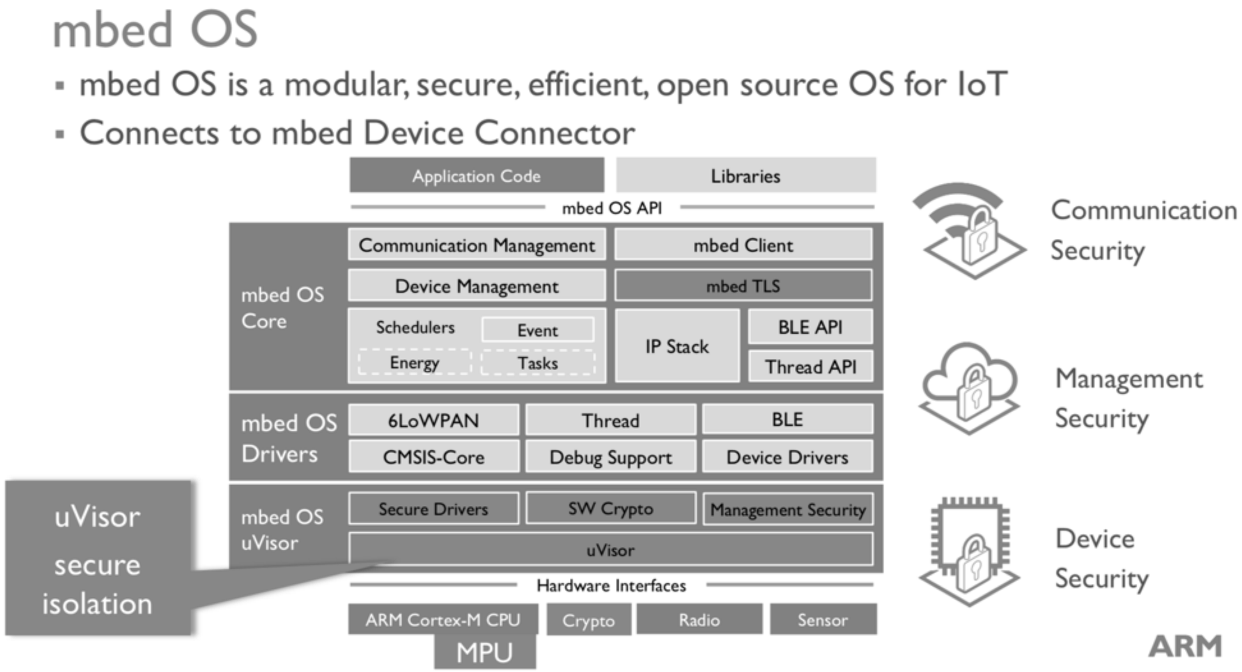
Arm Mbed uVisor Security



Arm Ltd. in Cambridge, UK

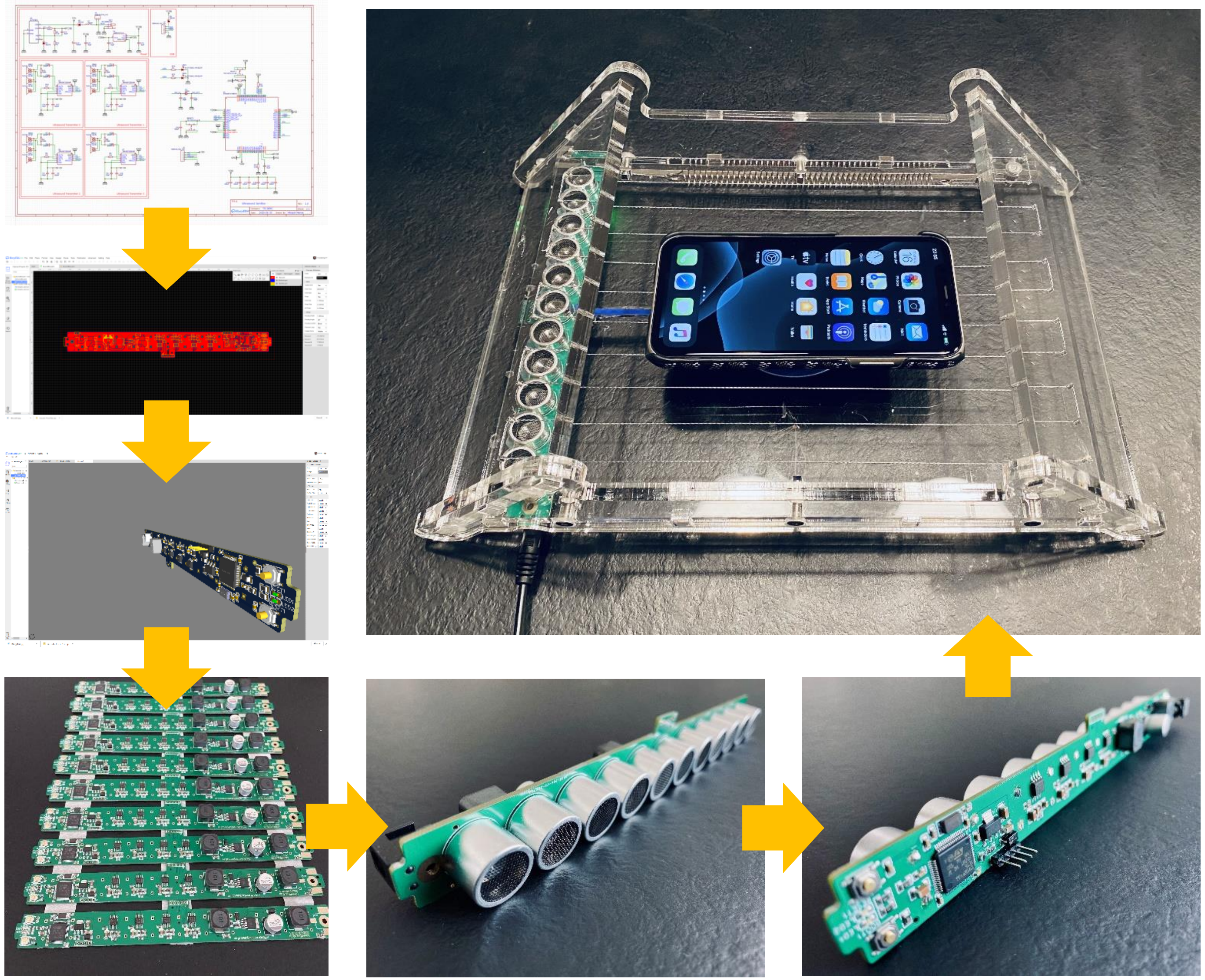
Initiated and led Arm Mbed OS uVisor code compartmentalization project for Arm microcontrollers. Re-purposes existing architecture features for virtualized isolation of code and data on Arm v7M/v8M microcontrollers: Think of docker, but for microcontrollers with tiny RAM & Flash memories. Later led the Arm Security Research team.

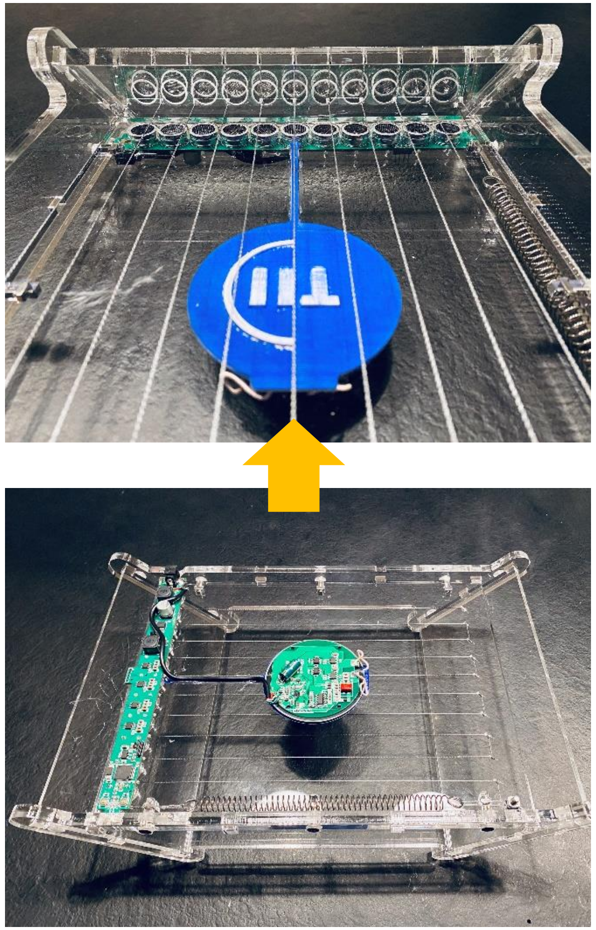
Laser Cutting:

Quick Introduction

Why use Laser Cutters?

Design, prototyping & testing mechanical properties within hours





Quick acoustic-proof phone charger prototyping: Block smartphone microphones to prevent adversaries from listening in on the user in case of phone-OS or compromised user applications – while wirelessly charging the owner's phone.

Laser Cutter Advantages:

- **Avoid supply chain issues** by creating precise custom parts & tools on demand from generic sheet material.
- **Repeatability**: Create tools and fixtures for holding sensors and assemblies in place during experiments
- **Scalability**: From enabling remote 3rd parties to recreate your experiments and small production runs.
- **Quick Learning Curve**: After two hours training, even unskilled operators can use laser cutters and 2D design software for producing simple designs.
- **Customization** of existing parts like cases and front plates for high quality products.
- **Quick design iterations** between minutes to a few hours.

When to use Laser Cutters …

… and how do they differ from 3D printers

Additive Manufacturing: 3D Printer

When: Full design freedom for small & medium sized complex 3D shapes.

- Design process requires complex-to-learn 3D-design software
- Limited material selection – customization options of material very limited, mostly only by integration with other parts.
- Print time scales horribly with size – easily 4-18 hours depending on part size.
- Enables printing of "pre-assembled" moving parts

versus

Subtractive Manufacturing: Laser

When: For medium and large 3D shapes that can be simplified into individual 2D slices.

- Design process only requires simple 2D-drawing software (Inkscape, Corel Draw, Affinity Designer, Adobe Illustrator). Enables quick, cheap and interactive design iterations.
- High flexibility on material choice – including customization of pre-fabricated complex parts (cutting/engraving cases etc.).
- Print time scales excellent for large prints (minutes!) – but limited to 2.5 dimensions. Excellent for building small batches of designs.

Summary:

- **Very low entrance barrier**: Getting started with simple 2D drawing software
- **Enable precise & reproducible designs**: Perfect for remote collaboration and small production runs. No need for DIY skills – replaces a plentitude of manufacturing tools.

Maker Space Al Zeina in Abu Dhabi with four VLS4.60 Laser Cutters

How Laser Cutters work

Quick Overview

Laser cutters in publicly accessible Makerspaces are usually CO_2 Lasers with 10.6µm wavelength (beam invisible to humans) with 60-80W power.

CO_2 Laser Cutter Features:

- Laser wavelength not well suited for cutting metal – but pretty much for everything else:
  - **If it's solid and you can set it on fire** – you can laser cut and engrave it.
  - **If you can't set it on fire** – you can at least engrave it. In selected cases like steel you require a temporary paint coating prior to the engraving process.
- Most Laser cutters support cutting and engraving of Acrylic, wood, cardboard, paper, fabric, leather and engraving of glass and anodized aluminium.
- With high power CO_2 Lasers in the kW-range – and the addition of nitrogen or oxygen gas – even thick metal plates can be cut with Lasers.

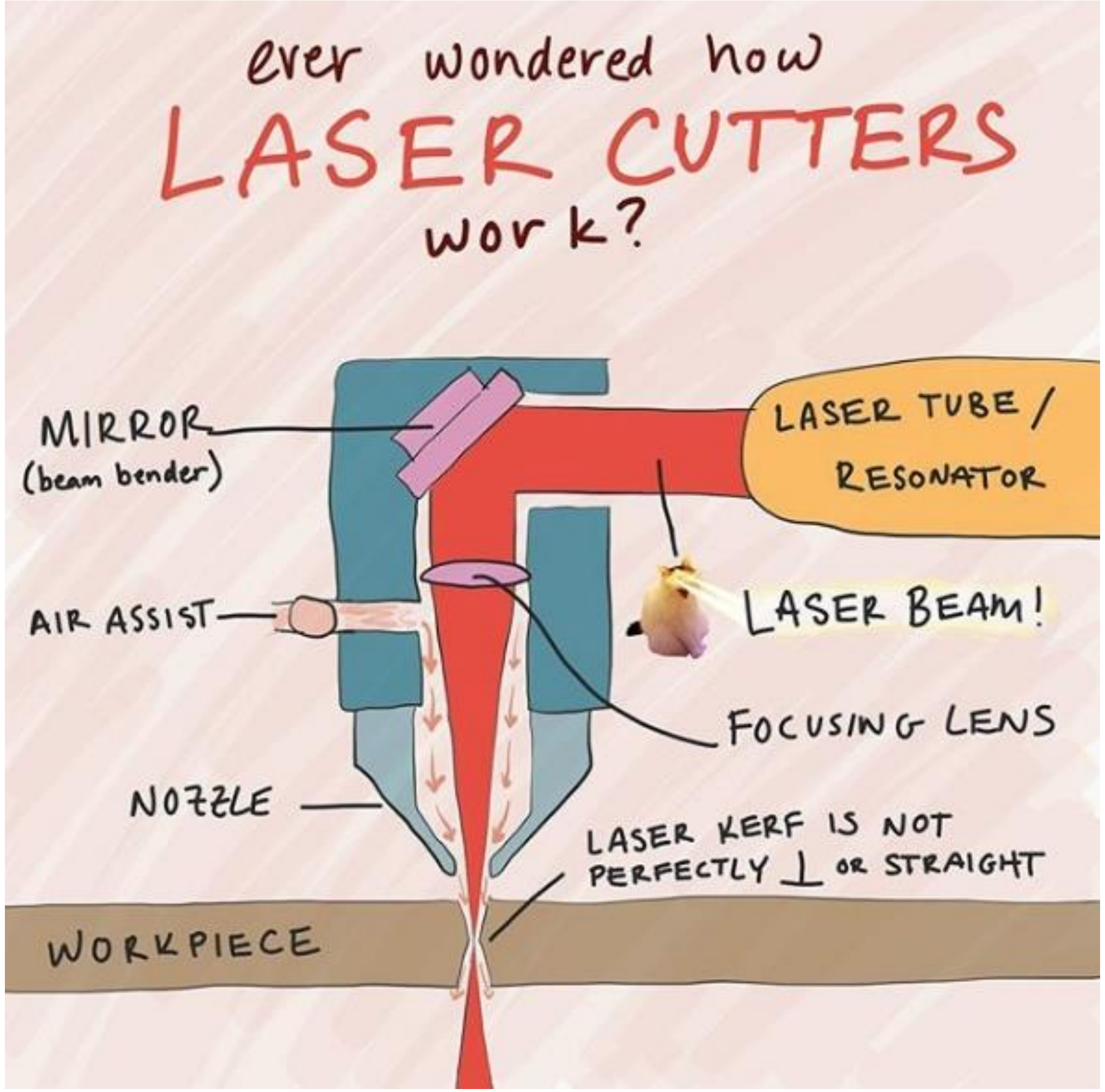


Image from "The History & Basics of Laser Cutters" – Beauty and The Bolt

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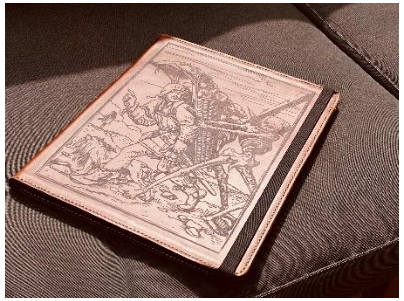
Laser Cutting:

Tips & Practical Applications

Showcase: Entry-Level Usage of Laser Cutters I

Customization Techniques: Engraving & Outline Cutting



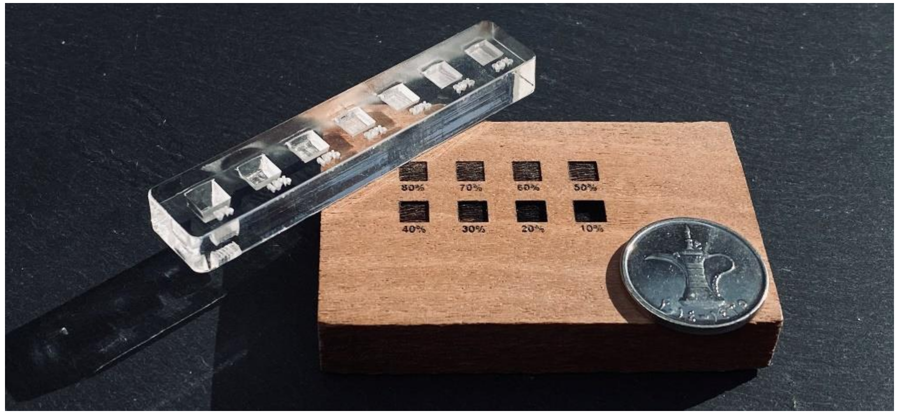
Showcase: Entry-Level Usage of Laser Cutters II

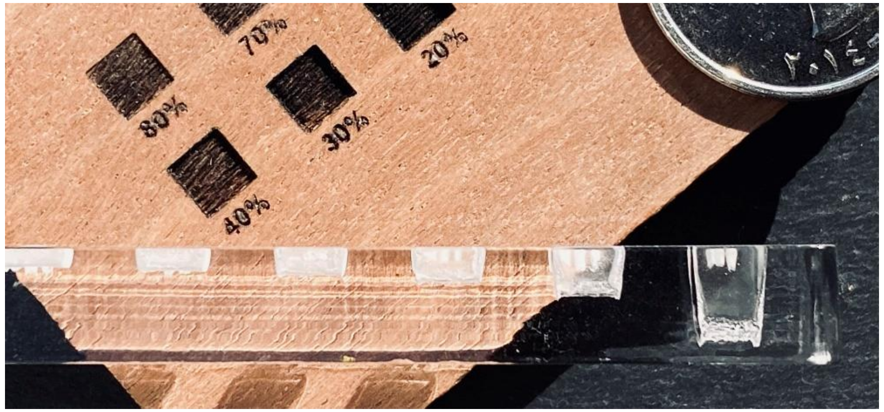
Customization Technique: Deep engraving or “2.5D”-Laser cutting

By engraving a mirrored positive image into light wood…

..., and lasering the negative image unmirrored into darker word, both can be glued together and the backing of the lighter wood sanded away.

After polishing and application of lacquer, the contrast between the two wood types pops. The whole process is easy and takes less than five minutes of work. It nicely shows the incredible precision of the laser cutter even for tiny font details.



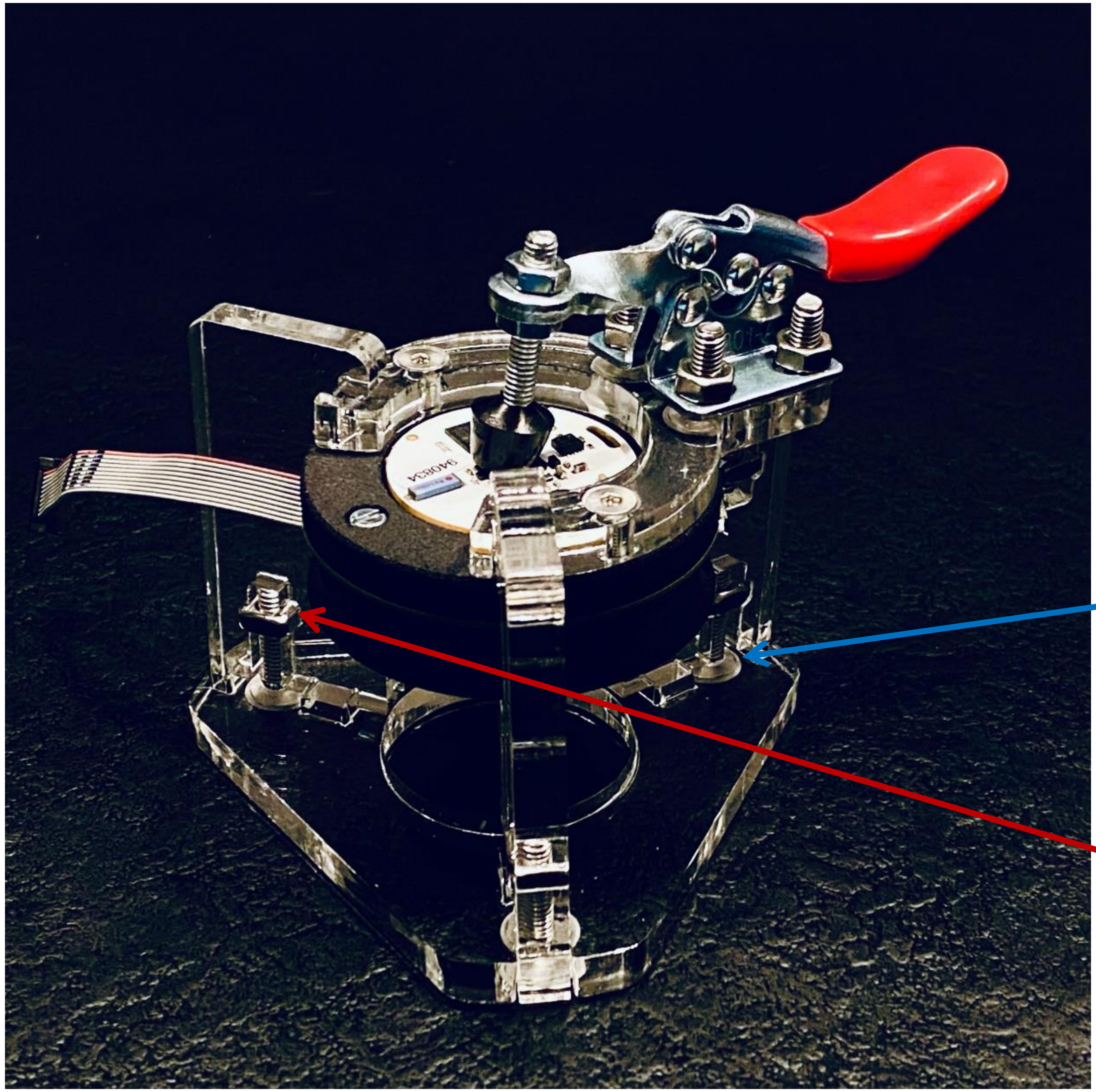


To estimate the Laser engraving depth, a piece of the target material is Lasered at different Laser Head movement speeds and power levels. By measuring depth, the correct setting for any given material is then estimated by picking the closest depth in the reference piece.

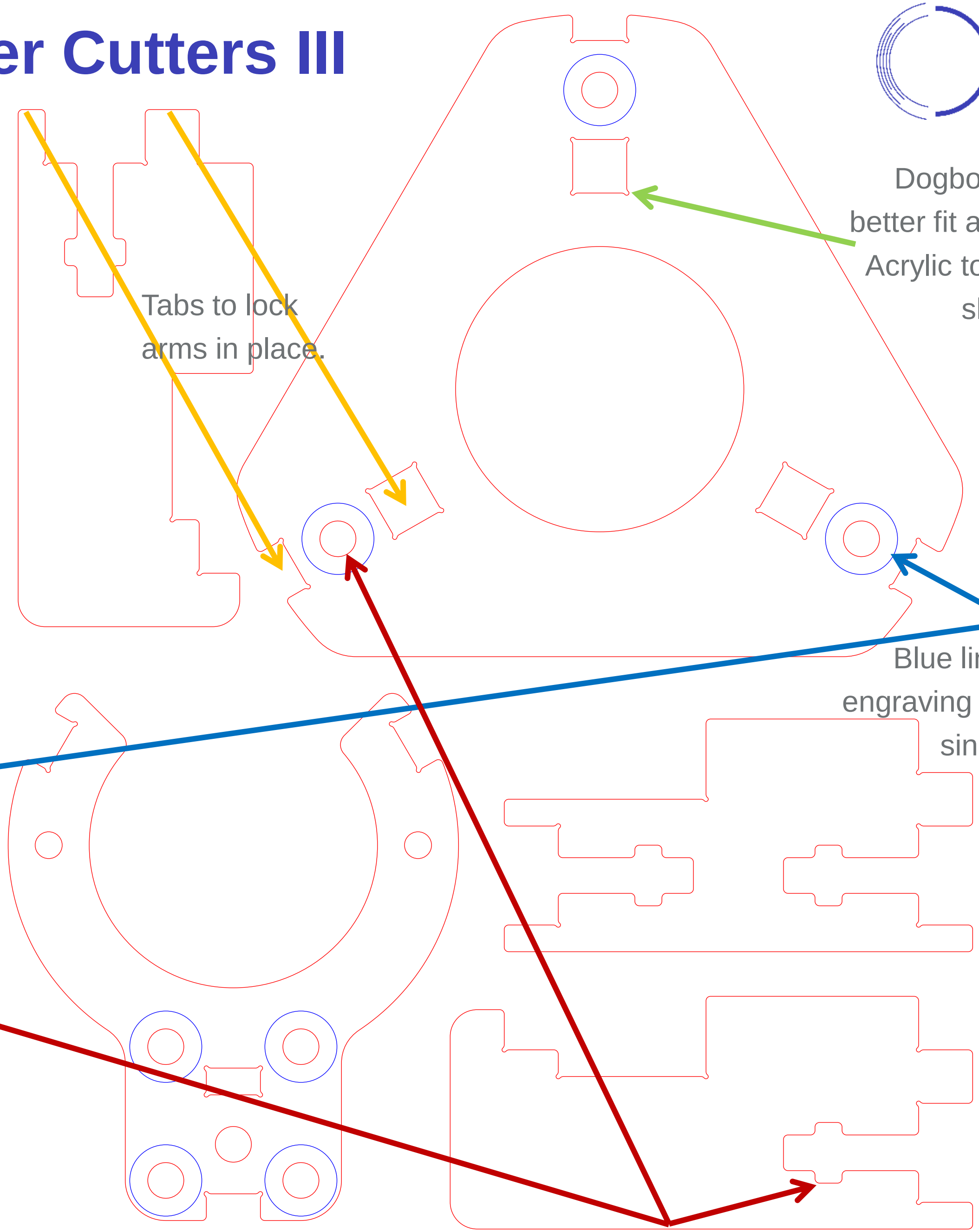
For convenience the laser settings can be engraved next to each example. On the left the power is set at the maximum of 60W, only the speed varies (% of maximum speed).

Showcase: Entry-Level Usage of Laser Cutters III

Design Technique: Tab & Slot with Nut-Lock



OpenBeacon Project badge programmer holder – see https://www.meriac.com/openbeacon for more information.



Dogbone fillets for better fit and avoiding Acrylic to crack from sharp edges.

Blue line indicates engraving for counter-sinking screws

Cut-Out for square M4 Nut to lock design in place

Showcase: Entry-Level Usage of Laser Cutters IV

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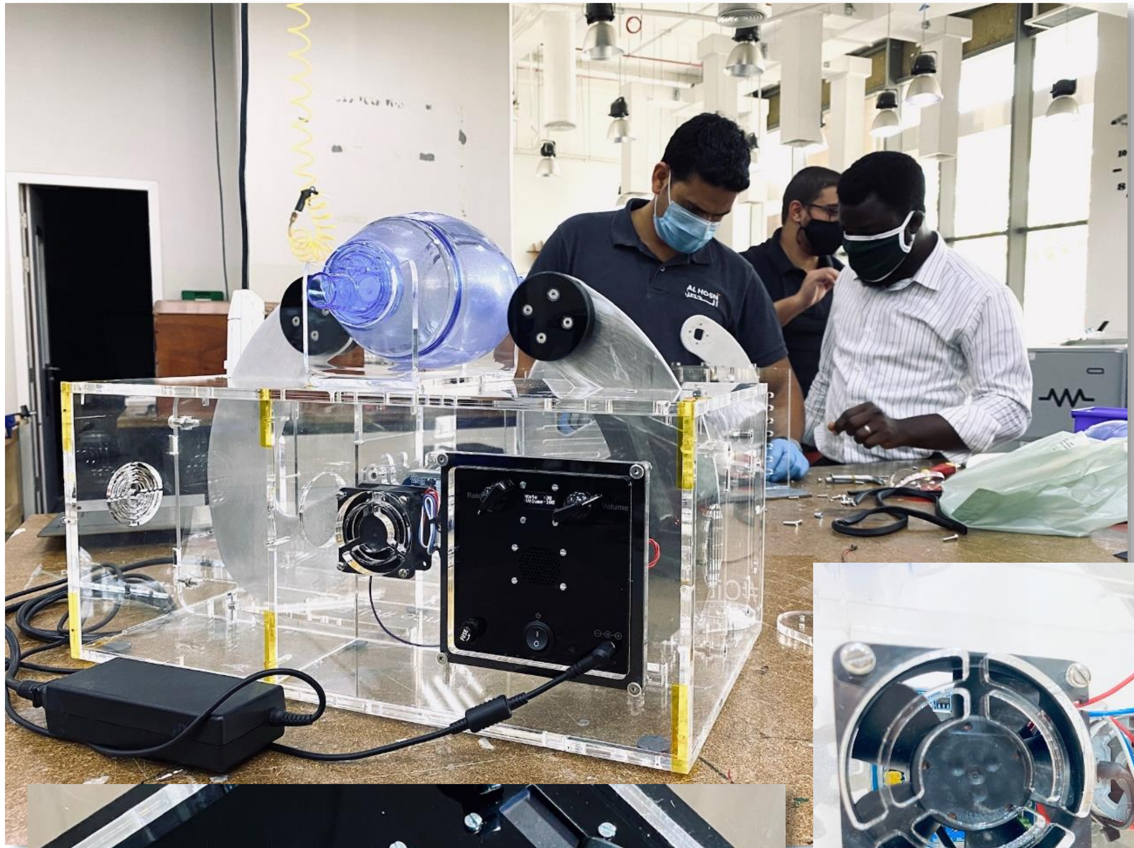
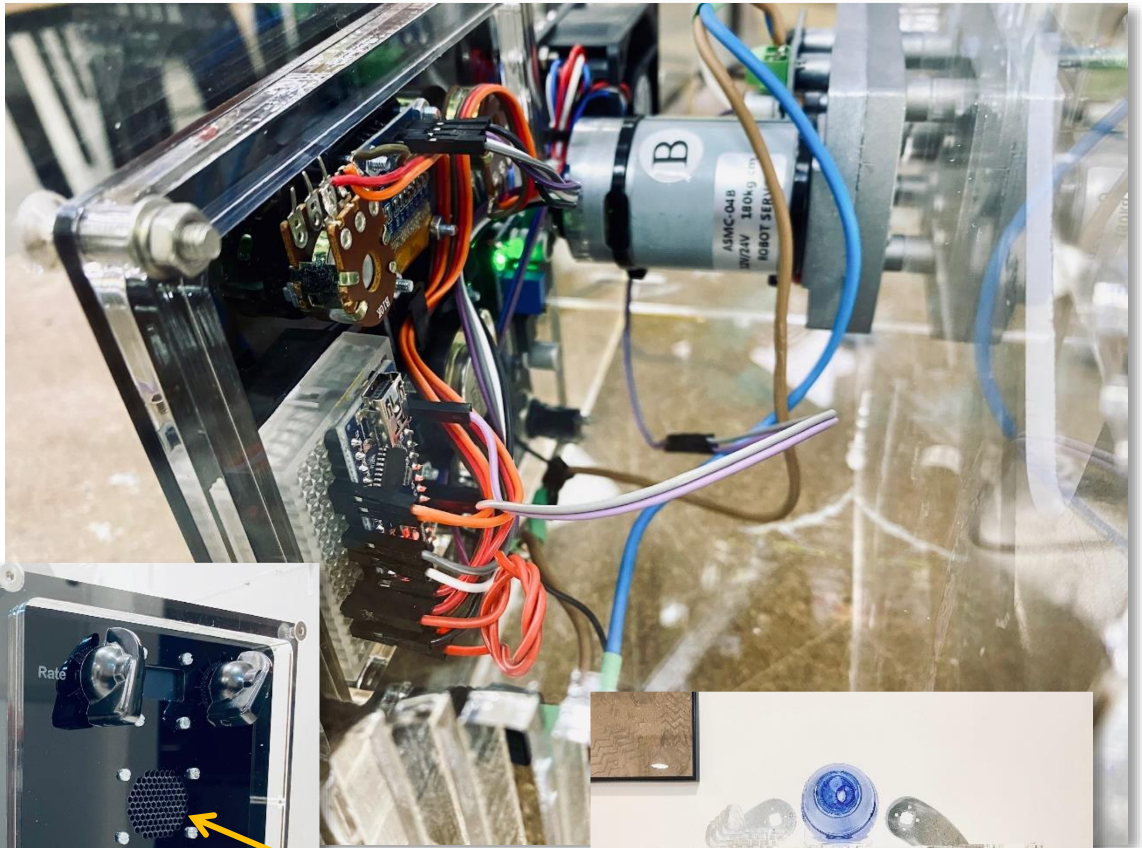
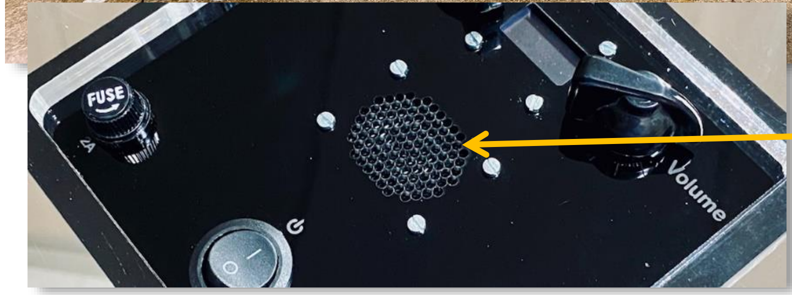
Laser-Cut Front Panels for our TII citizenscience.ae Ventilator Project







Honeycomb Structure for Alarm-Buzzer

Entry-Level Usage of Laser Cutters V - Customization

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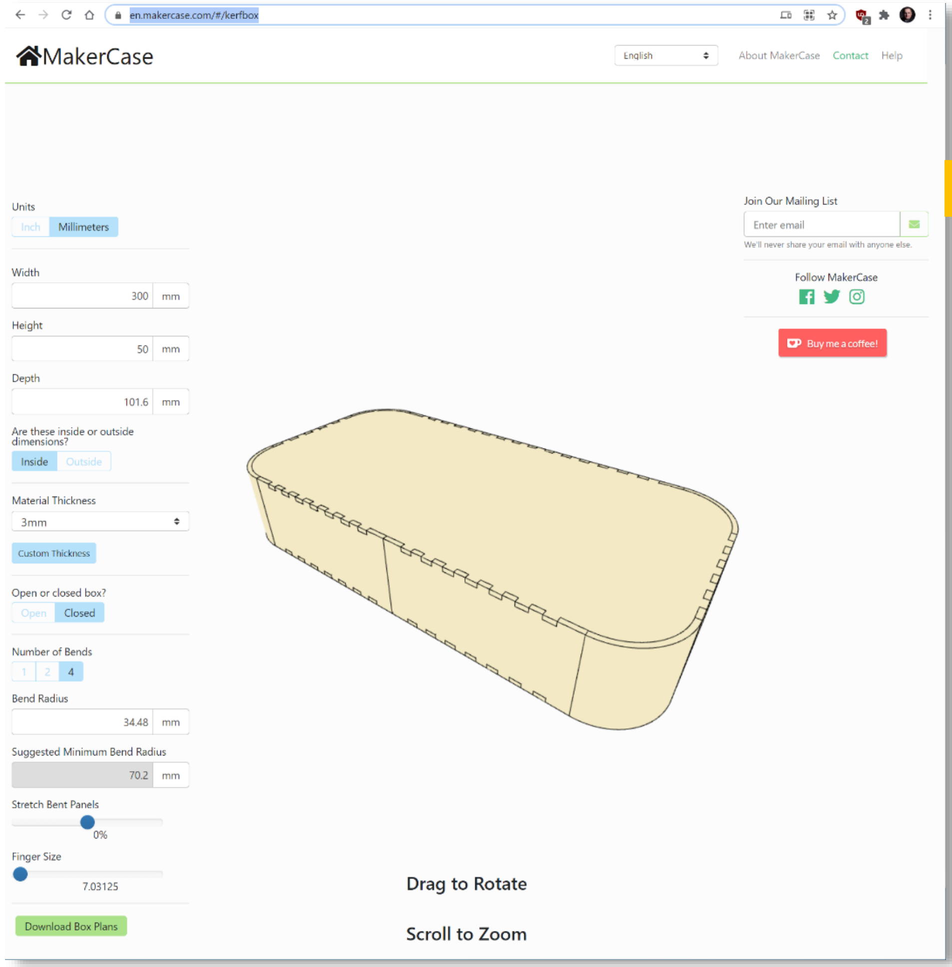
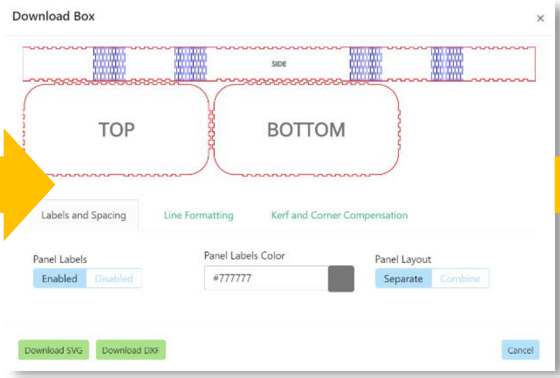
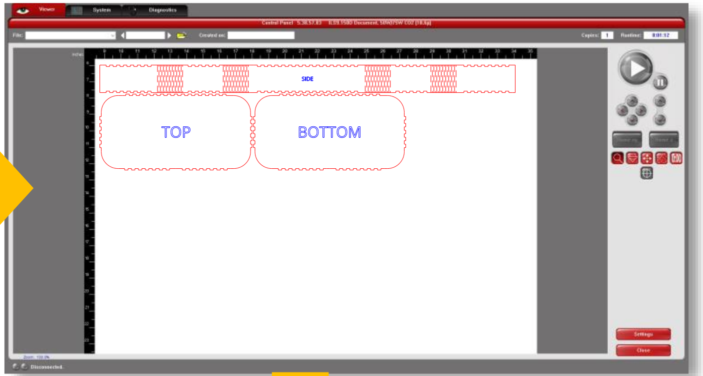
Web based 3D box generator and customization by 2D post-editing





Customize!



Today's laser cutting technology is easy & kids-friendly

FlexiPi + Raspberry Pi case using Kerf patterning for bends by Iron Momo @ thingiverse.com.

makercase.com enables simple creation of laser-cuting box templates that can be easily customized in 2D drawing software like Corel Draw or Inkscape with custom holes for buttons/displays for your electronic projects

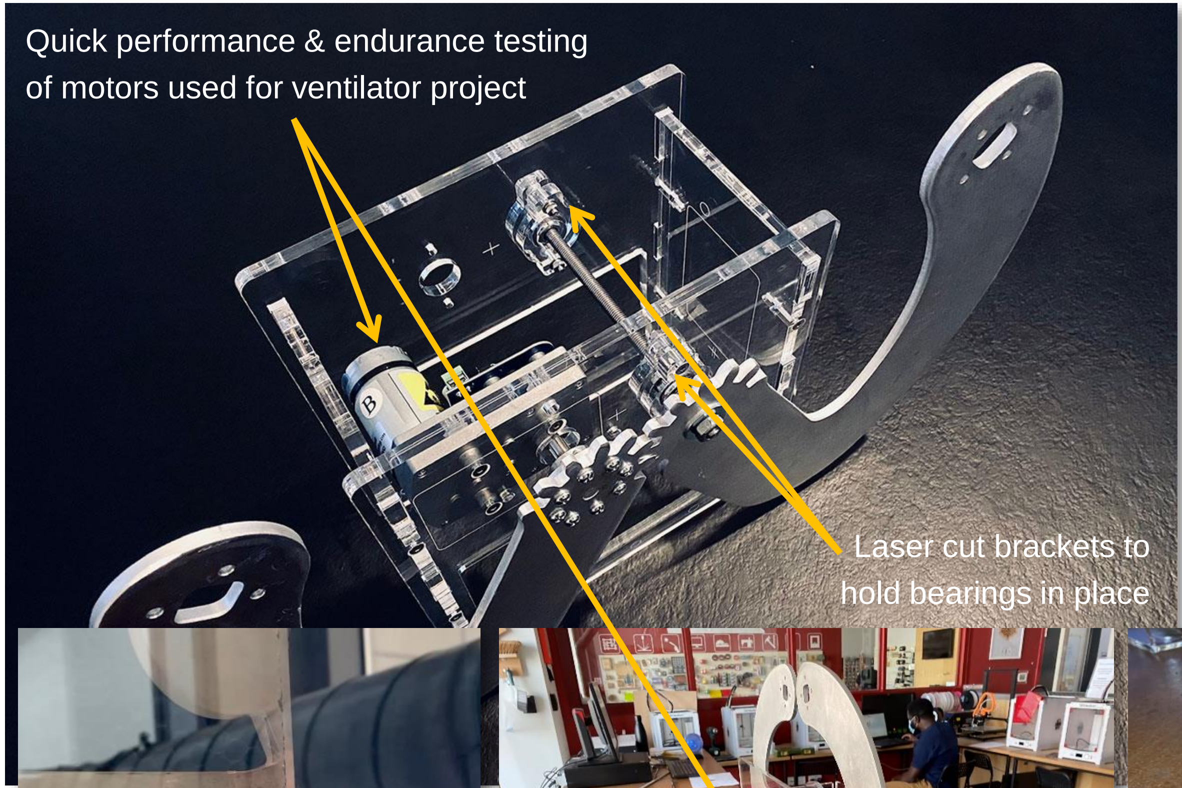
Showcase: Intermediate-Level Usage of Laser Cutters

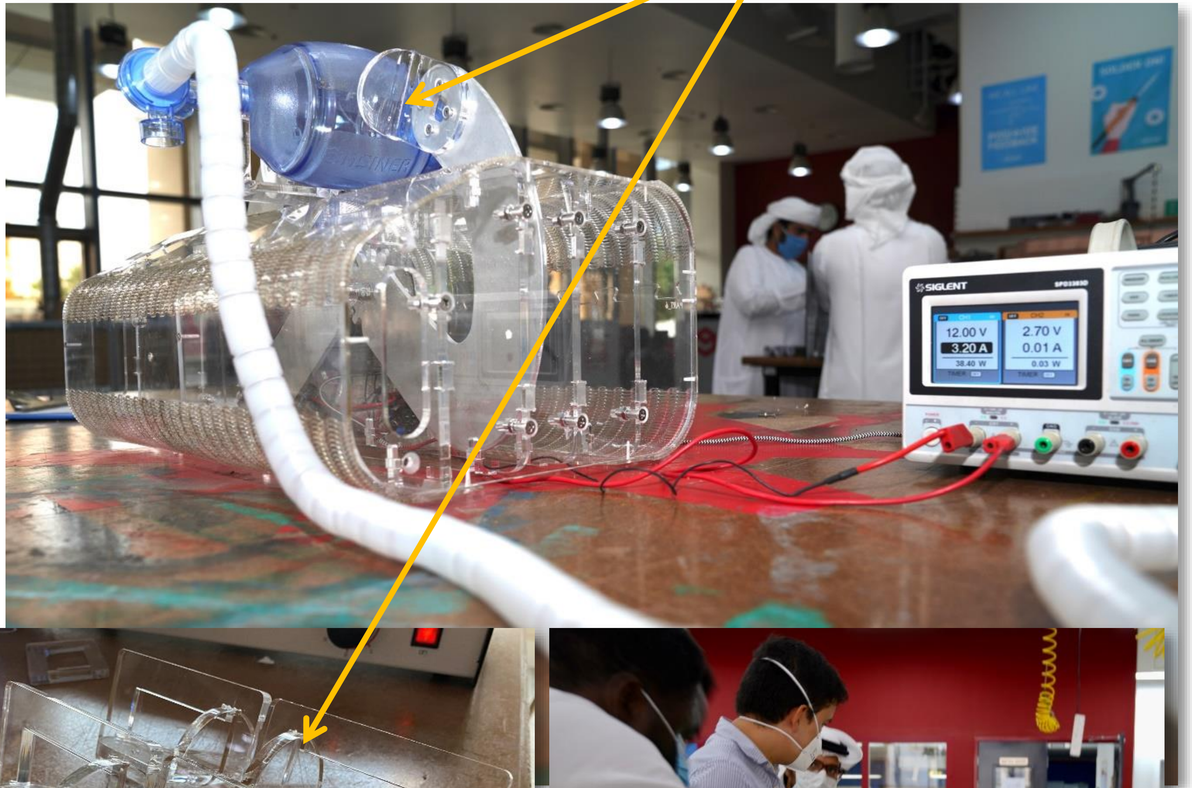
Rapid 2D mechanical “brainstorming” for TII citizenscience.ae Ventilator Project

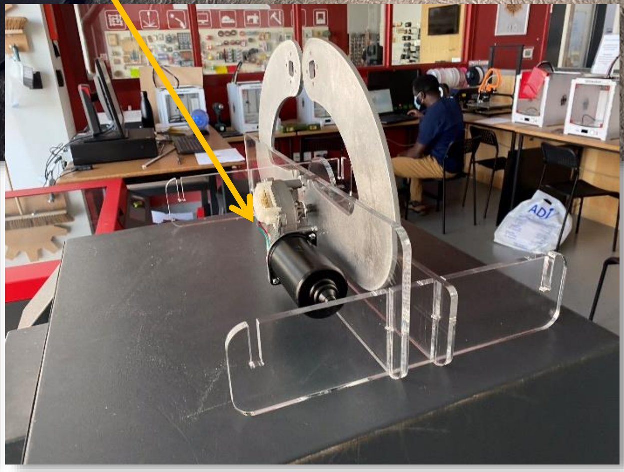
Laser cut tooling for precise thermal bending of Acrylic

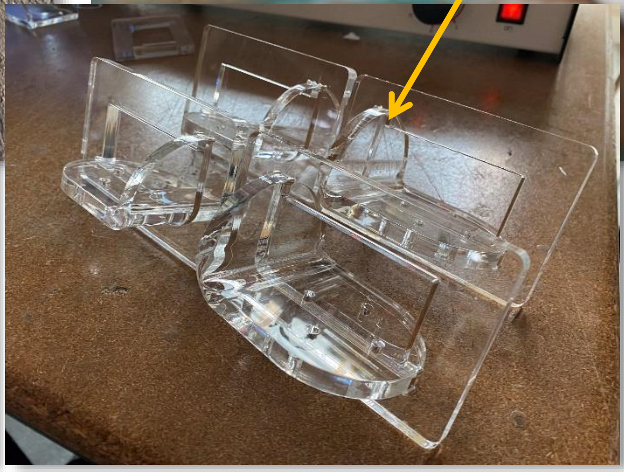
Quick performance & endurance testing of motors used for ventilator project

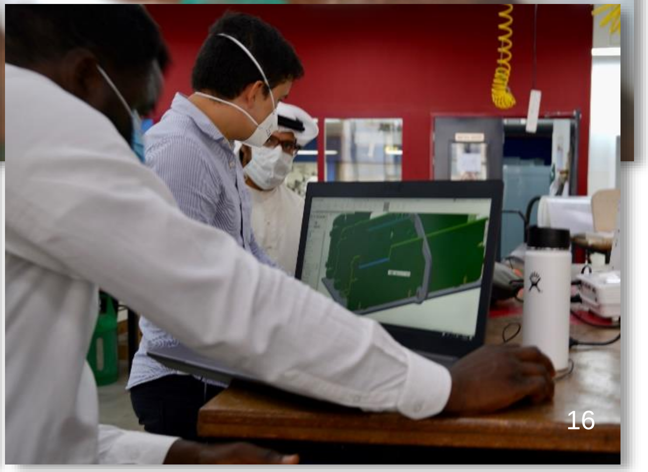
Laser cut brackets to hold bearings in place











Showcase: Intermediate-Level Usage of Laser Cutters

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Rapid 2D mechanical “brainstorming” for TII citizenscience.ae projects

Showcase: Advanced Usage of Laser Cutters

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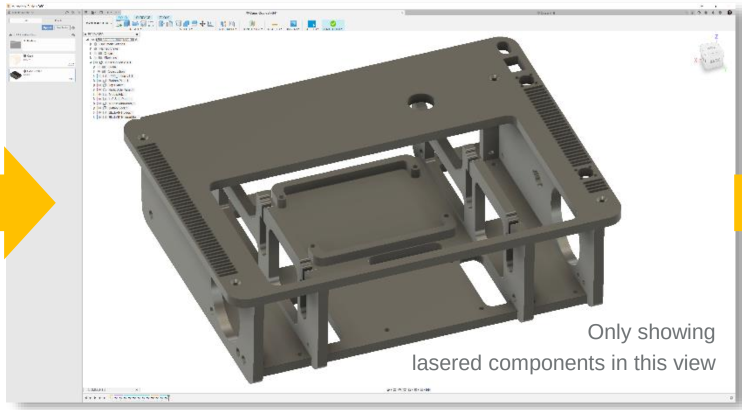
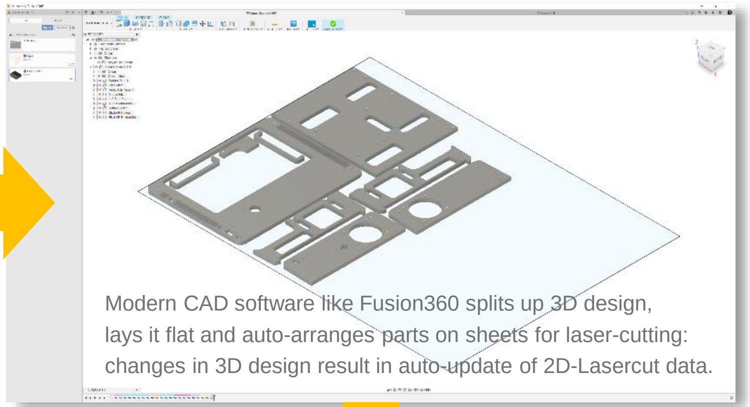
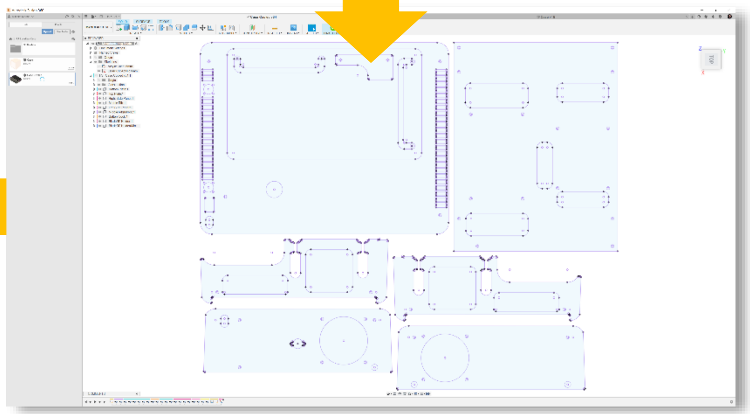
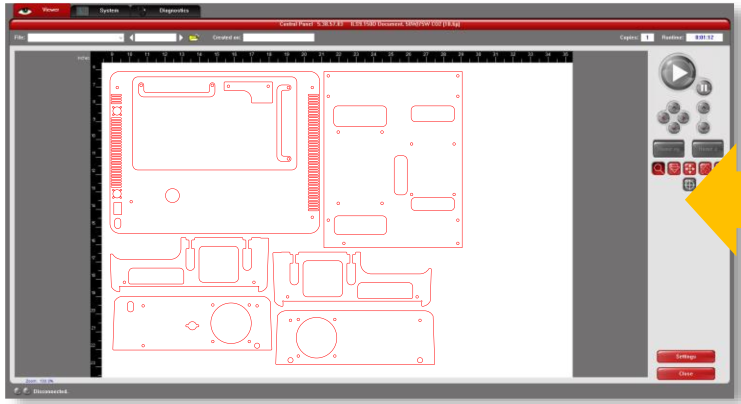
Rapidly turning 3D into 2D & back: Fusion360 CAD workflow for portable SDR Platform



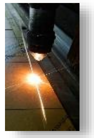




2D-Lasercut data is usually exported in DXF format.



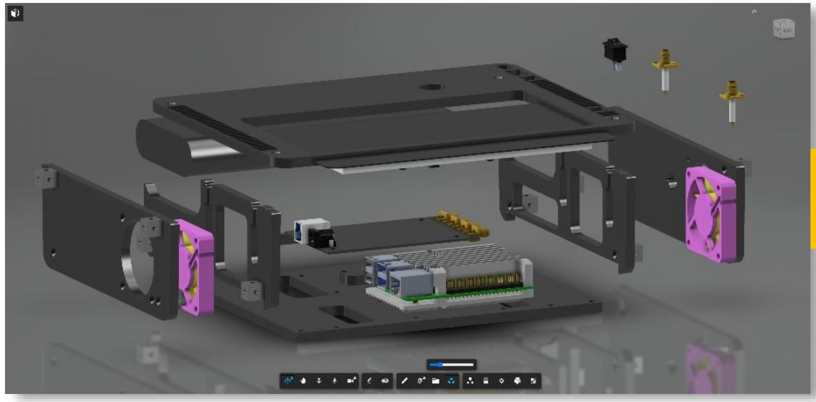
The DXF data can be directly processed by the Lasercutter controller and turned transparently into Laser control commands - commonly CNC G-code.



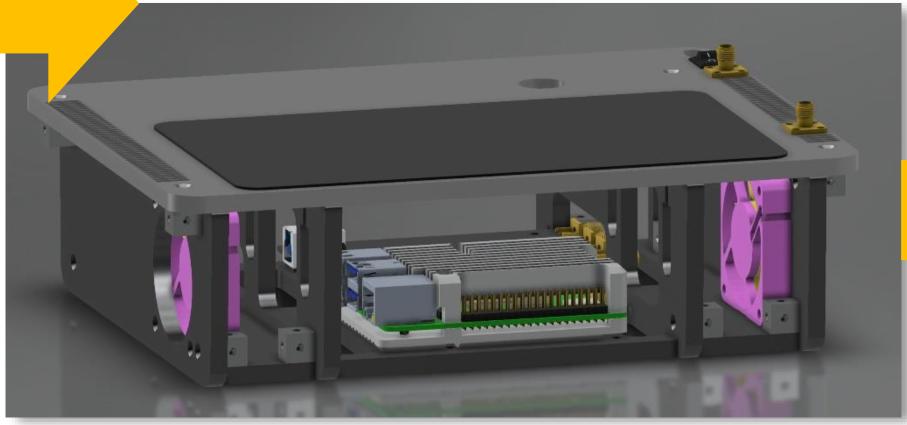
Laser cutting the above design into 6mm Acrylic sheet takes around 15 minutes with a low-power 60W CO_2 Laser Cutter.

Showcase: Advanced Usage of Laser Cutters

Rapidly turning 3D into 2D & back: Final Assembly of SDR Platform



Used grabcad.com for getting common 3D models like the Raspberry Pi 4, the SMA sockets, the Raspberry touch display, the power switch and the 50mm fans. For the BladeRF SDR and the Anker Power Bank I created 3D simplified models with only the relevant connectors.



Design is custom-fit for a Pelican 1200 protector case.

Laser Cutting:

Precision Design & Compliant Mechanisms

Laser Cutting Accuracy:
Novel Mechanical Design Processes

- Precision depends on movement speed – but commonly between 10-100µm absolute positioning accuracy. The relative positioning accuracy is even higher.
- Common Laser heads cut around 150µm wide and up to 10mm deep depending on the material (usually wood, Acrylic).
- Cutting complete design in one go – including mounting holes - enables high precision manufacturing processes.
- Utilizing flexibility of materials enables extreme precision not achievable by traditional joints: **Compliant Mechanisms**

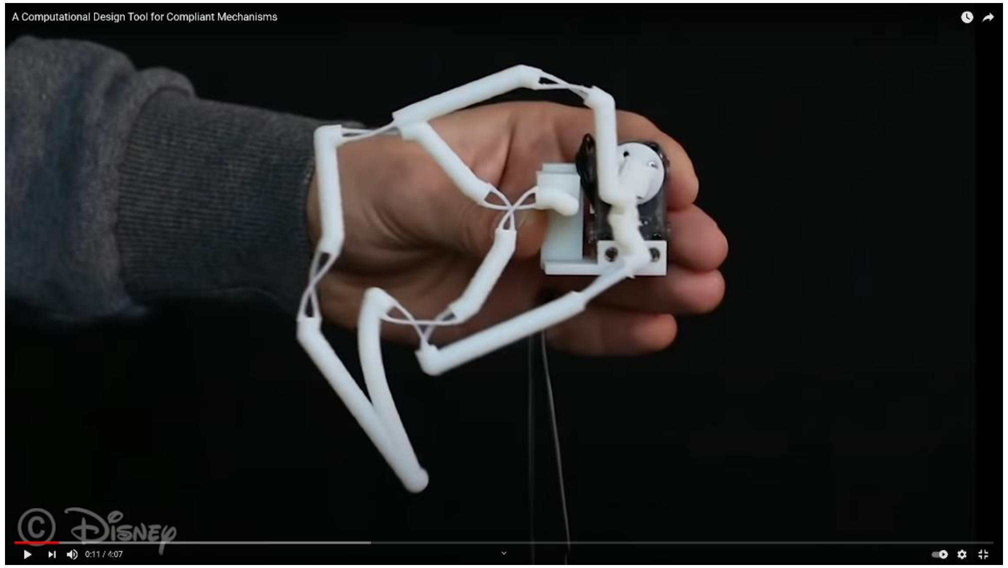
BYU Complex Mechanism Research: Compliant Plier Mechanism

Machines that bend are better

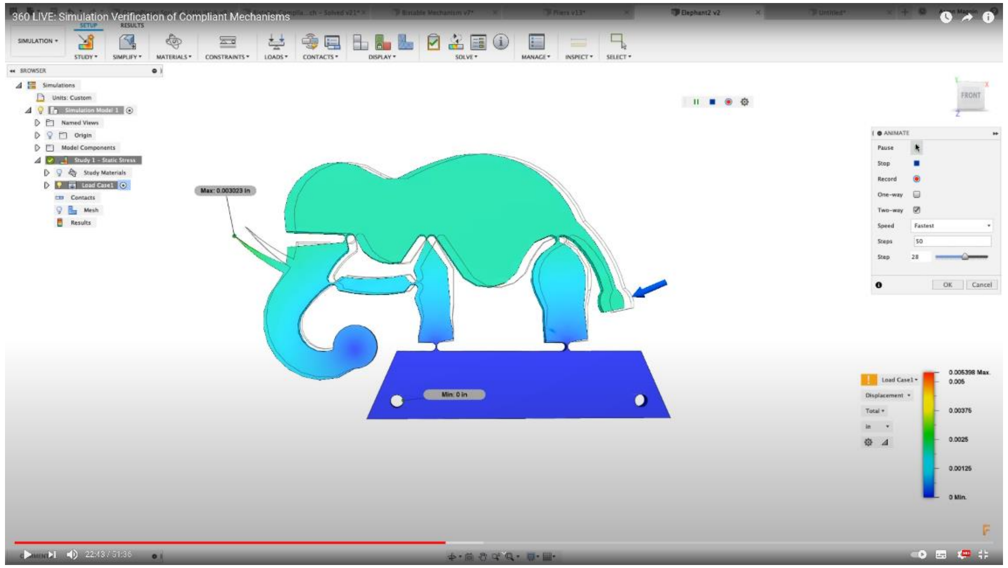
Eight P's of Compliant Mechanisms

1. **Part Count Reduction** - having flexible parts instead of bearings, springs or hinges.
2. **Production Process Simplification** by 3D-printing or laser-cutting functional devices that are "assembled by design"
3. **Price Reduction** through simpler production and reduced assembly effort
4. **Precise Motion** by absence of backlash, less wear, and low friction
5. **Performance** No outgassing, doesn't require lubricant for bearings or axles.
6. **Proportions** - Reduced by different production processes
7. **Portability** - Lightweight due to simpler, reduced part count designs
8. **Predictability** - Devices are reliable over a long period of time

__Note__: 8 P's established by Derek Muller (@Veritasium): see his amazing YouTube Video "Why Machines That Bend Are Better".



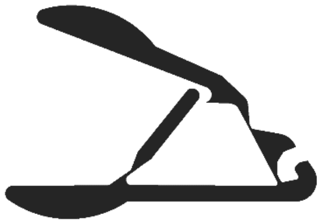
Flexures of a Compliant Mechanism shown in "A Computational Design Tool for Compliant Mechanisms" by Disney Research.

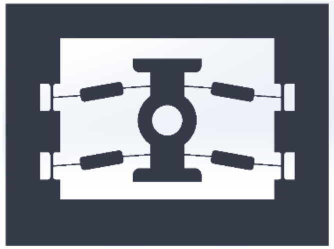


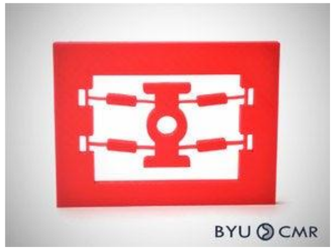
Simulation & Verification of Compliant Mechanisms in Fusion 360

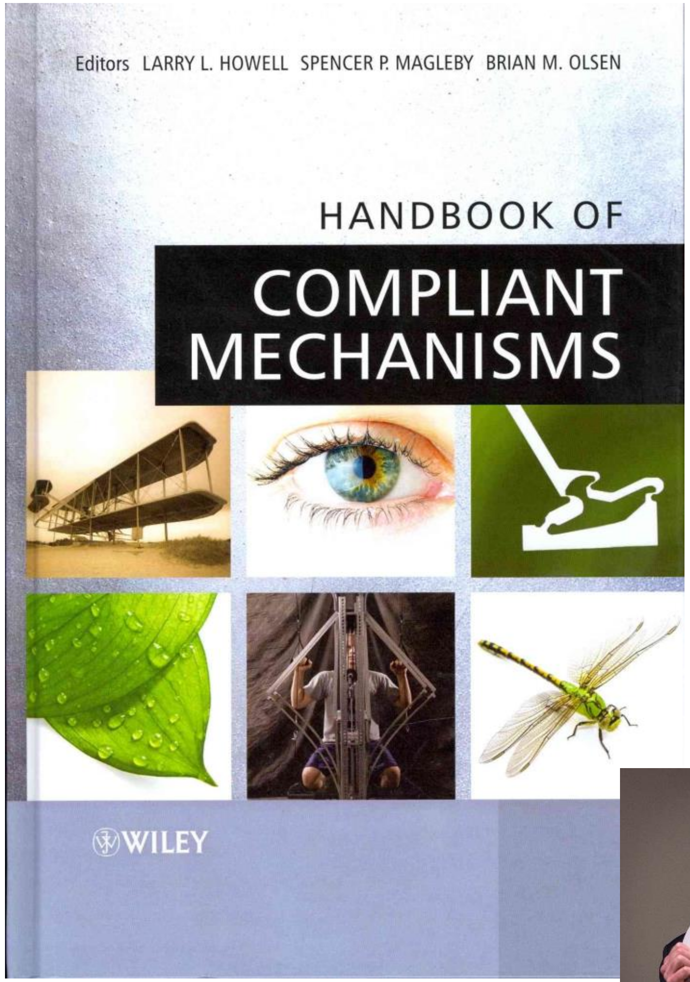
Machines that bend are better

Further Reading



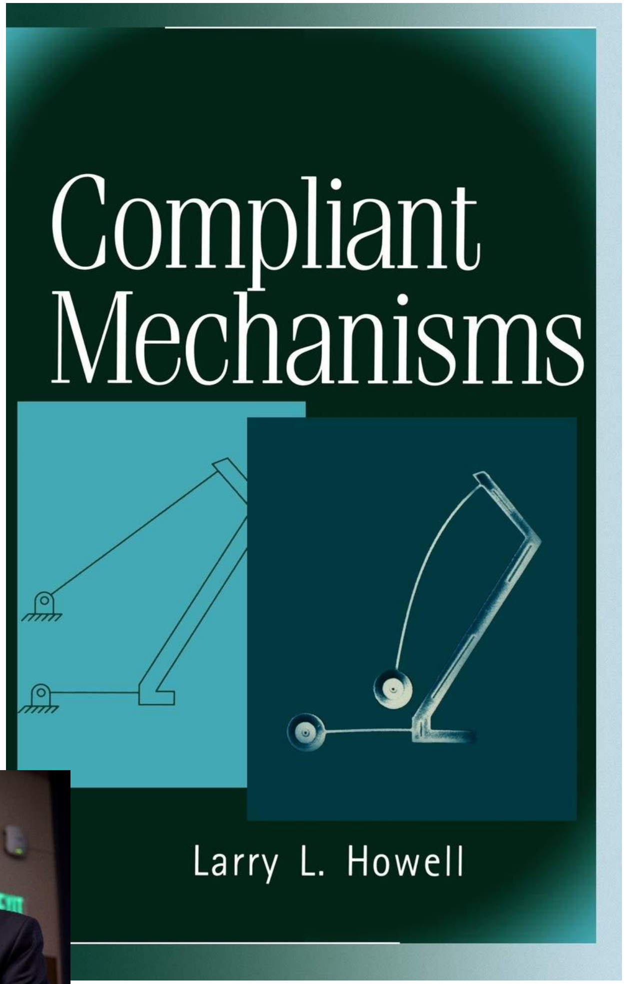




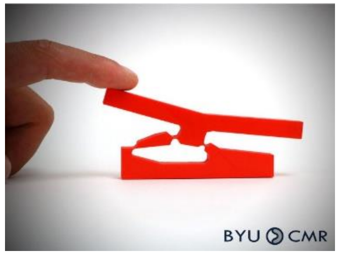


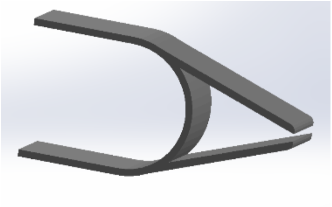
Practical Introduction into
Compliant Mechanisms for Engineers
(book link)

Author: Larry L. Howell



Deep Dive into the theory
behind compliant Mechanisms
(book link)



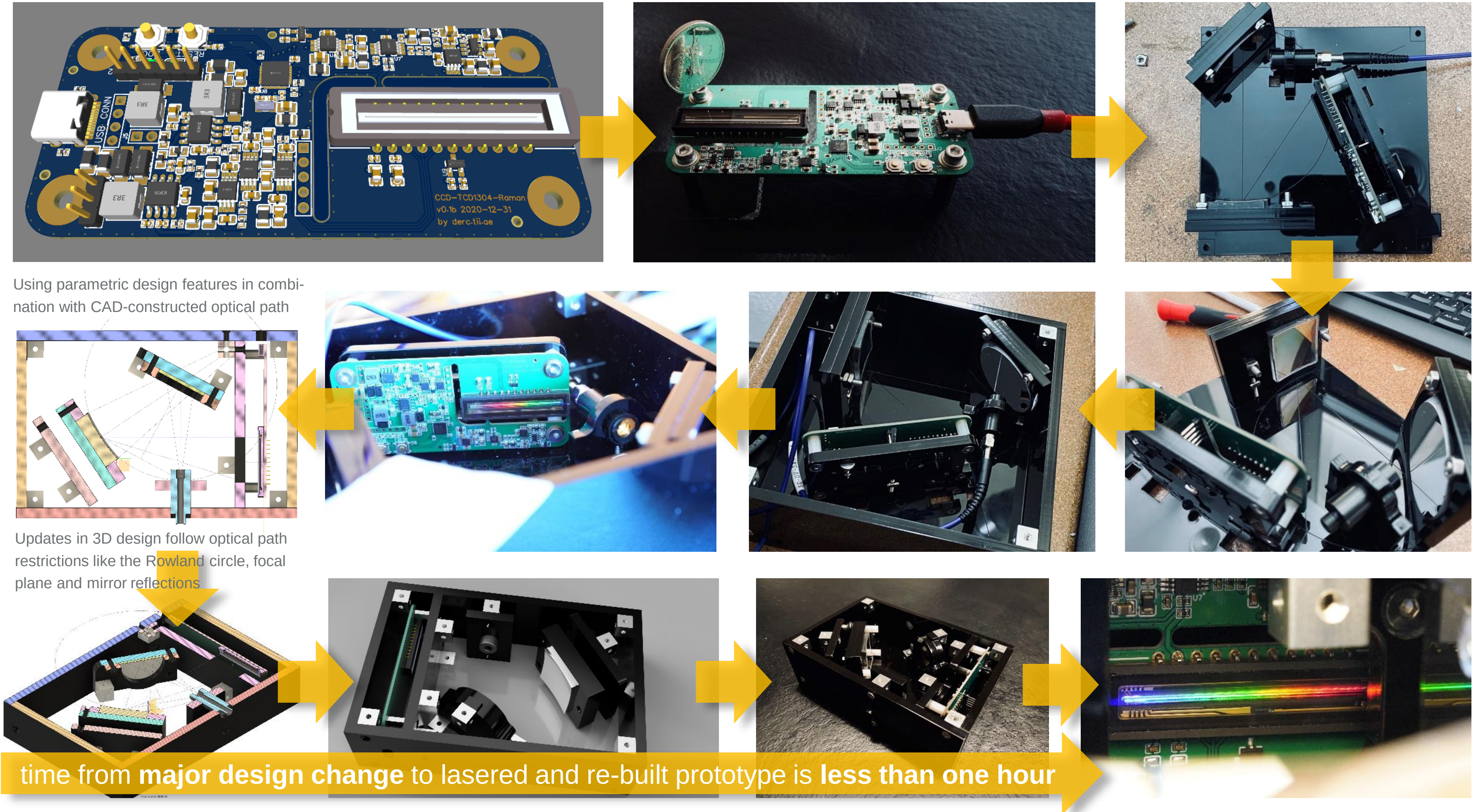


Compliant Mechanisms:
Precision Design Show Case

Showcase: Rapid Precision Design

Directed Energy Research Centre

Using CAD as a Compiler, but for Hardware — Raman Spectrometer Assembly



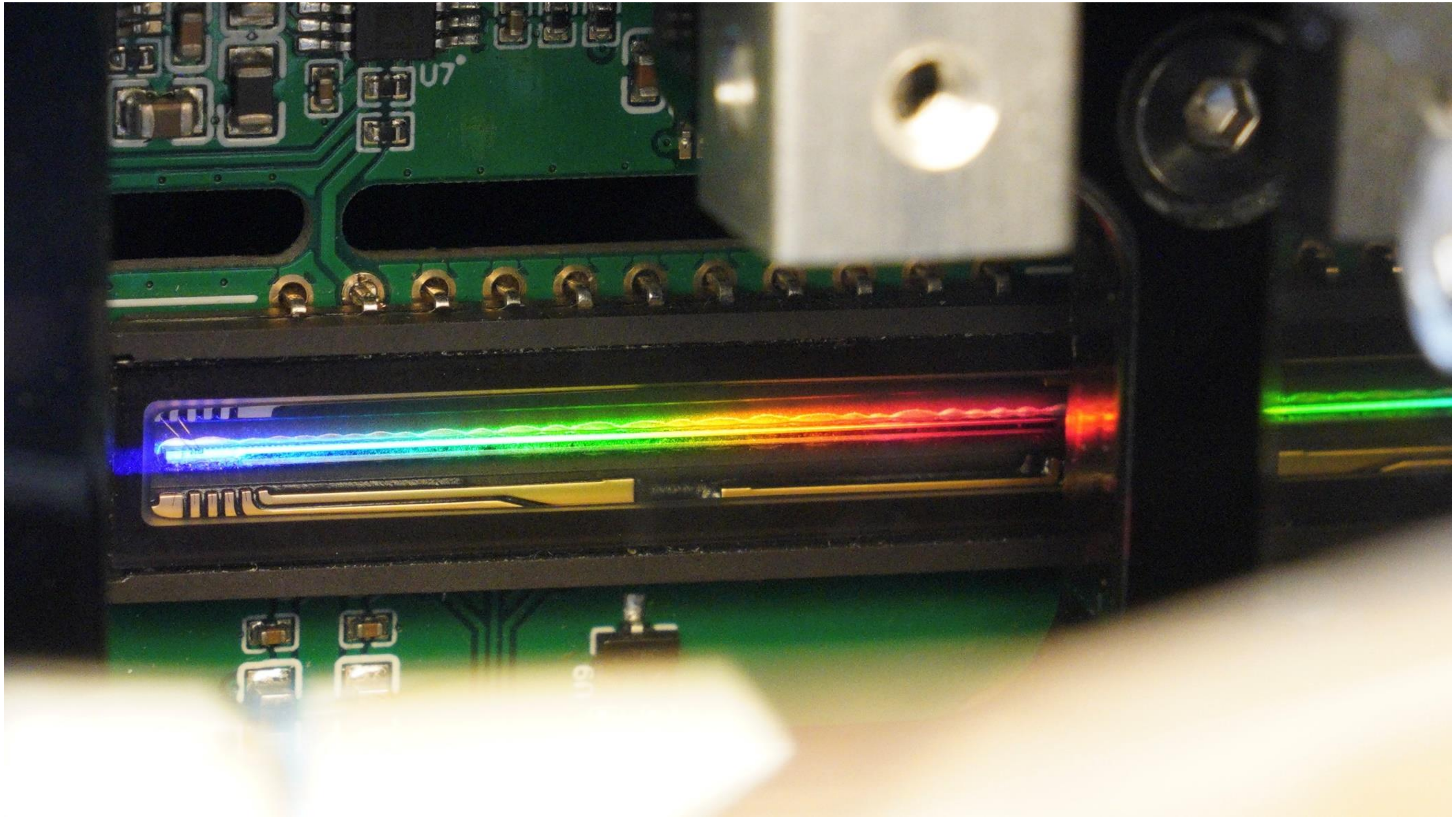
Using parametric design features in combination with CAD-constructed optical path

Updates in 3D design follow optical path restrictions like the Rowland circle, focal plane and mirror reflections

time from **major design change** to lasered and re-built prototype is **less than one hour**

Showcase: Rapid Precision Design

Optical Assembly for Spectrometer Experiment



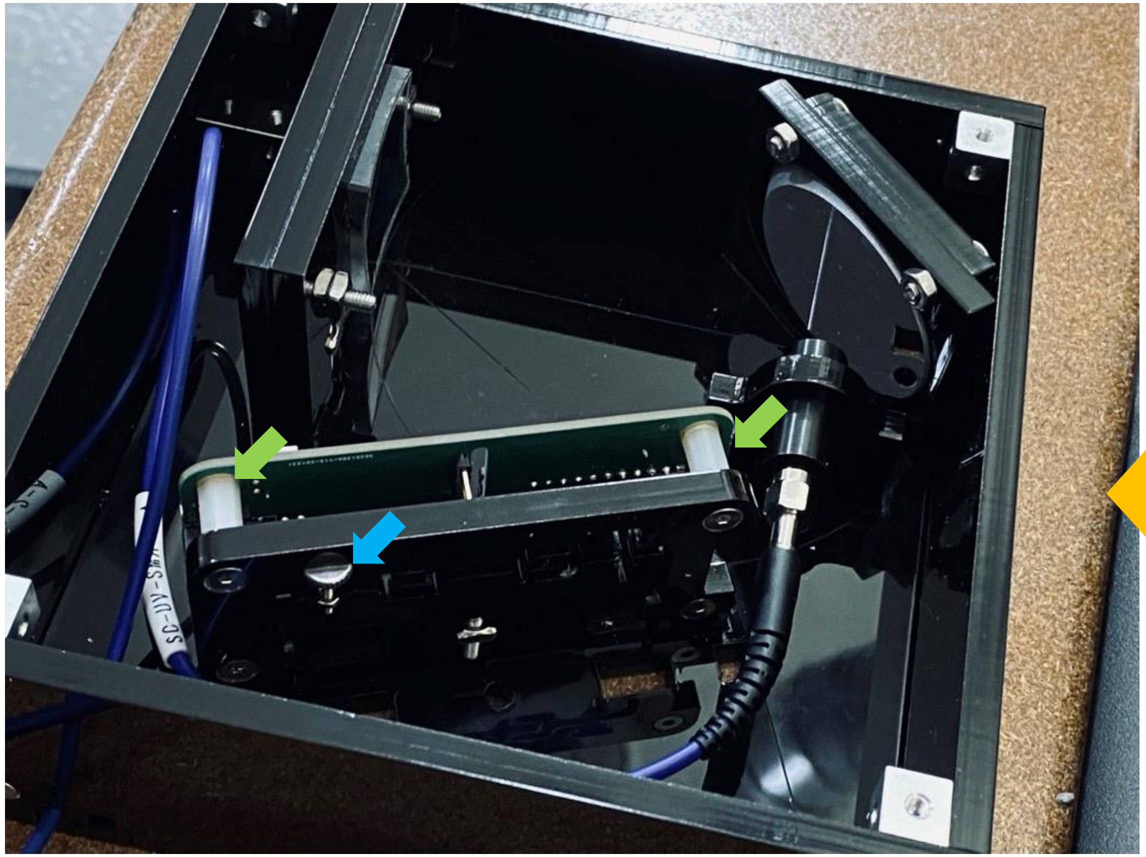
Light coupled into device is diffracted, precisely focused by concave grating – and projected exactly onto CCD camera line sensor.

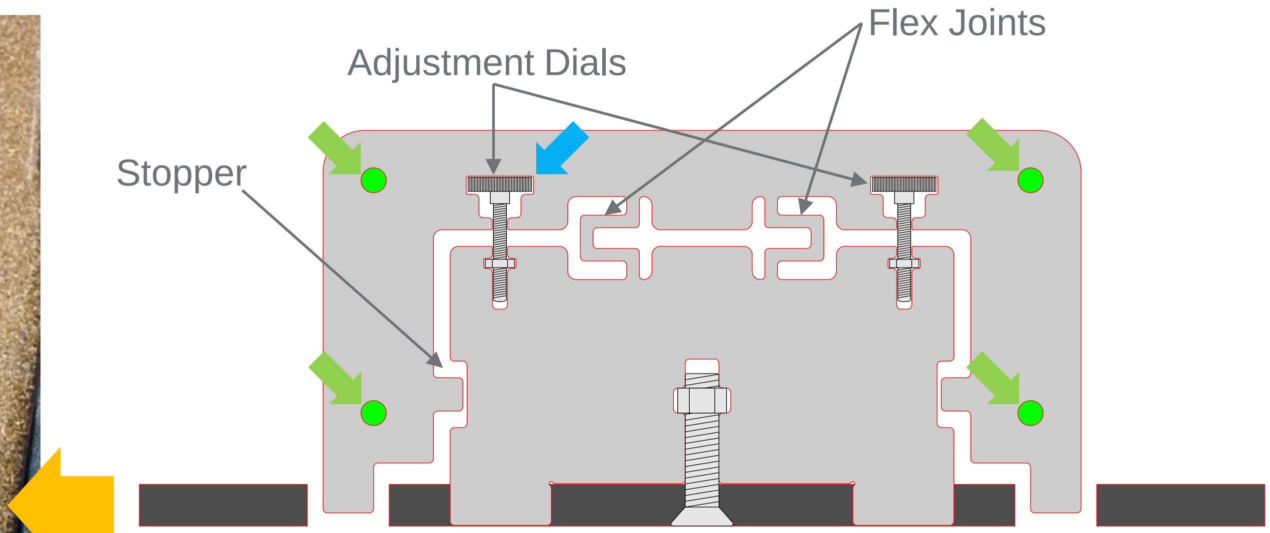
Technical Setup:

- TCD1304DG with 3648 pixel
- 8µm x 200µm pixel size
- Halogen light spectrum

Showcase: Rapid Precision Design

Optical Assembly for Spectrometer Experiment: Precise Compliant Mechanisms

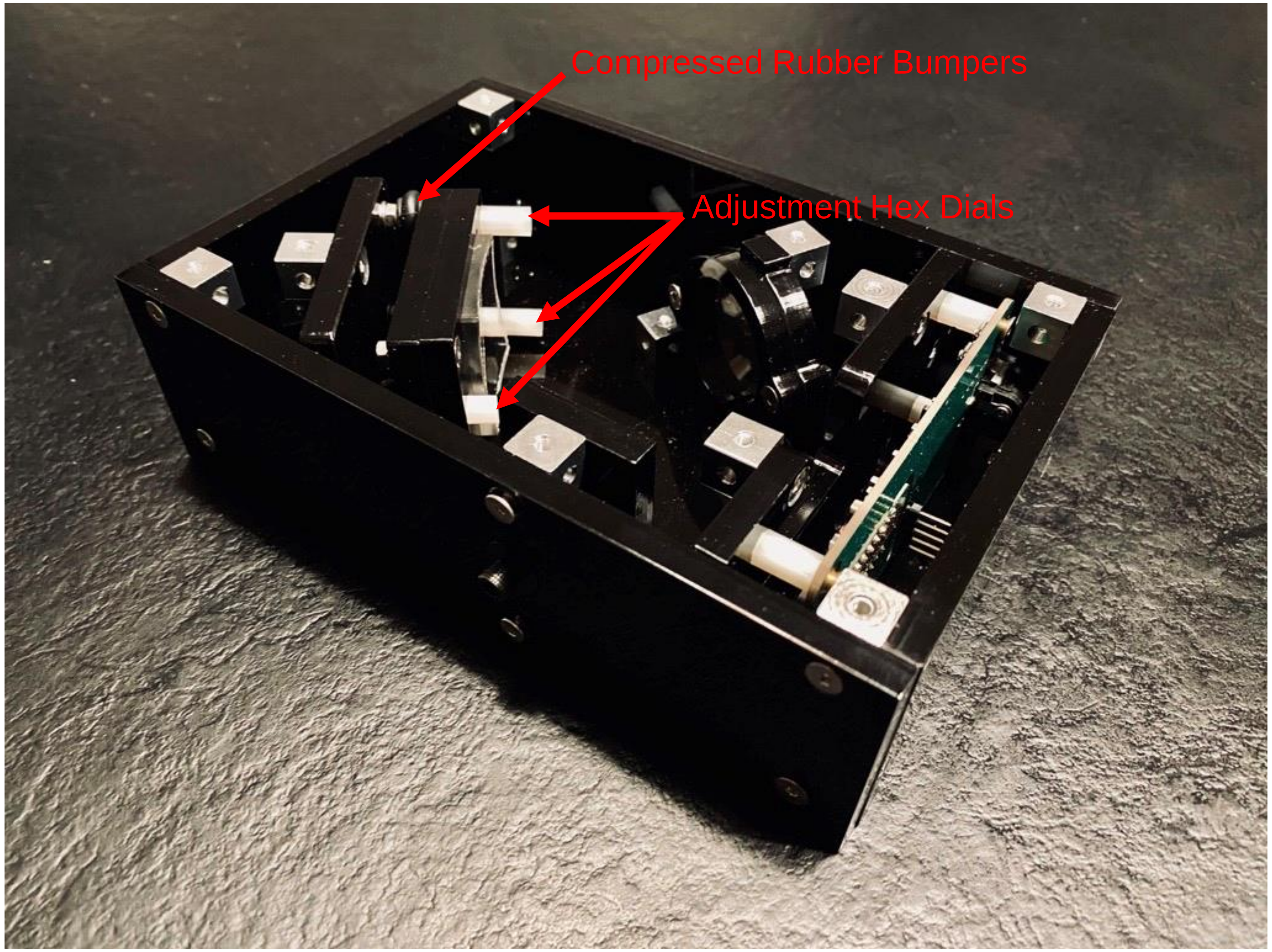




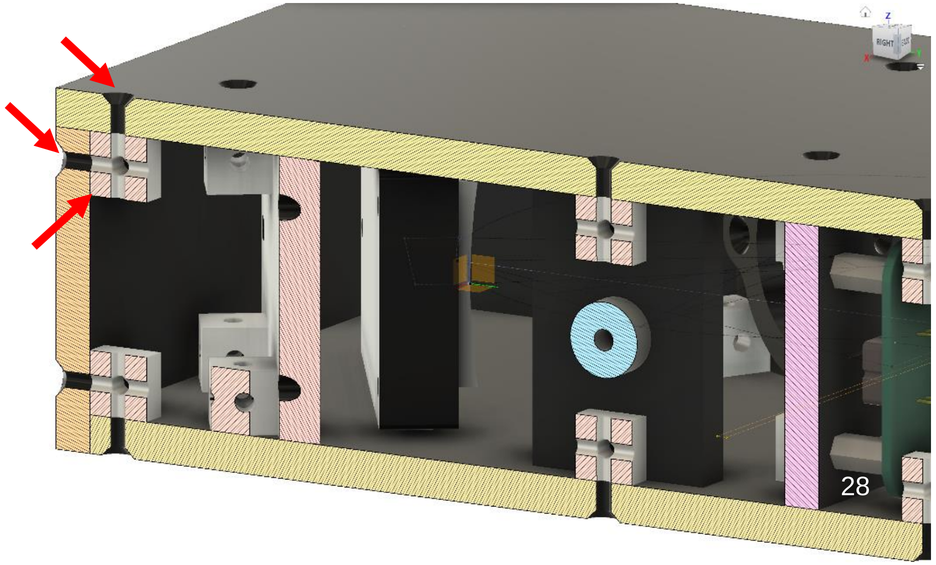
- Enables easy compensation of production-tolerances
- Green mounting points for CCD Sensor PCB on outer part:
  - Inner part of fixed to bottom carrier panel
  - Outer part can be moved up, down or tilted by turning adjustment dials
  - Inner and outer part joined by flex joints
- Stoppers prevent stressing the flex joint and possible breakage
- Slots in bottom plate guide outer assembly with the PCB

Showcase: Precision Design Details

Spectrometer design using compressible Structures & Threaded Aluminum Cubes

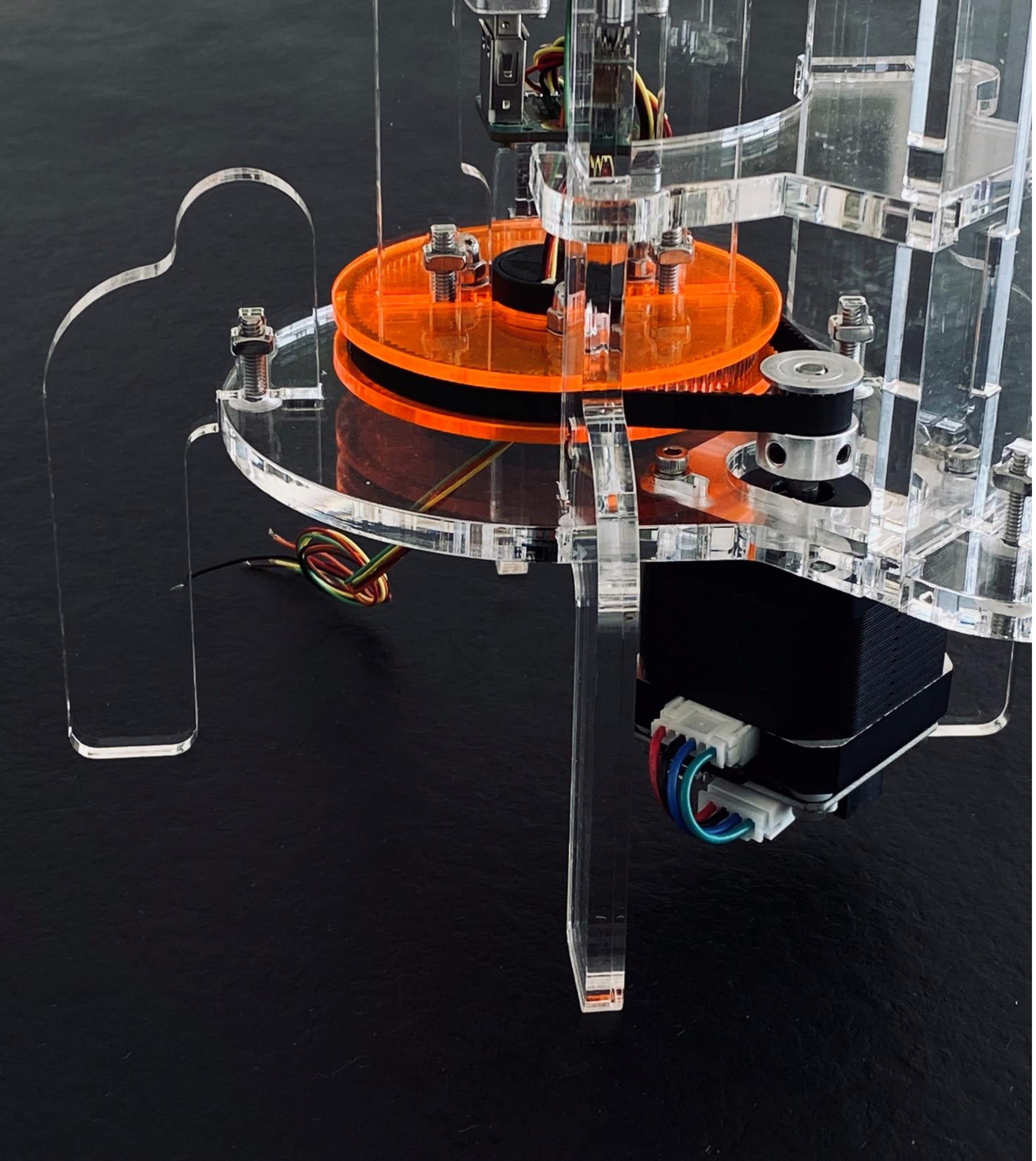


- Using the three hex dials, both the orientation and focus plane of the concave grating mirror can be precisely adjusted without backlash.
- Six-sided M3-threaded Aluminium cubes ensure rigidity and enforce right angles for all acrylic parts. The design clamps components firmly in place independent of Laser Kerf.
- Countersunk screws ensure precise positioning of M3-blocks.
- Laser cutter enables quick design iteration and avoids sourcing problems and pricy generalized optical bank components – and unlocks very compact designs.



Precision Design:

Movement & Motors



Don’t Fear the Gear

Automation with Tooth Belts & Steppers

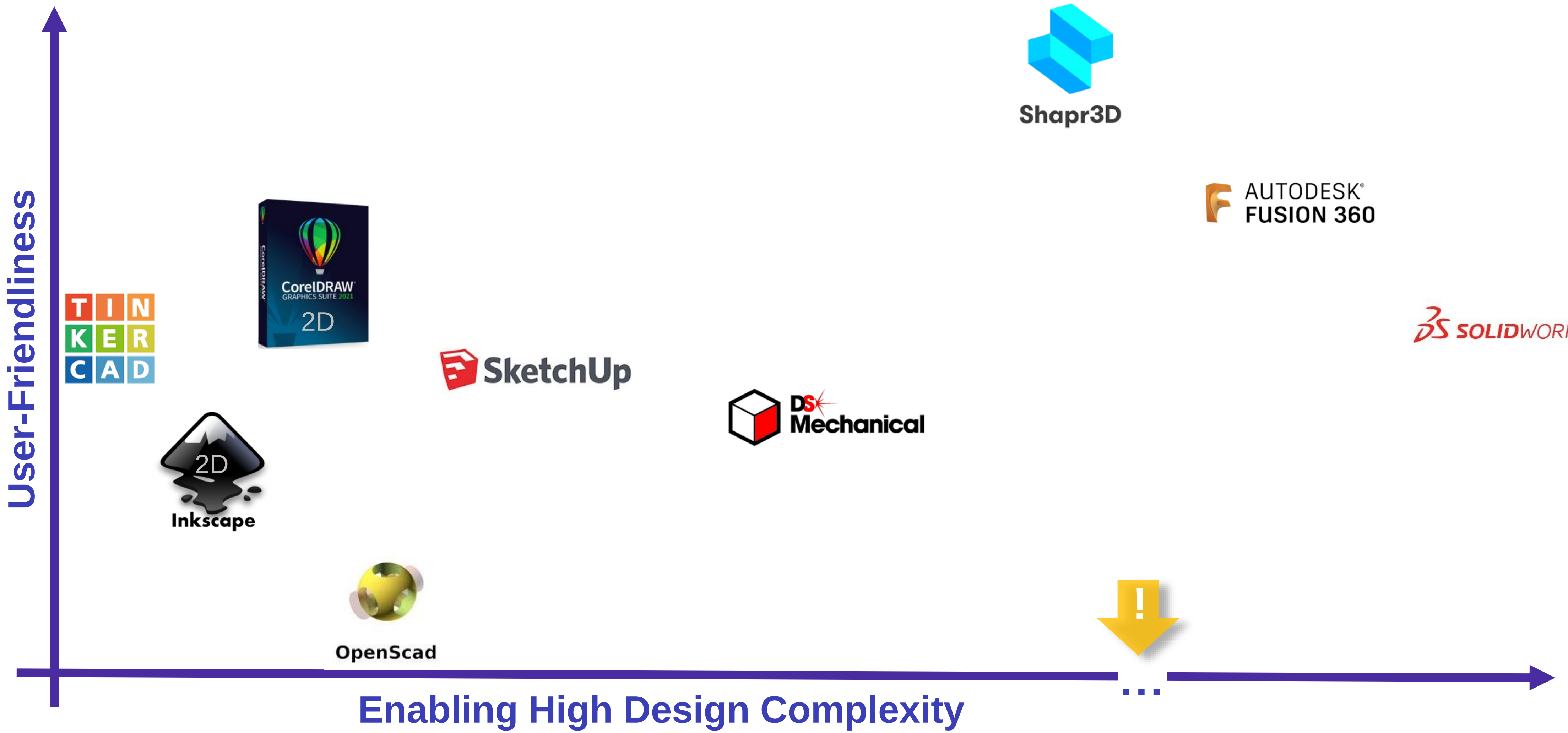
- Laser cutter precision more than sufficient for cutting precise parts like tooth belt gears.
- Tooth belts reduce noise and wear of design compare to gears-only designs – higher durability, speed and power over traditional toy-servo-motors.
- By using stepper motors with built-in closed-loop controllers and magnetic encoders, precision control can be achieved.
  - NMEA Smart Stepper Controllers by misfittech.net for integration on stepper motor (see left)
  - Makerbase servos on AliExpress.com
- Avoid complex CAD software by auto-generating gears and exporting them into your 2D drawings – check geargenerator.com and OpenSCAD tooth belt generators. You can find numerous web-calculators for gear distance based on belt length and tooth size.

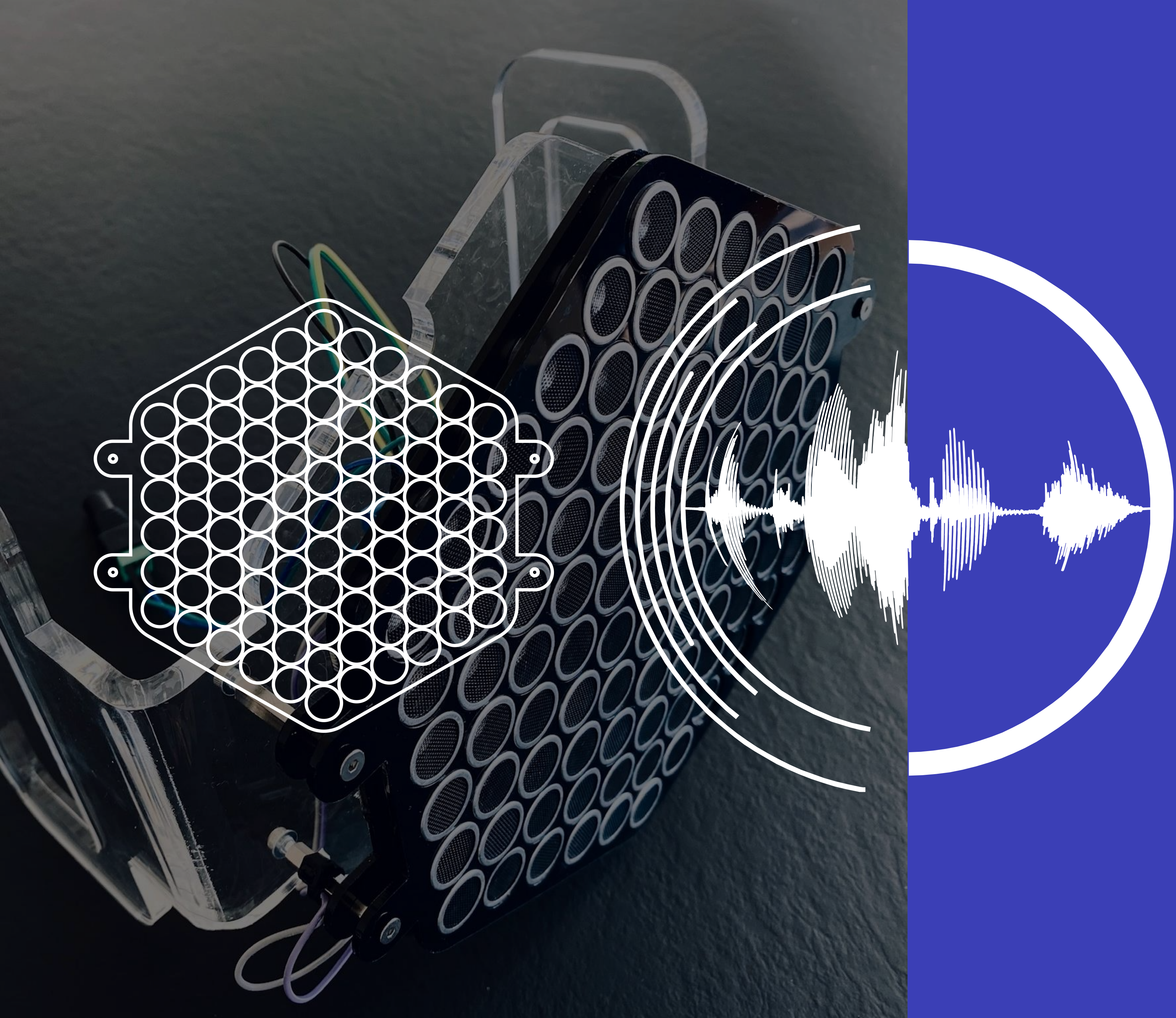
Pick your poison:

CAD Software for Laser Cutting

Picking a CAD Software for Laser Cutting

Leaving Dunning-Kruger's "Valley of Despair" behind: Subjective Comparison





Questions?

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