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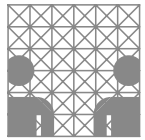

Automated integration of screw nuts into 3D printing

Bachelor Thesis

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Technical Aspects of Multimodal Systems

January 21, 2020

Overview

Motivation

- 3d printed threads are weak
- Standardized connections
- Dismountable objects
- Objects larger than print area
- Automated insertion can reduce extra work

Pick and place

Figure: Industrial pick and place machine [Cor15]

3d printing electronic parts

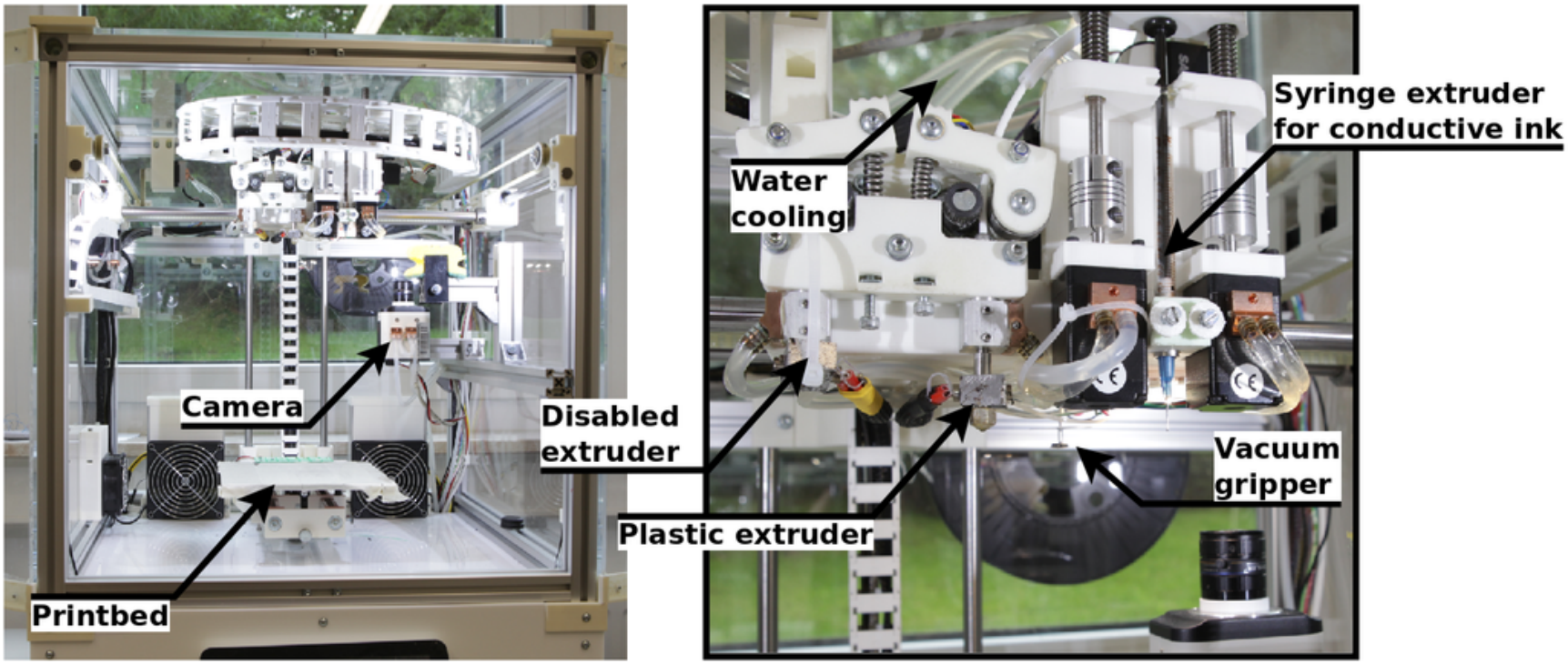
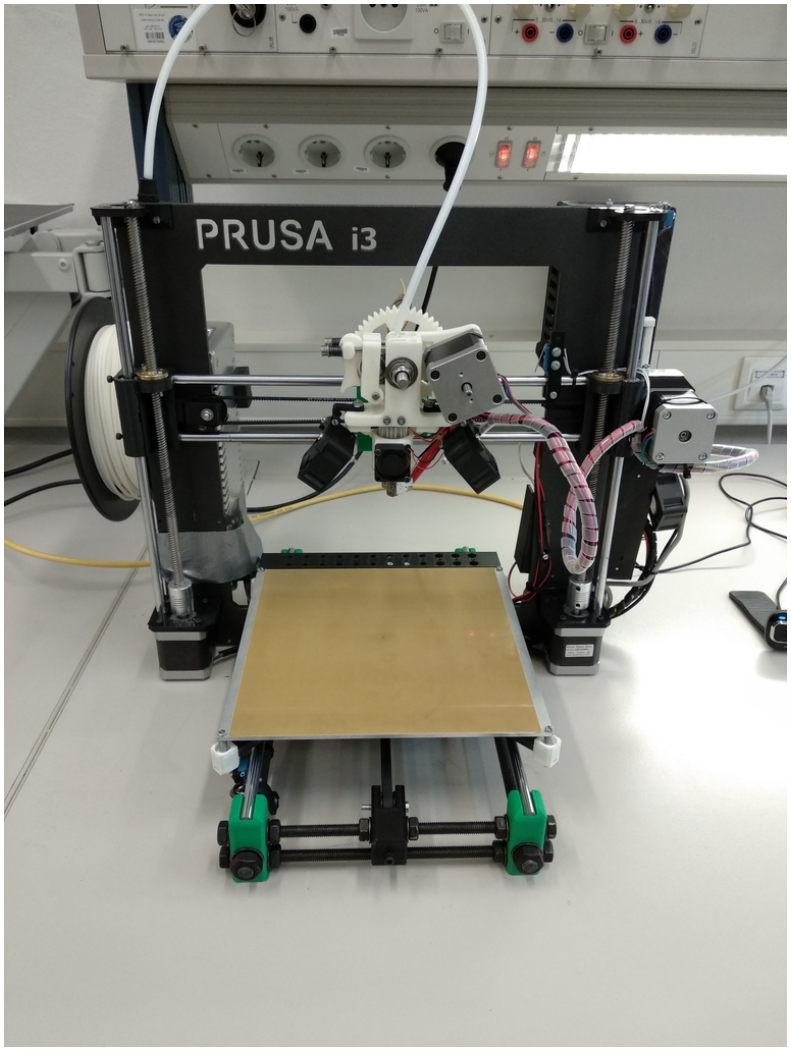


Figure: 3d printer for electronics [Was]

Disadvantages of the electronics 3d printer

- Complicated setup
- Needs two cameras
- Needs vacuum pump
- Not suitable for small printers
- Vacuum nozzle can not pick up screw nuts
- Expensive hardware

Prusa i3 3d printer



(a) Prusa i3

- Print volume 25 cm x 21 cm x 20 cm
- Relatively cheap
- Large user base
- Extendable

Current printing workflow

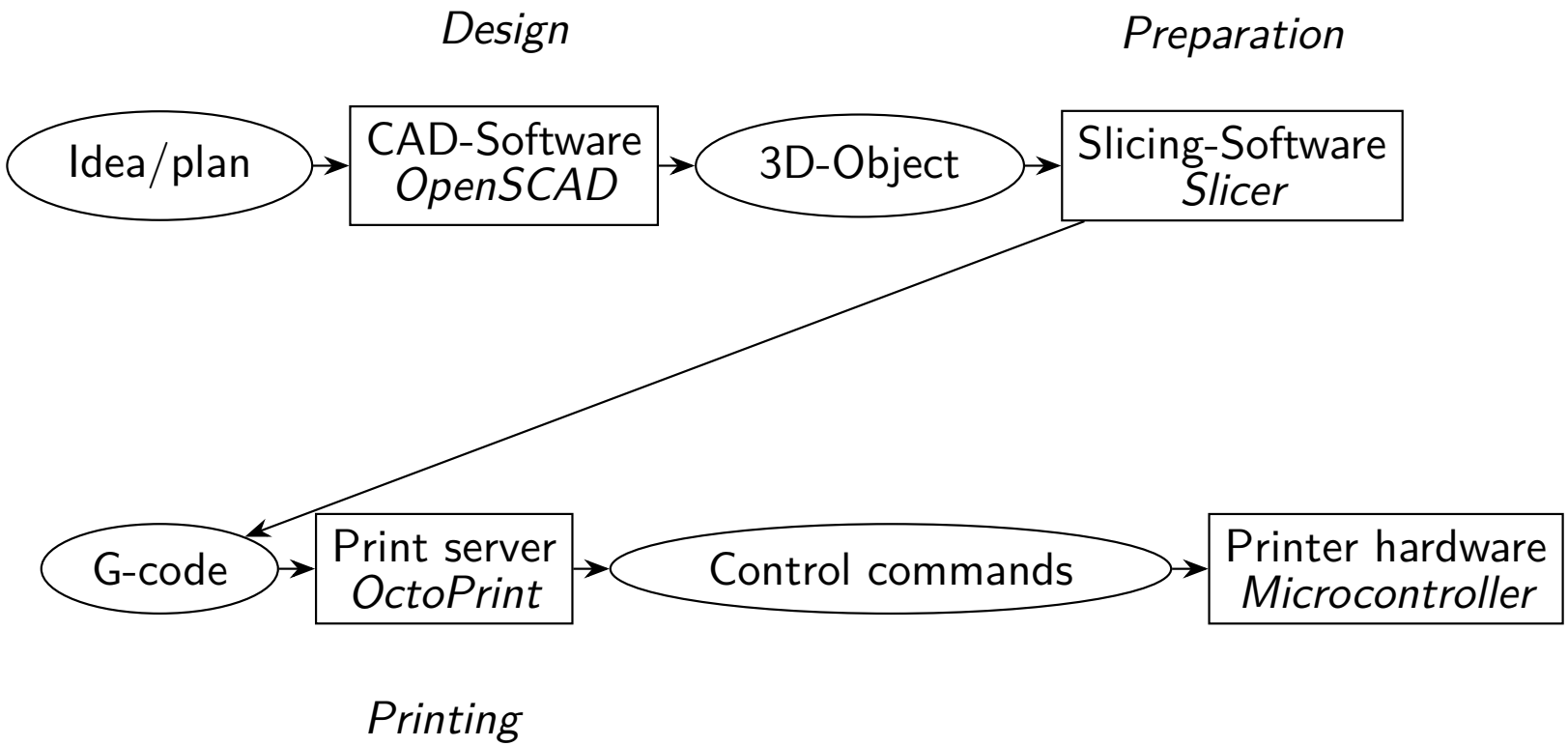
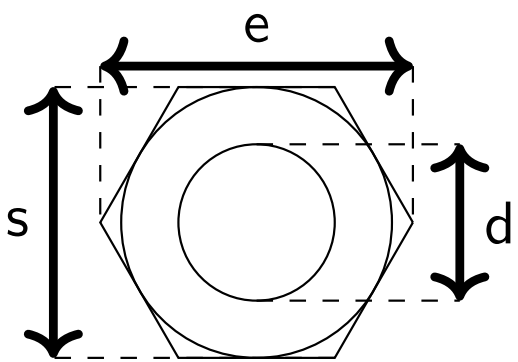


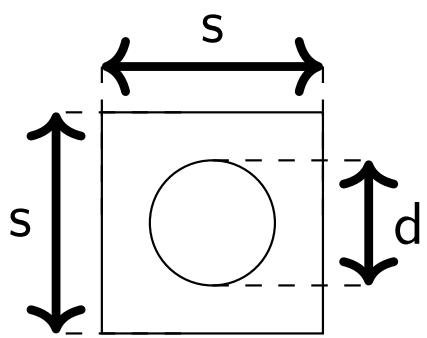
Figure: Printing workflow

Hardware requirements

- Automated insertion of hex and square nuts
- Part tray next to print bed
- Simple and inexpensive actuator: electromagnet
- Rotatable and switchable electromagnet
- Electromagnet mounted next to printing nozzle
- Electromagnet can be controlled via print server
- Electromagnet can reach part tray



(a) Hex nut



(b) Square nut

Software requirements

Slicing software

- Graphical print object preview to place screw nuts with the cursor
- Adjust screw nut properties e.g. position, rotation, height
- Restrict screw nut orientation
- Data format for communication with print server
- Include screw nut dimensions

Software requirements cont.

Print server plugin

- Parser for data format
- Configuration for electromagnet and part tray
- Calibration
- Preview part tray

Workflow

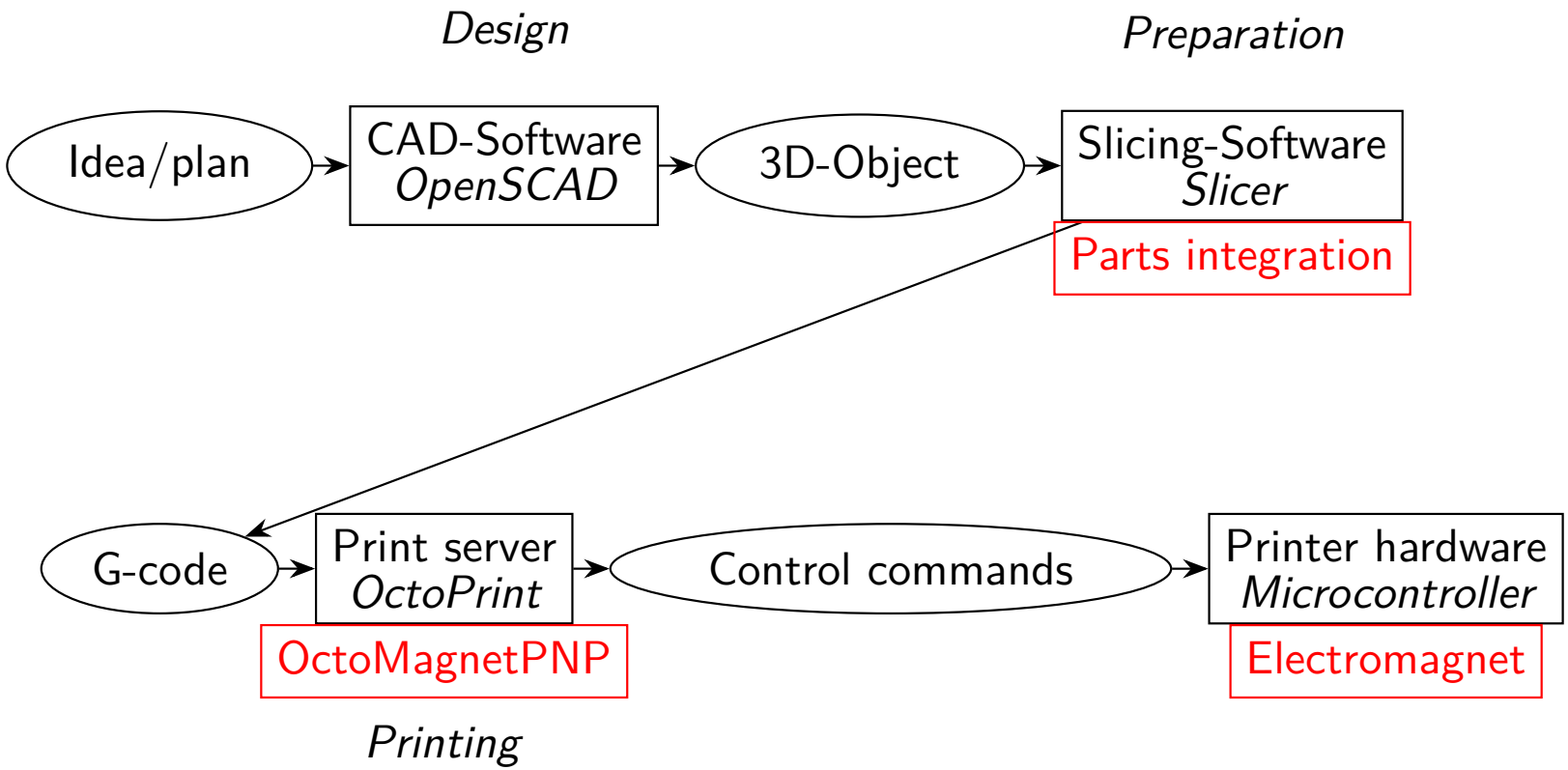


Figure: Printing workflow with additions

Part tray

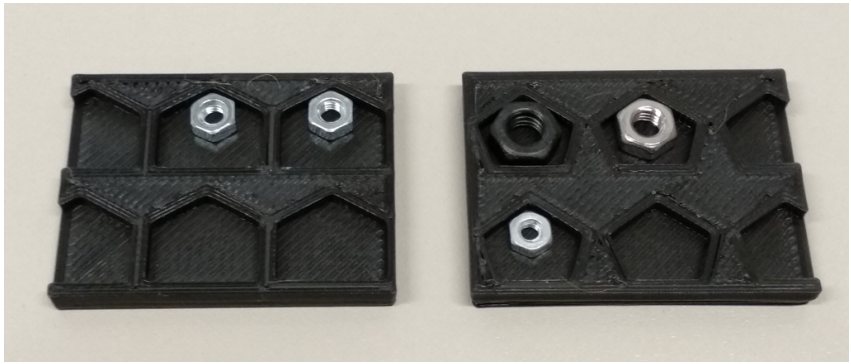
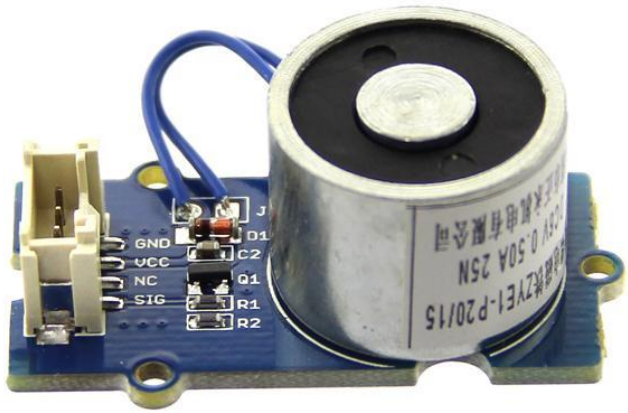


Figure: Different approaches

Figure: Working part tray with fixed size slots

Magnet



(a) Electromagnet [Stu]

- Lifting force 1 kg
- Operating voltage 5 V
- Controlled via output pin of the printer microcontroller board

Magnet mount

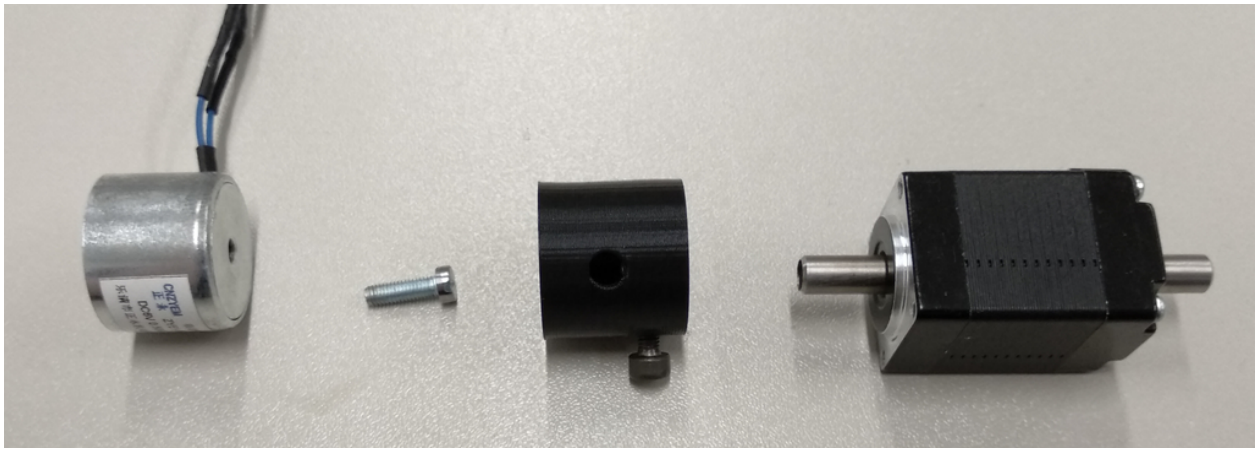


Figure: Electromagnet, connection part and stepper motor with hollow shaft

Magnet assembly

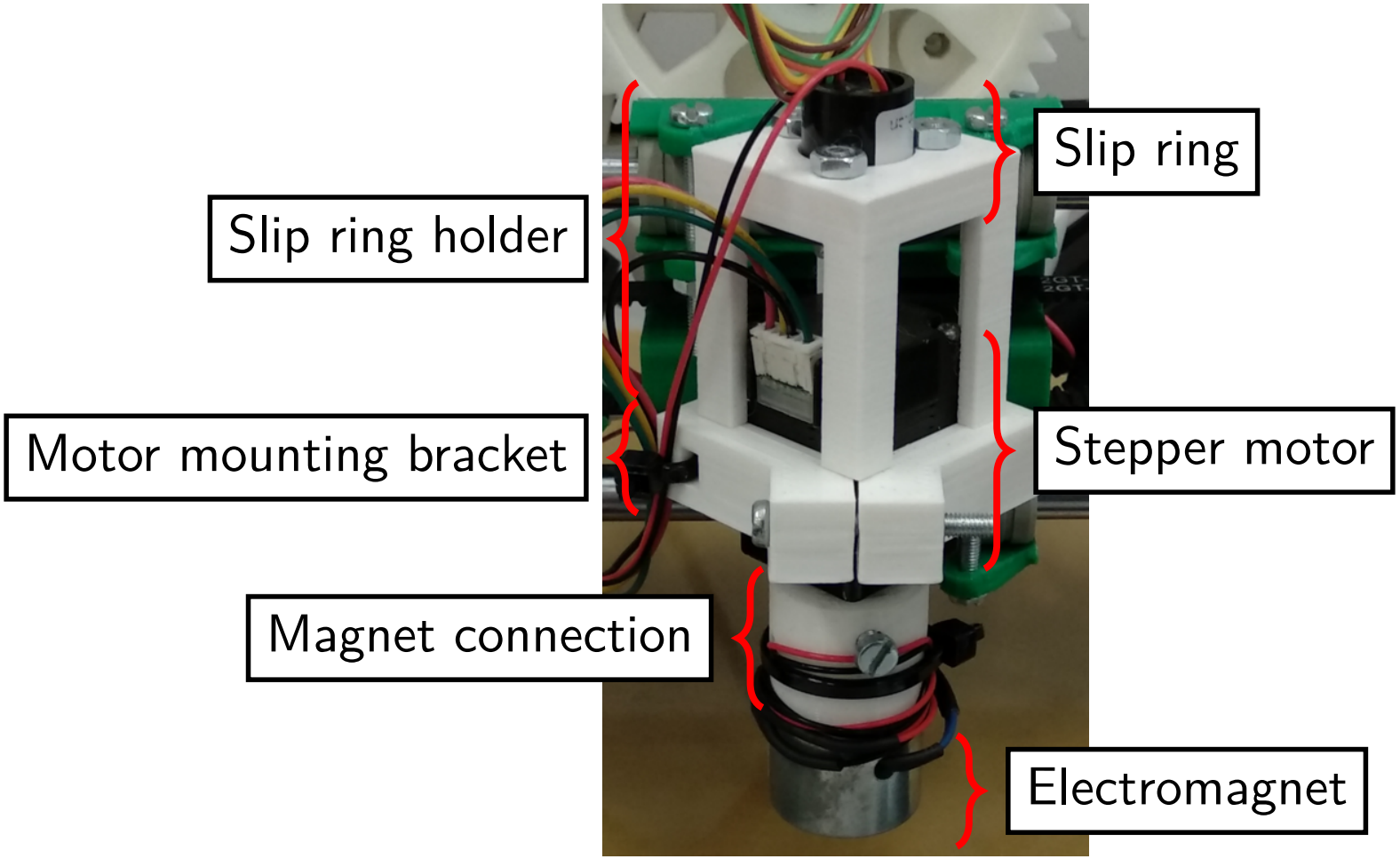


Figure: Electromagnet with stepper motor and mounting parts

Magnet control

- Stepper motor is connected to stepper motor driver
- Magnet is installed as second extruder
  $\rightarrow$ command to extrude by 1 unit rotates the magnet by 1 degree
- Output pin can be controlled via g-code

Printer with modifications installed

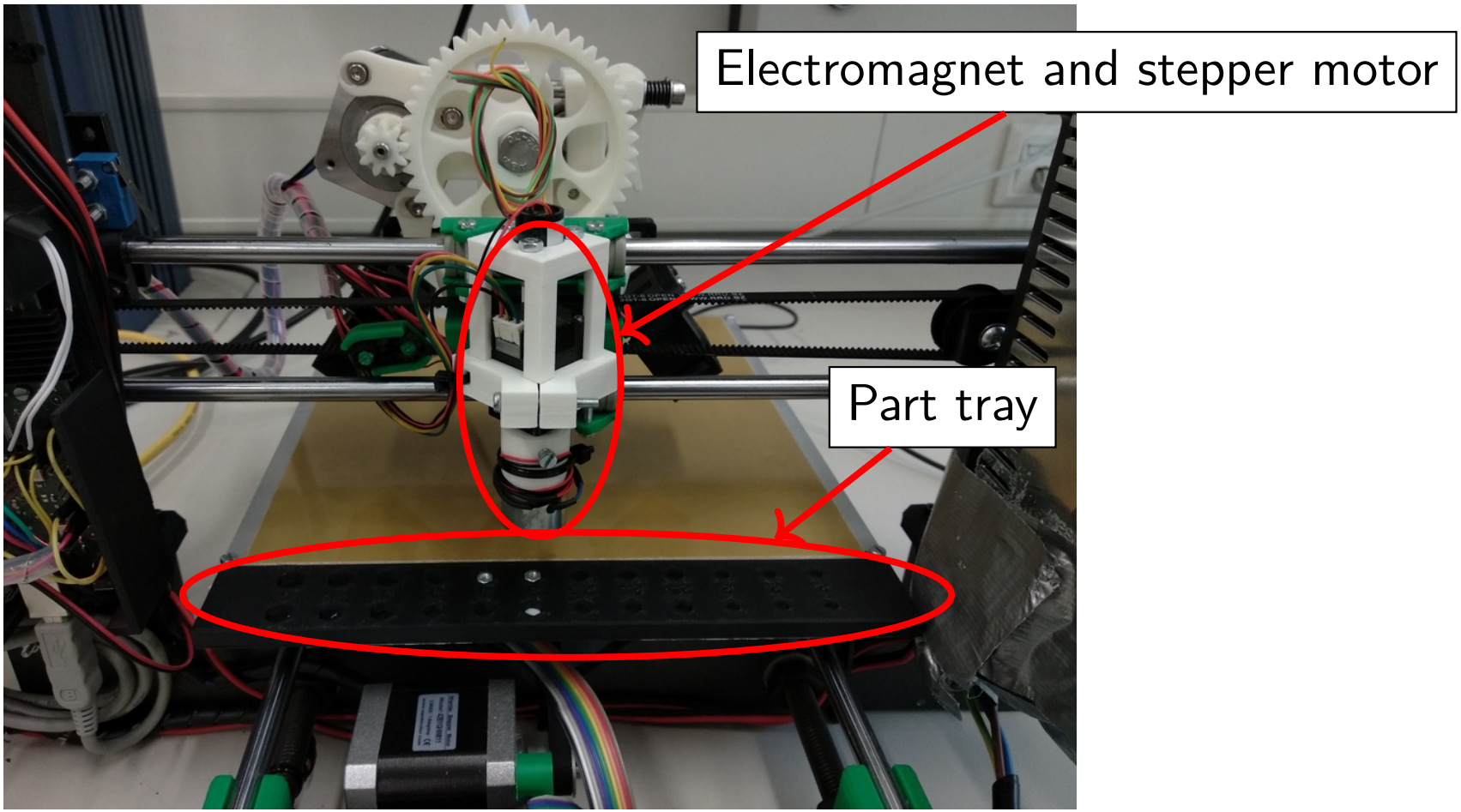


Figure: Installed electromagnet and part tray

Part tray and magnet

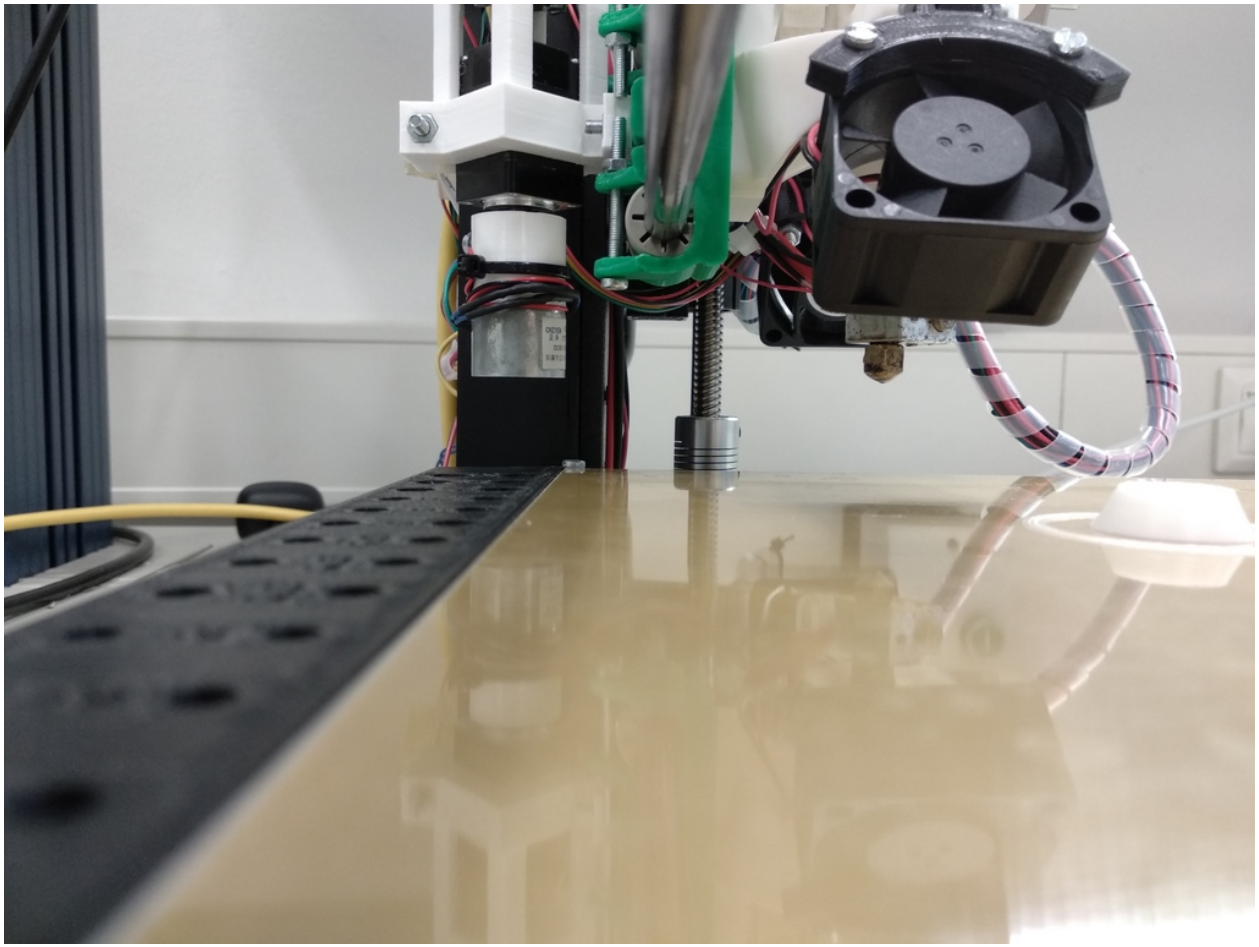


Figure: Installed modifications

- OctoPrint plugin
- Based on OctoPNP [Was15]
- Remove all image processing components
- Change part tray visualization
- Keeps track of calibration data
- Main functionality:
  - Organize part tray
  - Parse gcode for special part place command

```
M361 PX
```

Figure: Gcode command to place part with part id X

```
T1                      ; select tool 1 (magnet)
G1 X111.5 Y118.5        ; move to nut position in tray
G1 Z0                   ; move to z layer 0
G4 P1                   ; wait for action to be finished
M42 P48 S255            ; turn magnet on
G1 Z10                  ; lift nut
G92 E0                  ; reset magnet rotation
G1 E30                  ; rotate magnet by 30 degrees
G1 Z13.9                ; lift part above placement height
G1 X97.293 Y95.276      ; move magnet to placement position
G1 Z3.9                 ; insert part at correct z height
G4 P500                 ; wait 0.5s
M42 P48 S0              ; turn magnet off
G1 Z13.9                ; lift magnet
T0                      ; select tool 0 (extruder)
```

OctoMagnetPNP Calibration

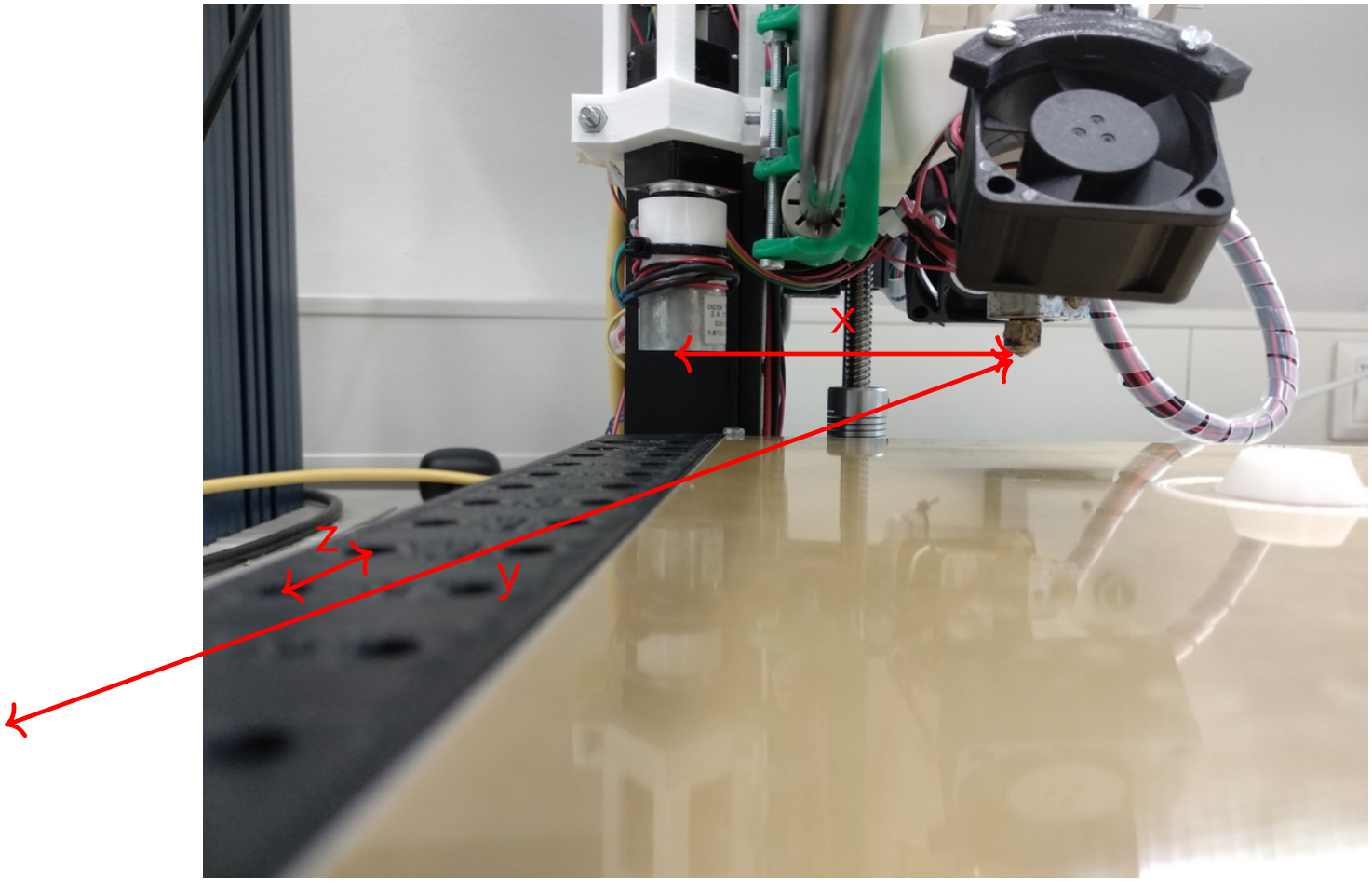


Figure: Measurments for calibration

Figure: Part tray in OctoMagnetPNP

```
[
  {
    "thread_size": "2",
    "nut": "hexnut",
    "slot_orientation" : "flat"
  },
  {
    "thread_size": "2.5",
    "nut": "hexnut",
    "slot_orientation" : "flat"
  },
  {
    "thread_size": "3",
    "nut": "hexnut",
    "slot_orientation" : "flat"
  },
  ...
]
```

"Slic3r is the tool you need to convert a 3D model into printing instructions for your 3D printer. It cuts the model into horizontal slices (layers), generates toolpaths to fill them and calculates the amount of material to be extruded."[Sli]

- Open source
- Already extended to work with electronics

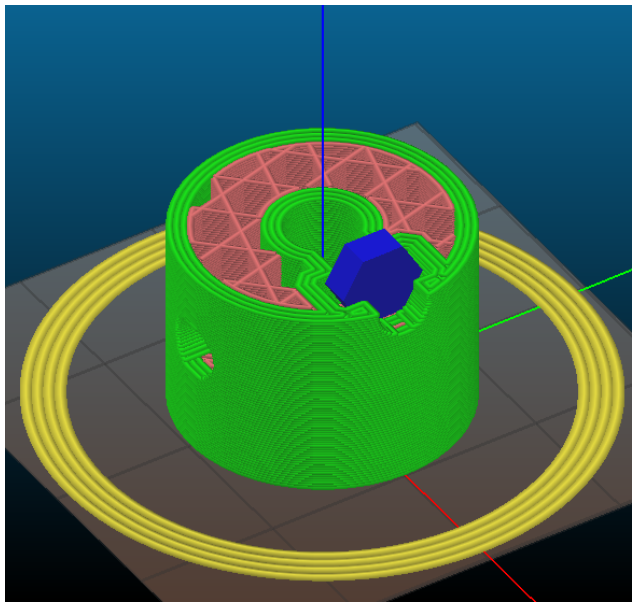
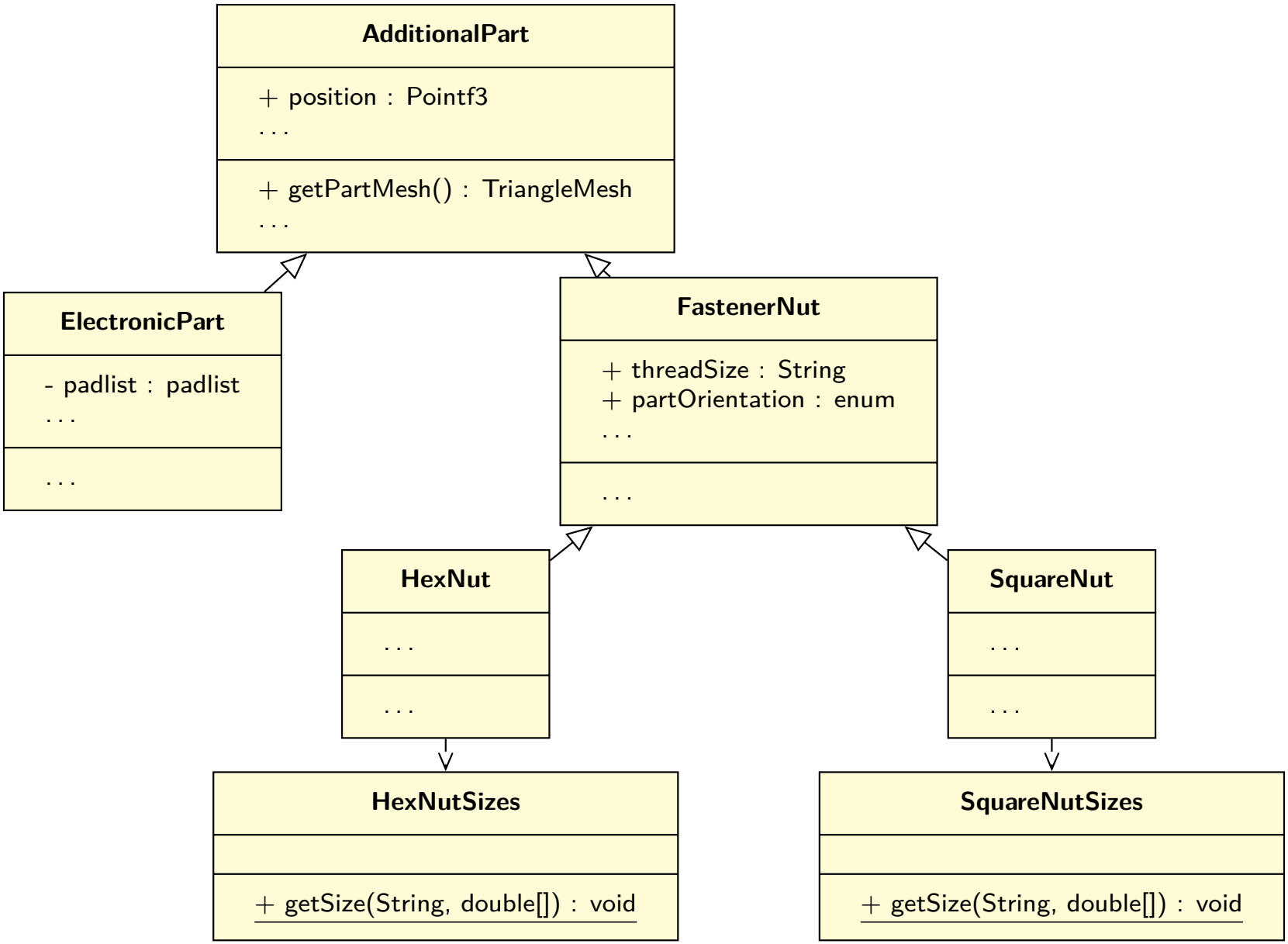


Figure: Sliced object in slic3r

Slic3r class hierarchy extract



- `getPartMesh`: returns 3d model of the current part
- `getHullPolygon`: returns a slice of the current part as polygon

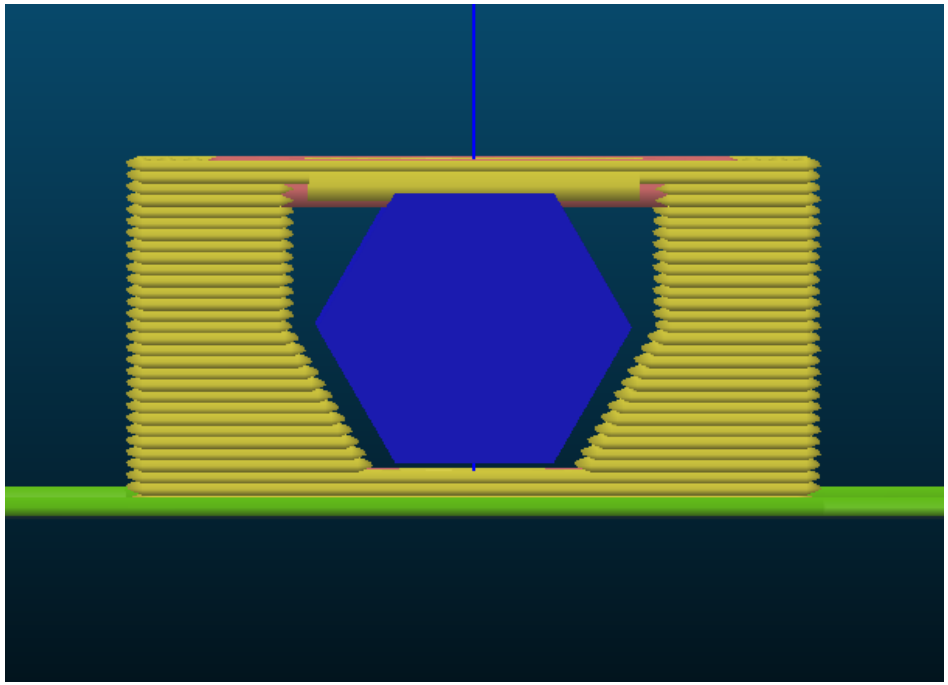
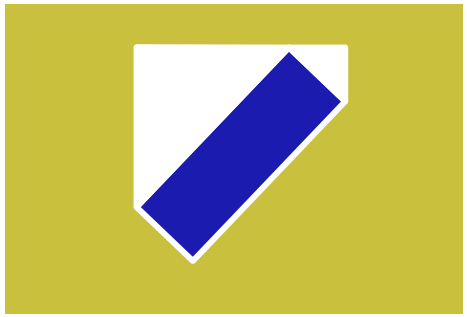


Figure: Side view sliced object with hex nut

Slic3r nut orientation

(a) Flat nut position



(b) Angled nut position

Slic3r gui

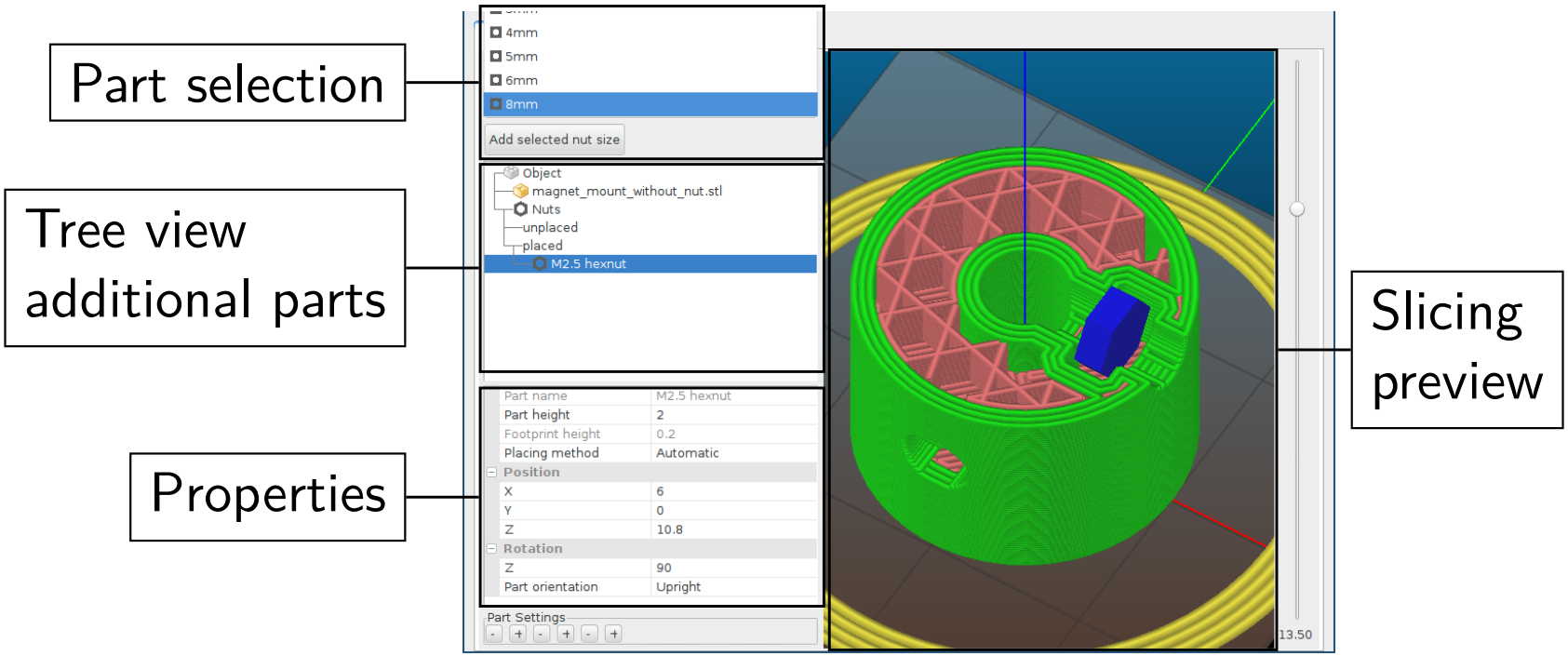


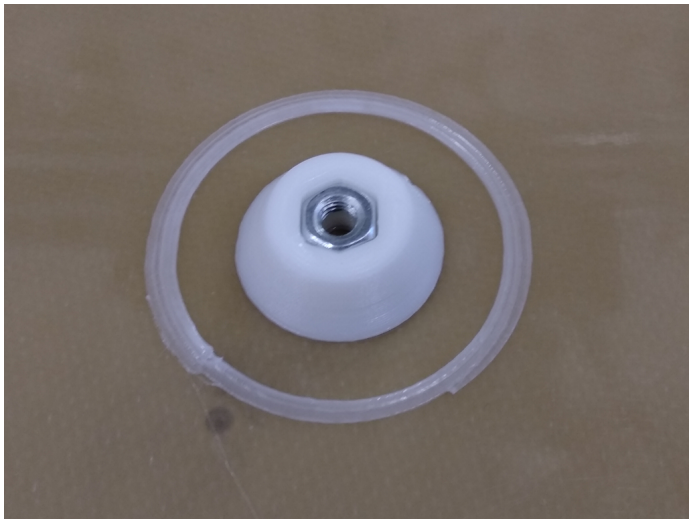
Figure: Slic3r graphical user interface

Slic3r exported gcode

```
...
<object name="roboter_stud.stl">
  <part id="1" name="M4 hexnut">
    <type identifier="hexnut" thread_size="4"/>
    <position box="1"/>
    <size height="3.2"/>
    <shape>
      <point x="-3.83" y="-3.5"/>
      <point x="-3.83" y="3.5"/>
      <point x="3.83" y="3.5"/>
      <point x="3.83" y="-3.5"/>
    </shape>
    <destination x="100" y="97.5" z="3"/>
    <orientation orientation="Flat"/>
    <rotation z="30"/>
  </part>
</object>
...
```

Figure: Embedded part information inside exported gcode

(a) Current stud (left), new stud (right)



(b) Cut of the new stud

Disadvantages

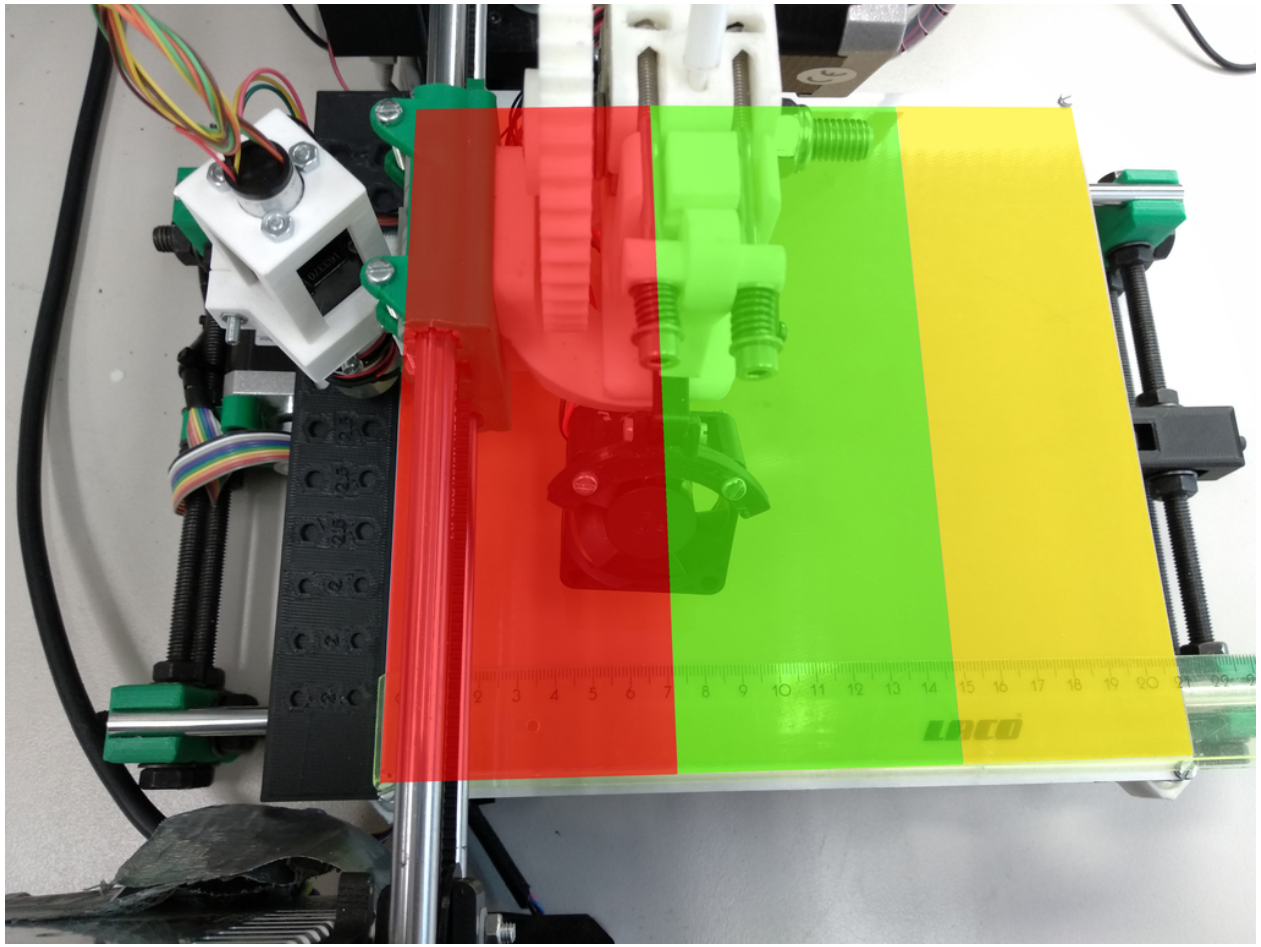


Figure: Usable print bed space (green)

Outlook

- Improve calibration method
- Integrate other parts
- Implement insertion of angled parts
- Improve printing after insertion

Thank you

Thank you for your attention.

References

[Cor15] Panasonic Corporation. *NPM Series*. 2015. URL: http://www.panasonicfa.com/sites/default/files/pdfs/npm_series_for_web.pdf (visited on 12/10/2019).

[Sli] Slicer. *Slic3r Open source 3D printing toolbox*. URL: https://slic3r.org/ (visited on 12/10/2019).

[Stu] Seeed Studio. *Grove-Electromagnet*. URL: https://raw.githubusercontent.com/SeeedDocument/Grove-Electromagnet/master/img/Grove_Electromagnet_02.jpg (visited on 01/19/2020).

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[Was] Florens Wasserfall. *Conductive Printing Project*. URL: https://tams.informatik.uni-hamburg.de/research/3d-printing/conductive_printing/ (visited on 01/19/2020).

[Was15] Florens Wasserfall. *OctoPrint plugin for camera based pick 'n place control*. 2015. URL: https://github.com/platsch/OctoPNP (visited on 12/10/2019).