Camera-based PCB Analysis for Solder Paste Dispensing

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Seminar: Image Processing and Content Analysis
Semester: Winter 2014/15

Institute of Imaging & Computer Vision (LfB)
RWTH Aachen University

Outline

- Motivation
- Objective
- Workflow
- Implementation
  - Software
  - Hardware
- Results
- Future

Motivation

- **All-in-one** machine for fabrication of PCBs for **small batches** & **prototypes**
- SMD components **are har**
- Cheap and fast **prototy**
- Reuse existing **3DP** ha
  - Save work space
  - Allow reuse of existing ma

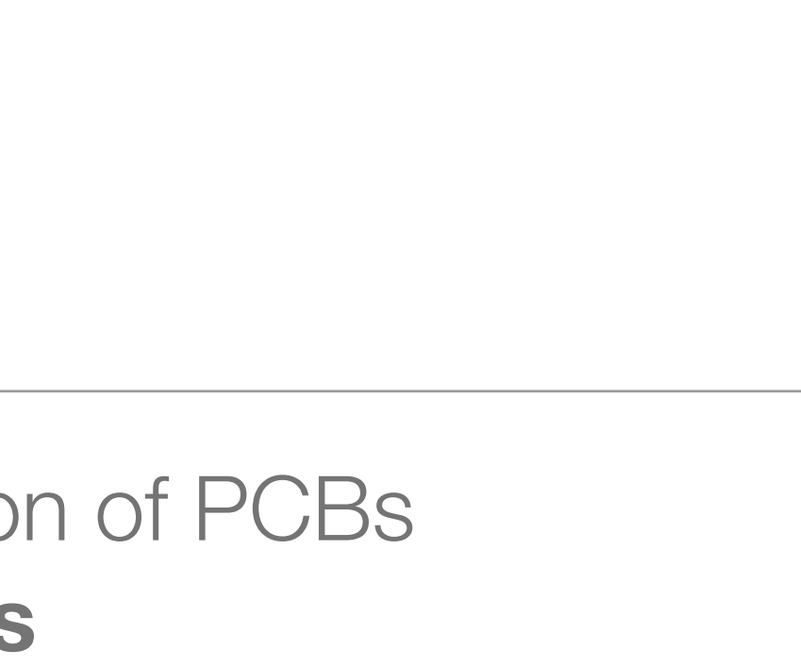
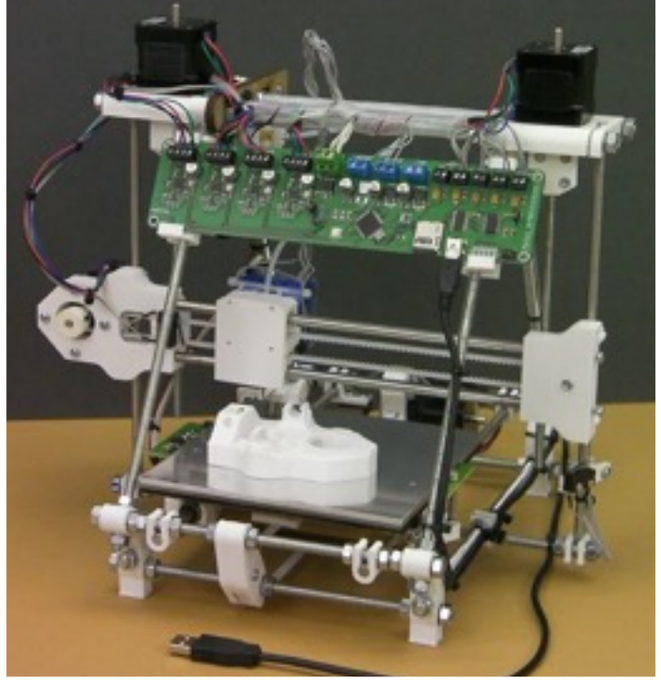


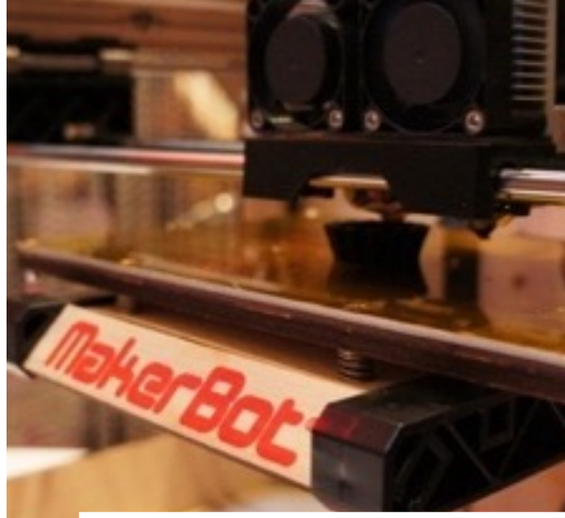
Figure 1: 0805 sized Resistor

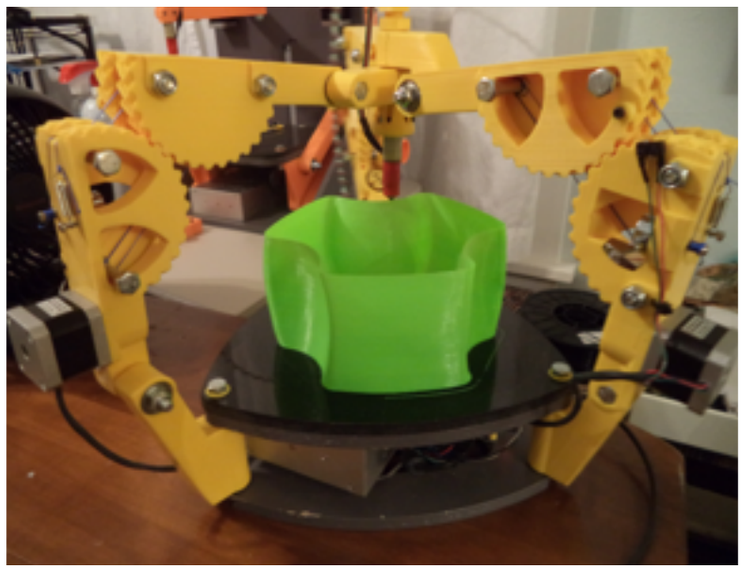
Figure 2: Solder Pad

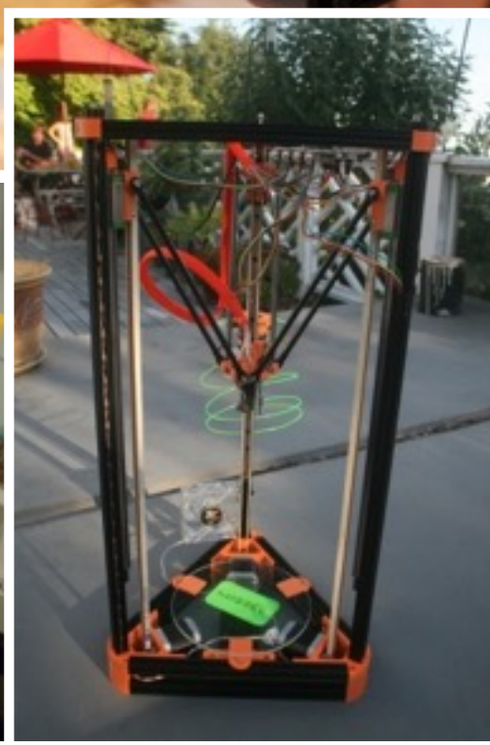
RepRap Project

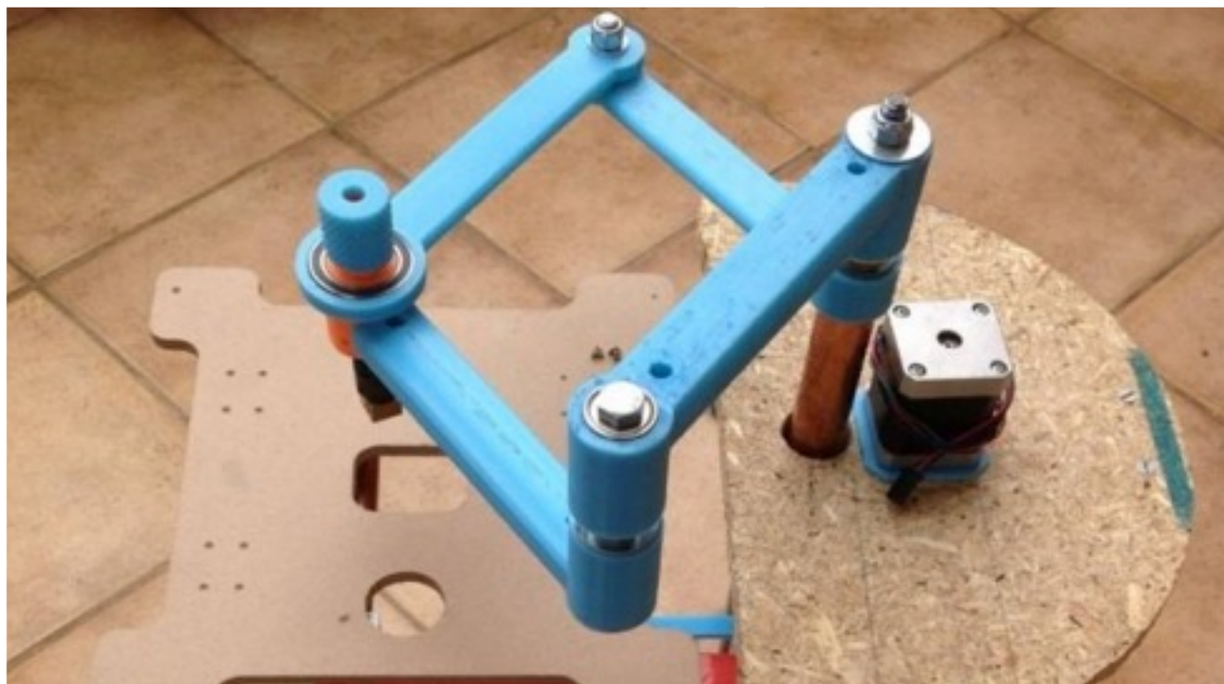
- Develops self-replicating 3d printers for DIY
- Open Source / Community effort
- Started 2005 by Adrian Bowyer at Bath University (UK)
- Print plastic, clay, chocolate, conductive materials etc.
- Provides Delta Robot platform with controller and firmware





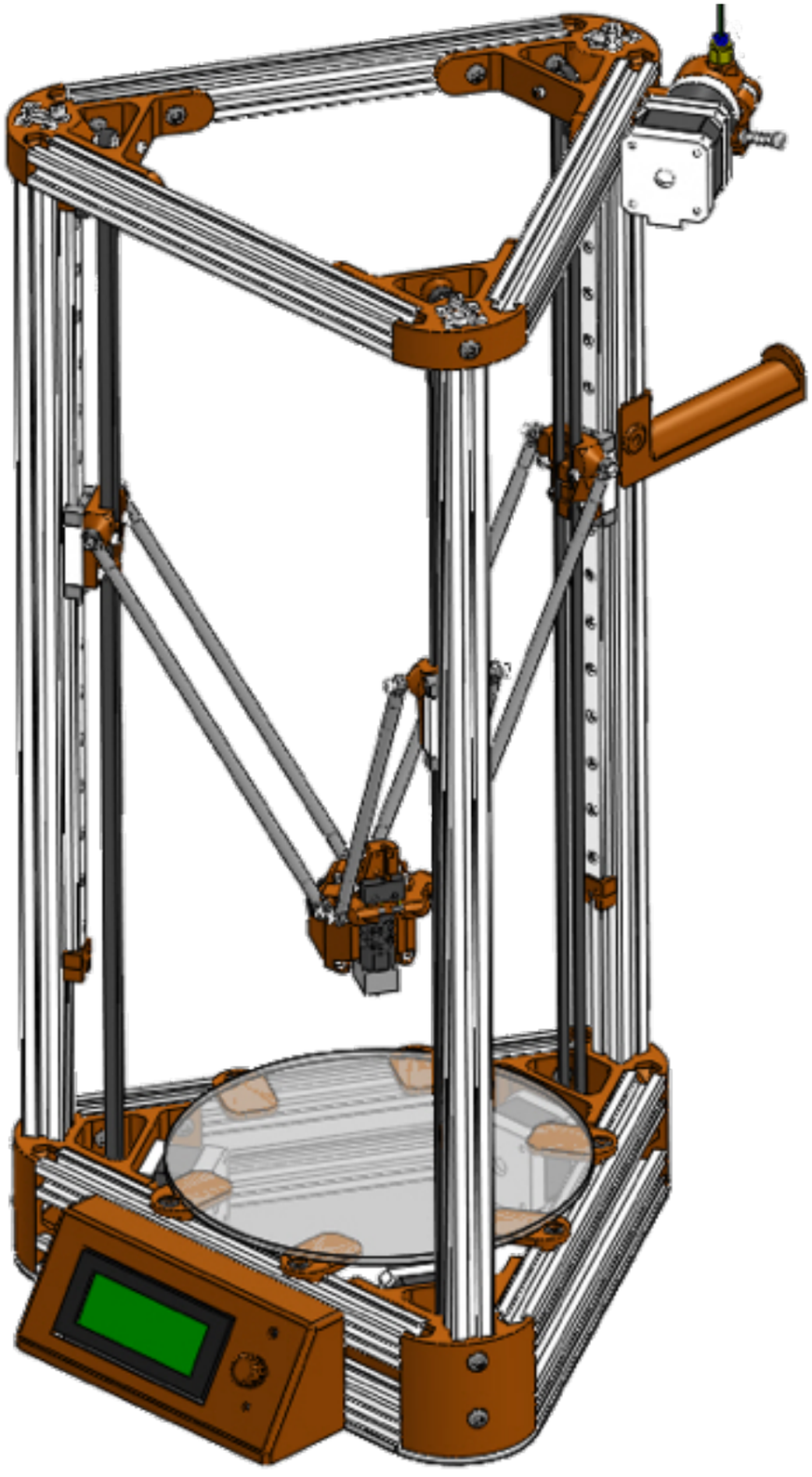




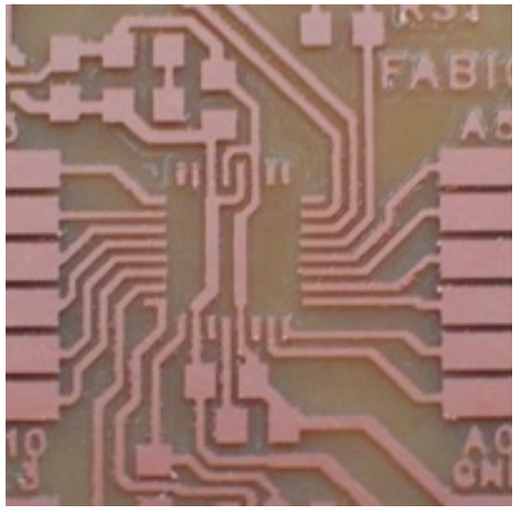


Mini Kossel

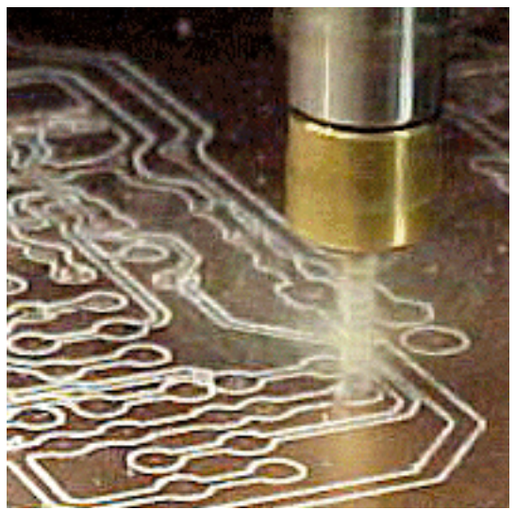
- Parallel kinematic 3D printer
- Stepper Motors: 3 DOG
- Resolution: 100 steps/mm with 0.03 mm repeatability
- Build volume:
  20 cm x 18 cm Ø cylindrical
- Automatic calibration: Bed Leveling
- Open-loop controller
- Interprets G-Code



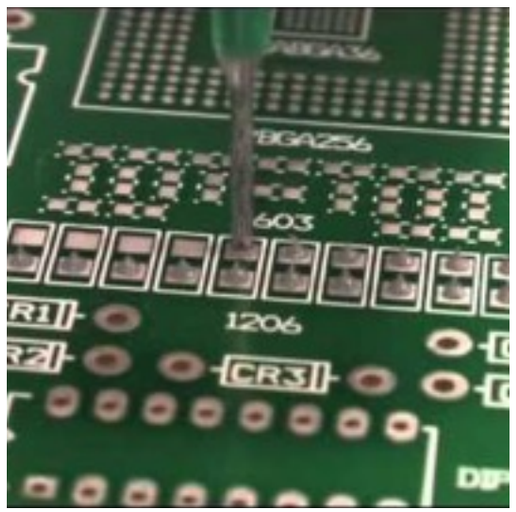
Workflow: Overview



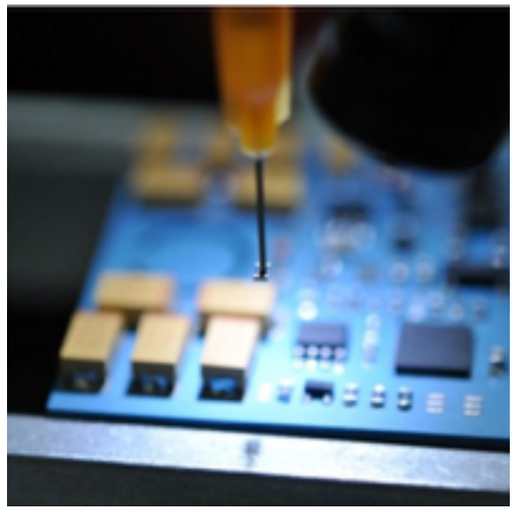
Milling / Plotting



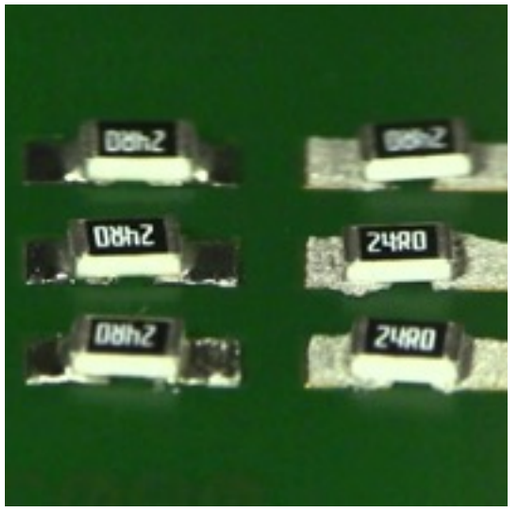
Drilling



Paste Dispensing



Pick-n-Place



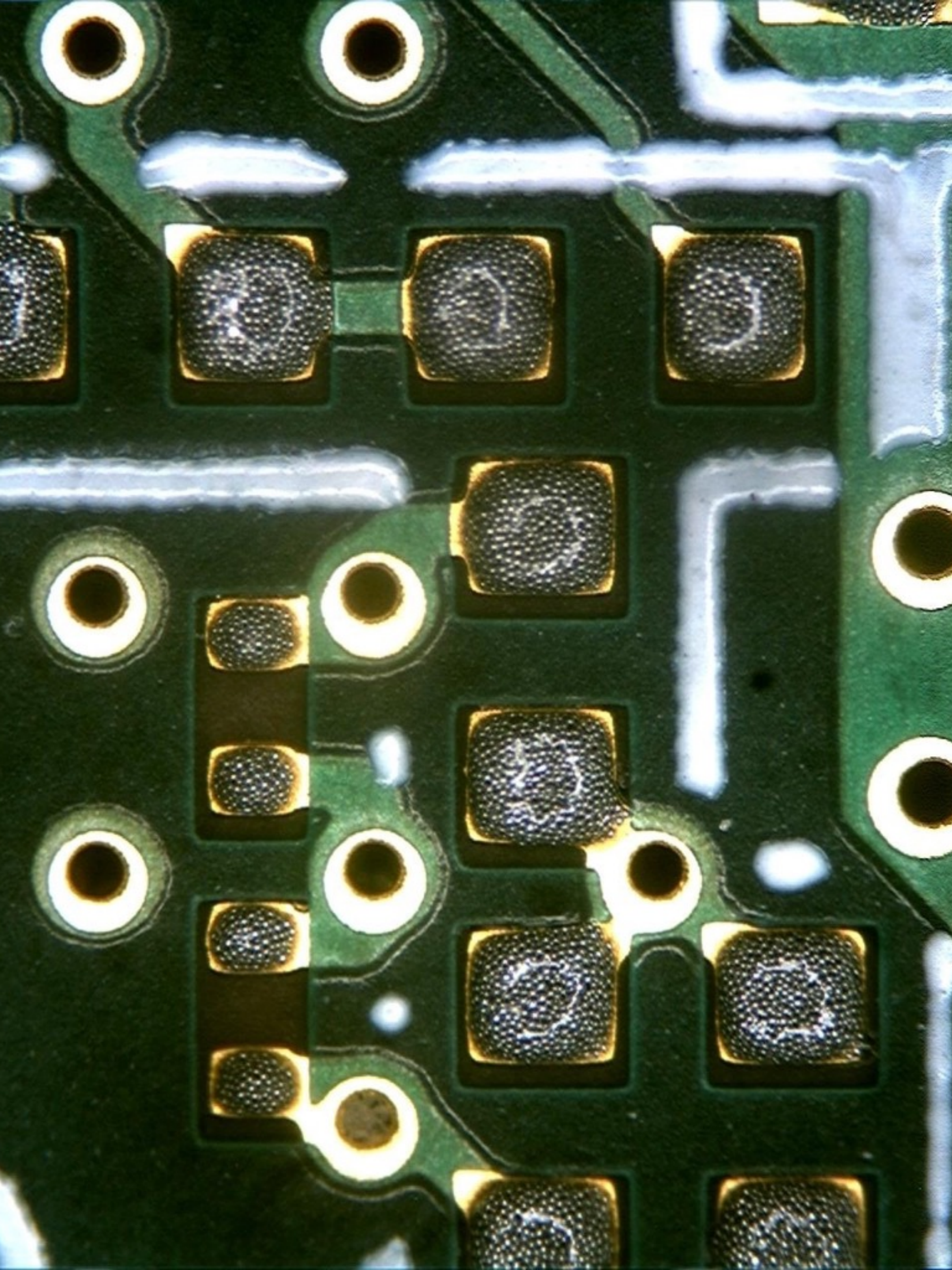
Reflow

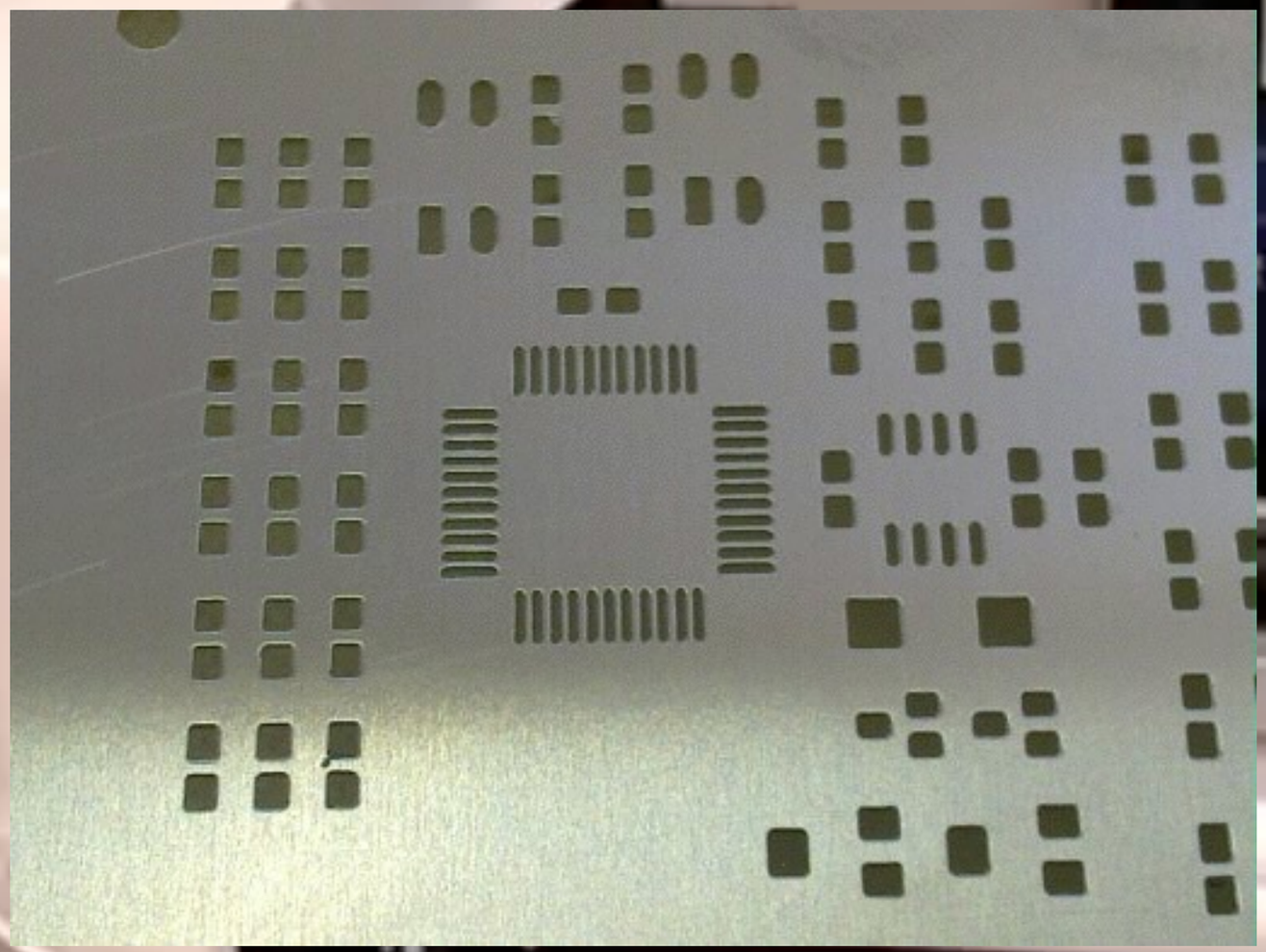
Objective

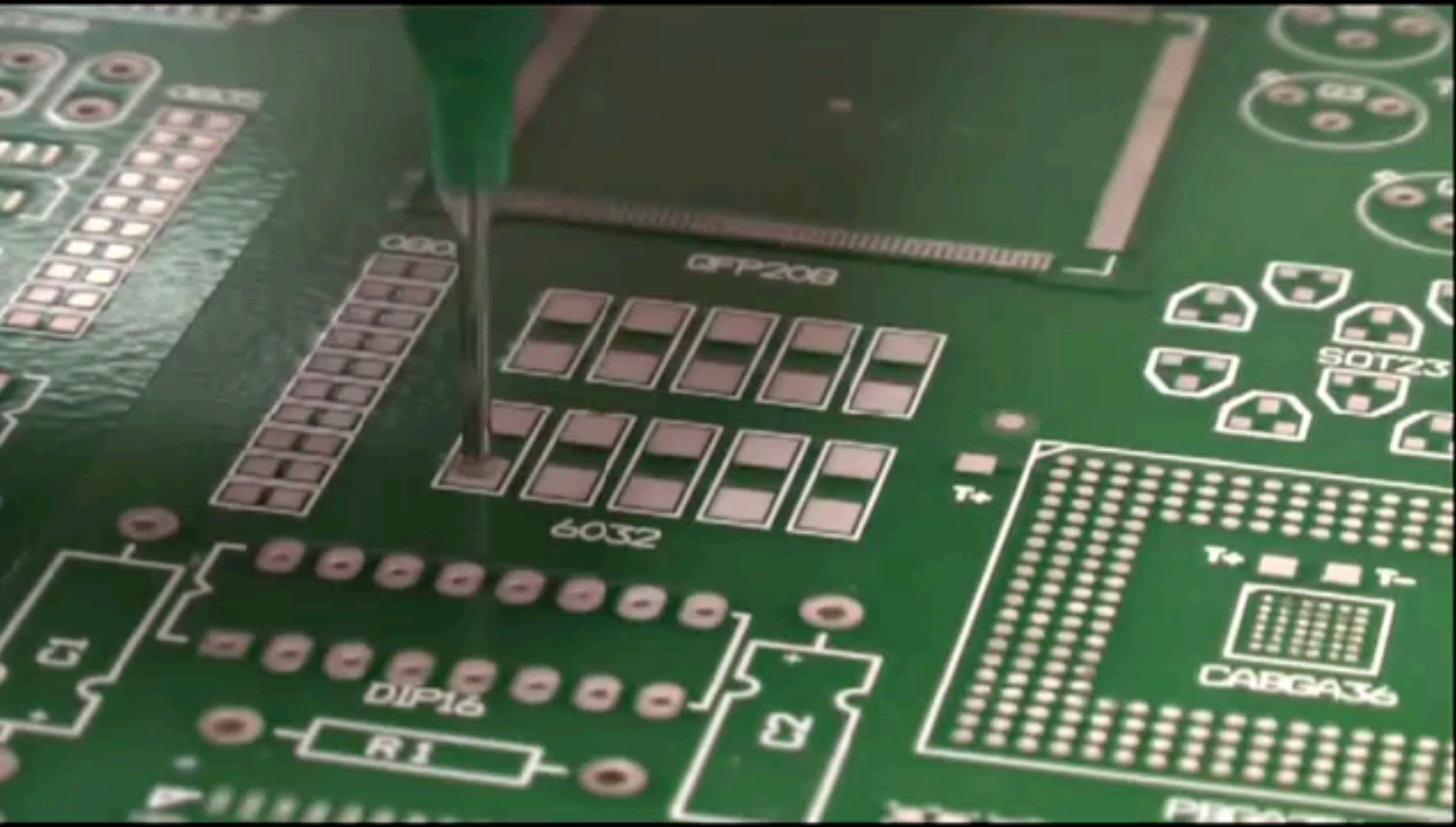
- Develop **workflow** & **tools** for solder paste dispensing
- Use commonly **available** & **cheap** tools for hobbyists / DIY
- **Automate** as much a possible by **CV**
  - Simple / **no reconfiguration** of machines
  - **No CAD** data required

⇒ Fundamentals for complex tasks

(Automated Pick-and-Place)



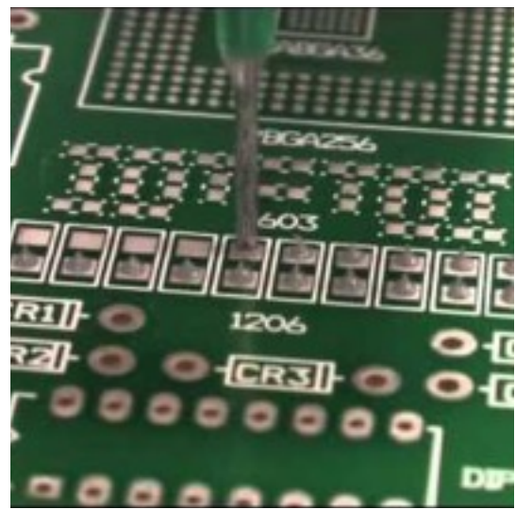



QFP208
SOT23
6032
DIP16
R1
CABGA36

Workflow: Overview

Milling / Plotting

Drilling

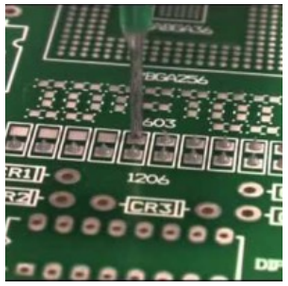


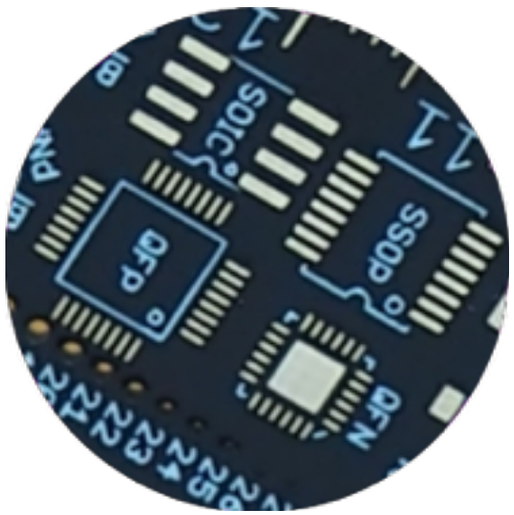
Paste Dispensing

Pick-n-Place

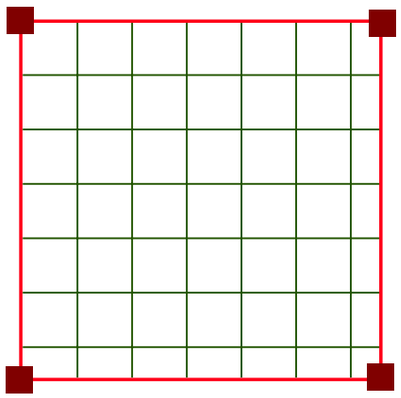
Reflow

Workflow: Paste Dispensing

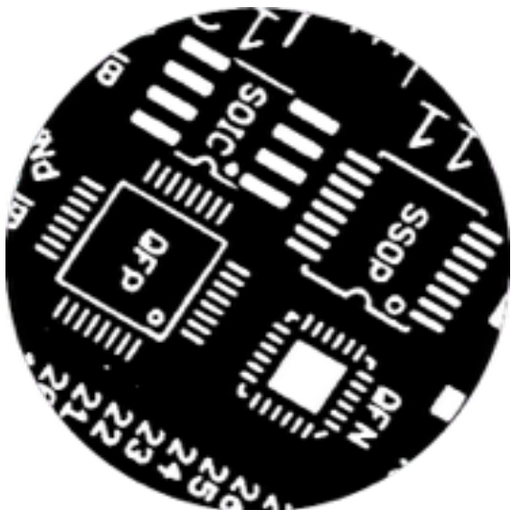




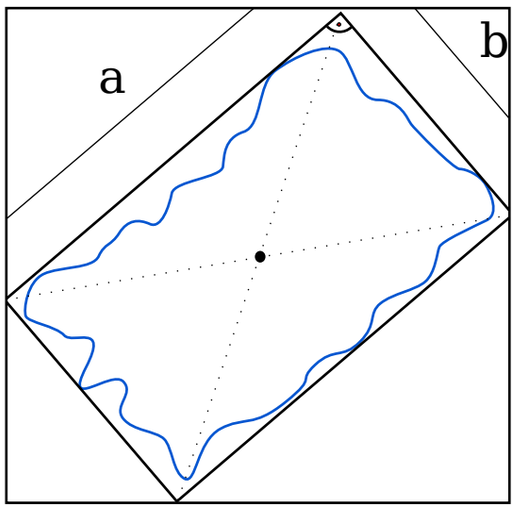
Imaging



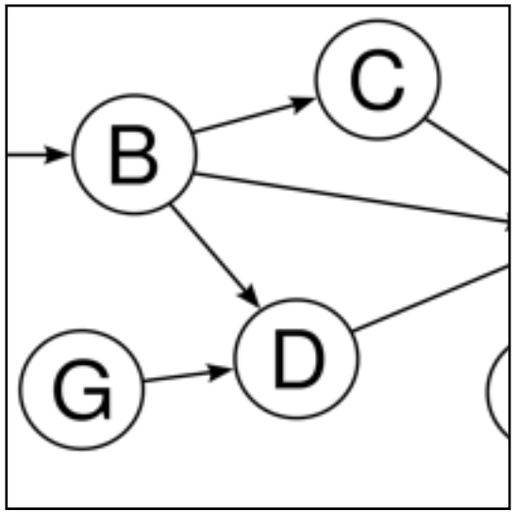
Undistortion



Segmentation



Pad Detection

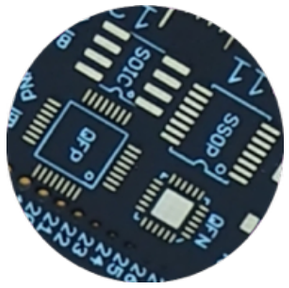


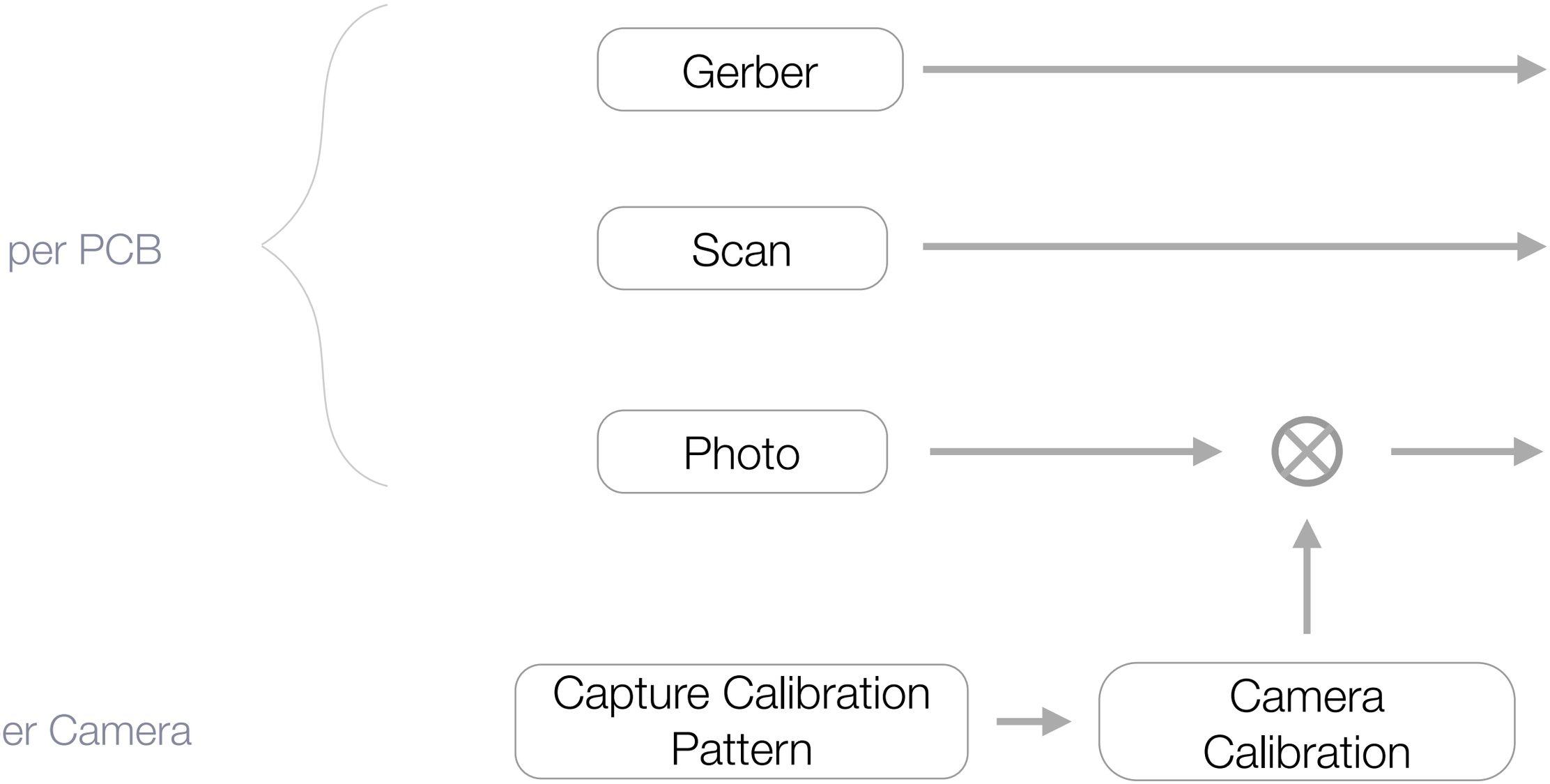
Path Planning

```
M204 S1000
G28
G29
G0 X10 Y-5
M112
```

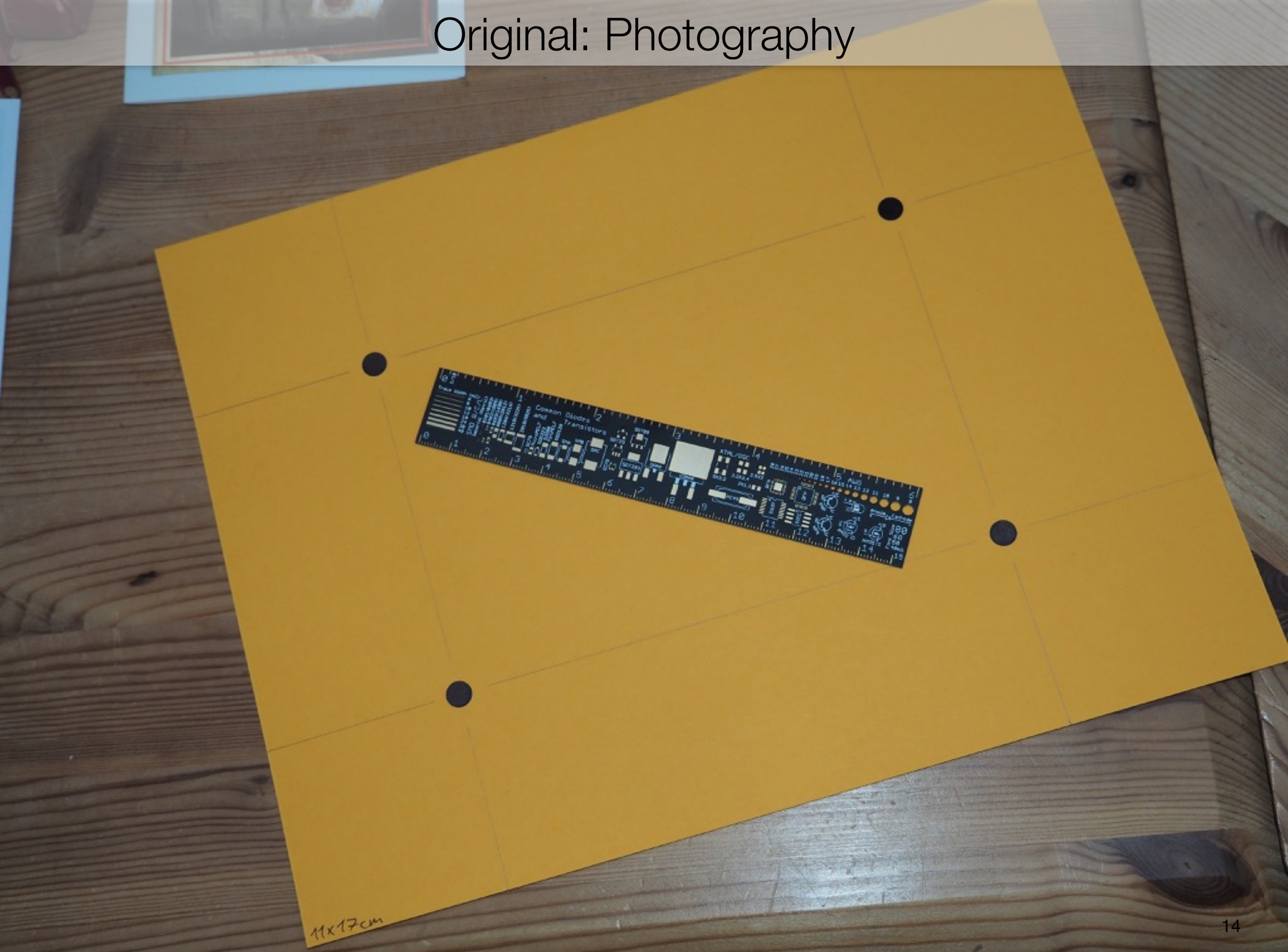
Printer Control

Workflow: Imaging

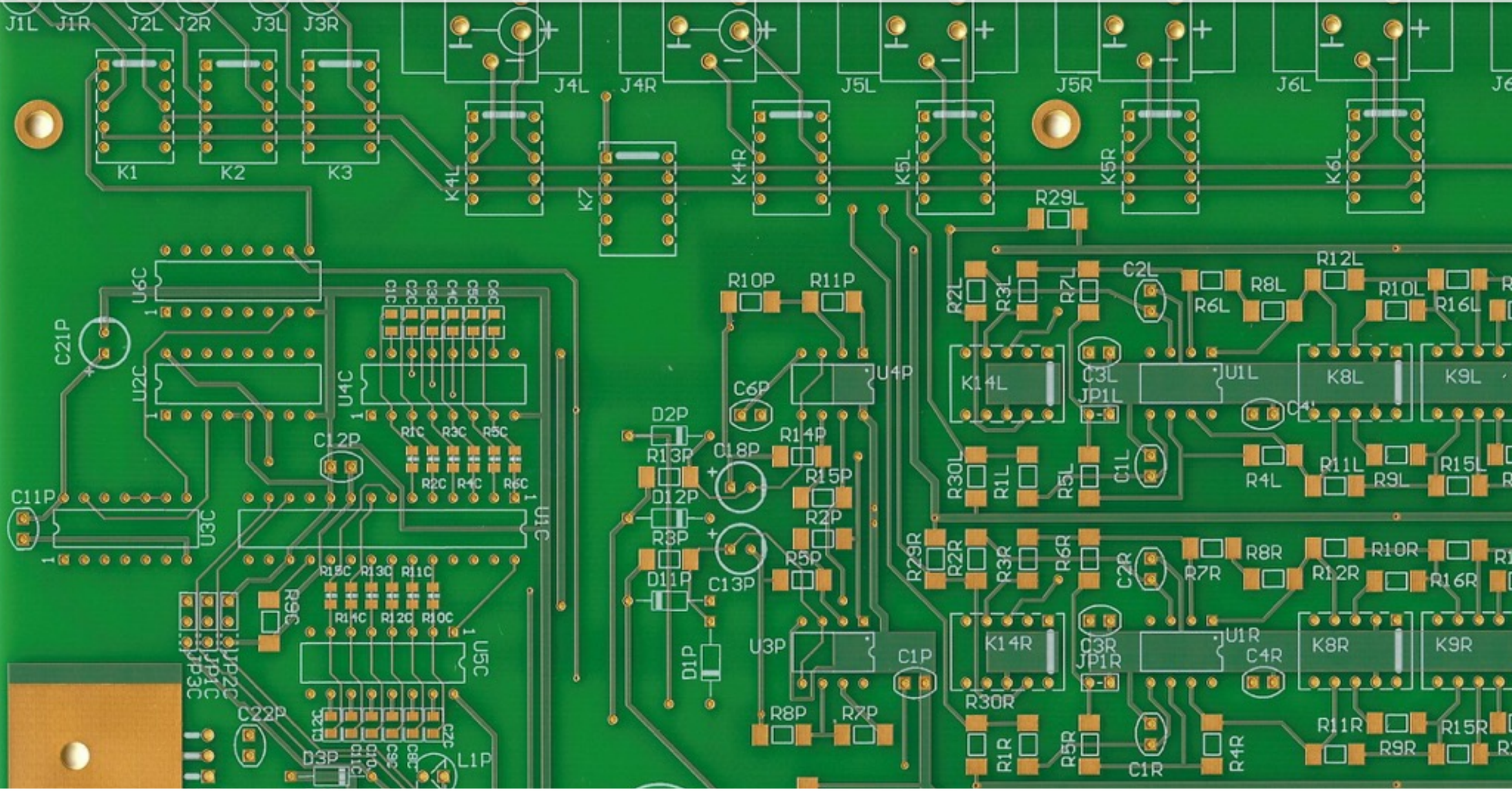


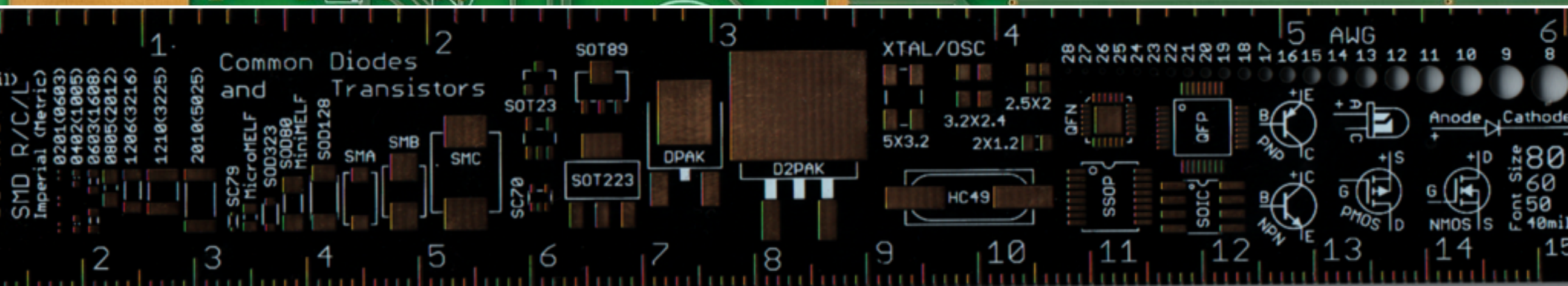


Original: Photography



Original: Flatbed scan





Original: Gerber mask

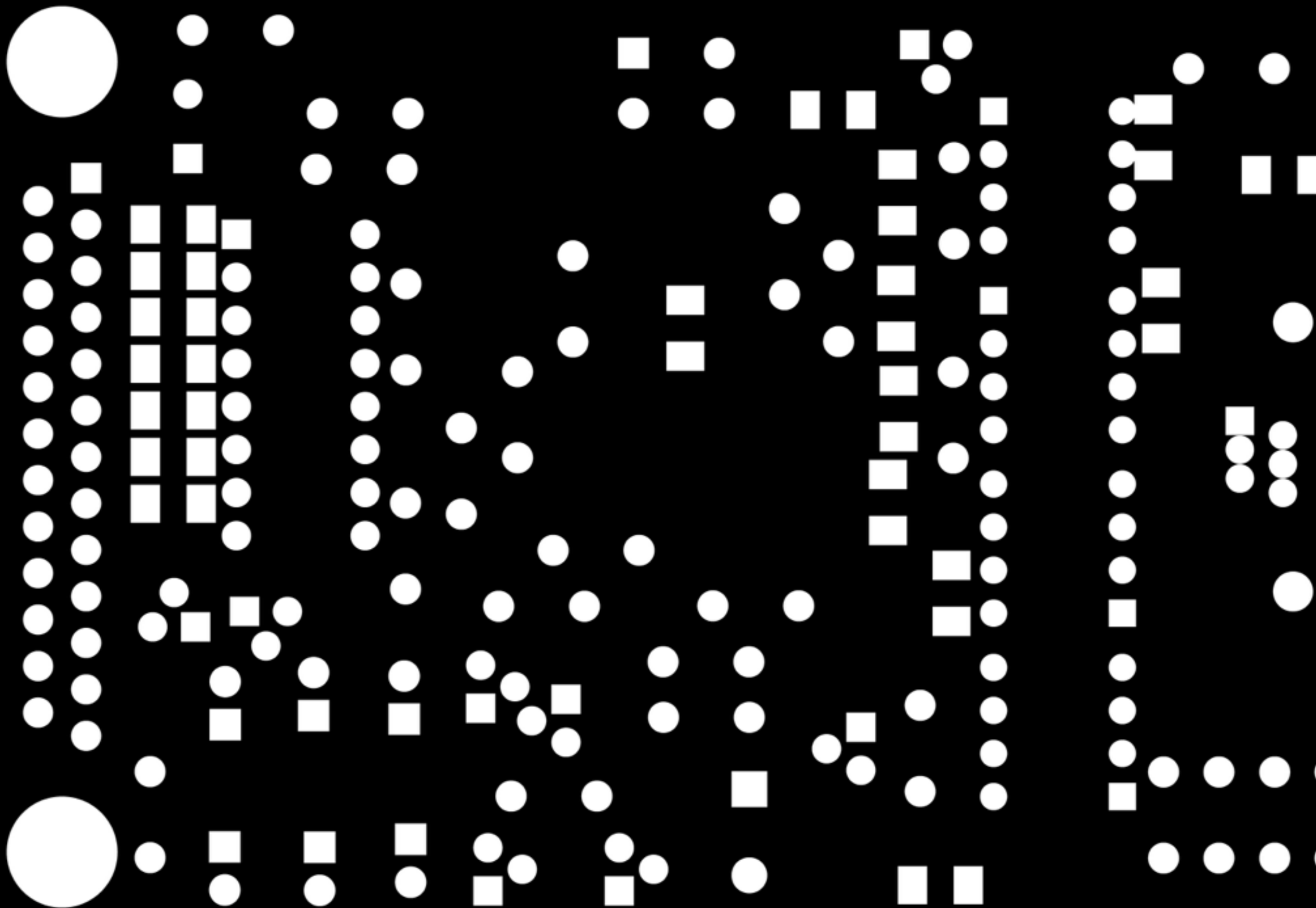
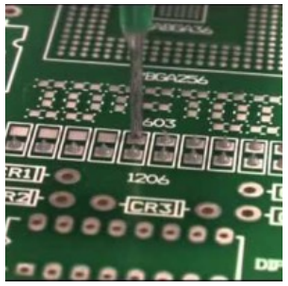
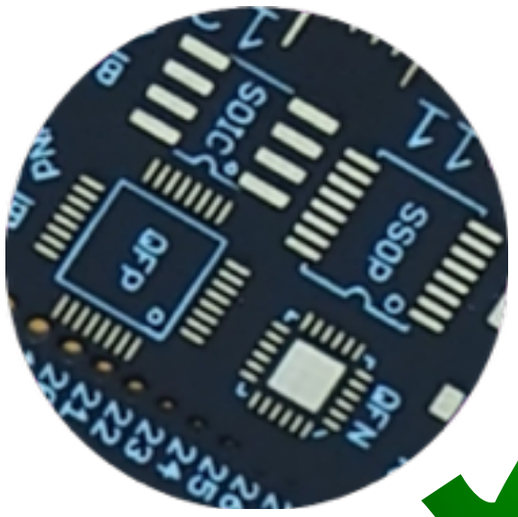


Image Sources

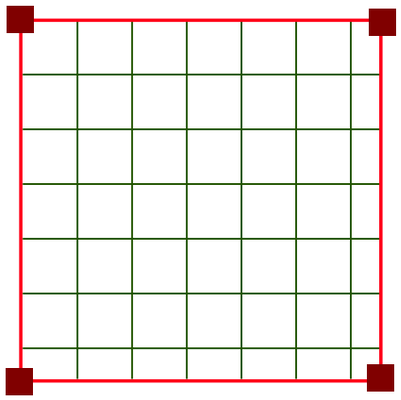
	Format	Resolution	Optics	Pro / Con
Webcam	Raster	1-3 MP	Manual focus	+ Cheap + Small - Distortion
Digital Camera	Raster	10-15 MP	Autofocus	- Expensive - (Distortion)
Flatbed Scanner	Raster	> 200 MP (2400 DPI)		+ No Perspective + Bad Lighting
Gerber CAD	Vector	∞	–	+ Layer seperation + Industry Standard

Workflow: Paste Dispensing



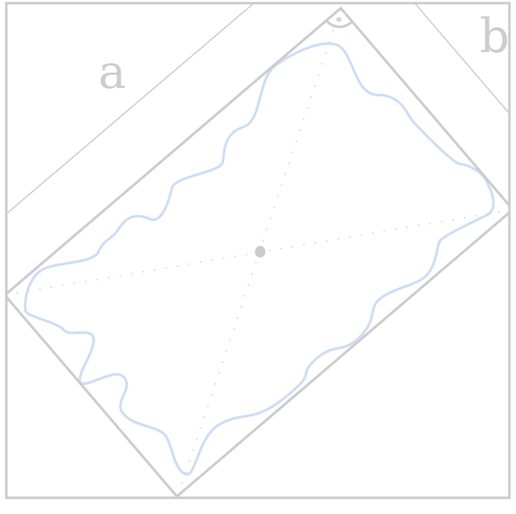


Imaging

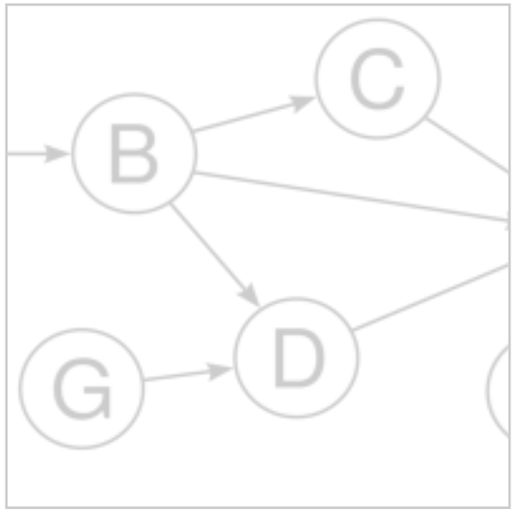


Undistortion

Segmentation



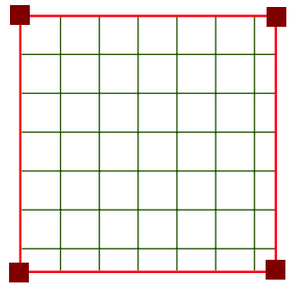
Pad Detection



Path Planning

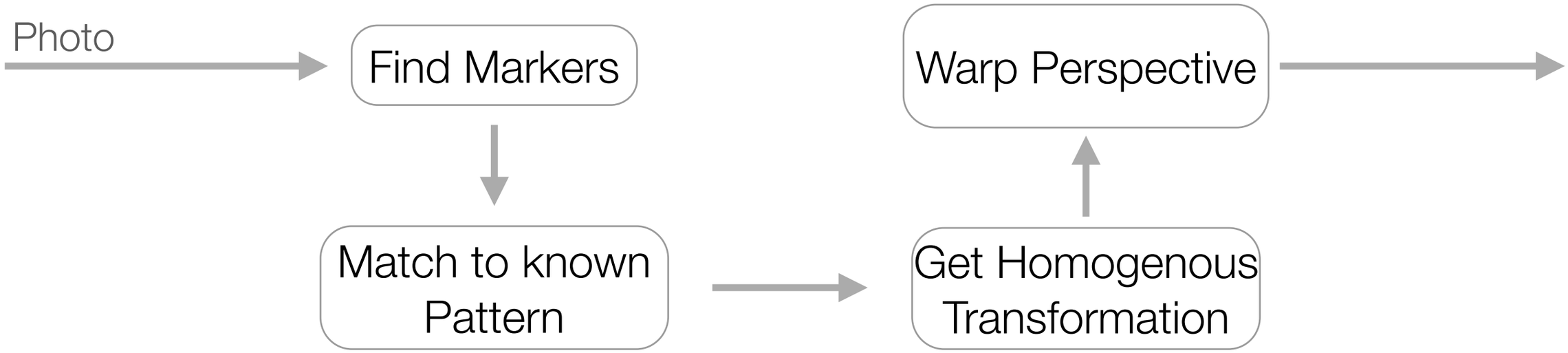
Printer Control

Workflow: Perspective Correction

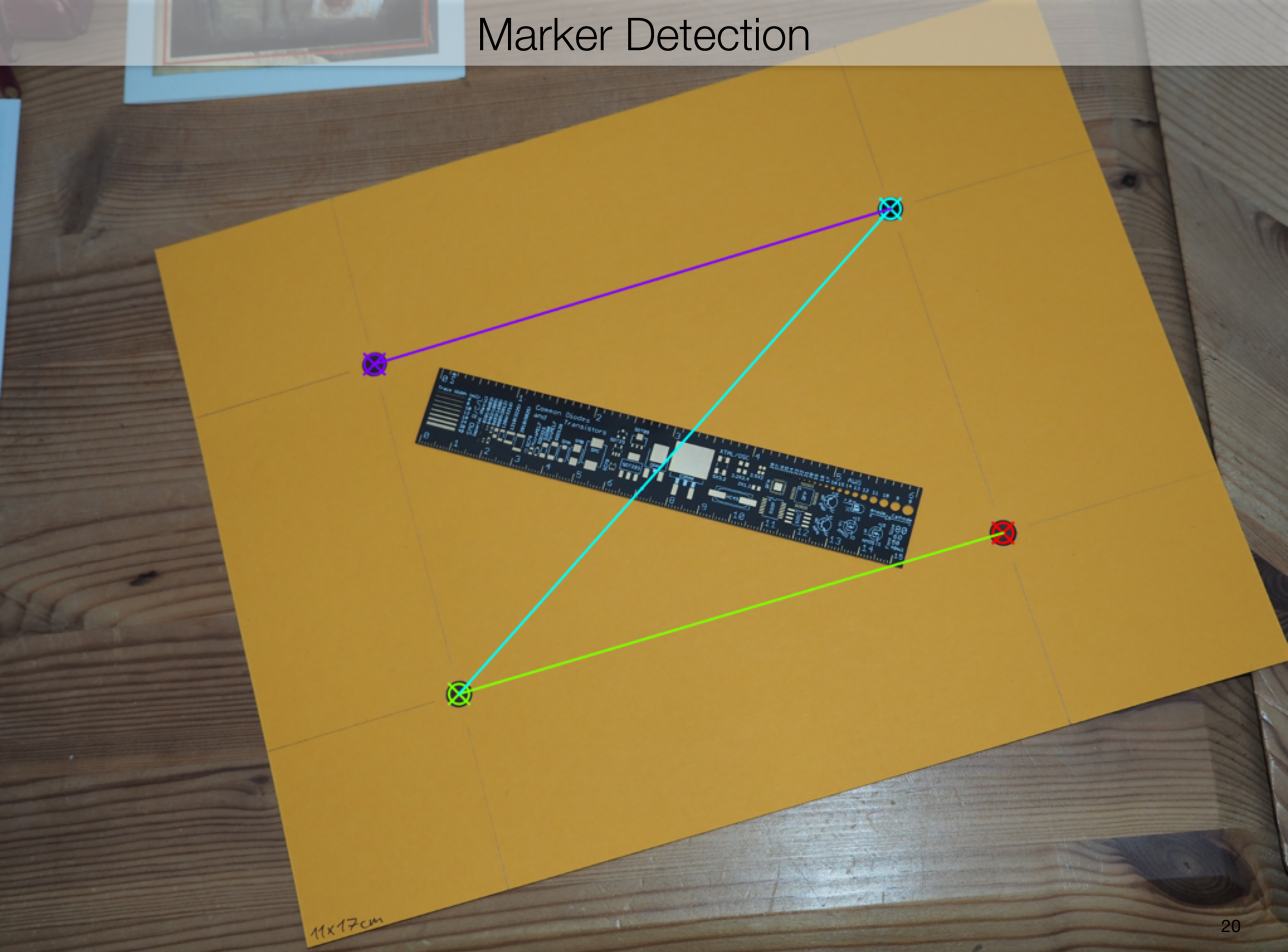


Gerber

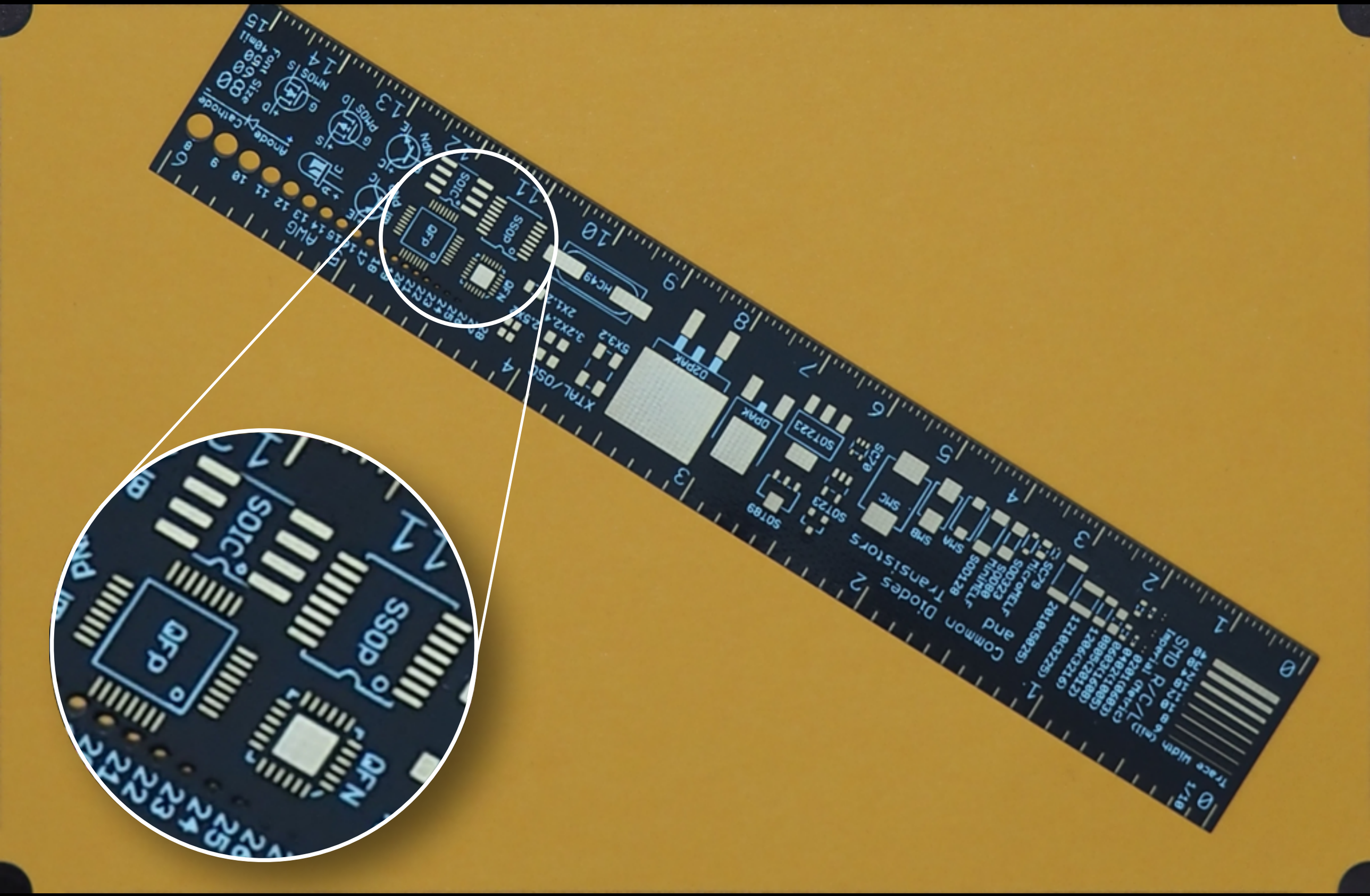
Scan



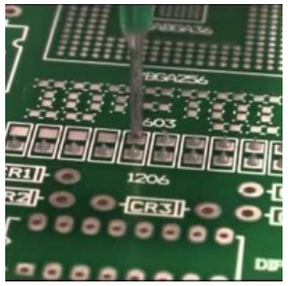
Marker Detection

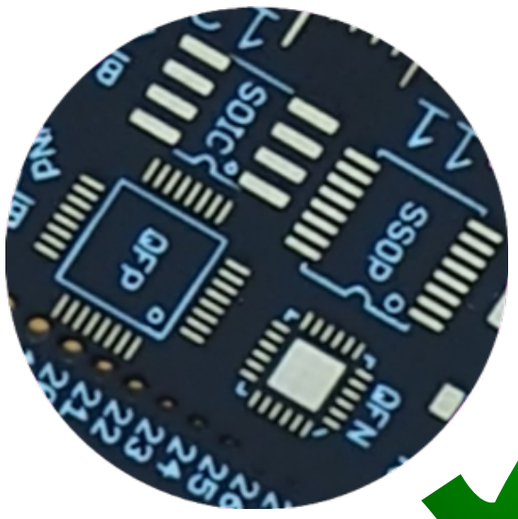


Perspective Warping

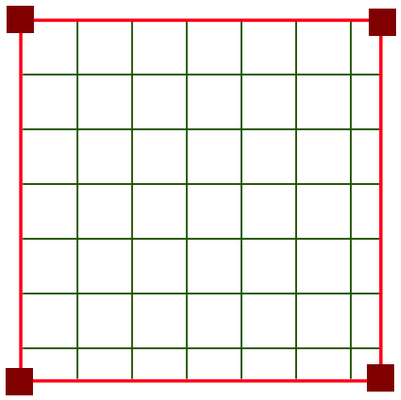


Workflow: Paste Dispensing

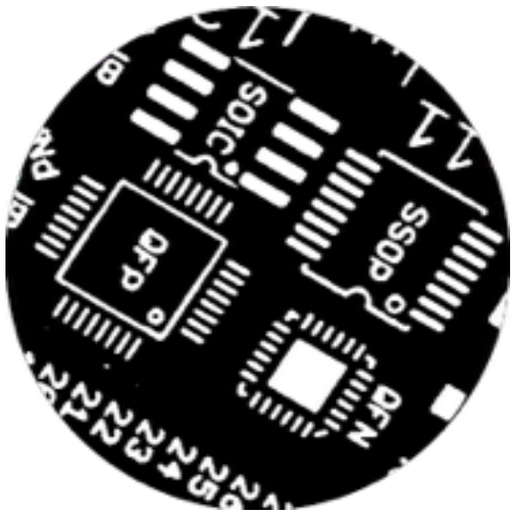




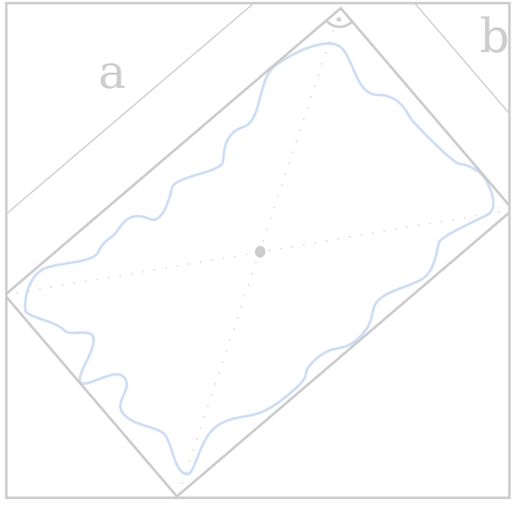
Imaging



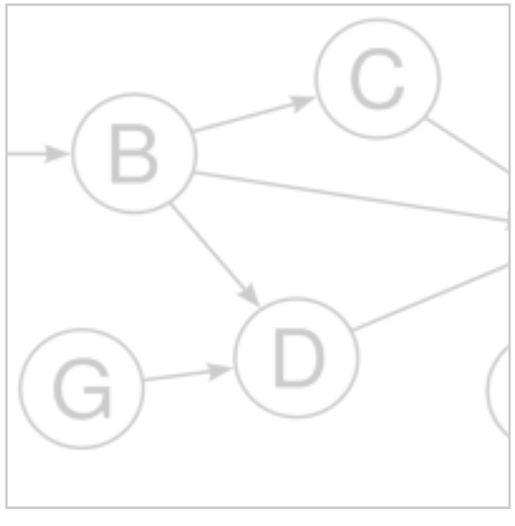
Undistortion



Segmentation



Pad Detection

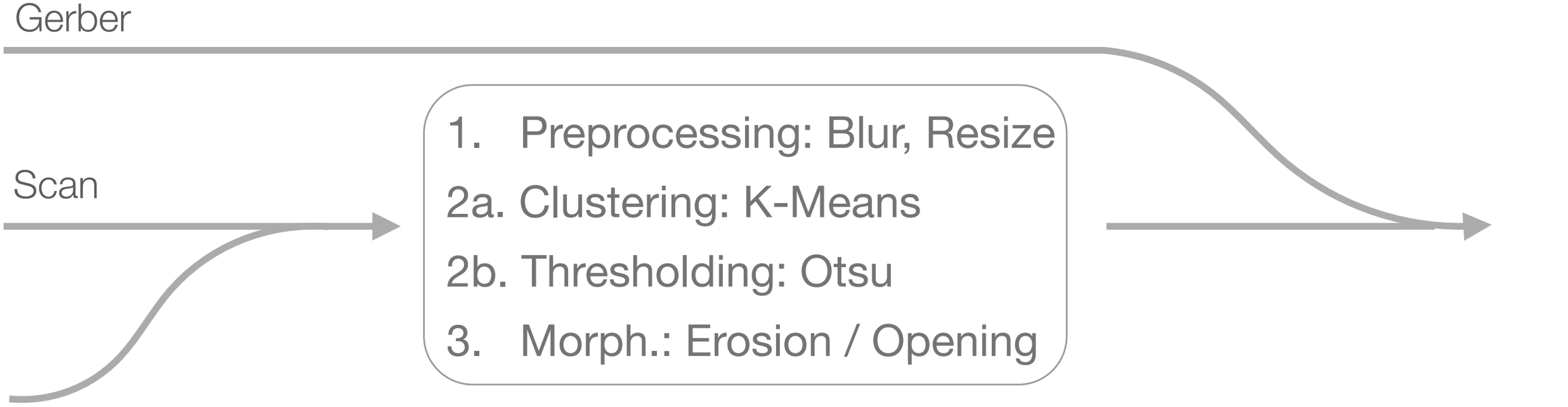


Path Planning

```
M204 S1000
G28
G29
G0 X10 Y-5
M112
```

Printer Control

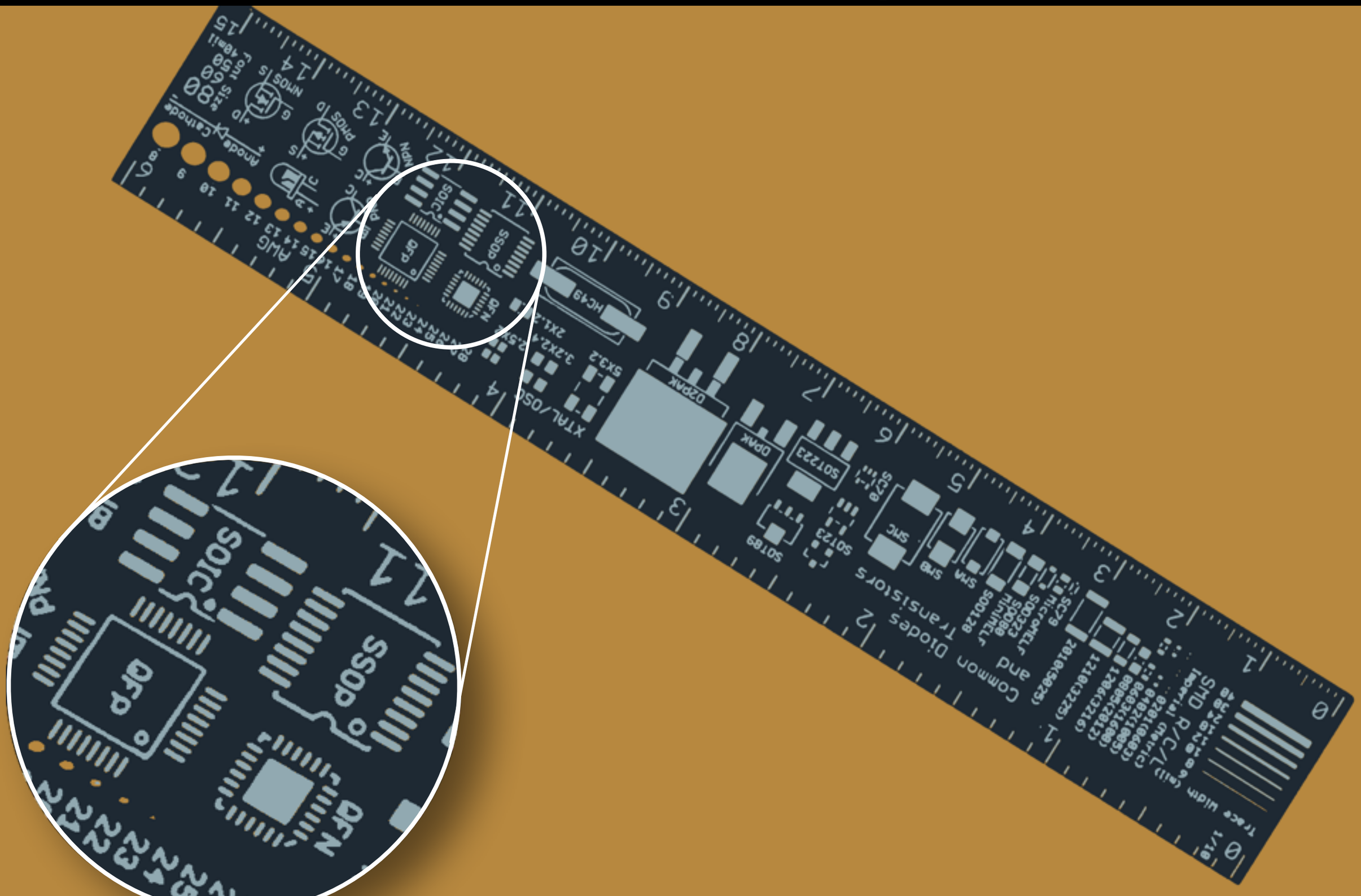
Workflow: Segmentation



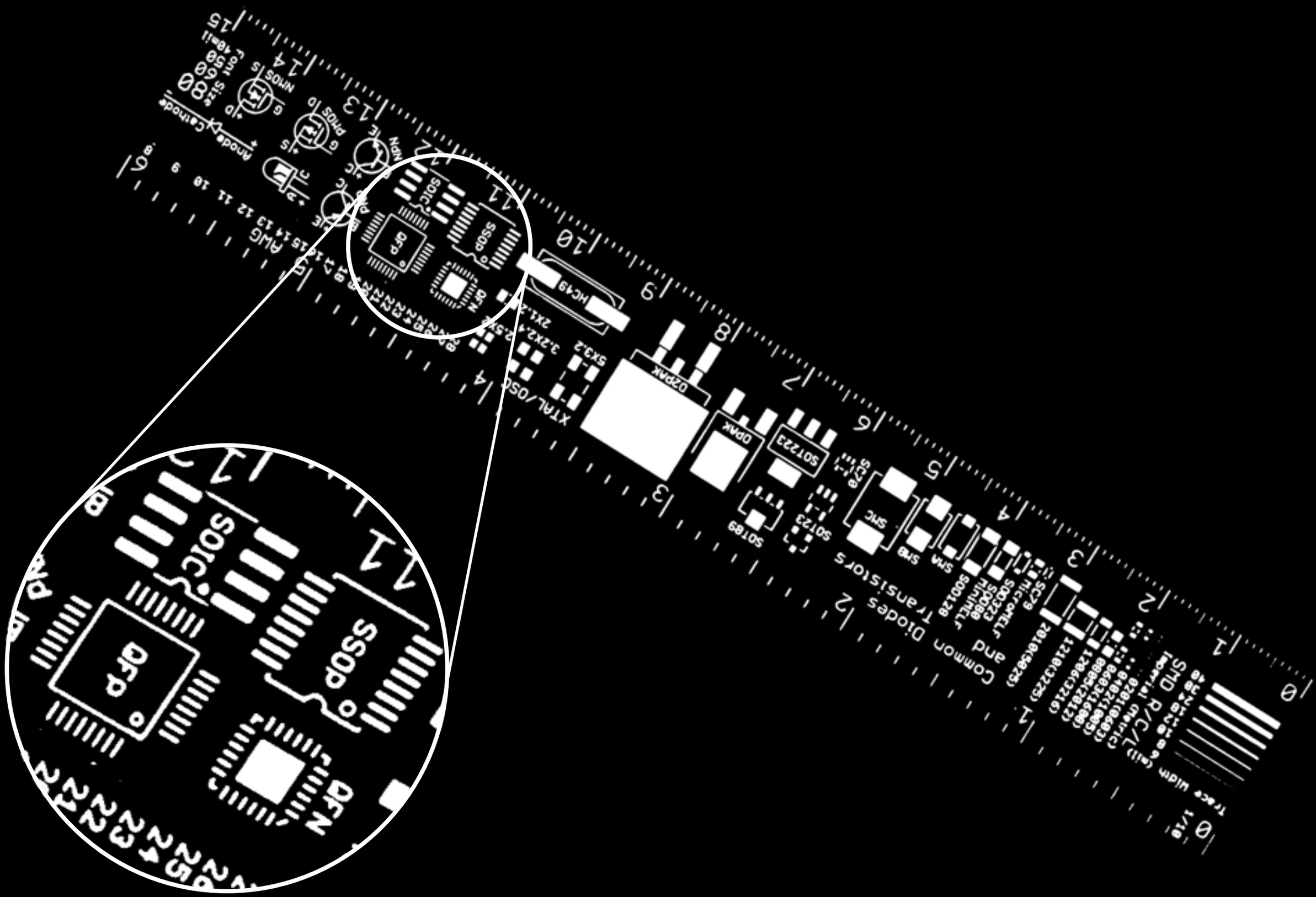
- Color based
- Detect:
  - Background
  - Base Material
  - Pads
  - Silkscreen

k = 4

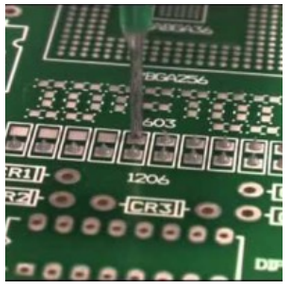
K-Means Clustering

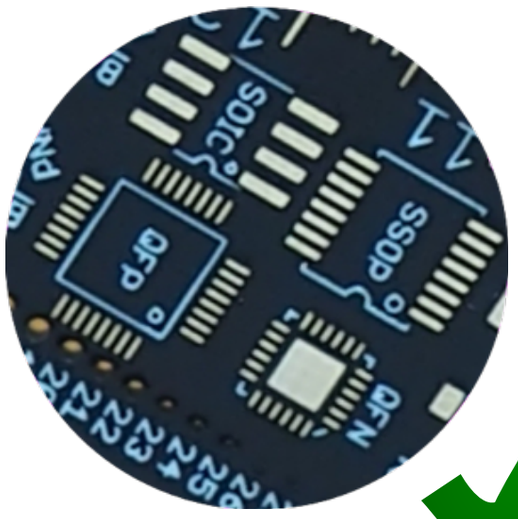


Color/Class Selection

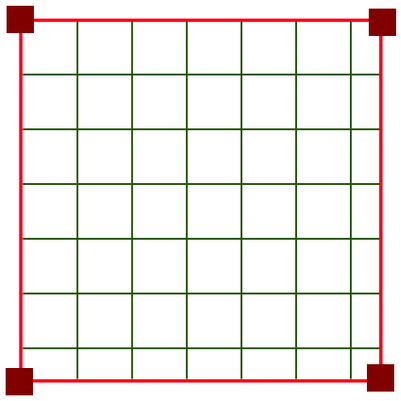


Workflow: Paste Dispensing

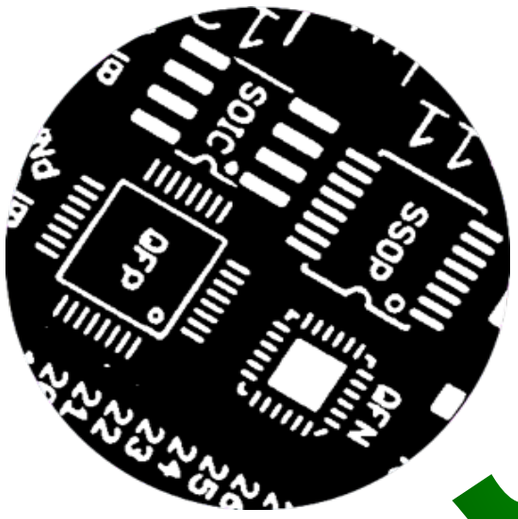




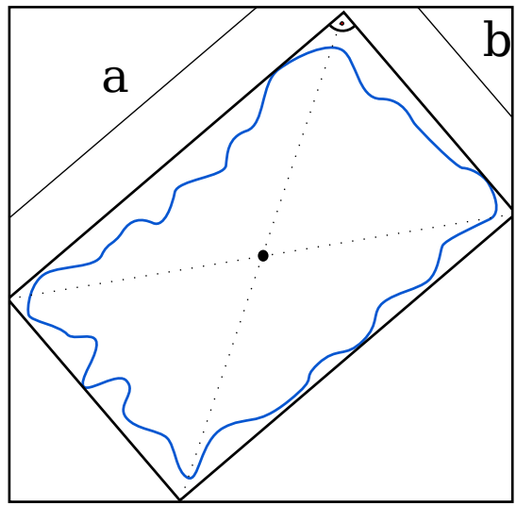
Imaging



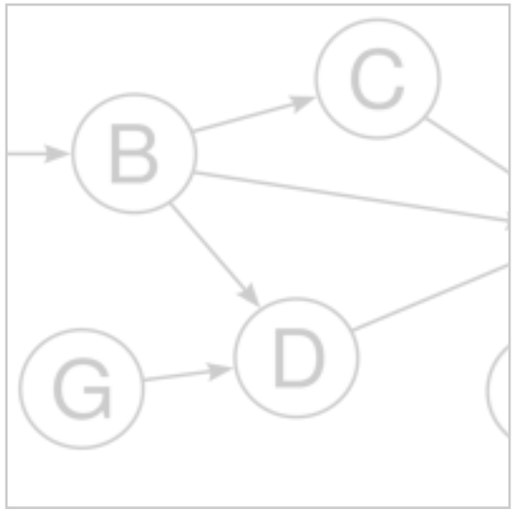
Undistortion



Segmentation



Pad Detection



Path Planning

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M204 S1000
G28
G29
G0 X10 Y-5
M112
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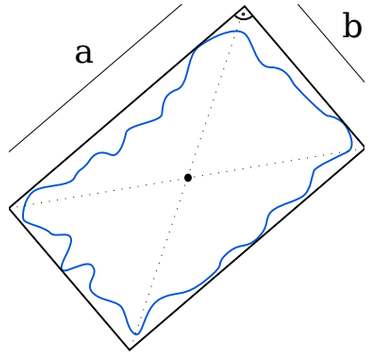
Printer Control

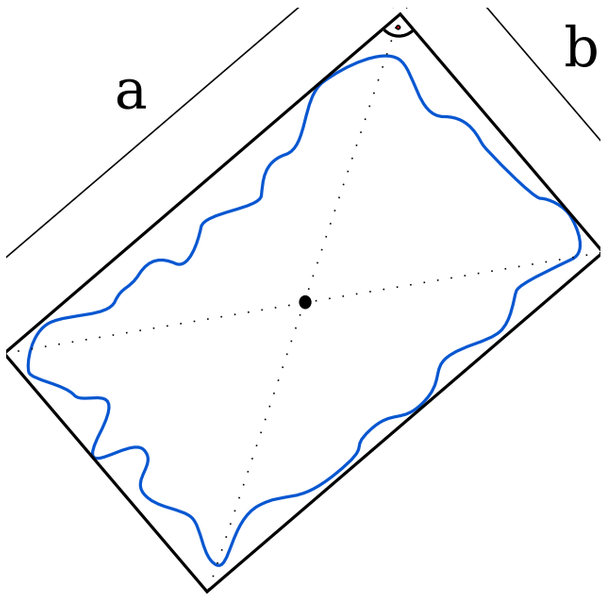
Workflow: Pad Detection



- From binary Image

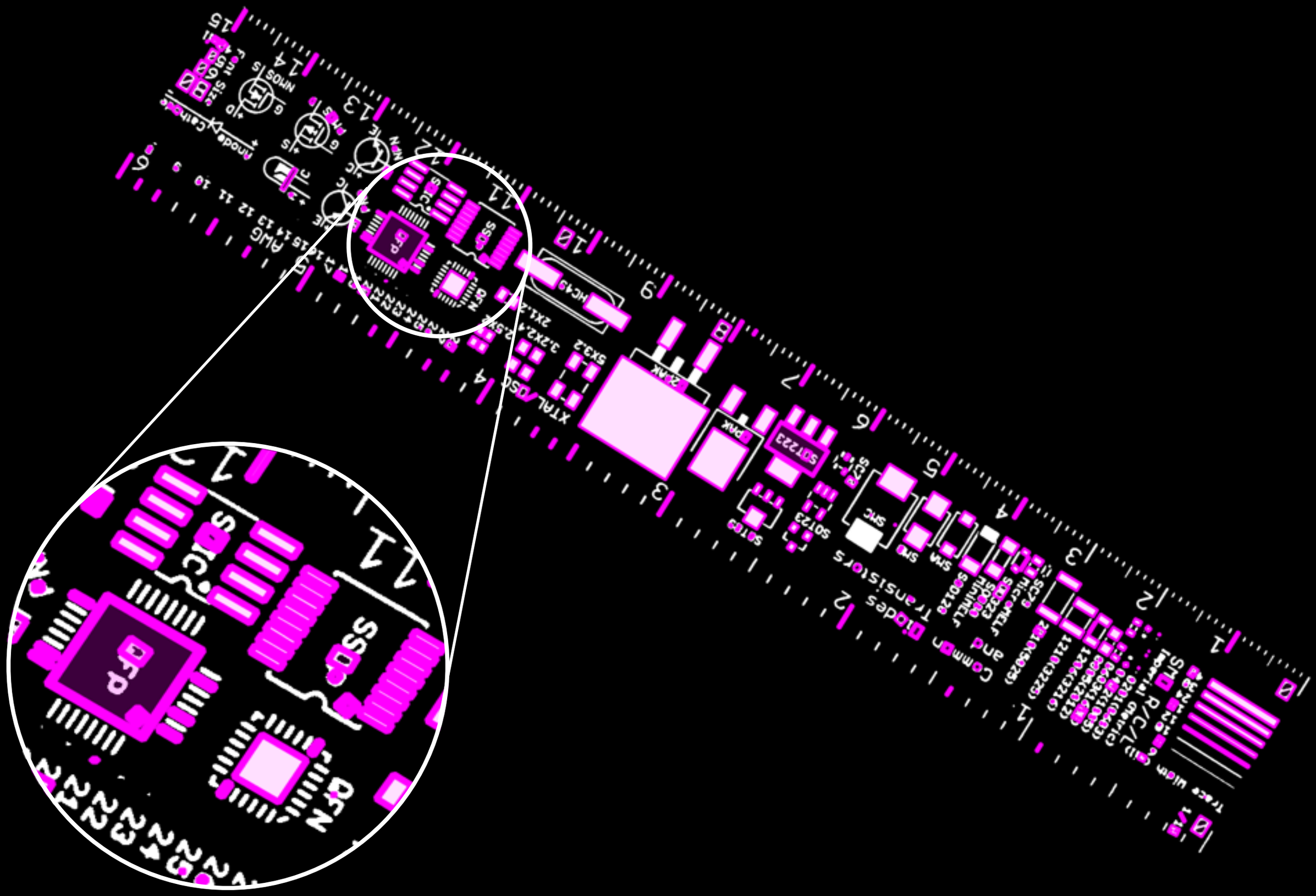
Detect Contours → Find Rectangles → Filter Pads →

- Area
- Aspect Ratio
- Overlaps

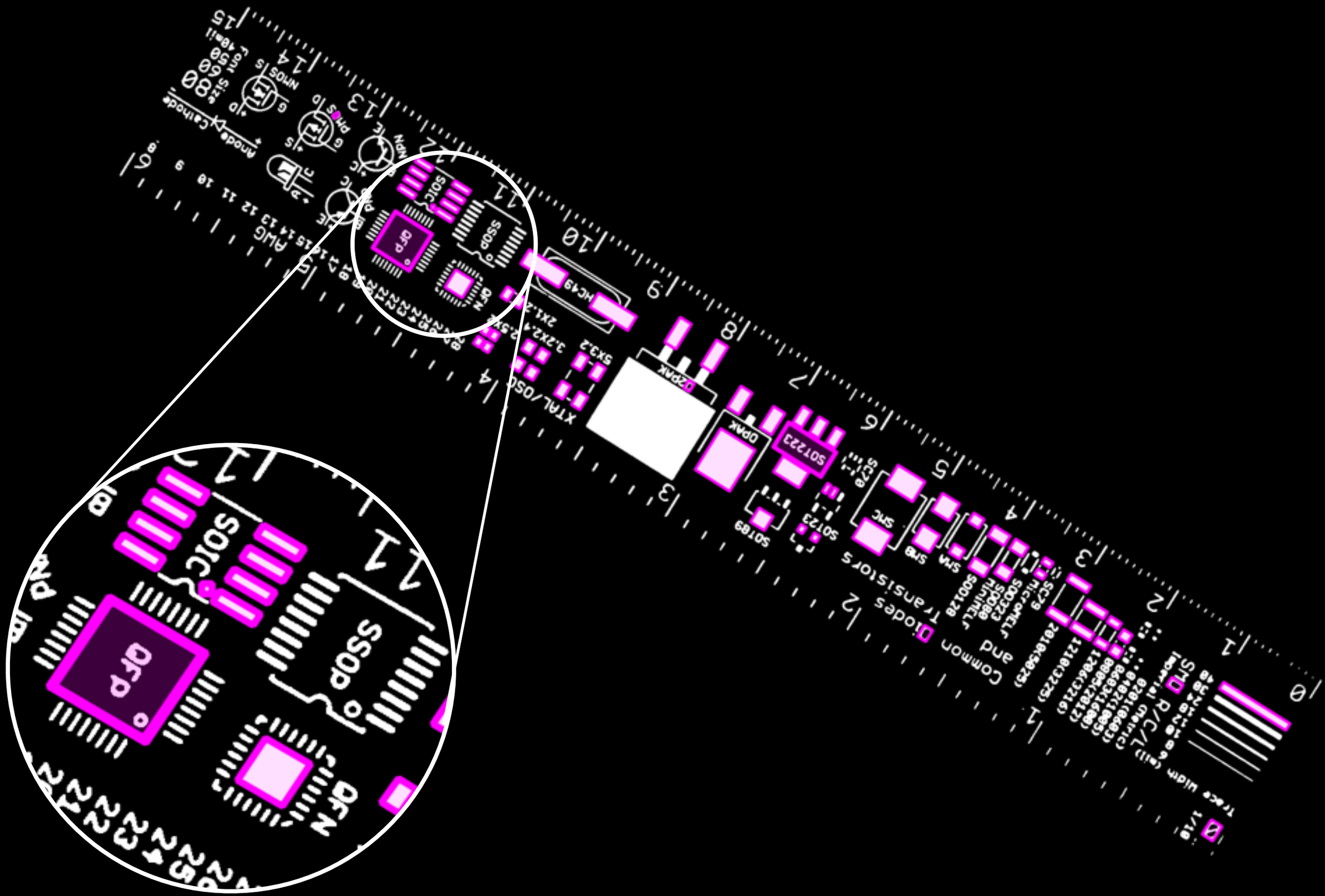


- Minimum bounding rect. vs. contour area
- Polygon approximation

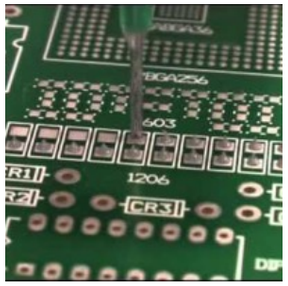
Pad Detection

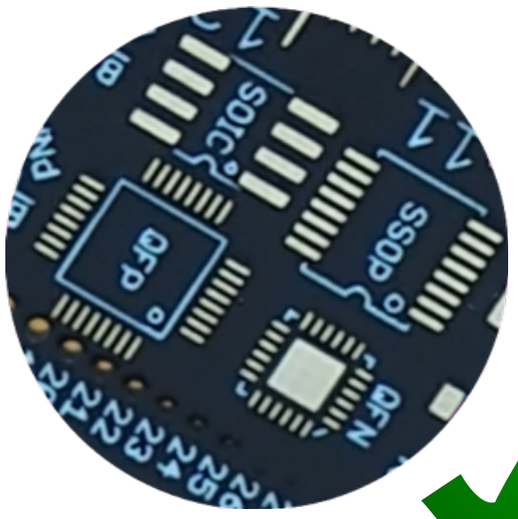


Pad Filtering

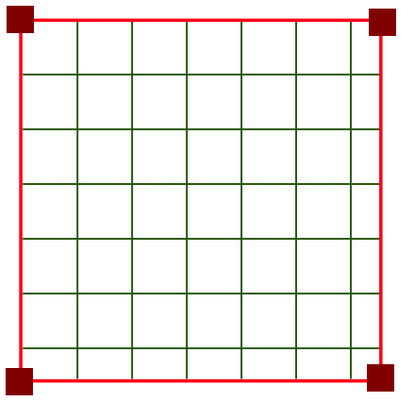


Workflow: Paste Dispensing

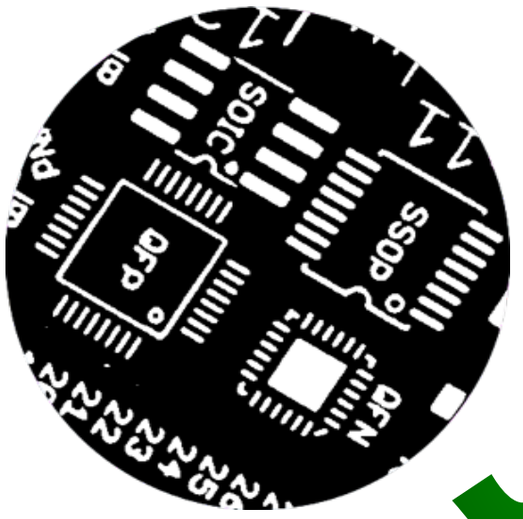




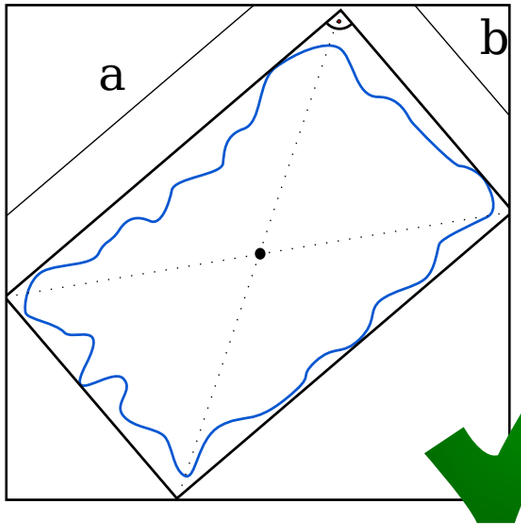
Imaging



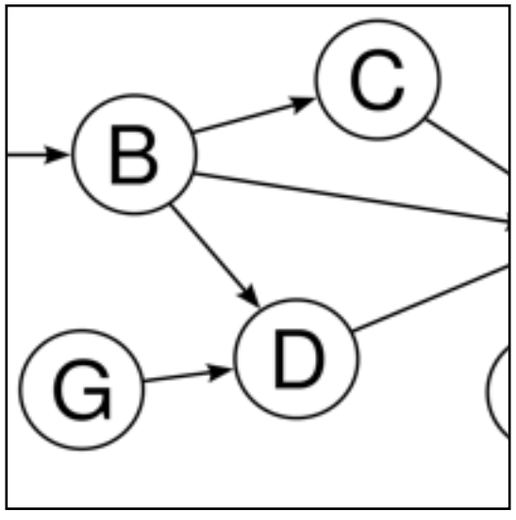
Undistortion



Segmentation



Pad Detection

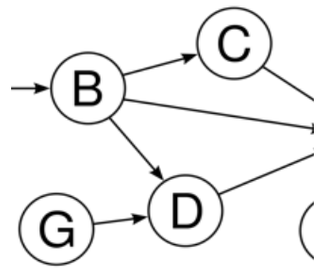


Path Planning

```
M204 S1000
G28
G29
G0 X10 Y-5
M112
```

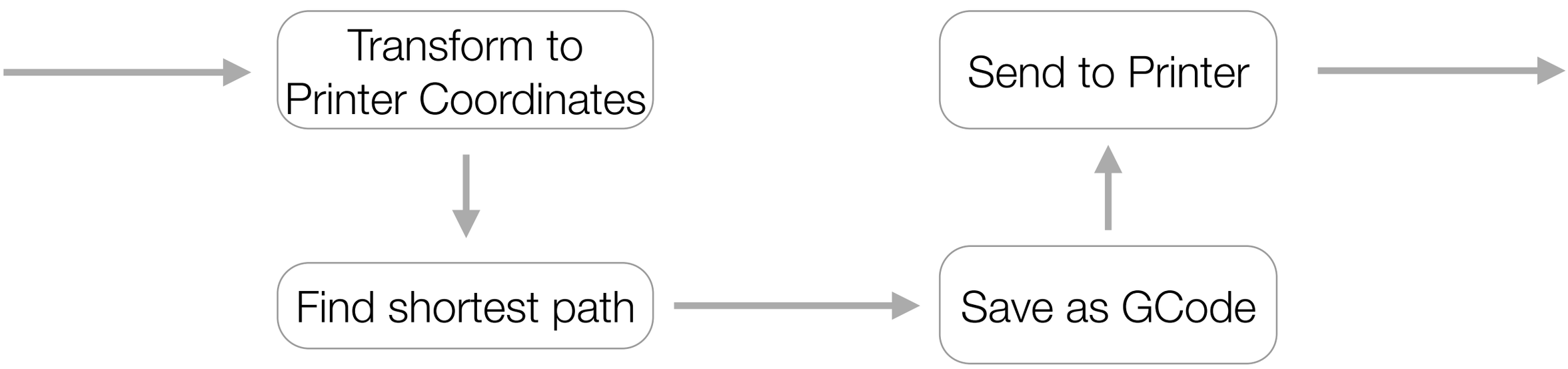
Printer Control

Workflow: Path Planning
Printer Control




```
M204 S1000
G28
G29
G0 X10 Y-5
M112
```

- Affine transformation
- Via SD card or serial port



- Nearest Neighbour Heuristic

GCode

- Industry standard for controlling CNC alike machines:
  - Laser Cutters, CNC, Lathes, 3D Printers

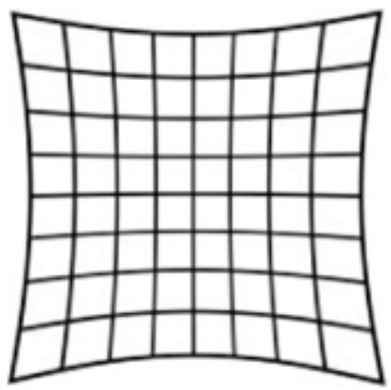
Example

```
M204 S1000 Z100 E500 ; set acceleration
G28                  ; home all axes
G29                  ; calibrate bed
G0 X10 Y-5 F100      ; move to x=10, y=-5
M112                 ; emergency stop
```

Coordinate Systems

Camera

non-linear



Undistorted

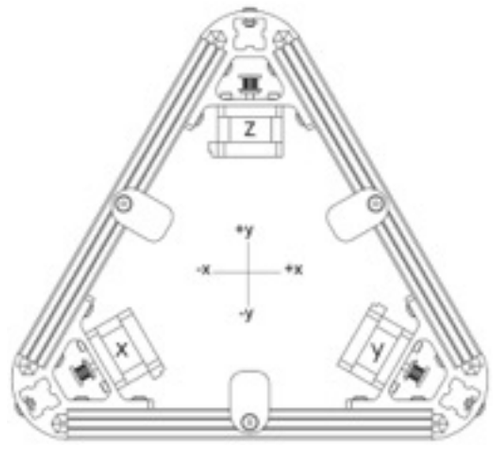
perspective (3x3)

Reference
(Markers)

affine (2x3)

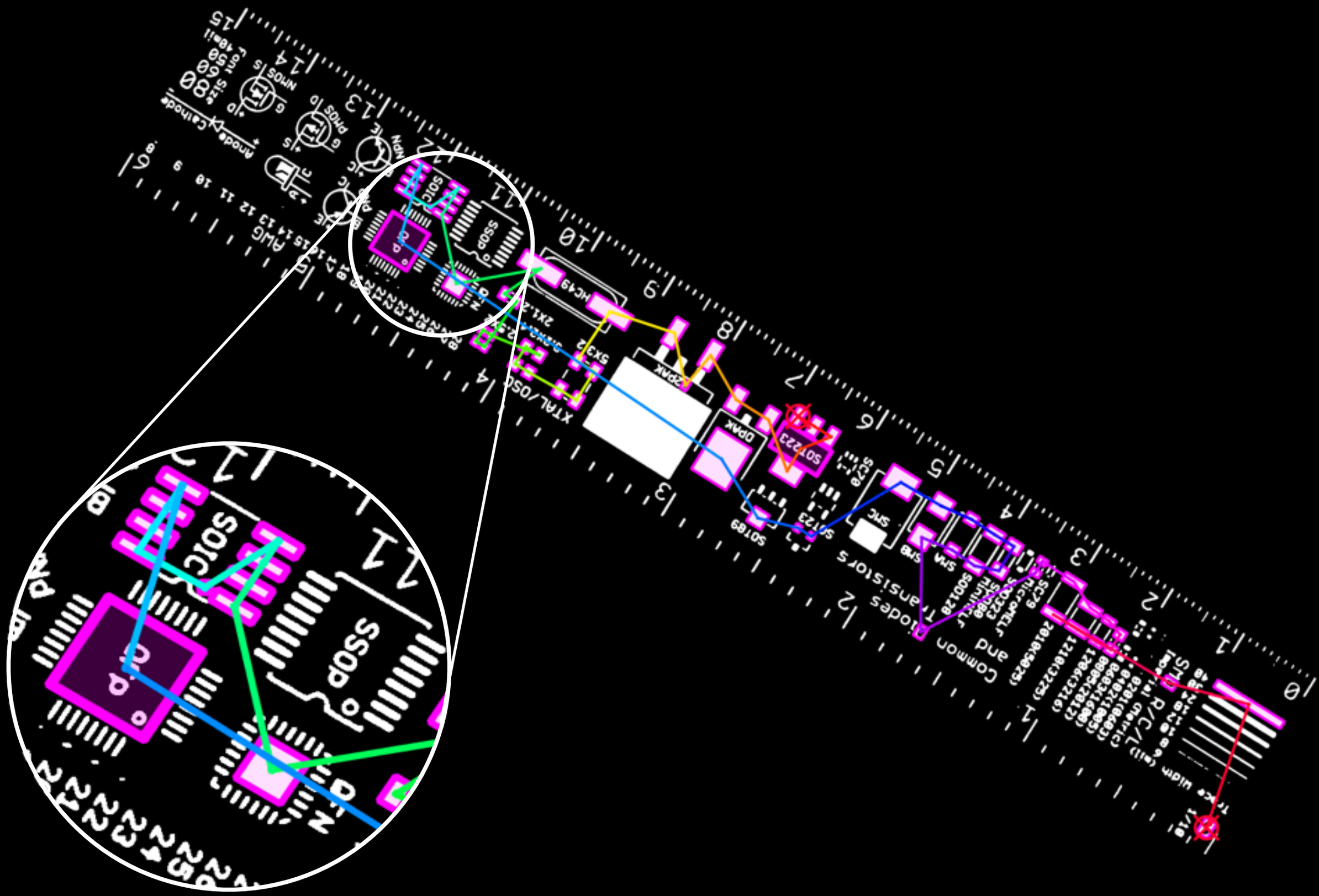
Scan & Gerber

affine (2x3)



Printer

Path Planning



Implementation: Pastie

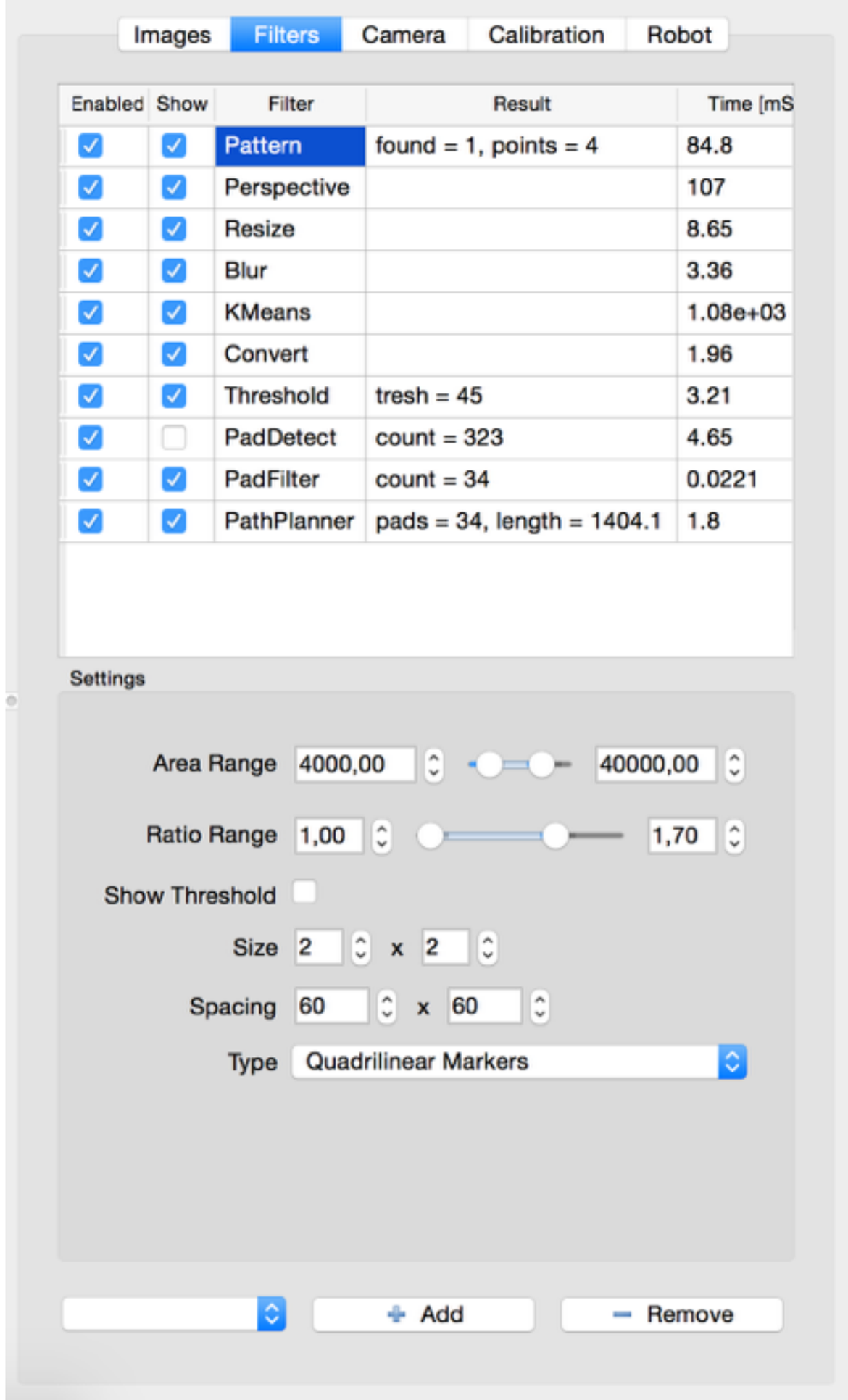
- Powerful GUI for various OpenCV functions
- Camera Calibration / Undistortion
- Live processing of webcam stream
- Filter Pipeline
- Zooming / Panning
- Import / Export
- Printer interface via GCode
  - Planned: Octoprint

Implementation: Pastie

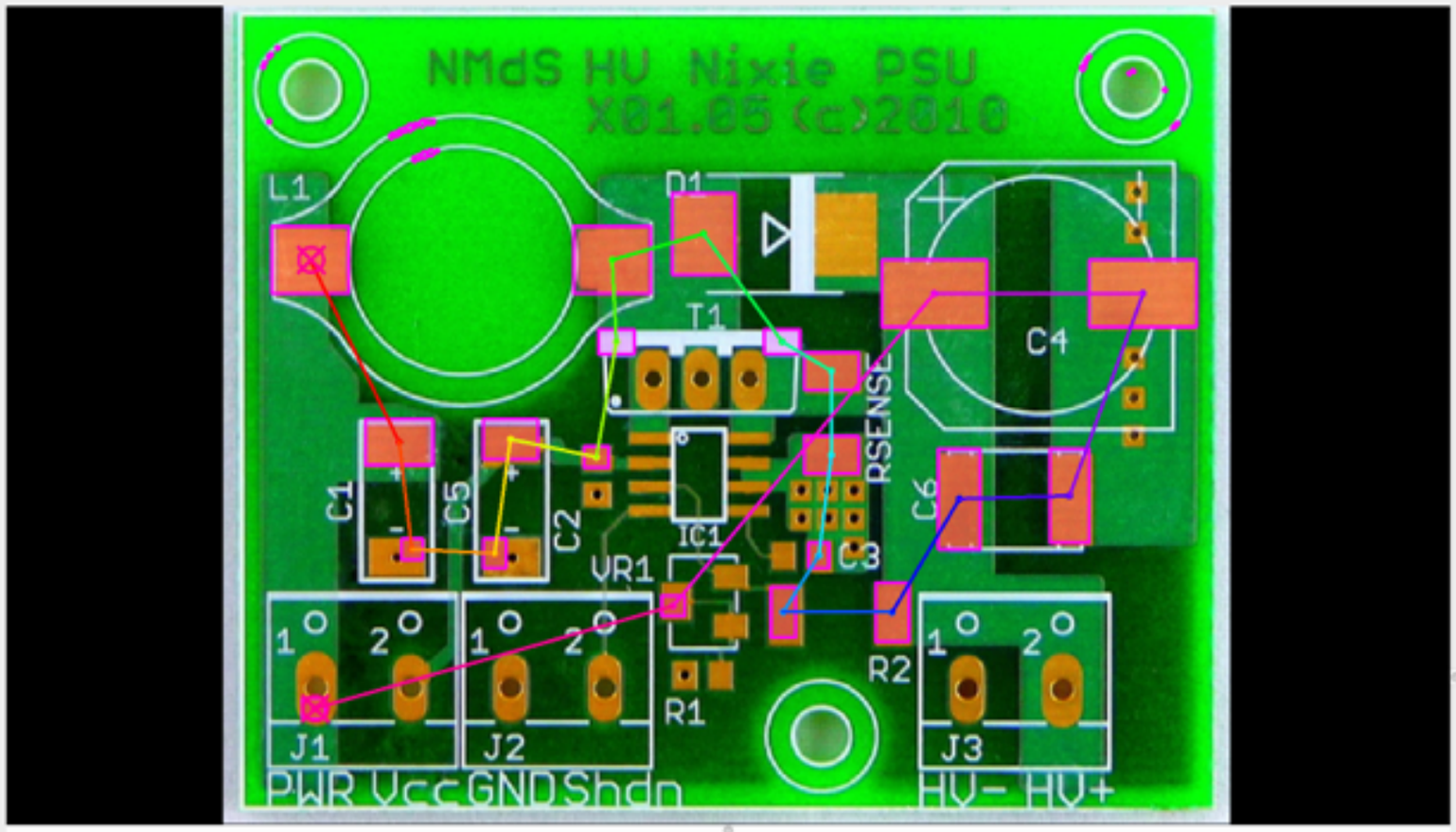
- C++11
  - OpenCV 3.0 beta
  - Qt 5.4
- Portable: Windows / Mac / Linux / Android?
- Processing Time: typically 1-10 seconds
- Potential for optimizations

Processing Pipeline

1. Undistortion
2. Detect Edge Markers
3. Perspective Warping
4. Blur / Resize
5. K-Means Color Clustering
6. Filter Pad Colors
7. Morphology Erode / Closing
8. Detect Pads
9. Filter Pads
10. Toolpath Planner



Pastie




```
[Debug   ] Rendering completed
[Debug   ] mask =  QBitArray(1000) labelShape =  480 390
[Critical] /Users/stv0g/workspace/rwth-dbv/code/libs/opencv/modules/imgproc/src/color.cpp:5731: error:
(-215) scn == 3 || scn == 4 in function cvtColor
[Debug   ] Rendering completed
[Debug   ] mask =  QBitArray(0001) labelShape =  480 390
[Critical] /Users/stv0g/workspace/rwth-dbv/code/libs/opencv/modules/imgproc/src/color.cpp:5731: error:
(-215) scn == 3 || scn == 4 in function cvtColor
[Debug   ] Rendering completed
[Debug   ] mask =  QBitArray(0010) labelShape =  480 390
[Critical] /Users/stv0g/workspace/rwth-dbv/code/libs/opencv/modules/imgproc/src/color.cpp:5731: error:
(-215) scn == 3 || scn == 4 in function cvtColor
[Debug   ] Rendering completed
[Debug   ] Rendering completed
[Debug   ] Rendering completed
[Warning ] QNSView mouseDragged: Internal mouse button tracking invalid (missing Qt::LeftButton)
[Critical] /Users/stv0g/workspace/rwth-dbv/code/libs/opencv/modules/imgproc/src/thresh.cpp:1198: error:
(-215) src.type() == CV_8UC1 in function threshold
[Debug   ] Rendering completed
```

Images | Filters | Camera | Calibration | Robot

Enabled	Show	Filter	Result	Time [mSec]
☐	☐	Pattern		
☐	☐	Perspective		
☐	☐	Resize		
☐	☐	Blur		
☐	☐	KMeans		
☐	☐	Convert		
☑	☑	Threshold	tres…	0.238
☑	☑	Morph		0.446
☑	☑	PadDetect	cou…	4.52
☑	☑	PadFilter	cou…	0.00476
☑	☑	PathPlanner	pad…	0.163

Settings

Iterations 5

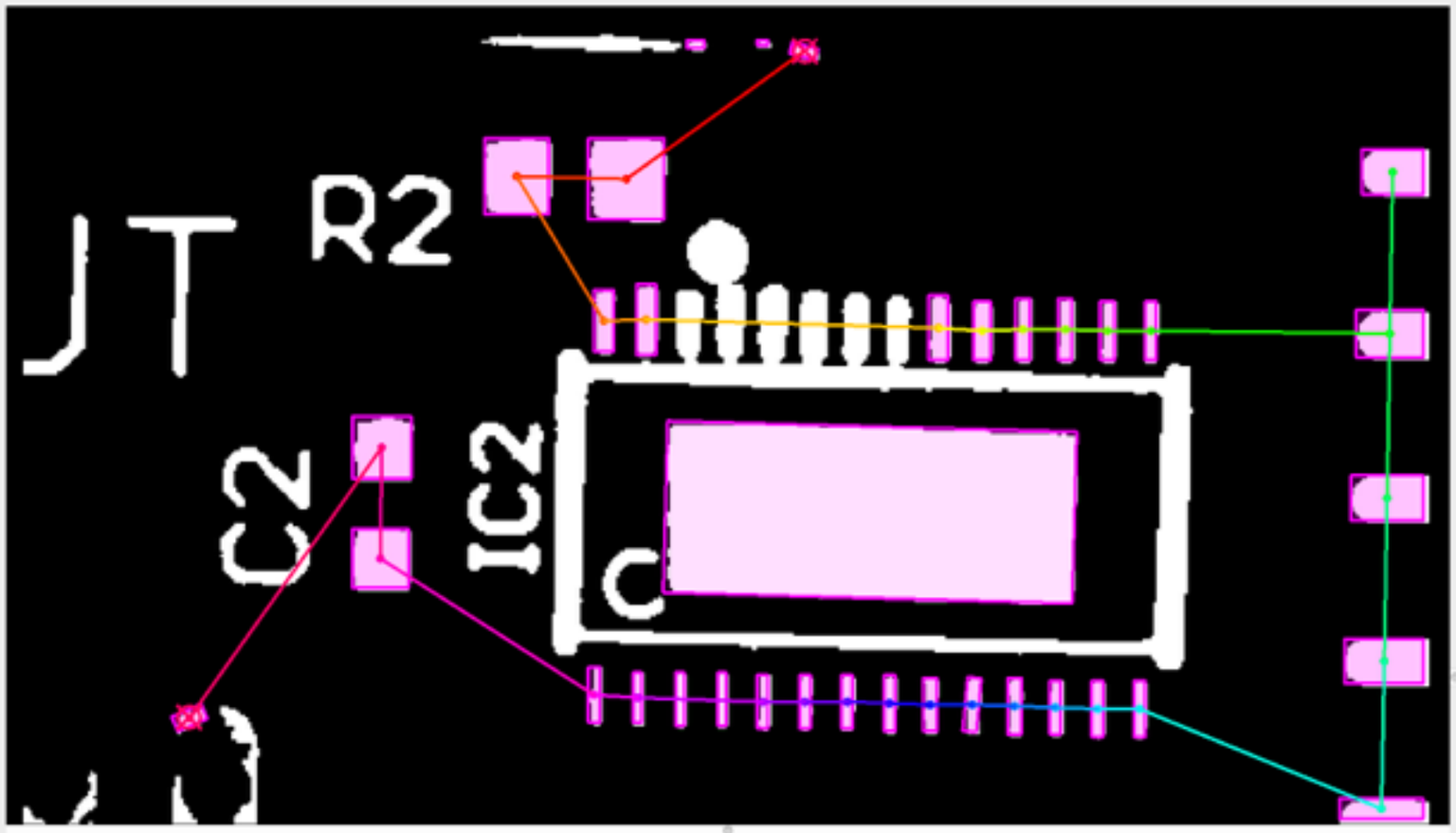
Operation Open

Shape Rectangle

Size 5 x 5

Threshold | + Add | − Remove

Pastie




```
[Debug   ] Rendering completed
[Critical] /Users/stv0g/workspace/rwth-dbv/code/libs/opencv/modules/imgproc/src/thresh.cpp:1198: error:
(-215) src.type() == CV_8UC1 in function threshold
[Debug   ] Rendering completed
[Debug   ] Clicked at:  QPoint(413,169) ( QPoint(691,279) )
[Debug   ] mask =  QBitArray(0001) labelShape =  500 291
[Debug   ] Rendering completed
[Debug   ] mask =  QBitArray(1000) labelShape =  500 291
[Debug   ] Rendering completed
[Debug   ] Set settings widget to  "PadFilter"
[Debug   ] mask =  QBitArray(0010) labelShape =  500 291
[Debug   ] Rendering completed
```

Images | Filters | Camera | Calibration | Robot

Control

Start
Abort
Calibrate
Save GCode

OctoPrint Server :
Connect

OctoPrint Key

z Swing 6,00

Bed Shape Circular

Bed Size x 17,00 y 17,00

Calibaration Points	1	2	3
x	0,00	0,00	0,00
y	0,00	0,00	0,00
z	0,80		

Acceleration xy 1500,00 z 1500,00

Pastie

Images | Filters | Camera | Calibration | Robot

Pattern: ✓ Chessboard
Circles Symmetric
Circles Asymmetric

Board Size:

Spacing: 25,00

Calibrate | Perspective | Reset

```
(-210) [Start]FindContours support only 8uC1 and 32sC1 images in function cvStartFindContours
[Debug   ] Rendering completed
[Critical] /Users/stv0g/workspace/rwth-dbv/code/libs/opencv/modules/imgproc/src/contours.cpp:196: error:
(-210) [Start]FindContours support only 8uC1 and 32sC1 images in function cvStartFindContours
[Debug   ] Rendering completed
[Debug   ] Rendering completed
[Debug   ] Rendering completed
[Warning ] QNSView mouseDragged: Internal mouse button tracking invalid (missing Qt::LeftButton)
[Debug   ] Rendering completed
[Debug   ] Rendering completed
[Debug   ] Rendering completed
[Debug   ] Rendering completed
```

Results

Average Reprojection Error: 0.166388

Cam Matrix:

3.949e-19	4.023	0
0	0	3.202e+3
0	0	0

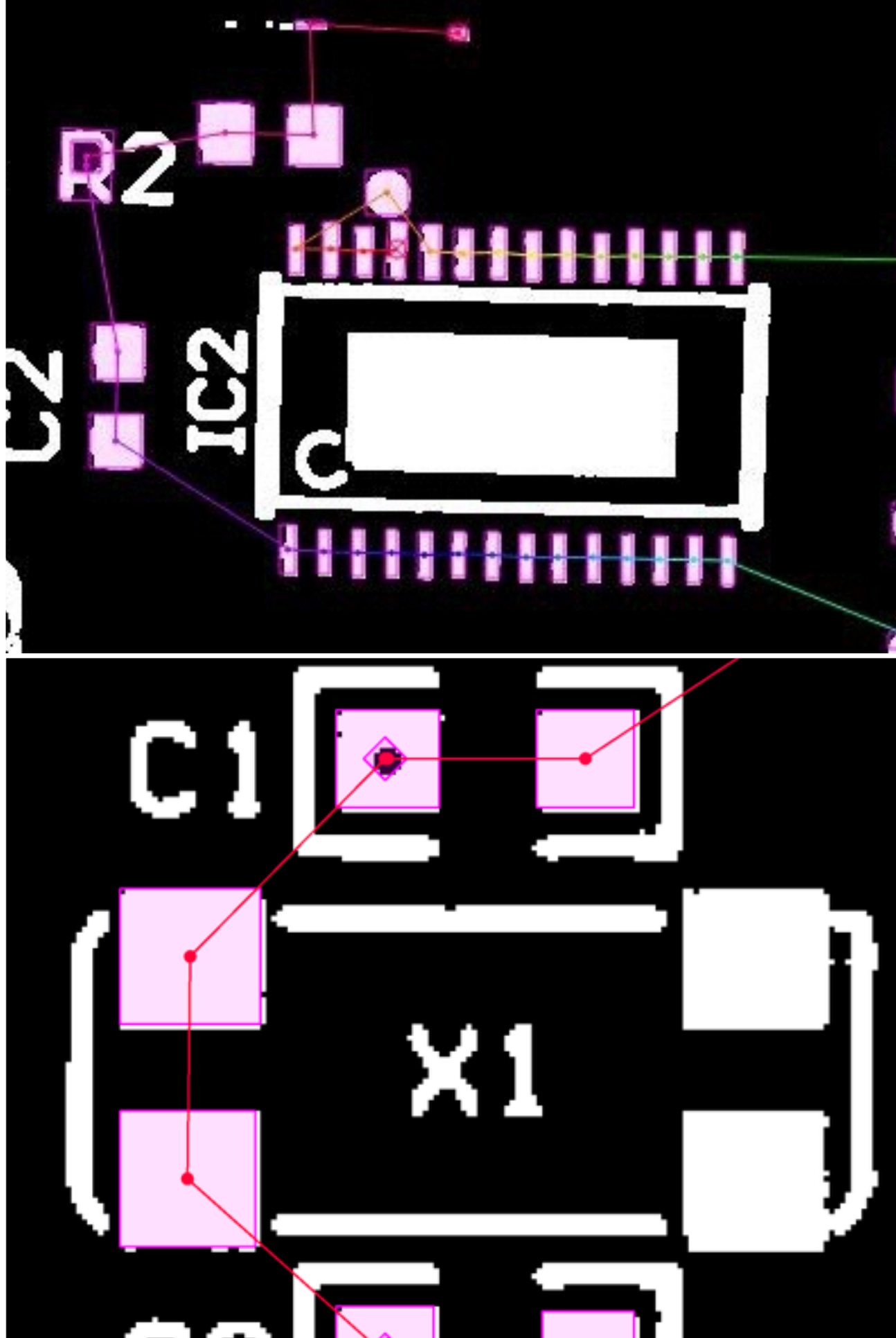
Distortion Coefficients:

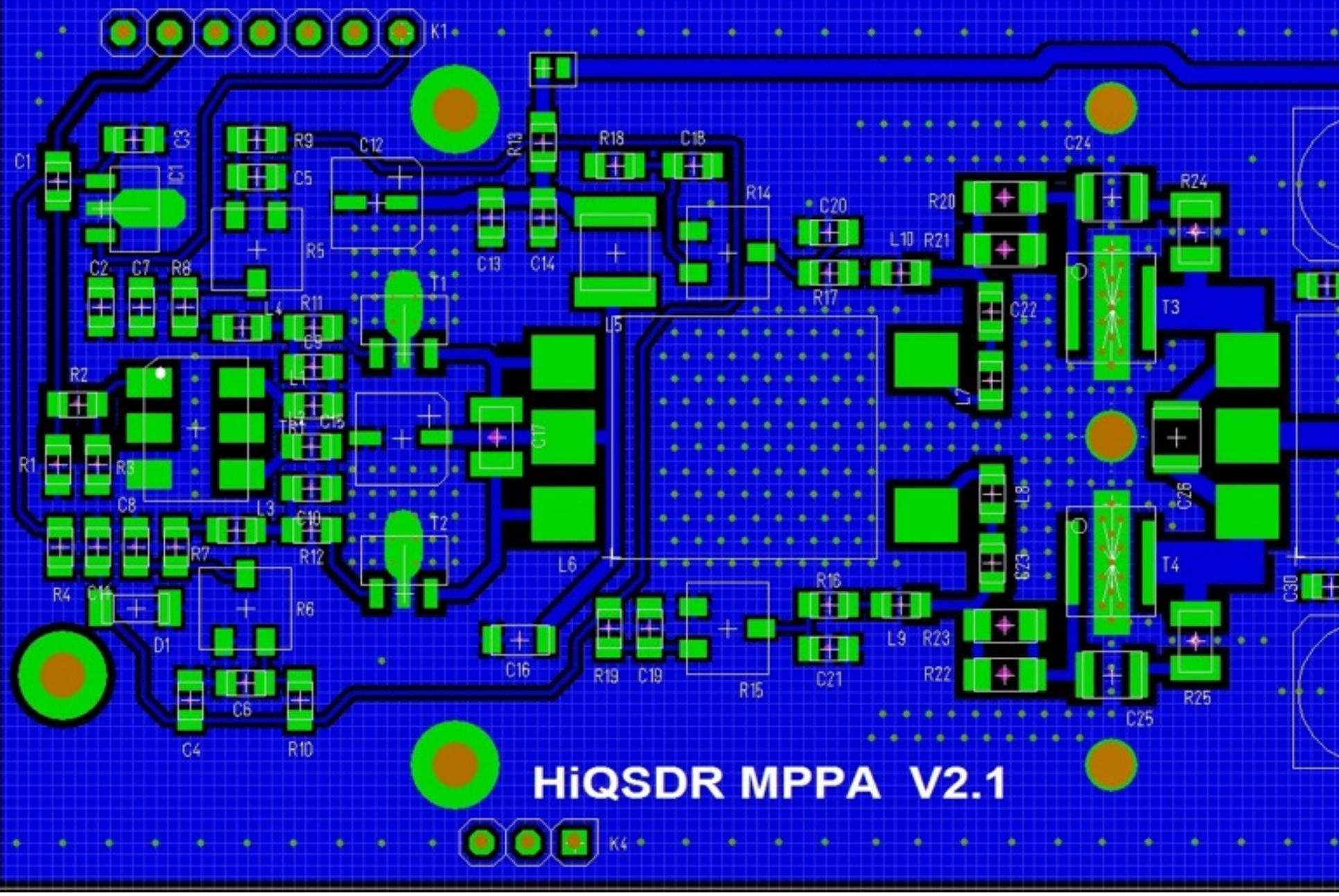
-2.056e-10	-4.975e-06	-1.209	-1.634	-1.242e-21

Problems

- Lightning
  - Reflexions & Shadows

  → Use flash & indirect illumination
- Image Resolution
  - WebCams not suitable
- Silk-screen
  - Color similar to Pads
  - Overlapping with Pads





K1
C1
C3
C1
R9
C5
C12
R13
R18
C18
C24
R24
R14
C20
R20
L10
R21
R5
C13
C14
C2
C7
R8
T1
L4
R11
R17
C22
T3
L5
C9
L1
R2
L2
TR1
C15
C17
R1
R3
C8
L3
C10
T2
R7
R12
L6
R16
L8
C23
C26
T4
R4
C11
R6
L9
R23
C30
D1
C16
R19
C19
R15
C21
R22
R25
C6
C25
C4
R10
HiQSDR MPPA V2.1
K4

Next goals

- Try Watershed & Harris Corner detection algorithms
- Further improvements of workflow
  - WiFi connection to camera & printer (libqt-omd)
  - Import Gerber files (libgerbv)
- Design of dispenser toolhead
- Try TSP solvers for tool path planning

Thank you for your kind attention.

Paper, Sources and Presentation will be available at:

http://www.noteblok.net/2015/01/30/seminar/

References / Code

http://www.reprap.org

http://www.opencv.org

http://www.qt-project.org

http://gerbv.geda-project.org

https://github.com/stv0g/libqt-omd/

https://github.com/stv0g/pastie/

https://www.youtube.com/watch?v=_IzsCN9Q-Zw

https://www.youtube.com/watch?v=oxYKggceIPQ

http://www.adafruit.com/product/1554