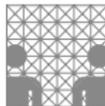




Universität Hamburg

DER FORSCHUNG | DER LEHRE | DER BILDUNG

MIN Faculty  
Department of Informatics



# Optical In-Situ Verification of 3D-Printed Electronic Circuits

Florens Wasserfall, Daniel Ahlers, Norman Hendrich, Dennis Struhs,  
Jianwei Zhang  
*wasserfall@informatik.uni-hamburg.de*

University of Hamburg  
TAMS

May 7, 2019

# Contents

1. Introduction / Hardware
2. Problem Statement
3. Collecting "Evidence"
4. Feature Segmentation
5. Fault Detection
6. Conclusion

# Hardware Setup - Printer

Introduction / Hardware

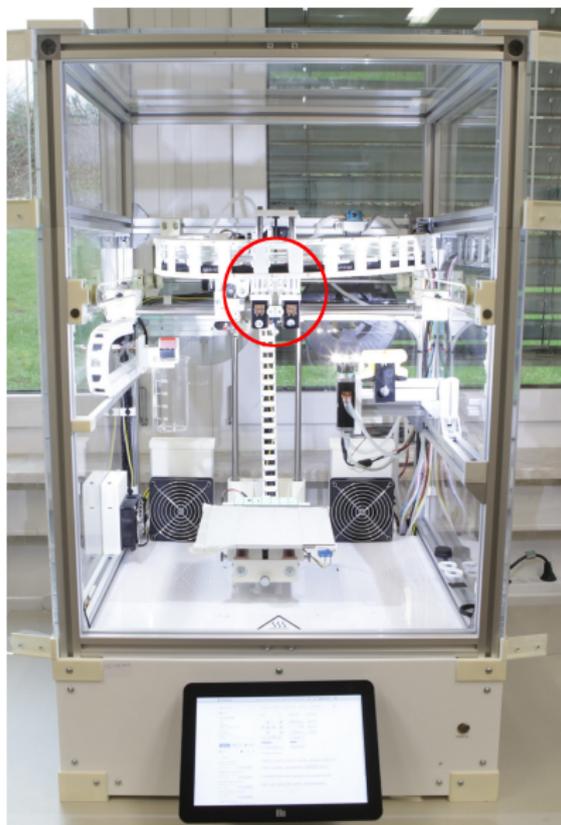
Problem Statement

Collecting "Evidence"

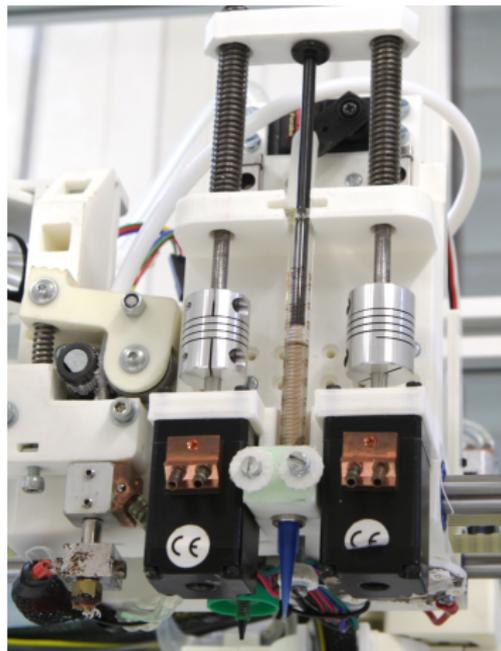
Feature Segmentation

Fault Detection

Conclusion



## Conductive ink extruder



# Hardware Setup - Printer

Introduction / Hardware

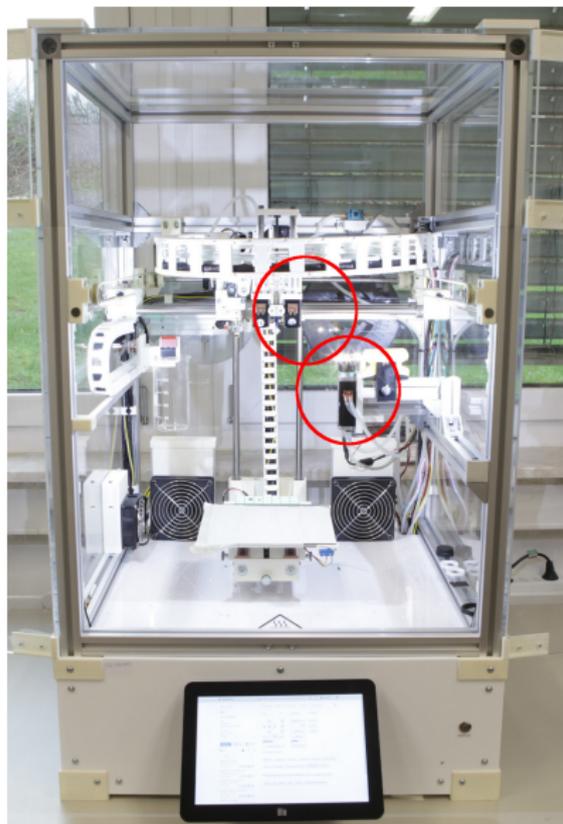
Problem Statement

Collecting "Evidence"

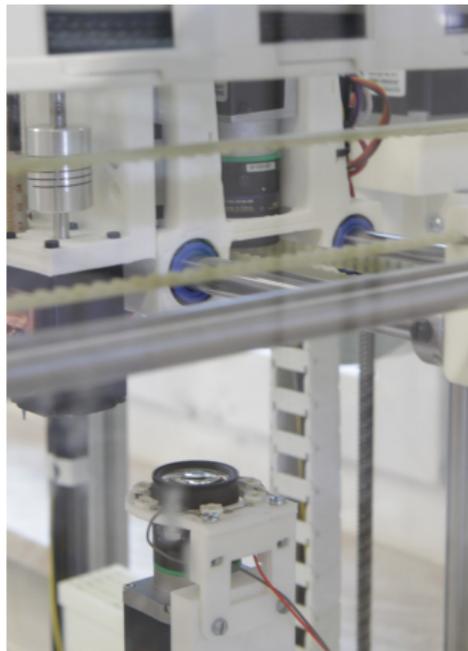
Feature Segmentation

Fault Detection

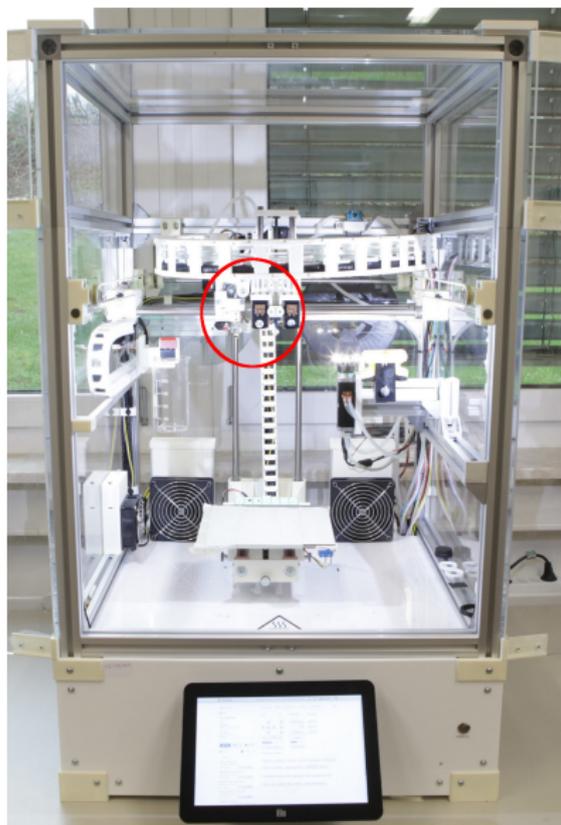
Conclusion



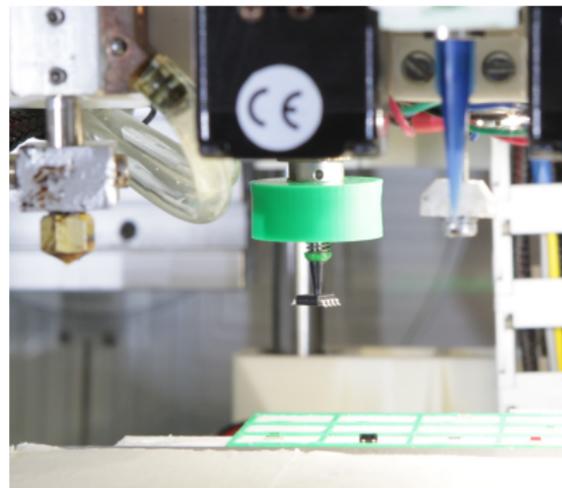
## Cameras



# Hardware Setup - Printer



Vacuum gripper



# Hardware Setup - Cameras

Introduction / Hardware

Problem Statement

Collecting "Evidence"

Feature Segmentation

Fault Detection

Conclusion



Ace (acA2500-14gc)



Pilot (piA2400-17gc)



C125-0818-5M lens

[Images ©: Basler AG]

# 3D-Electronics Design Software

Introduction / Hardware

Problem Statement

Collecting "Evidence"

Feature Segmentation

Fault Detection

Conclusion

Electronics

Load netlist Save netlist

Object

- stick\_attiny\_wide.stl
- placed
  - IC1
  - R1
  - R2
  - LED1
  - LED2
- unplaced

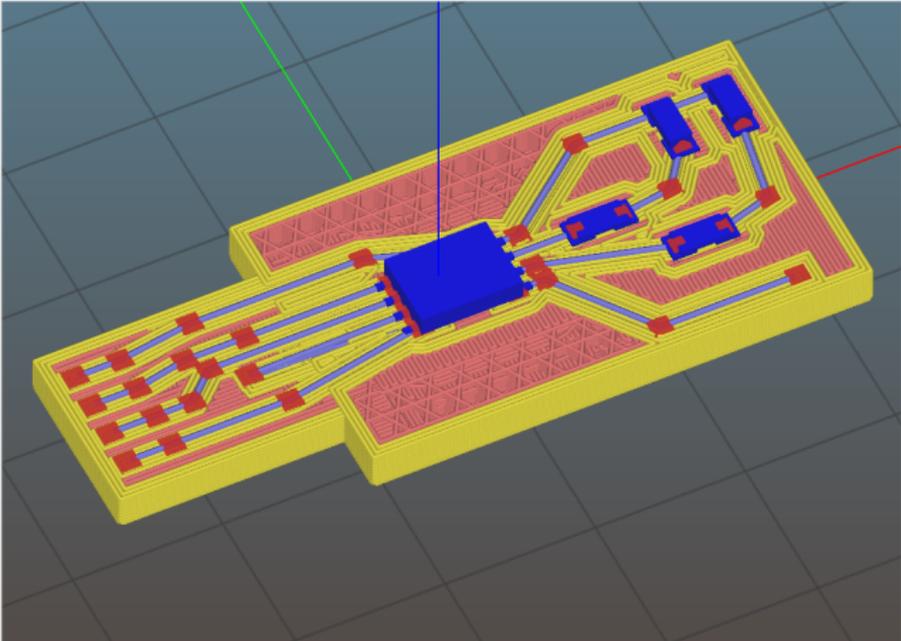
Part name	IC1
Library	atmel
Deviceset	AT90*2323
Device	S
Package	SOIC8
Part height	1.6
Footprint height	0.25
Placing method	None
Connection method	None

▼ Position

X	1
Y	0
Z	2.5

▼ Rotation

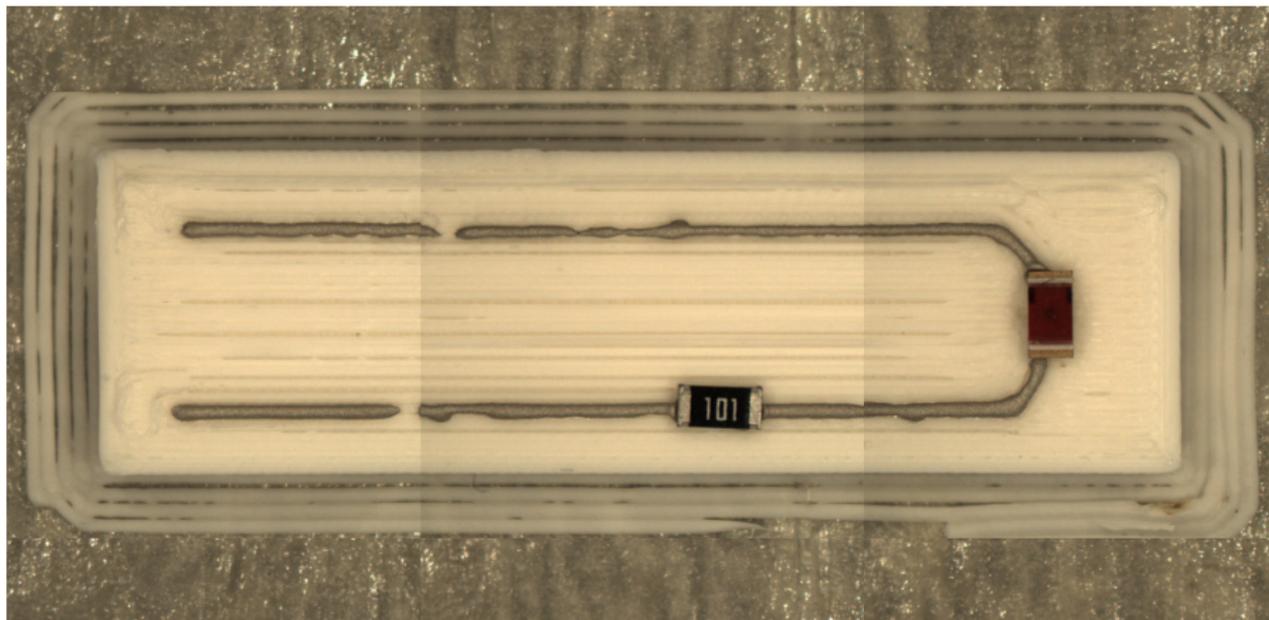
X	0
Y	0



2.75

The image shows a 3D perspective view of a PCB layout. The board is yellow, and the traces are blue and red. A central component, IC1, is highlighted in blue. Other components, including resistors (R1, R2) and LEDs (LED1, LED2), are also visible. The layout is set against a dark gray grid background. A vertical scale bar on the right side of the image indicates a height of 2.75 units.

# Common Fails



# Common Fails

Introduction / Hardware

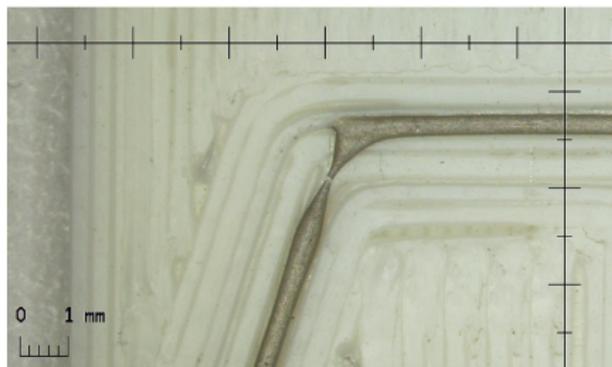
Problem Statement

Collecting "Evidence"

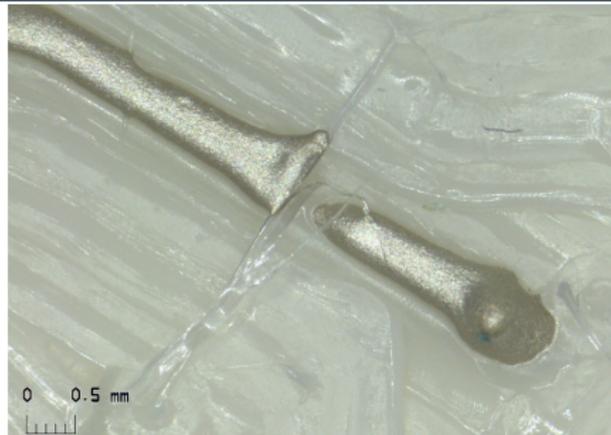
Feature Segmentation

Fault Detection

Conclusion



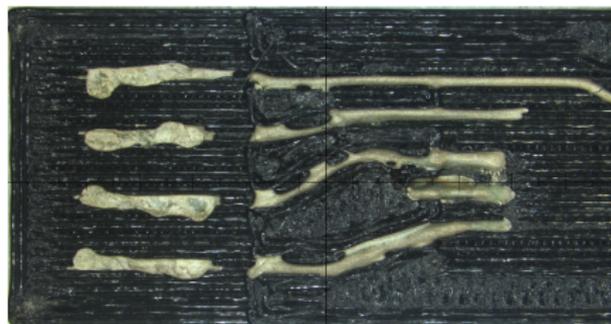
Underextrusion



Plastic strand



Short circuit

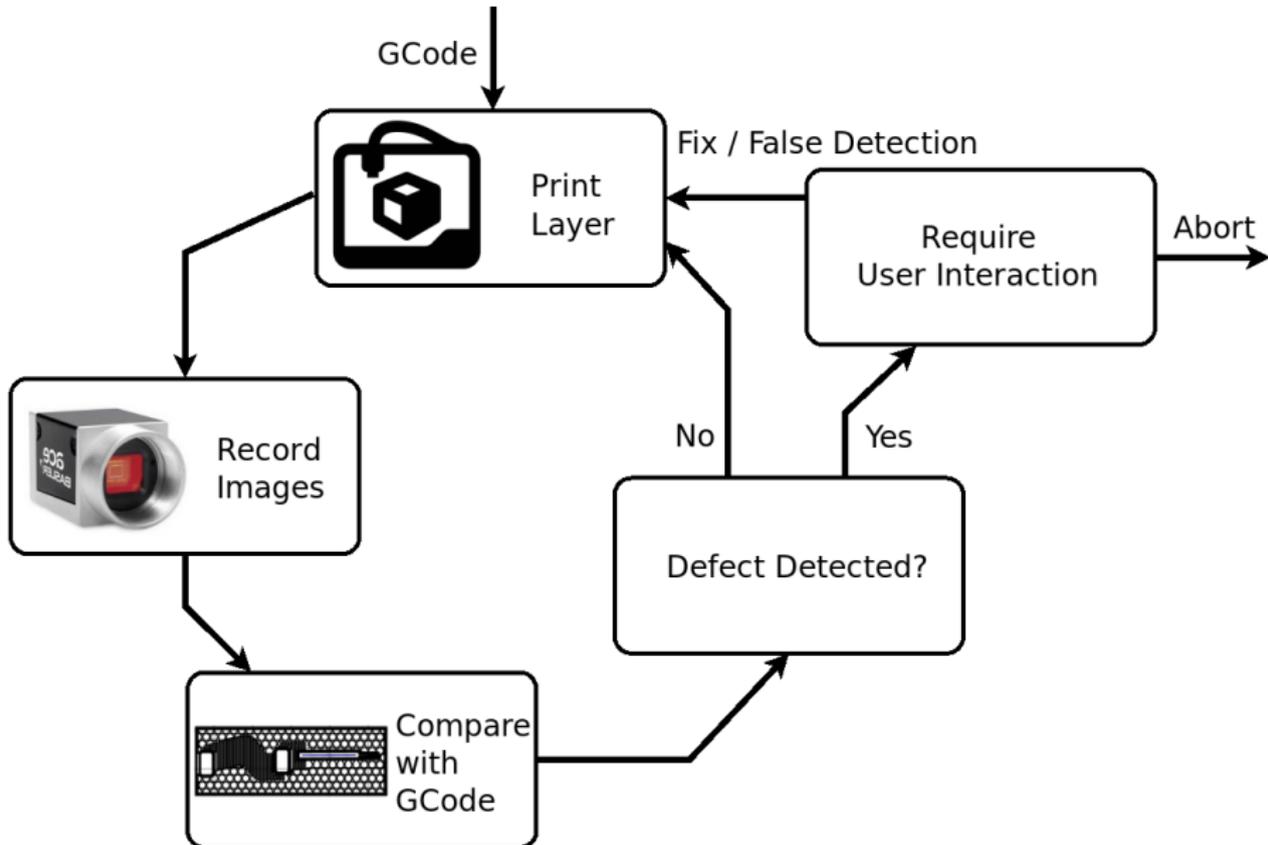


Surface structure

# Common Fails

<b>Class</b>	<b>Cause</b>
Interruptions	Ink Dispensing Positioning Plastic Strands Edges
Short Circuits	Overextrusion Smeared Ink
Interlayer Connections	
SMD-Components	Short Under Component Positioning / Alignment

# Detect Failure During Print-Time



# OctoCameraDocumentation

Introduction / Hardware

Problem Statement

Collecting "Evidence"

Feature Segmentation

Fault Detection

Conclusion

OctoPrint

Connection

State

State: **Operational**

File: **Wade\_gear\_tear\_47.gcode**

Timelapse: -

Filament (Tool 0): **2.18m / 13.88cm<sup>3</sup>**

Filament (Tool 1): **0.00m / 0.00cm<sup>3</sup>**

Approx. Total Print Time: **3 hours**

Print Time: -

Print Time Left: -

Printed: - / **5.4MB**

Print Pause Cancel

Files

Search...

battery\_cube\_holes\_prp.gcode  
Uploaded: 9 days ago  
Size: 1.2MB

cube\_x.gcode  
Uploaded: 8 days ago  
Size: 54.8KB

cylinder.gcode  
Uploaded: 8 days ago  
Size: 222.4KB

**Wade\_gear\_tear\_47.gcode**  
Uploaded: 7 minutes ago  
Size: 5.4MB

Free: 30.9GB / Total: 231.5GB

Create folder...

Upload Upload to SD

Temperature Control GCode Viewer Terminal

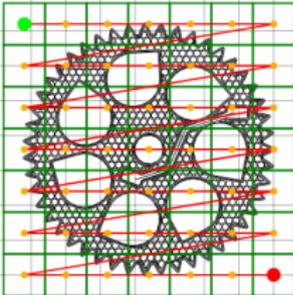
Camera Documentation Tool

GCode State: **Successfully created and loaded Camera Grid from GCode**

Grid tile size: **12x12**

Camera status:

Camera lookup grid on Layer: 14



← Previous layer Next layer →

# Stitching Tiles

Introduction / Hardware

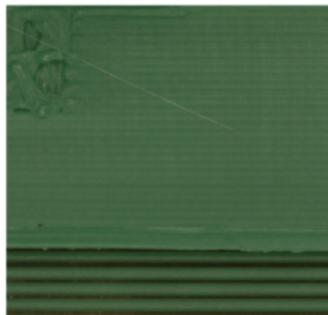
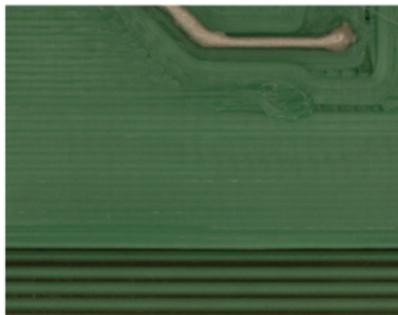
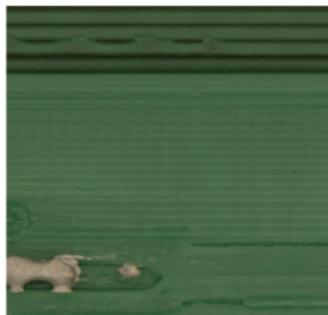
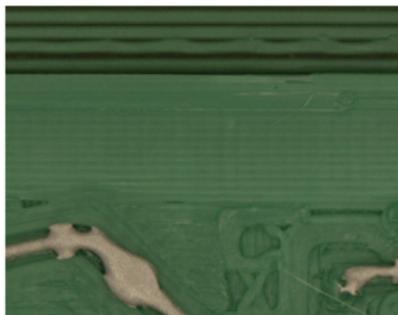
Problem Statement

Collecting "Evidence"

Feature Segmentation

Fault Detection

Conclusion



# Stitching Tiles

Introduction / Hardware

Problem Statement

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# Stitching Tiles

Introduction / Hardware

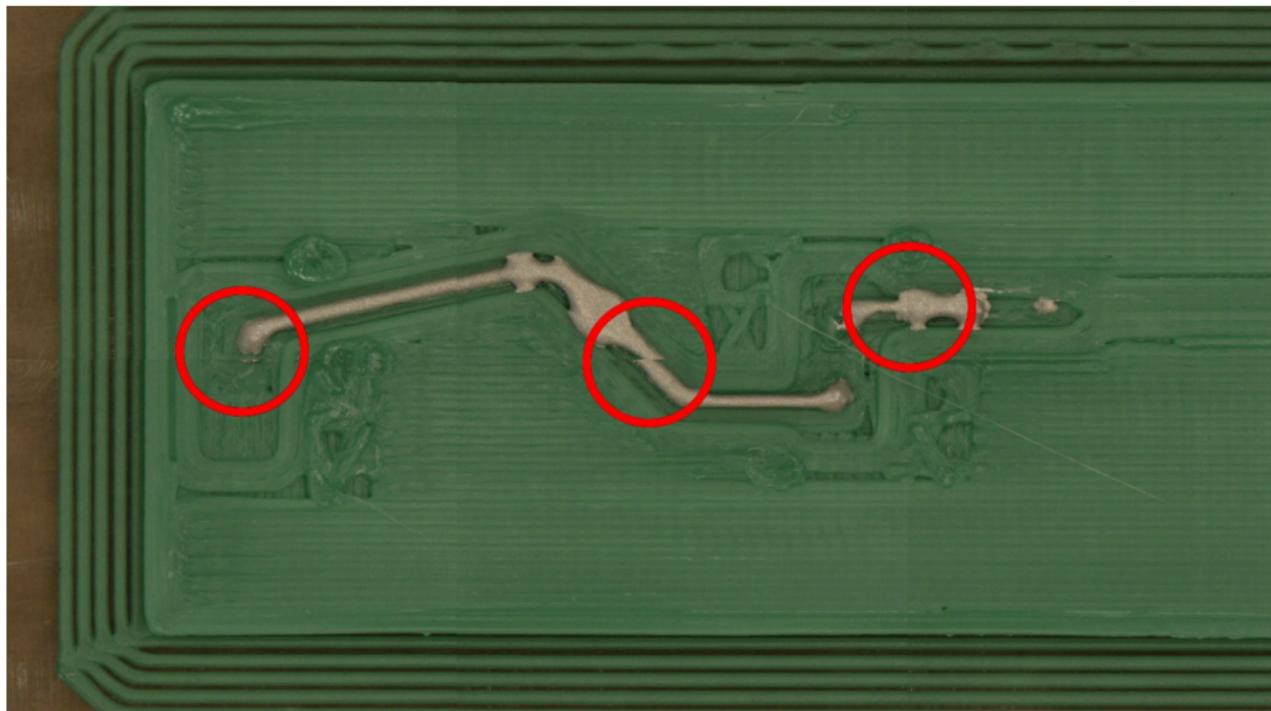
Problem Statement

Collecting "Evidence"

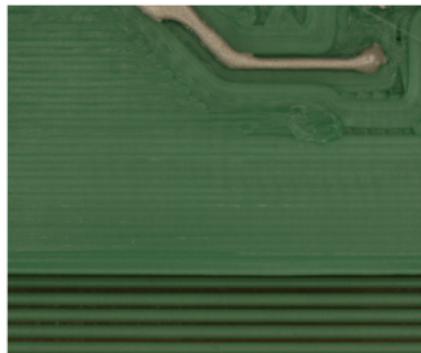
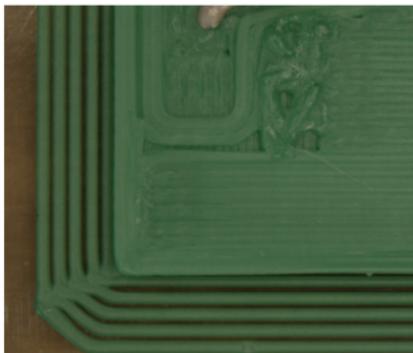
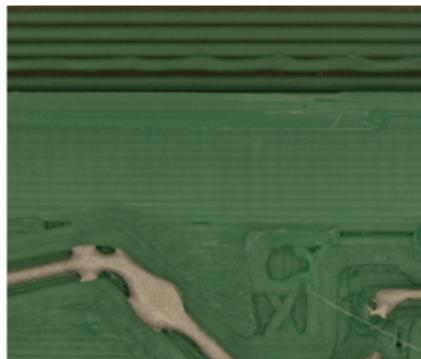
Feature Segmentation

Fault Detection

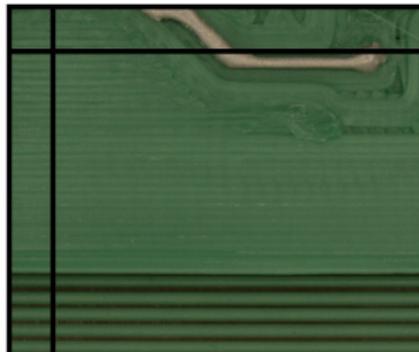
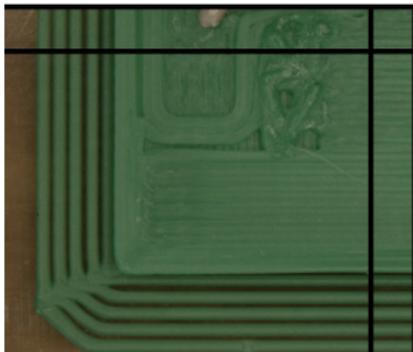
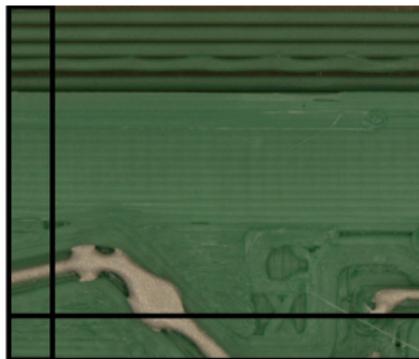
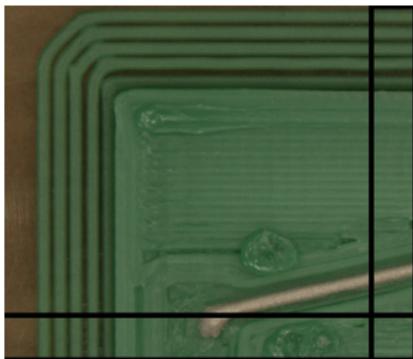
Conclusion



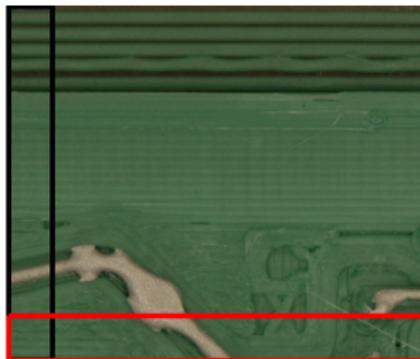
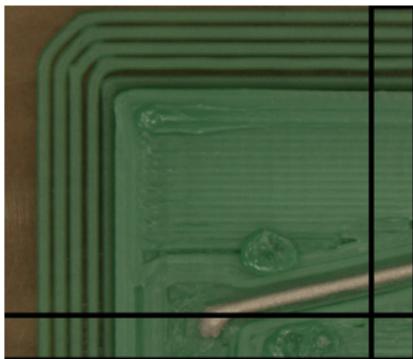
# Tile-Correlation Adjustment



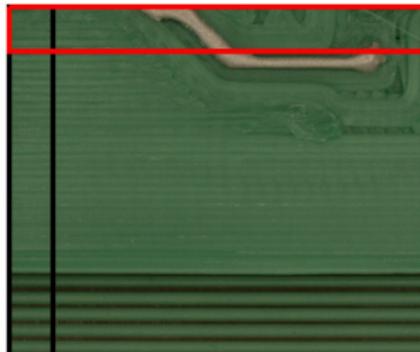
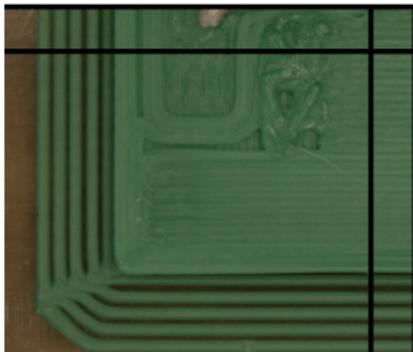
# Tile-Correlation Adjustment



# Tile-Correlation Adjustment



ECC-Correlation



# Tile-Correlation Adjustment

Introduction / Hardware

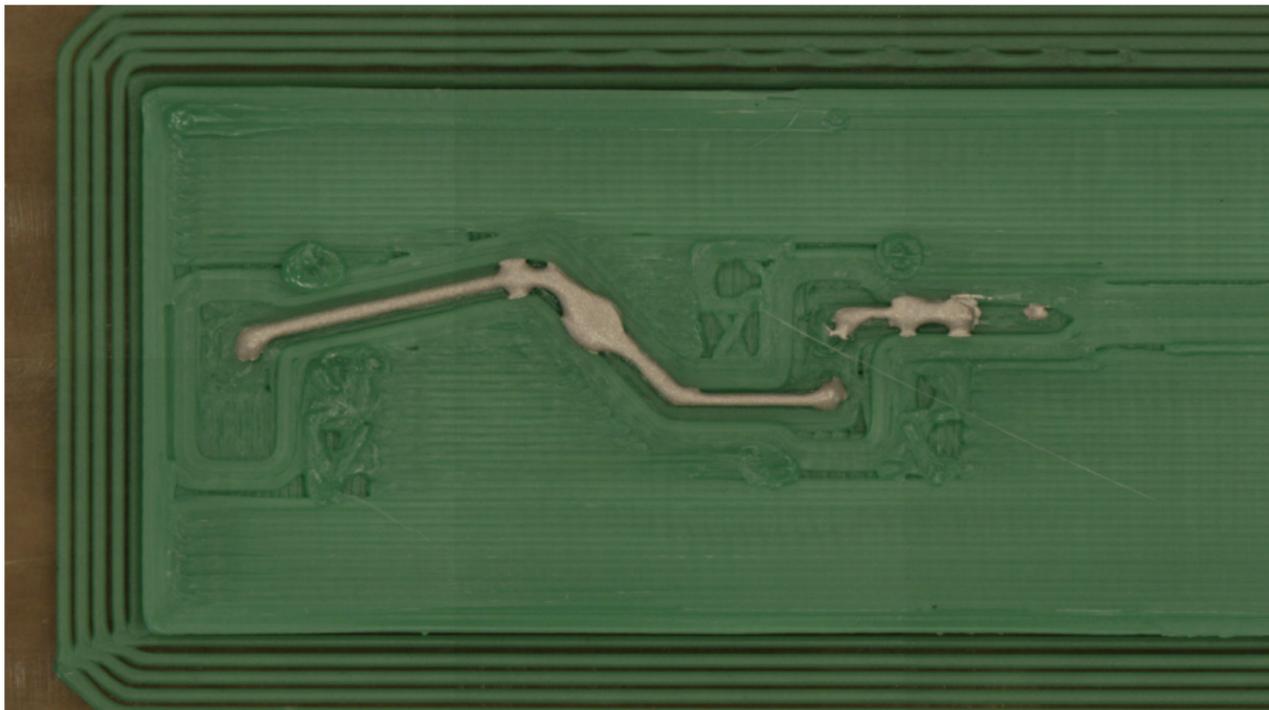
Problem Statement

Collecting "Evidence"

Feature Segmentation

Fault Detection

Conclusion



# Identify Ink vs. Plastic

Introduction / Hardware

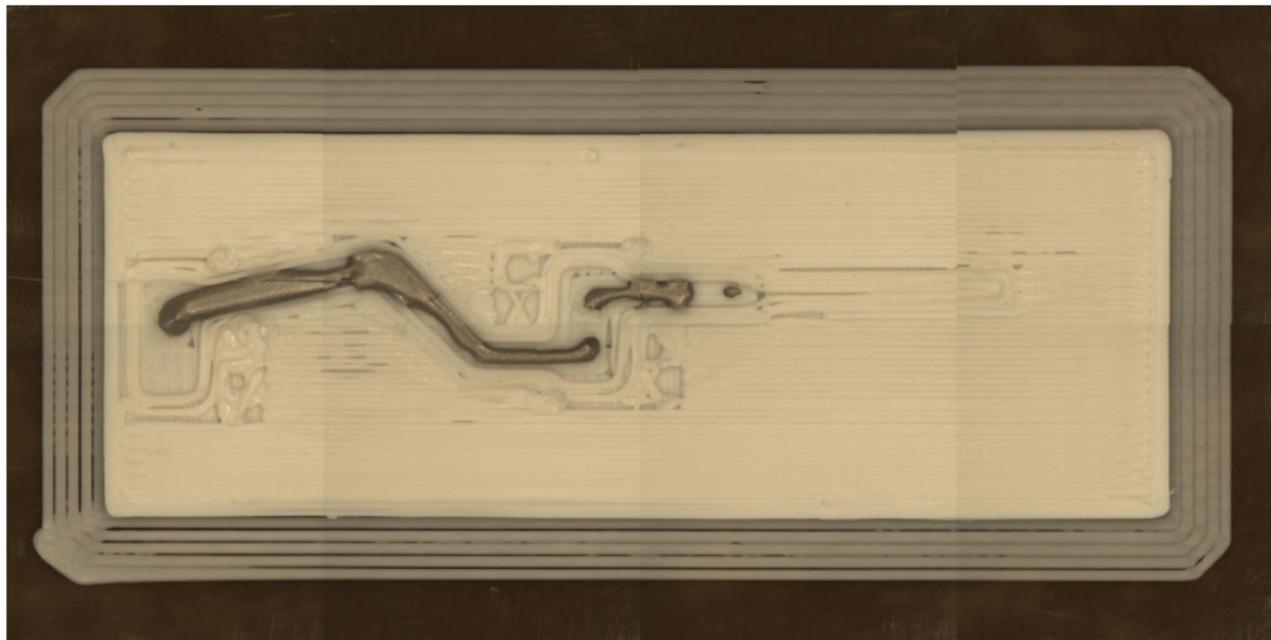
Problem Statement

Collecting "Evidence"

Feature Segmentation

Fault Detection

Conclusion



Raw image

# Identify Ink vs. Plastic

Introduction / Hardware

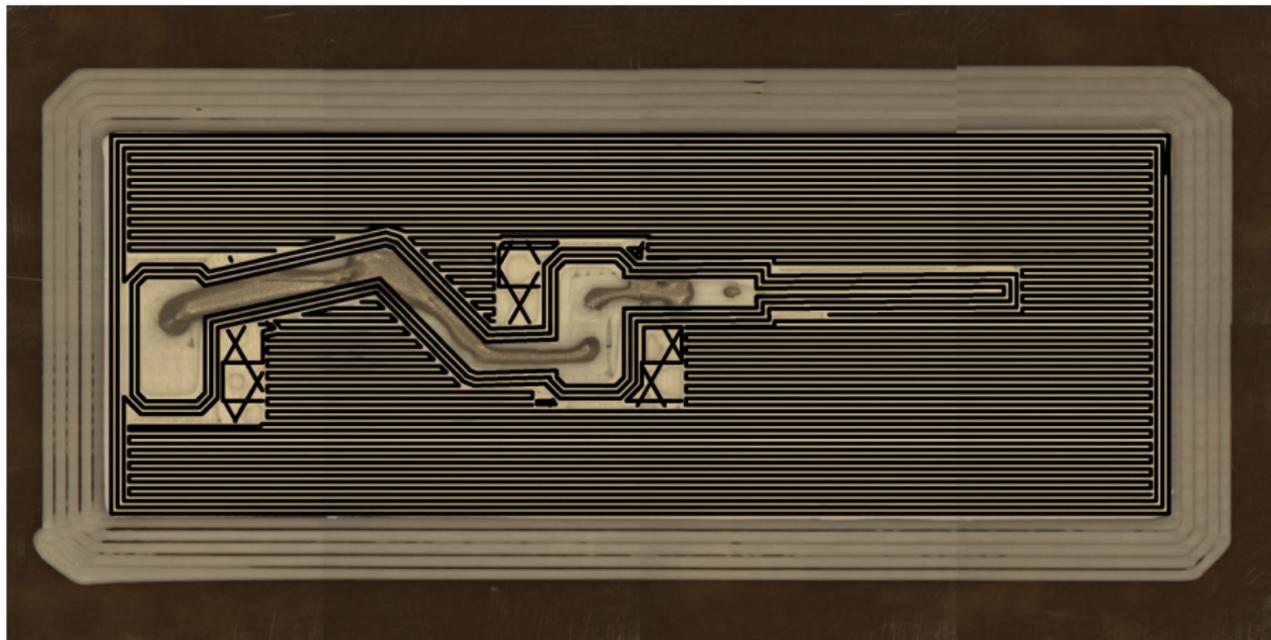
Problem Statement

Collecting "Evidence"

Feature Segmentation

Fault Detection

Conclusion



Overlay T0 (plastic extruder)

# Identify Ink vs. Plastic

Introduction / Hardware

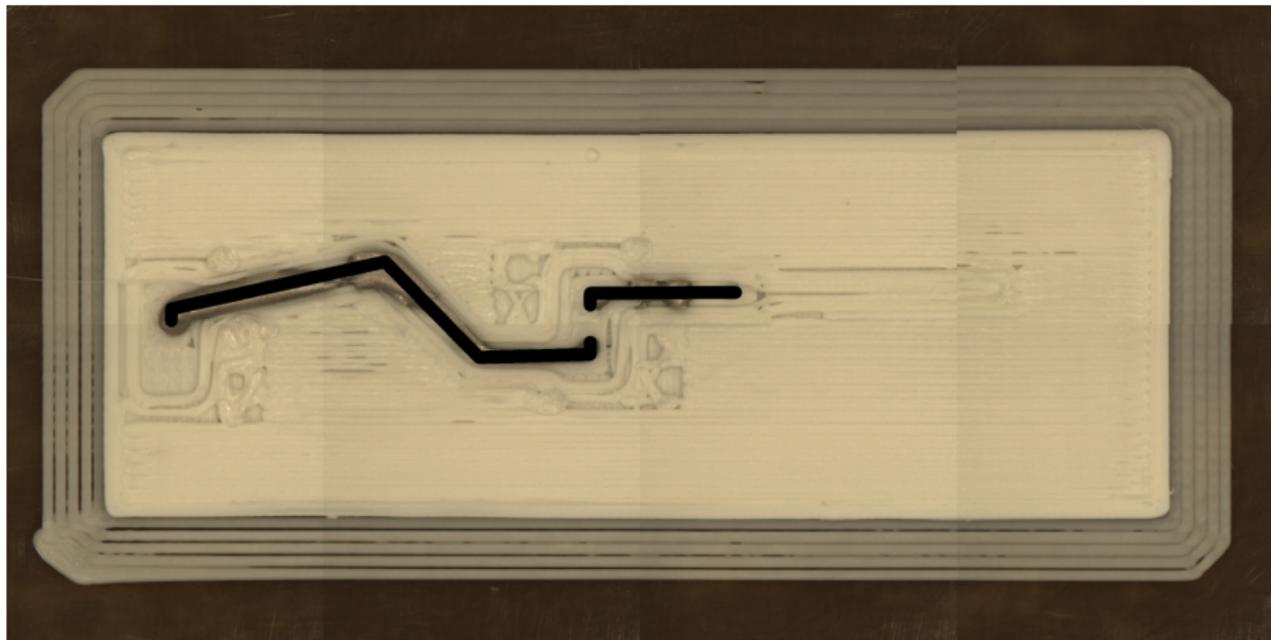
Problem Statement

Collecting "Evidence"

Feature Segmentation

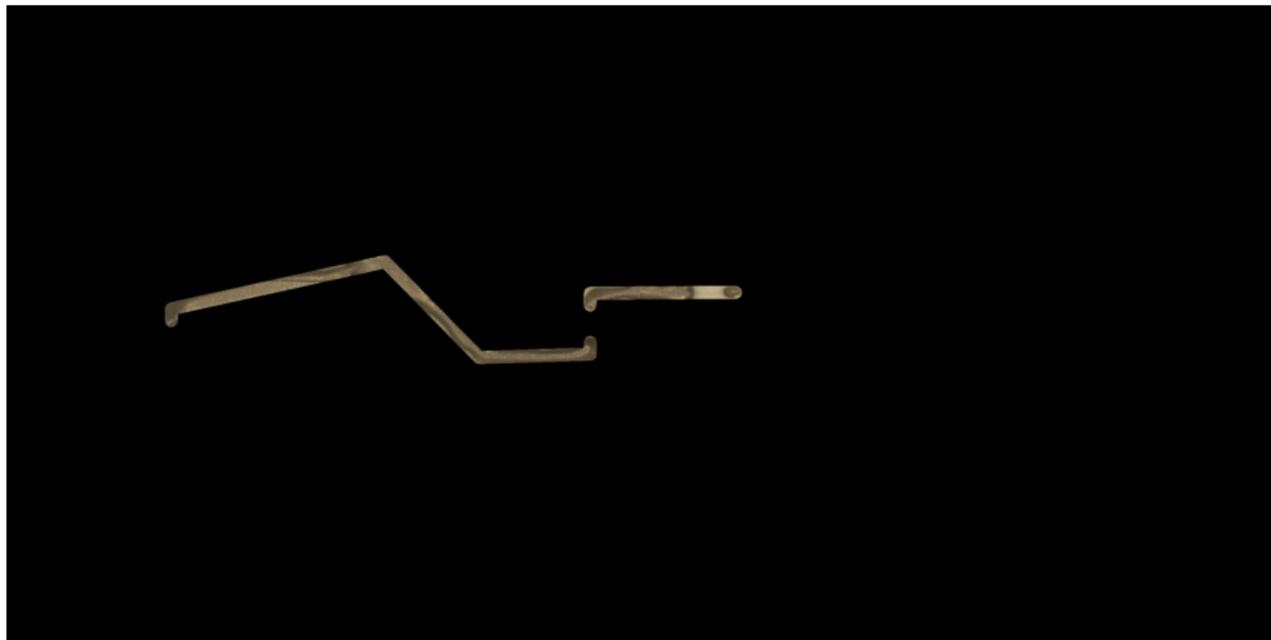
Fault Detection

Conclusion



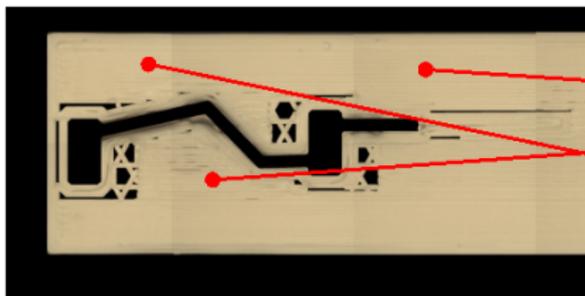
Overlay T1 (conductive extruder)

# Identify Ink vs. Plastic



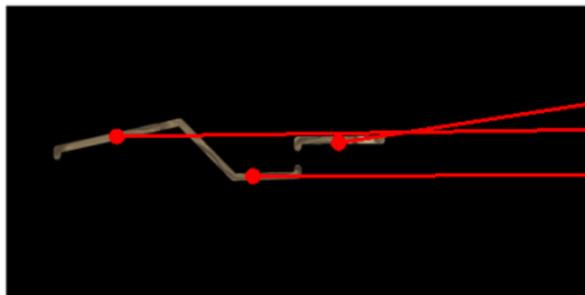
Masking all T1 pixels

# Identify Ink vs. Plastic



H	S	V	Class
21	180	76	A
9	211	61	A
87	180	96	A
...	...	...	A

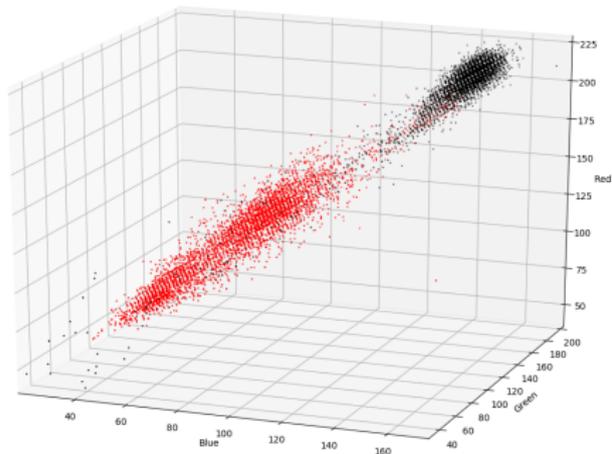
...



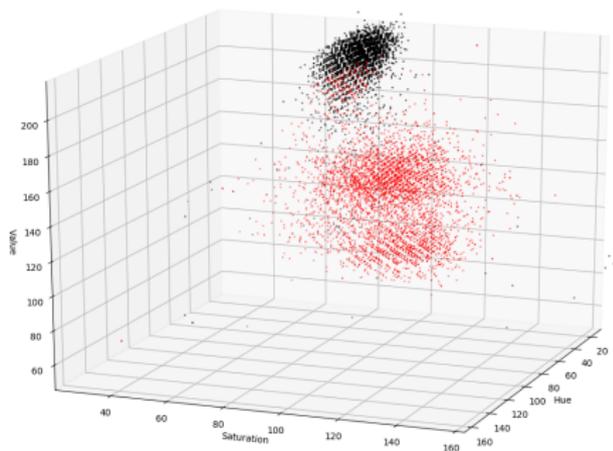
241	11	114	B
209	17	123	B
188	24	151	B
...	...	...	B

Extract random subsample of pixels

# Identify Ink vs. Plastic

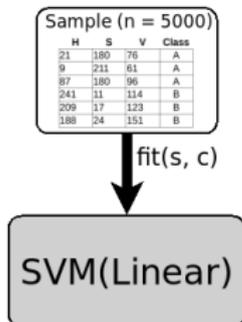


RGB

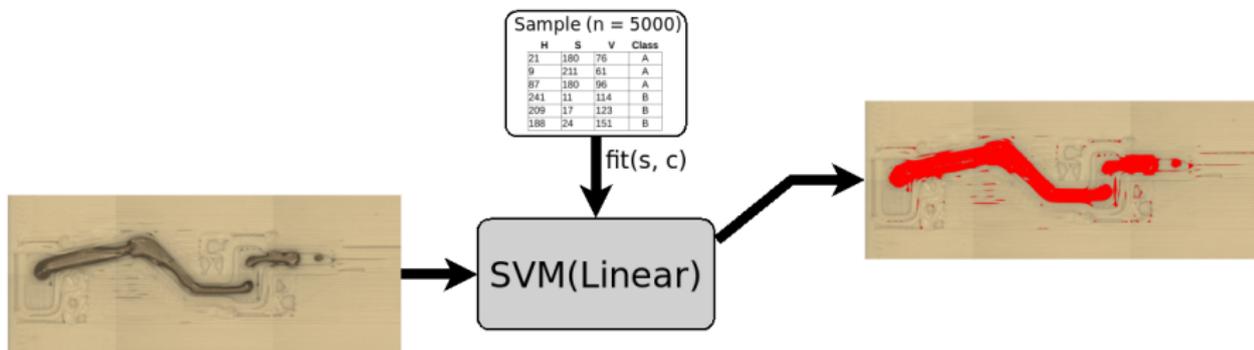


HSV

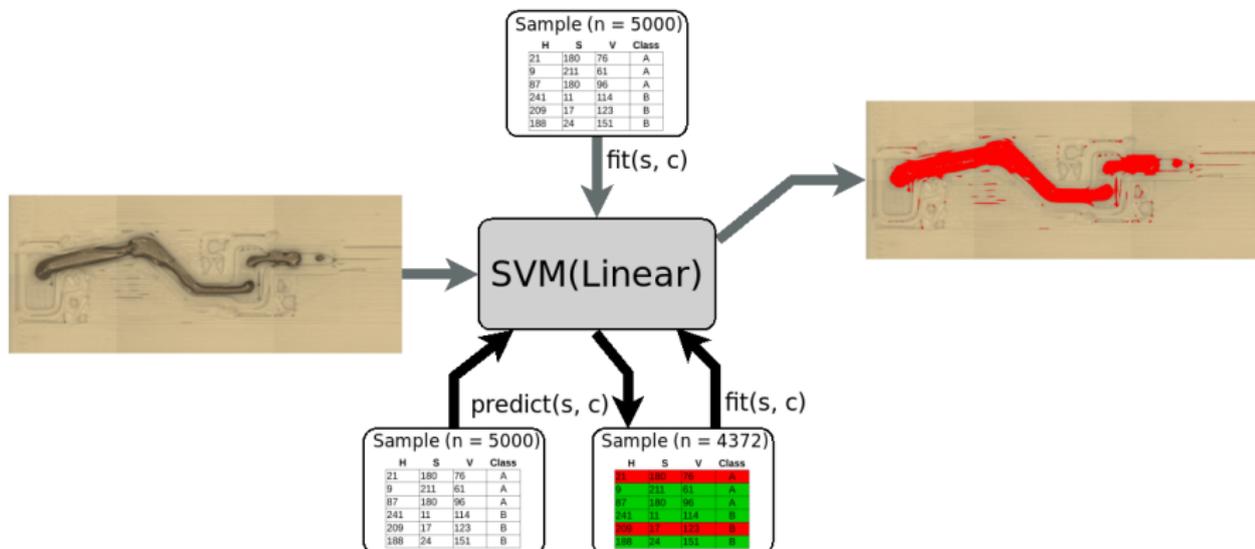
# Pixel Segmentation



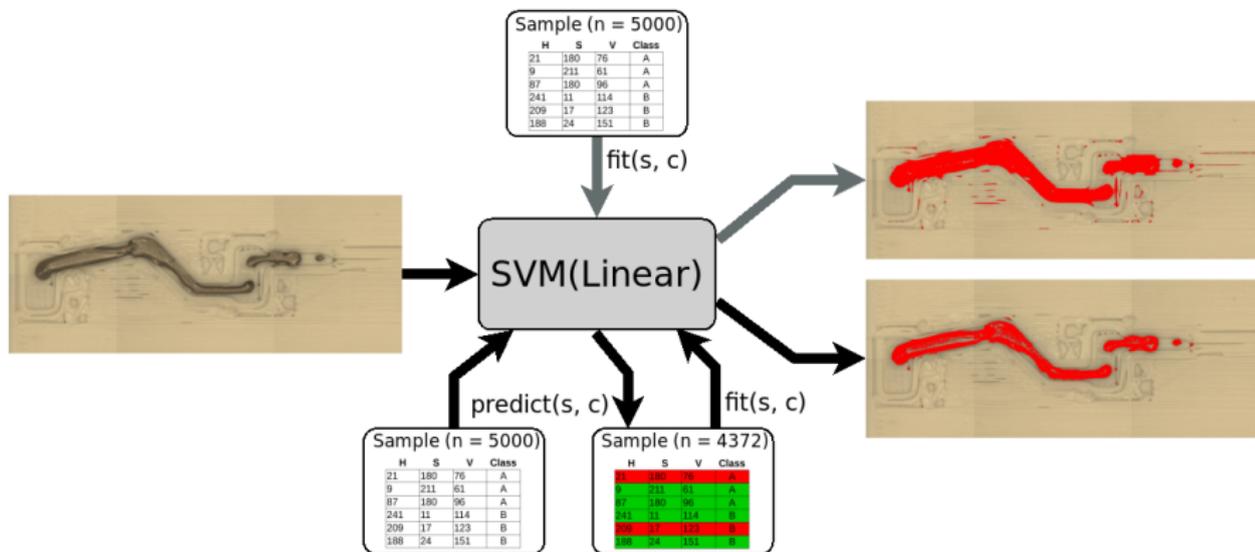
# Pixel Segmentation



# Pixel Segmentation



# Pixel Segmentation



# Other Filament Colors?

Introduction / Hardware

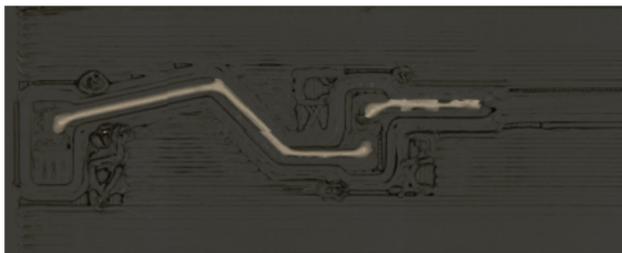
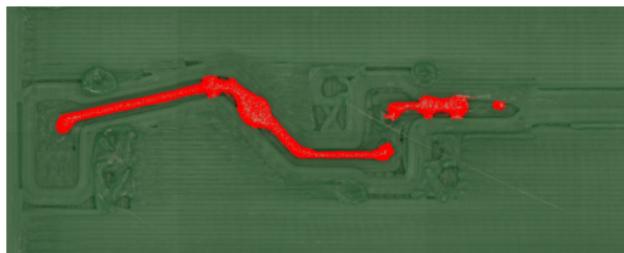
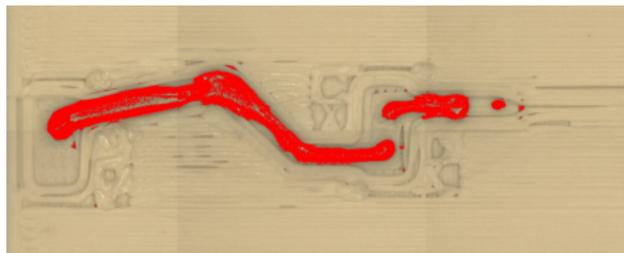
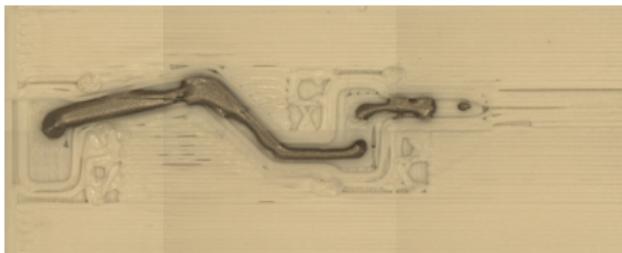
Problem Statement

Collecting "Evidence"

Feature Segmentation

Fault Detection

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# Sliding Window Detector

Introduction / Hardware

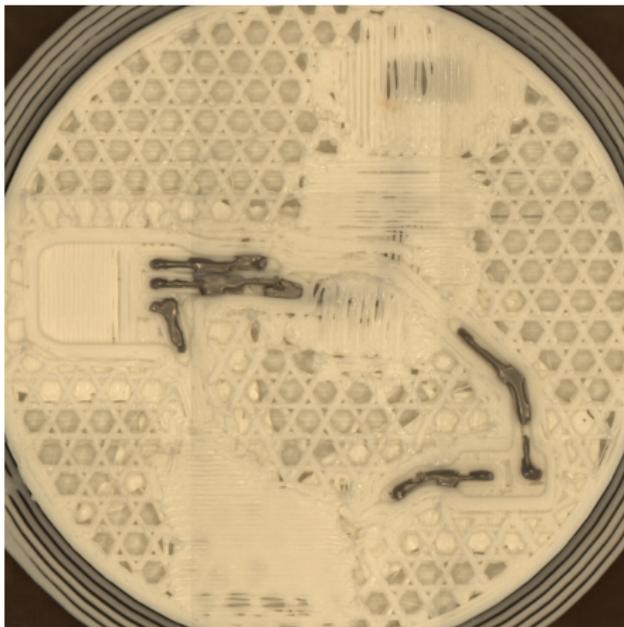
Problem Statement

Collecting "Evidence"

Feature Segmentation

**Fault Detection**

Conclusion



# Sliding Window Detector

Introduction / Hardware

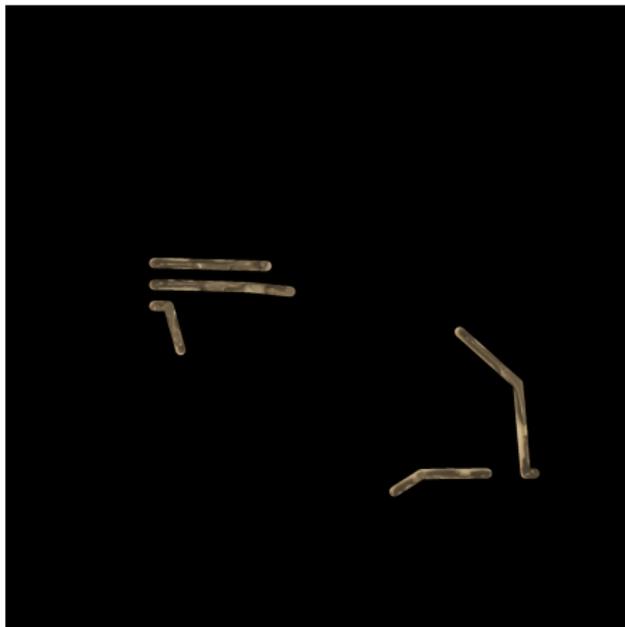
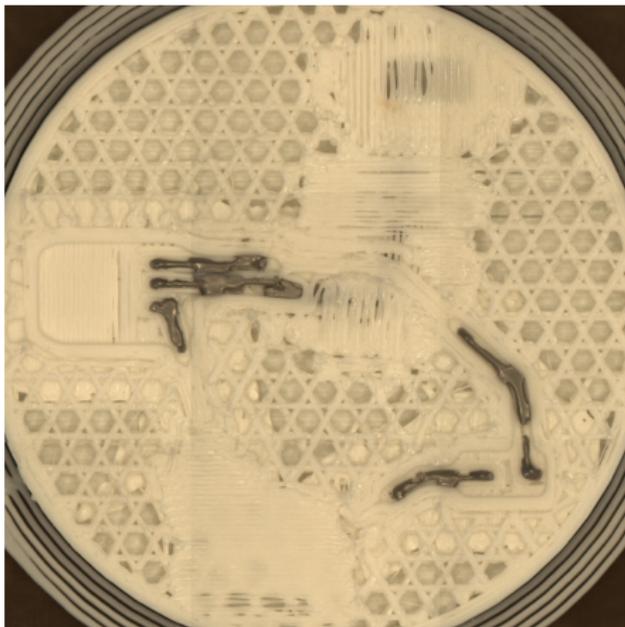
Problem Statement

Collecting "Evidence"

Feature Segmentation

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# Sliding Window Detector

Introduction / Hardware

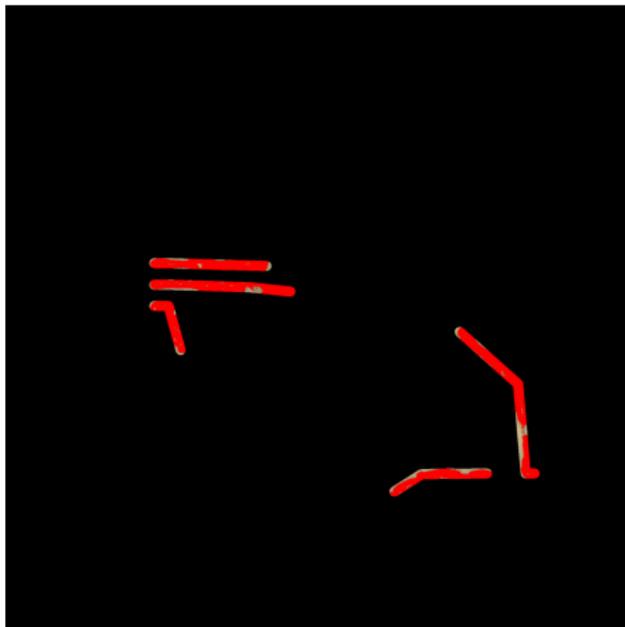
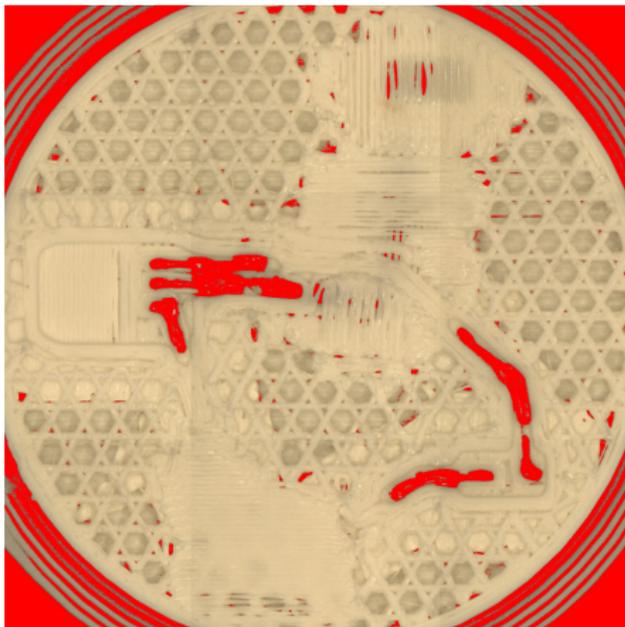
Problem Statement

Collecting "Evidence"

Feature Segmentation

Fault Detection

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# Sliding Window Detector

Introduction / Hardware

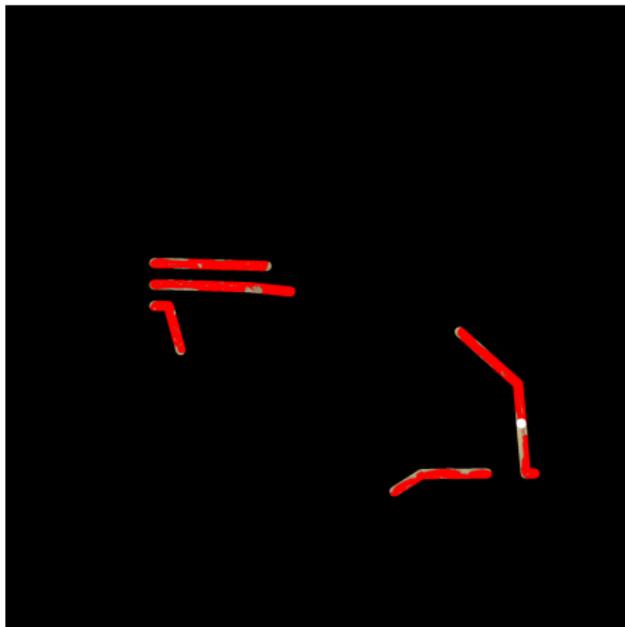
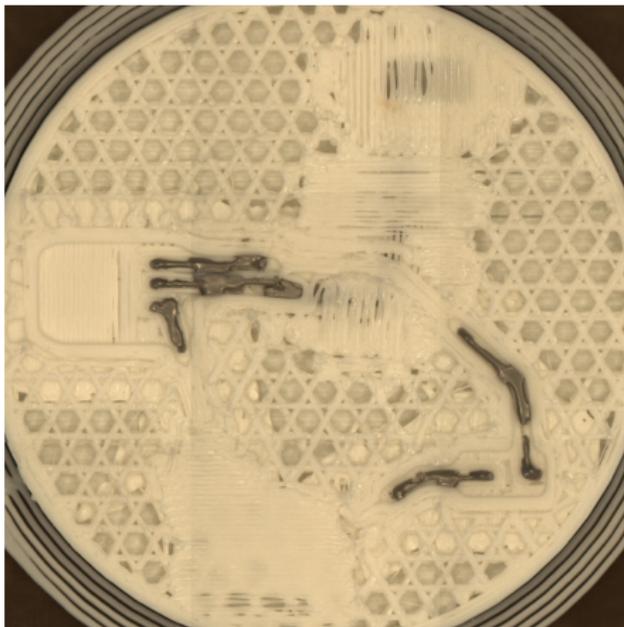
Problem Statement

Collecting "Evidence"

Feature Segmentation

Fault Detection

Conclusion



# Sliding Window Detector

Introduction / Hardware

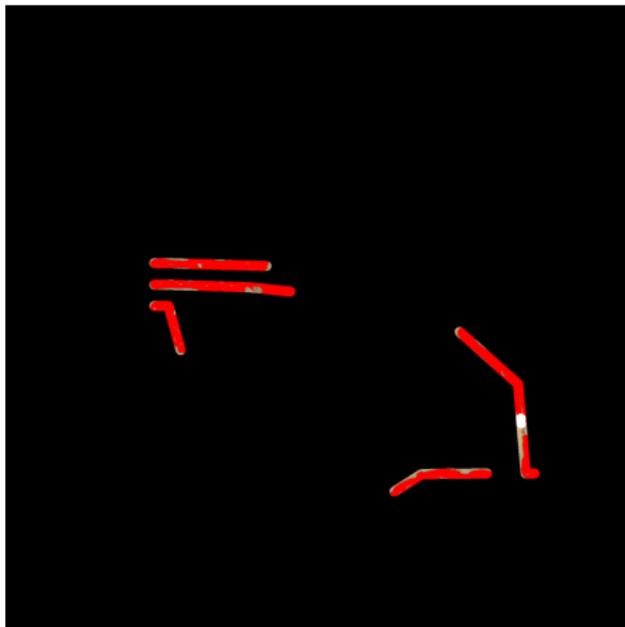
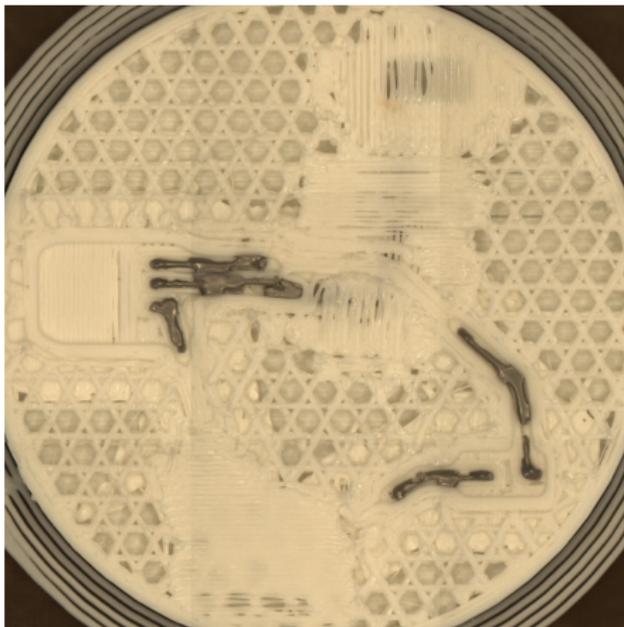
Problem Statement

Collecting "Evidence"

Feature Segmentation

Fault Detection

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# Sliding Window Detector

Introduction / Hardware

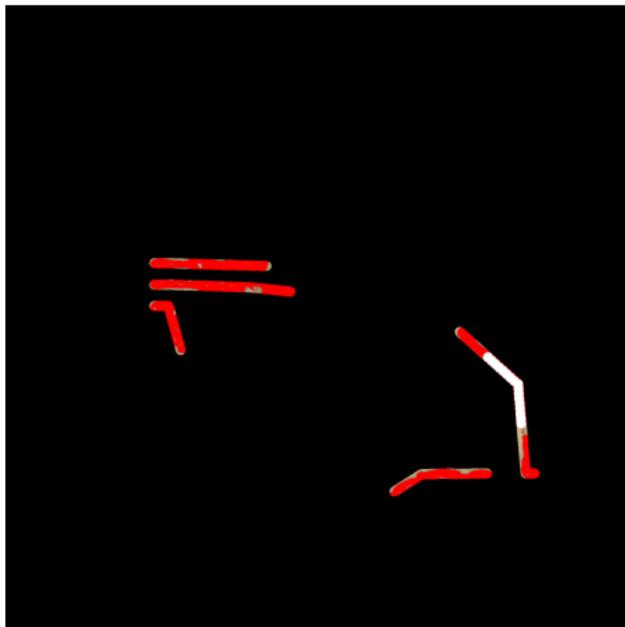
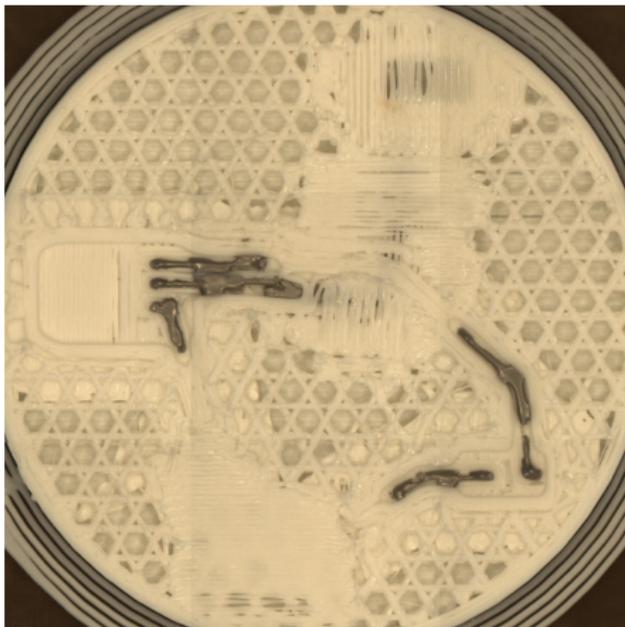
Problem Statement

Collecting "Evidence"

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# Sliding Window Detector

Introduction / Hardware

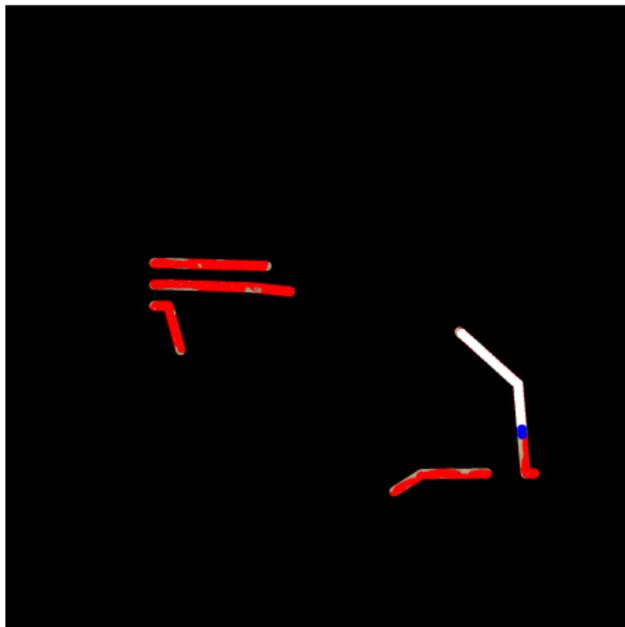
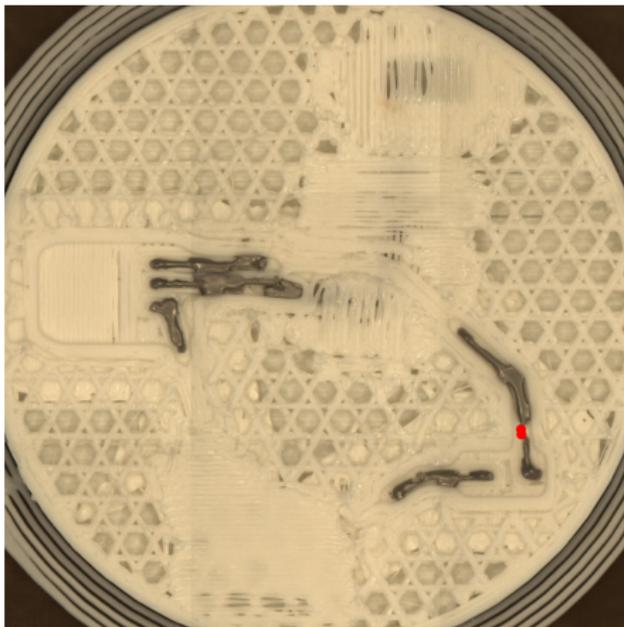
Problem Statement

Collecting "Evidence"

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# Results

Introduction / Hardware

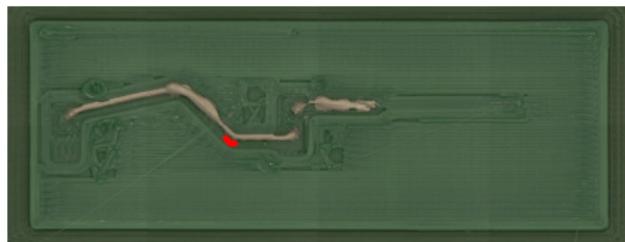
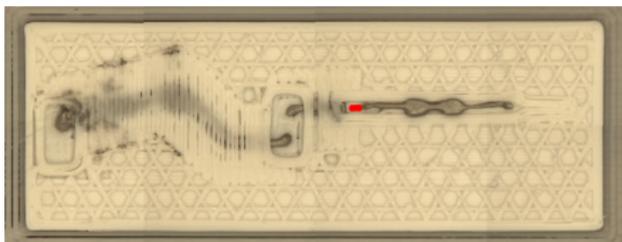
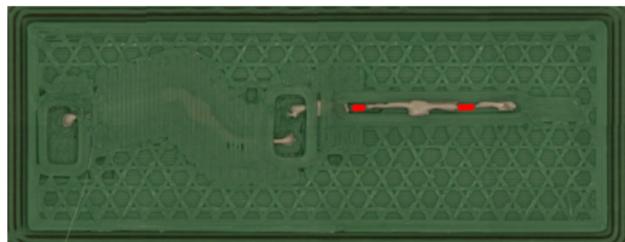
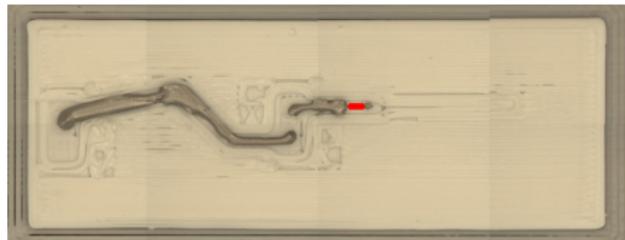
Problem Statement

Collecting "Evidence"

Feature Segmentation

Fault Detection

Conclusion



# Conclusion

Class	Cause	Solved?
Interruptions	Ink Dispensing	✓
	Positioning	✓
	Plastic Strands	?
	Edges	✓
Short Circuits	Overextrusion	?
	Smearred Ink	?
Interlayer Connections		✗
SMD-Components	Short Under Component	✗
	Positioning / Alignment	✗

# What's Next?

- ▶ More sophisticated detection methods:
  - ▶ Test for absence of ink
  - ▶ Connected components
  - ▶ Neural networks?

# What's Next?

- ▶ More sophisticated detection methods:
  - ▶ Test for absence of ink
  - ▶ Connected components
  - ▶ Neural networks?
- ▶ Surprisingly: calibration is important!! 😊

Download / Sourcecode:

*[tams.informatik.uni-hamburg.de/research/3d-printing/conductive\\_printing](https://tams.informatik.uni-hamburg.de/research/3d-printing/conductive_printing)*

—

*[github.com/platsch/OctoCameraDocumentation](https://github.com/platsch/OctoCameraDocumentation)*