Feature Detection and System Identification

Laser triangulation based deposition feature detection and steady-state input-output modelling

Ali Toyserkani, Gijs Houtam

Goals

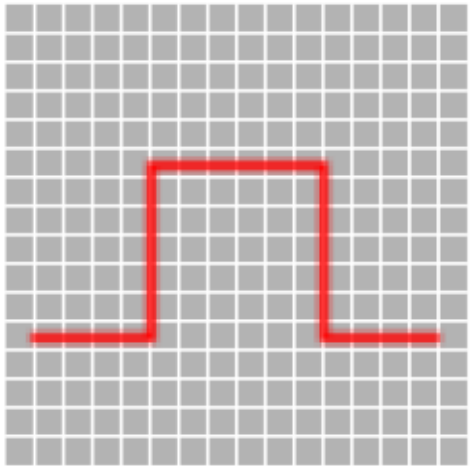
Proof-of-Concept:

Is it possible to make a low-cost vision sensing technique able to detect deposition height and width accurately in a real-time setup?

Hardware:	Software:
• Low-Cost components	• Fast Detection Algorithm
• Applicable to existing 3D-printers	• Constant execution time
• Commercially attractive	

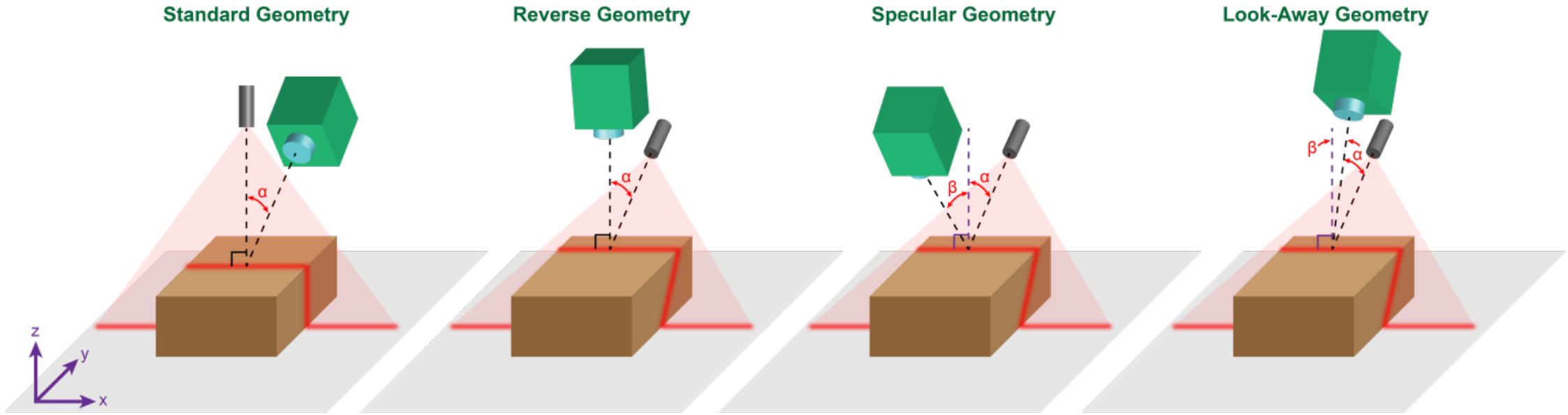
Laser Triangulation

- Angular positioning exposes deposition geometry
- Many implementations possible



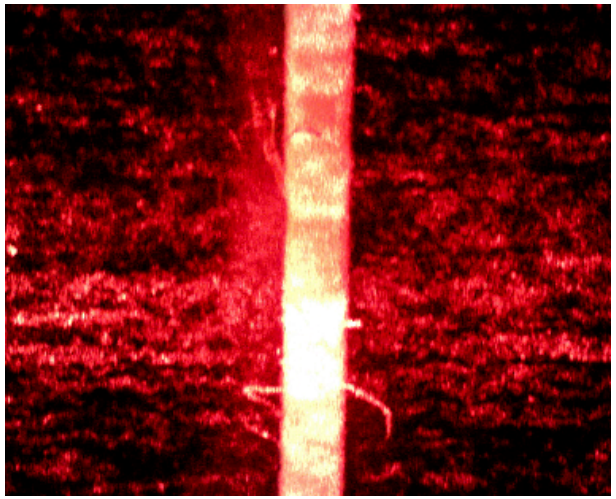
Reverse Geometry:

- Good Camera Focusing
- Good Height Resolution through high α

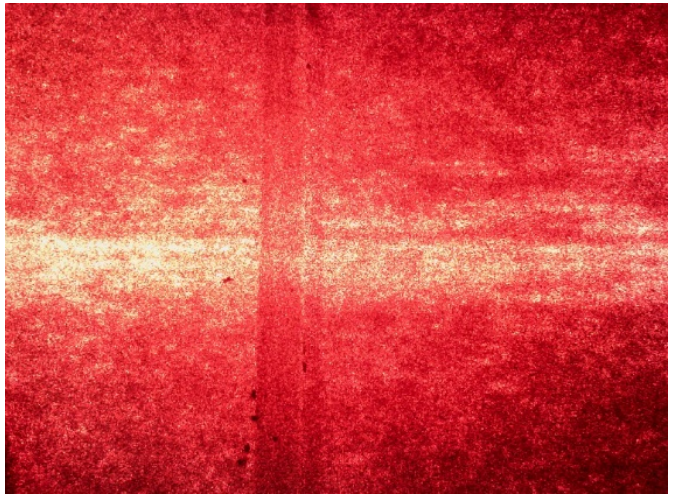


Camera Visuals

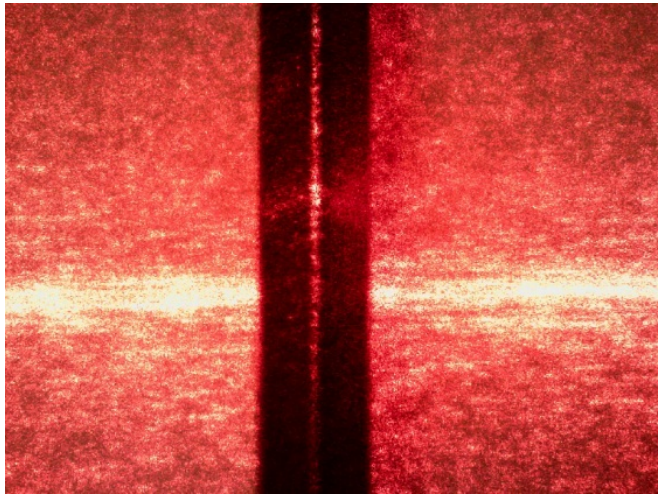
Problem Sources:	Opportunities:
• Laser Lens distortion → Noise	• Separate pixel by intensity
• Pixel Saturation → No difference	• Use lens distortions as Pattern
• Reflection or Absorption	



White object



Transparent object

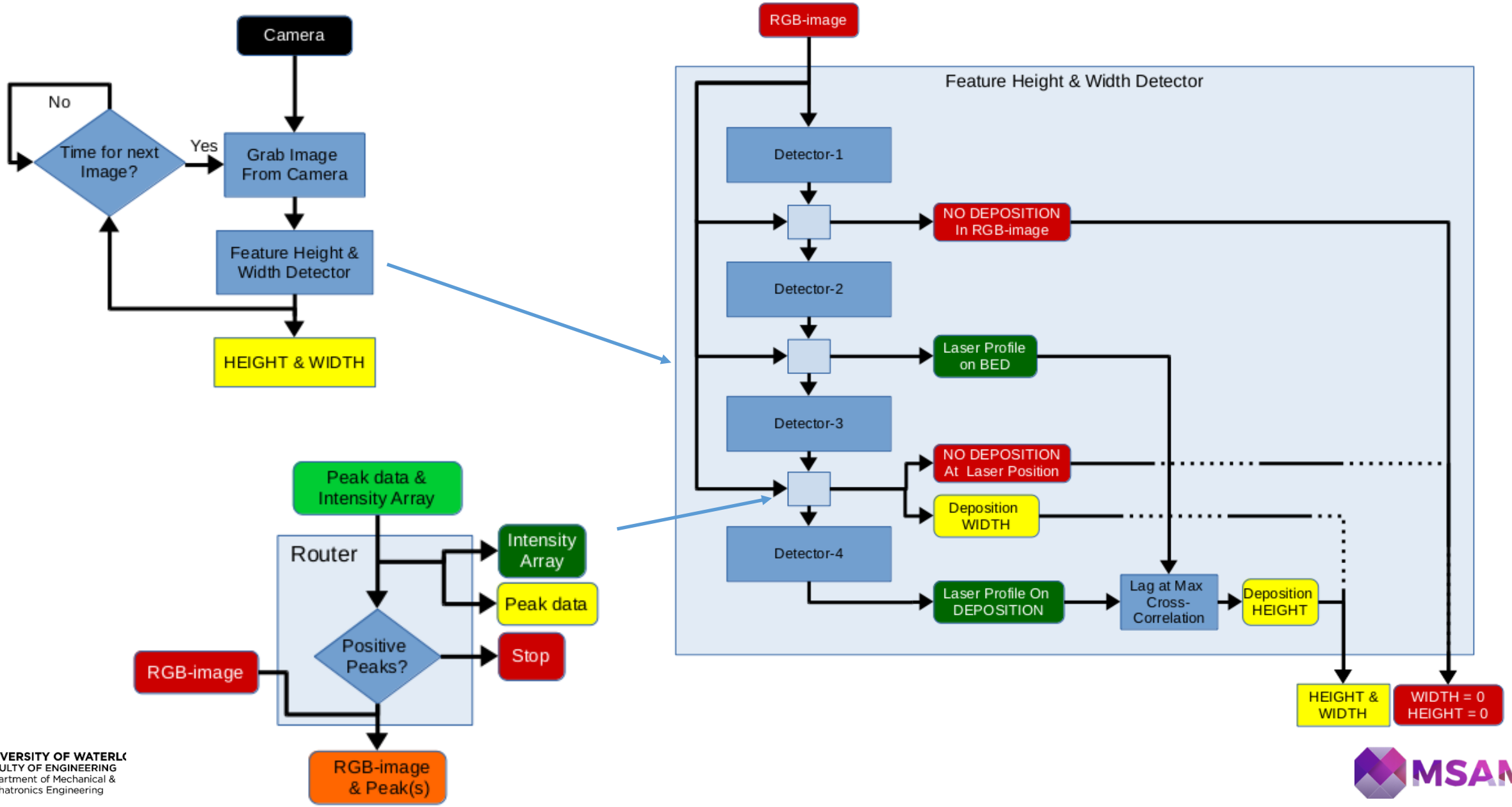


Black object

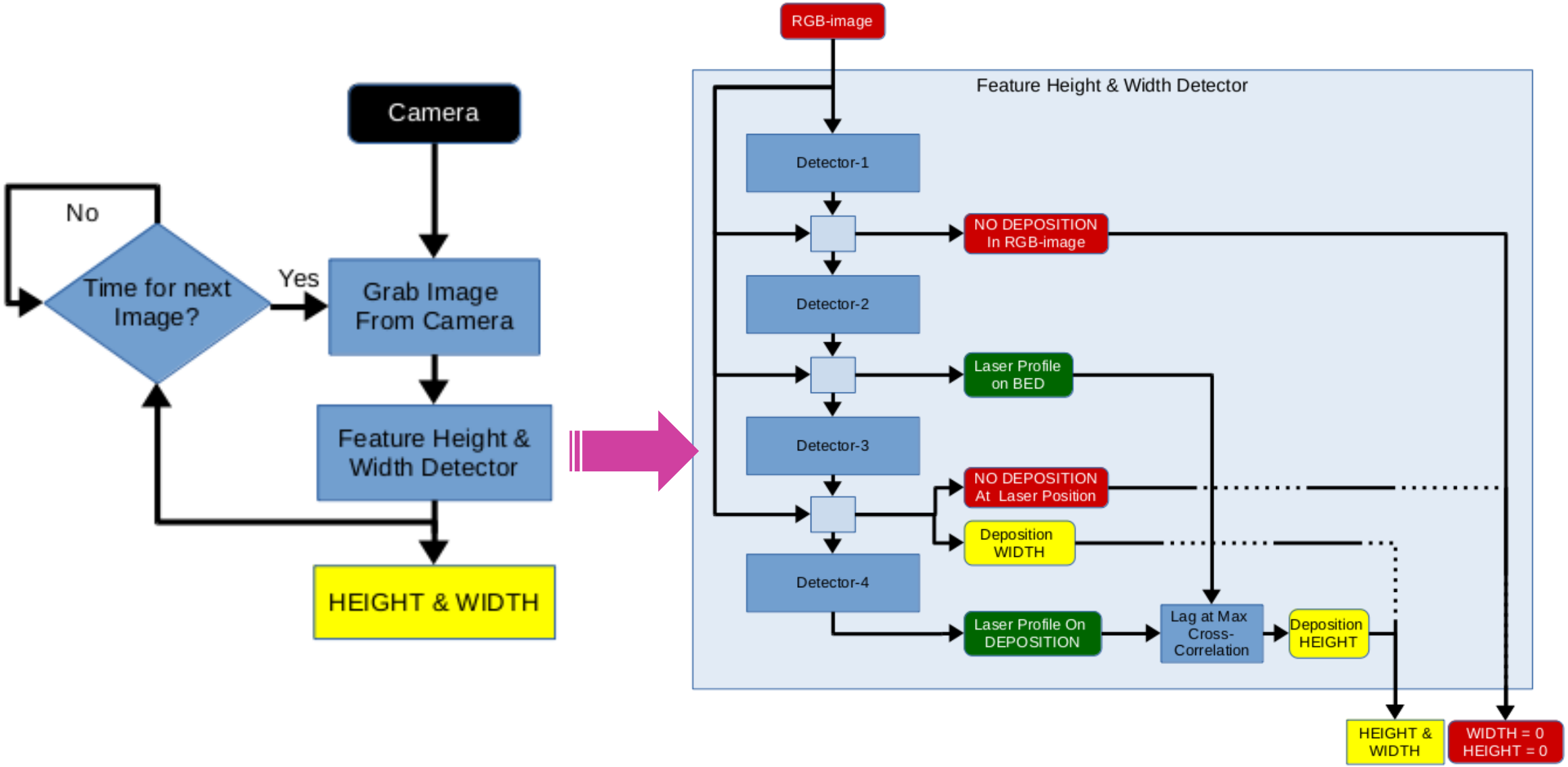
Computational matters

Problem Sources:	Opportunities:
• 8-bit RGB-images (15 million integers) → **Operations are costly**	• Find regions of interest → **Reduce operation cost**
• Avoid common 2D computer vision operations e.g. convolution filtering, edge detection → **Low Speed**	• Use fast 1D operations e.g. 1D filtering, differencing → **High Speed**
• Avoid optimization algorithms → **Timing consistency**	• Use consistent computational elements e.g. fixed array size → **Consistency**

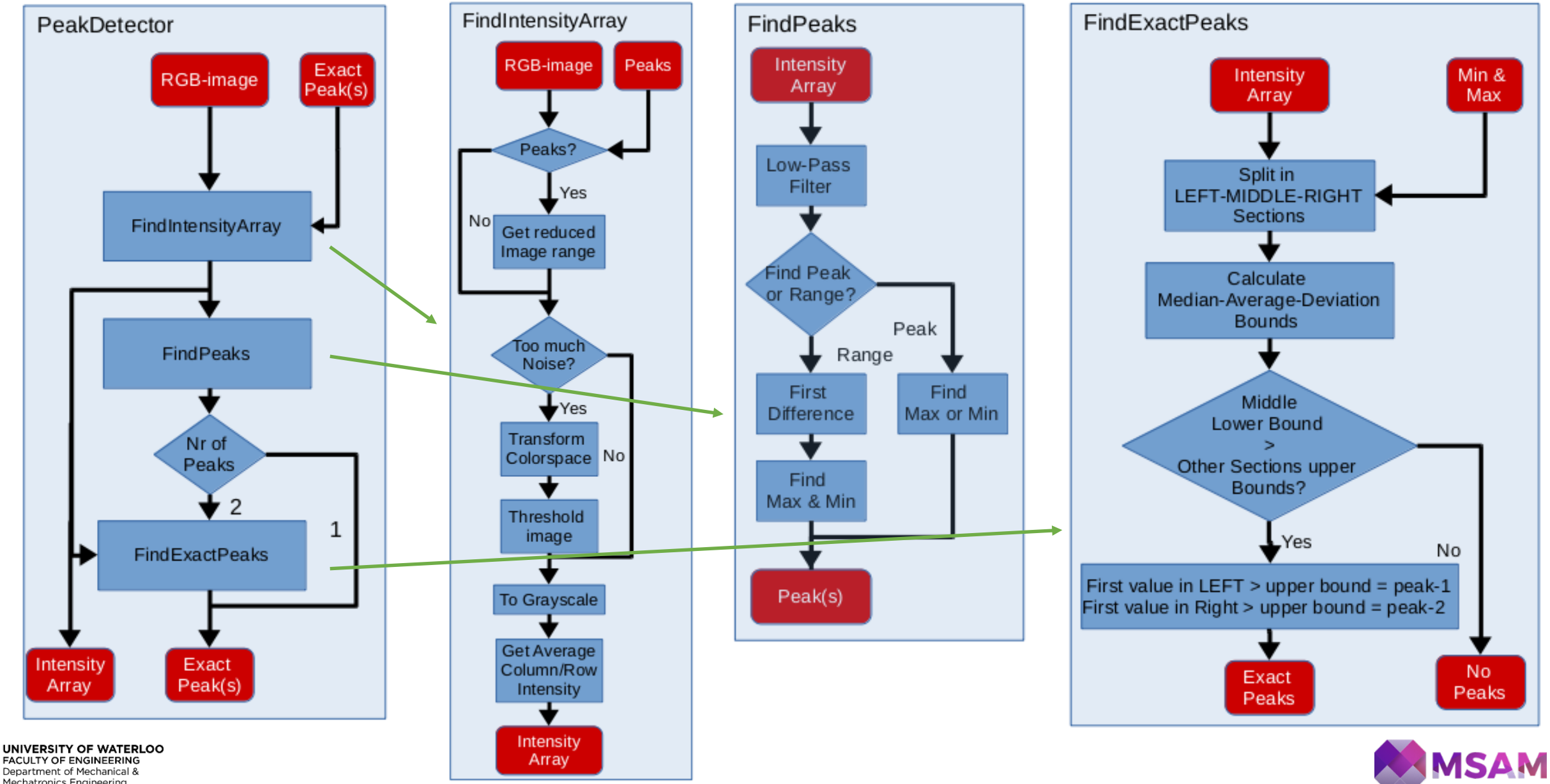
Detection Algorithm – Main Loop



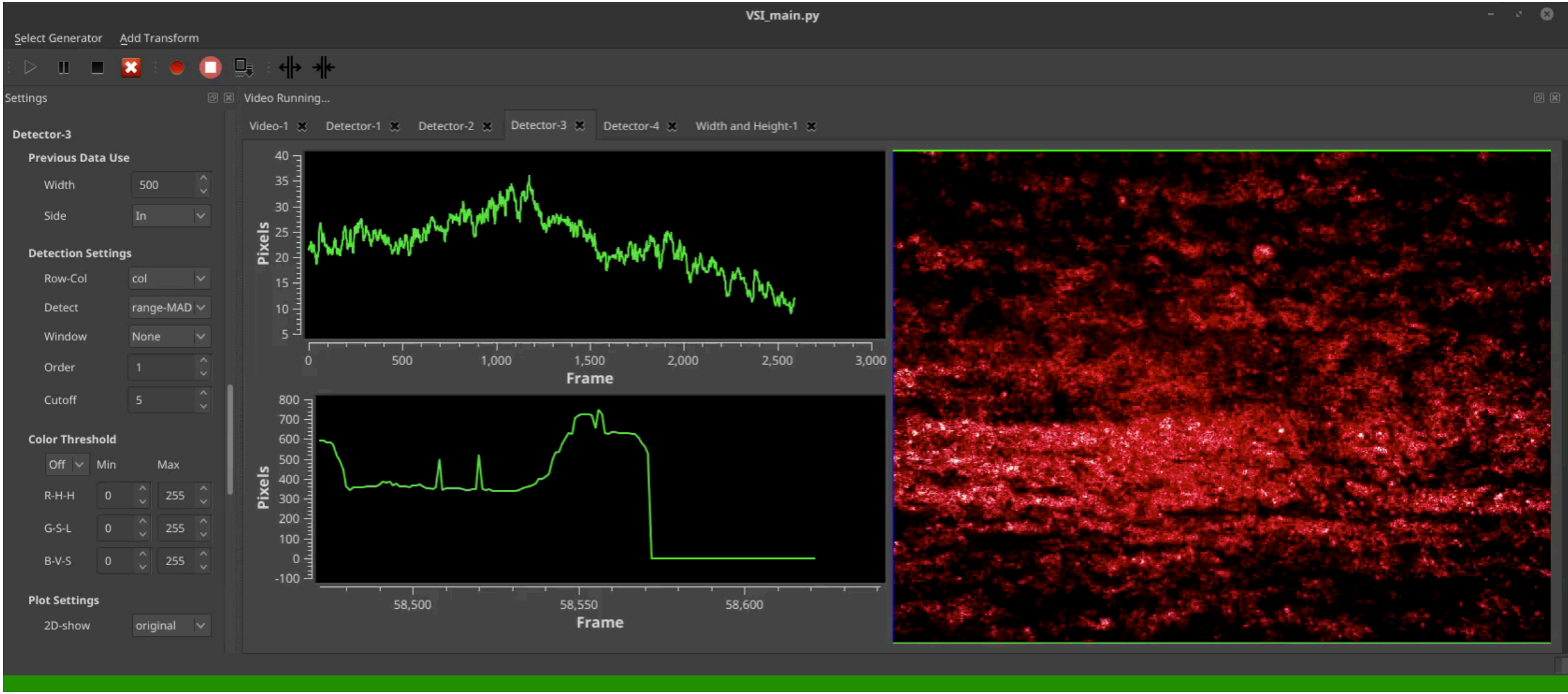
Detection Algorithm – Main Loop



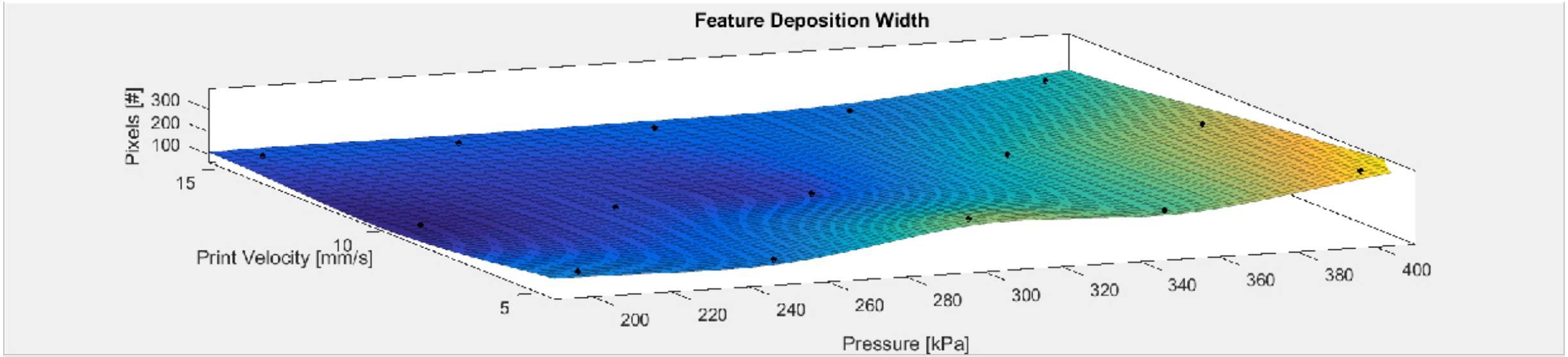
Detection Algorithm – Detector

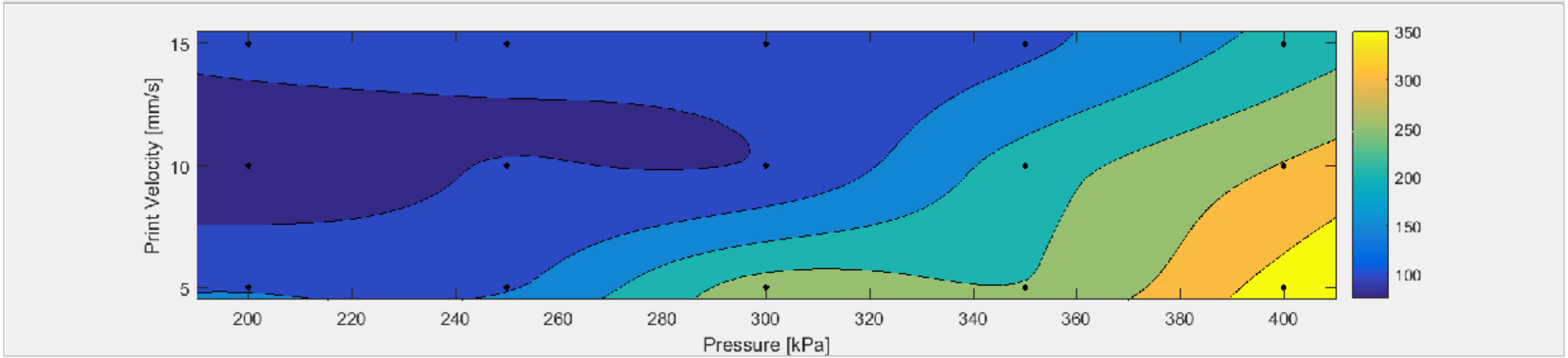


Detection Algorithm – Demo

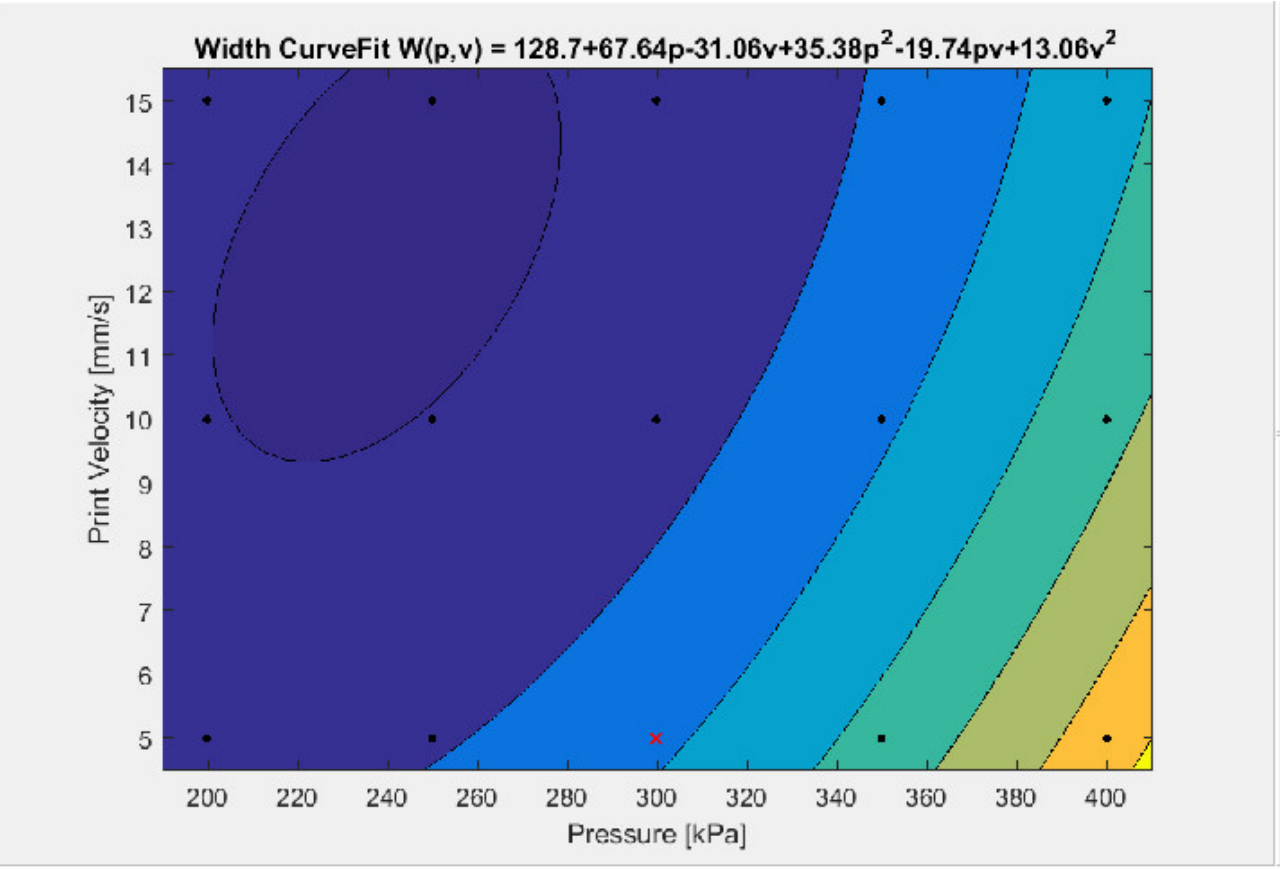


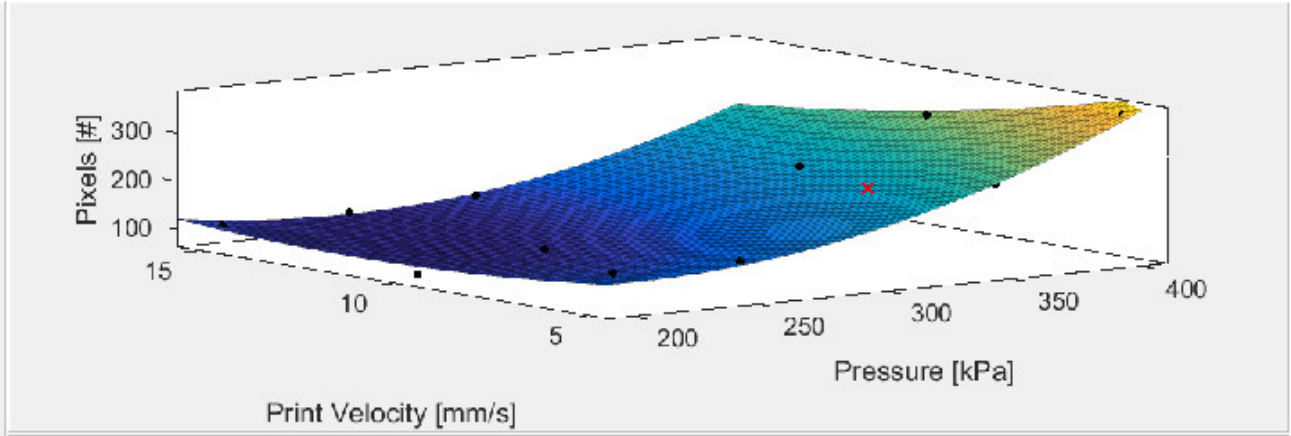
Profile Map of Width vs Pressure and Deposition Velocity

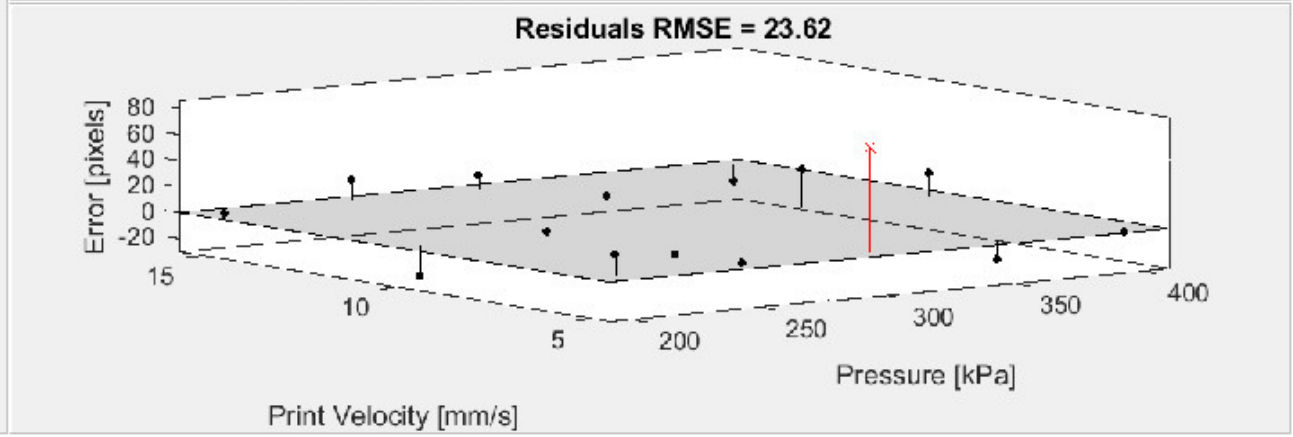




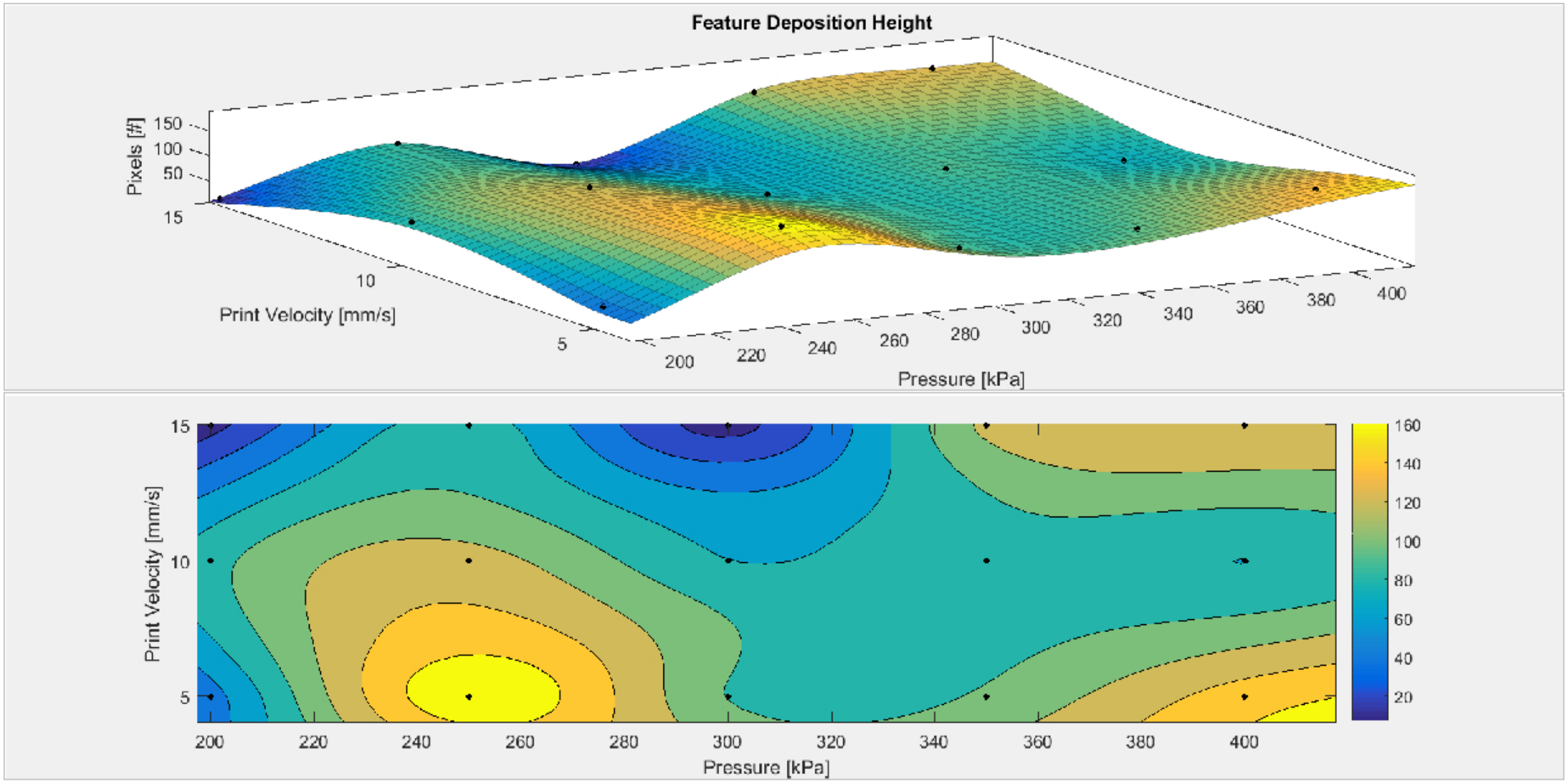
Steady-State Modeling – Width Fit



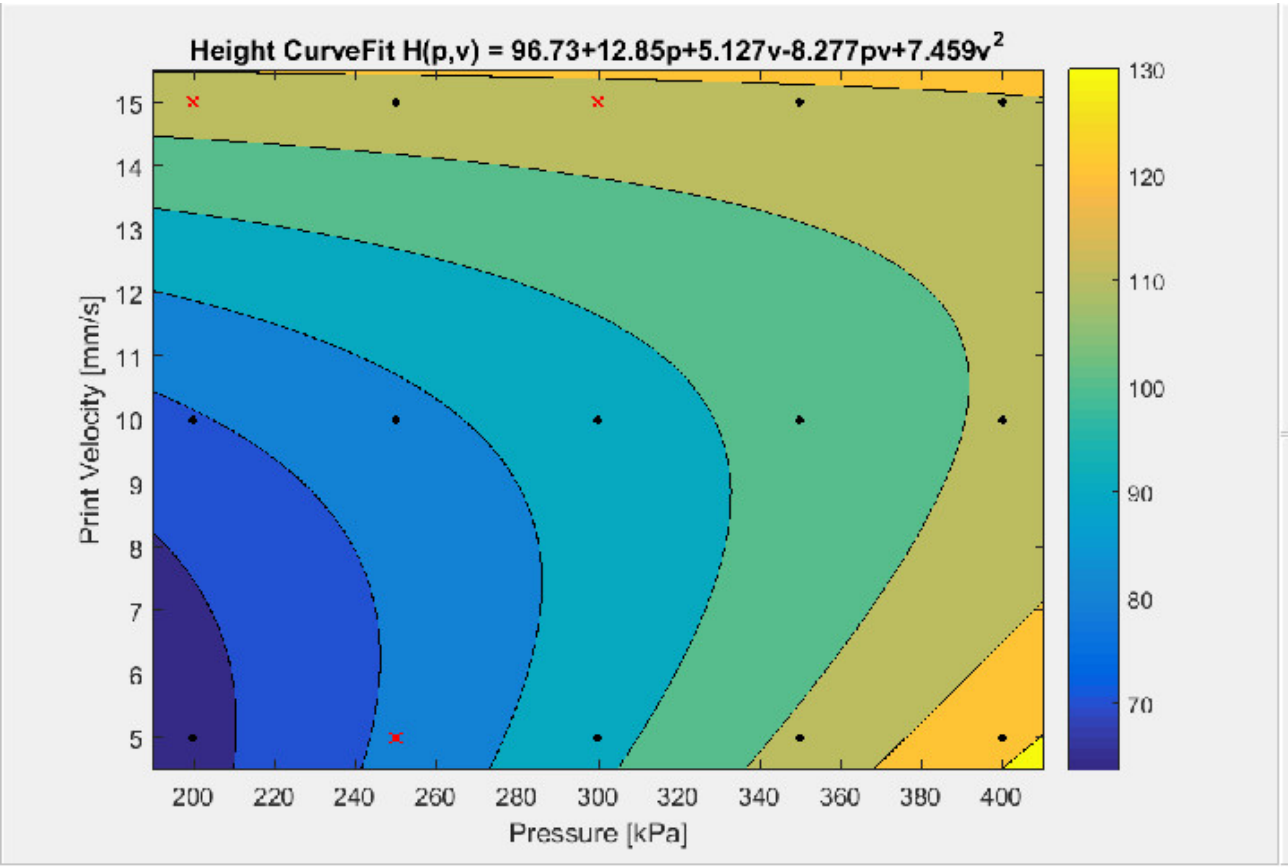


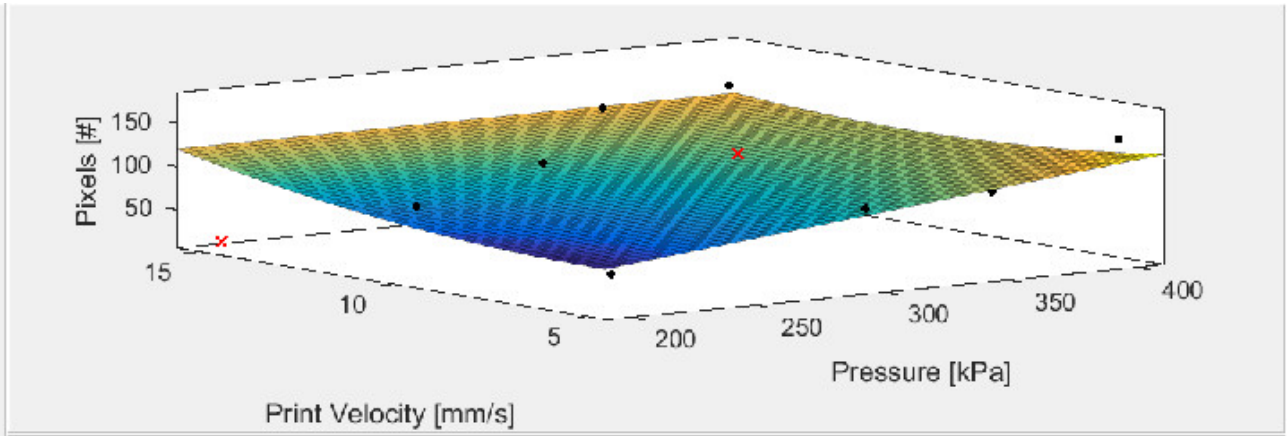


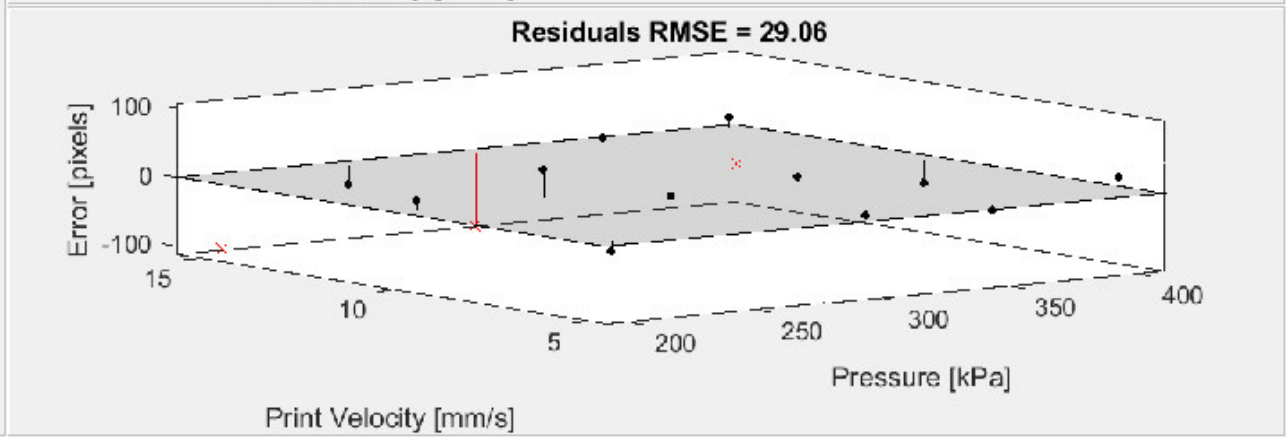
Steady-State Modeling – Height results



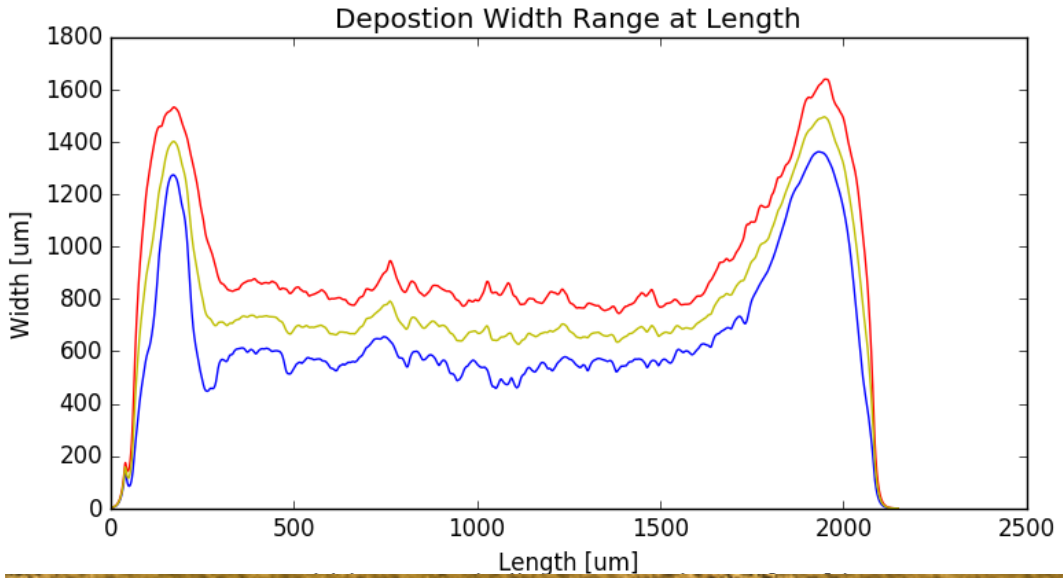
Steady-State Modeling – Height results

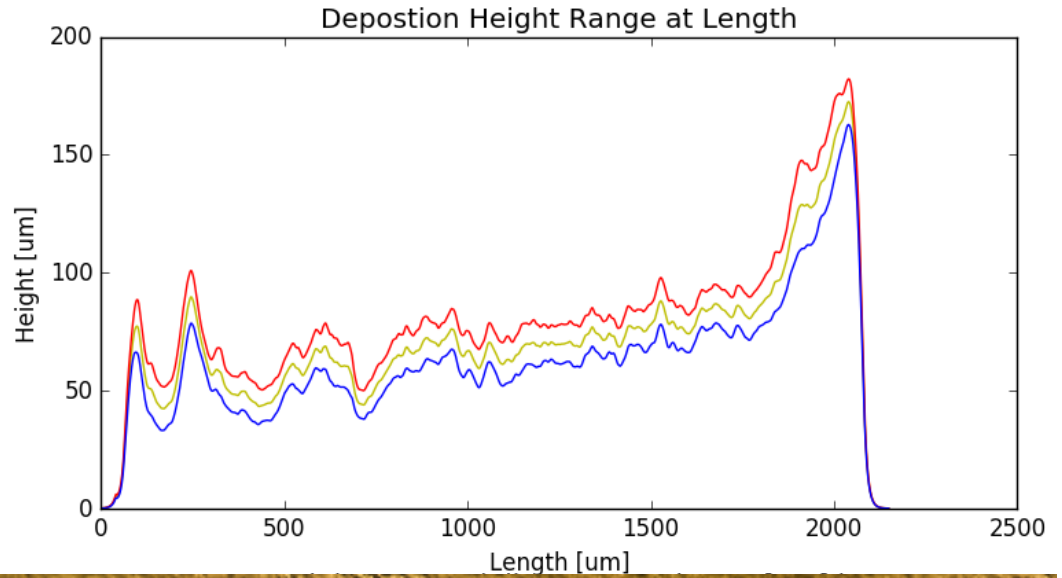






Profilometry Measurement - Calibration

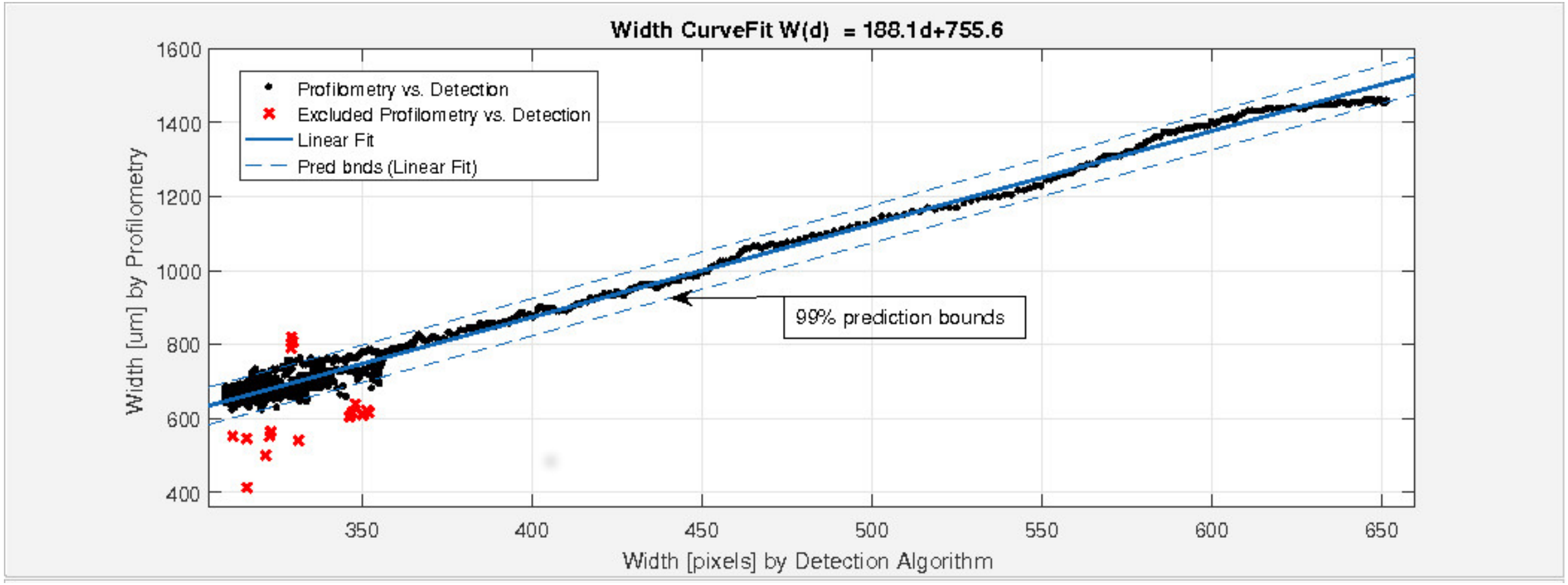




Width [um]

Width [um]

Profilometry Measurement - Validation



Steady-State Modeling - Principle

Inputs - Gridding:

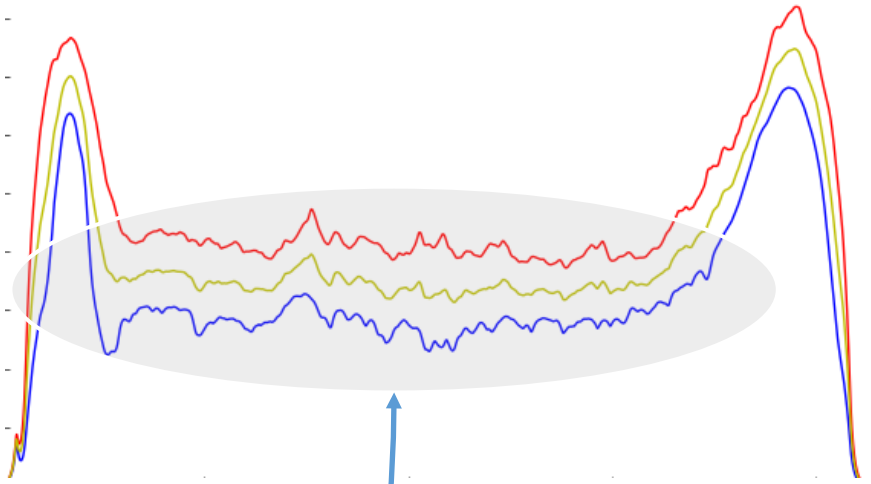
- V - Printer bed velocity
- P - Syringe pressure

Outputs:

- H - Deposition Height [um]
- W - Deposition Width [um]

Steady-State system identification:

- Theory: Static input → Output @ time → ∞
- Practical: Take static response part of output



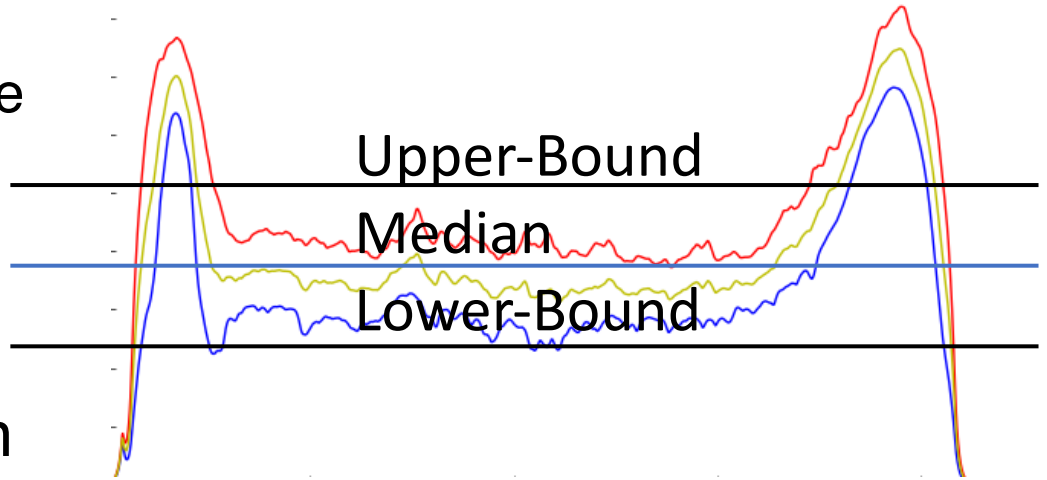
Steady-State Modeling – Implementation

Input:

- Apply all static input combinations between:
  - V → [5,10,15] mm/s
  - P → [200,250,300,350,400] kPa
- Use multiple samples → Account for:
  - Internal changing dynamics e.g. Temperature
  - Setup changes
  - Human error

Output:

- Median-Average-Deviation → Detect region
- Median of region → Sample output
- Mean of samples → Mean output



Steady-State Modeling – Summary

Width:

- Low velocity & High pressure → Large Width
- High velocity & Low pressure → Small Width

Height:

- No clear pattern

How to use results?

- Cubic model fit → direct mapping from input to output
- Table lookup → Use interpolated grid values

Steady-State Modeling – Discussion

Paper as print foundation:

- Flexibility → foundation height changes