Optimizing Pattern Matching on Silicon Sensors for the Assembly of the ATLAS Experiment ITk Detector

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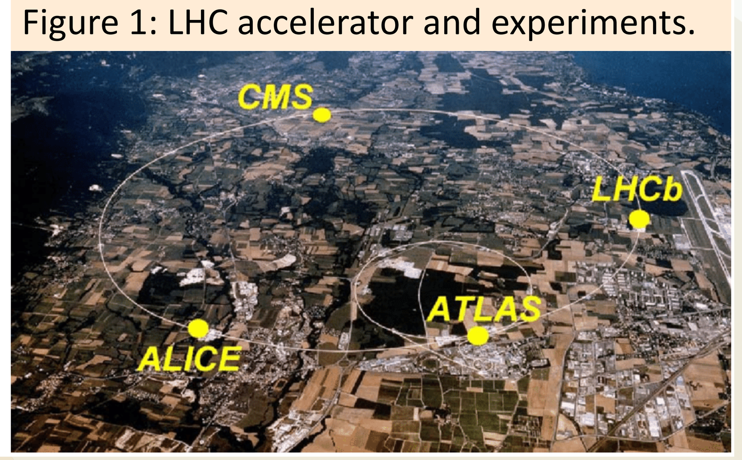
Introduction

The Large Hadron Collider (LHC) at CERN in Geneva, Switzerland is the largest and most powerful particle collider in the world.

- Protons at nearly the speed of light collide at four points, where experiments detect the particles resulting from the collision.
- The largest experiment is ATLAS. Major objectives include the search for the Higgs Boson and Dark Matter.

In 2026, the LHC and its experiments are to be upgraded to increase the number of collisions per second by x10. Faster and more precise detectors will be needed to keep up with the LHC.

Figure 1: LHC accelerator and experiments.



Context and Objectives

Figure 2: The ATLAS experiment.

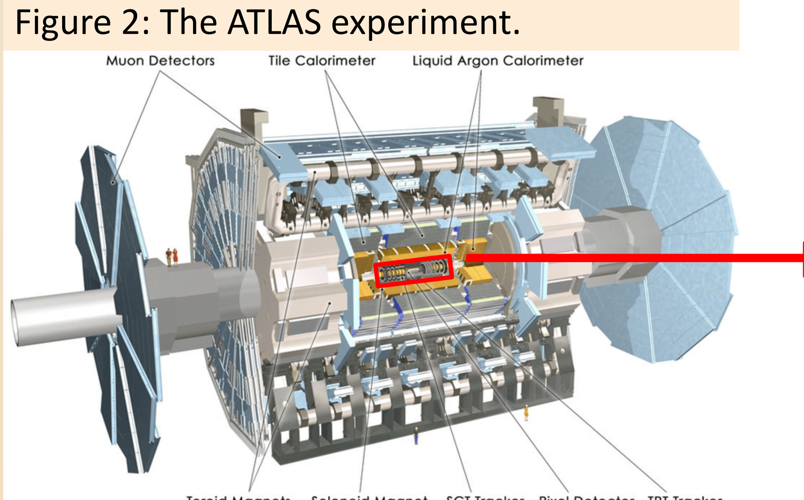
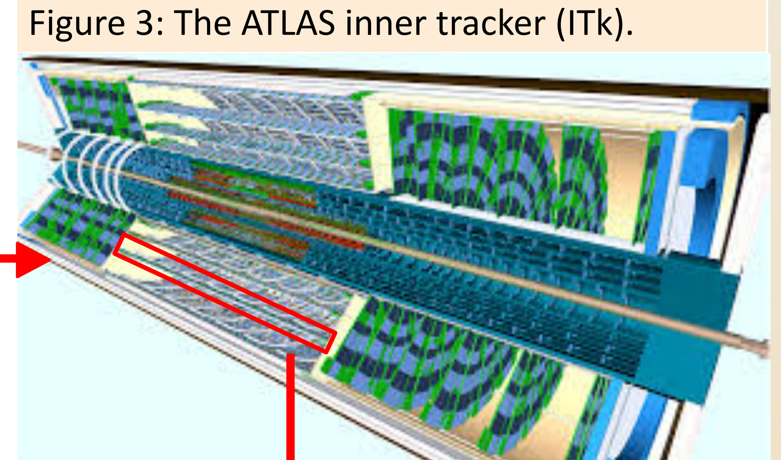


Figure 3: The ATLAS inner tracker (ITk).



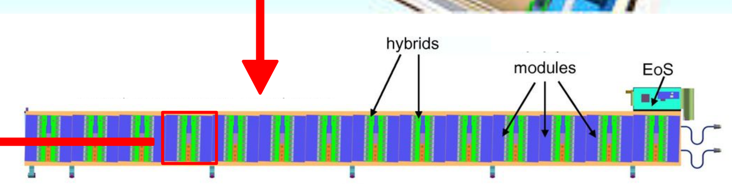


Figure 4: An ITk stave, consisting of a stave core and 14 modules glued to each side. Each module has a silicon sensor and read-out electronics.

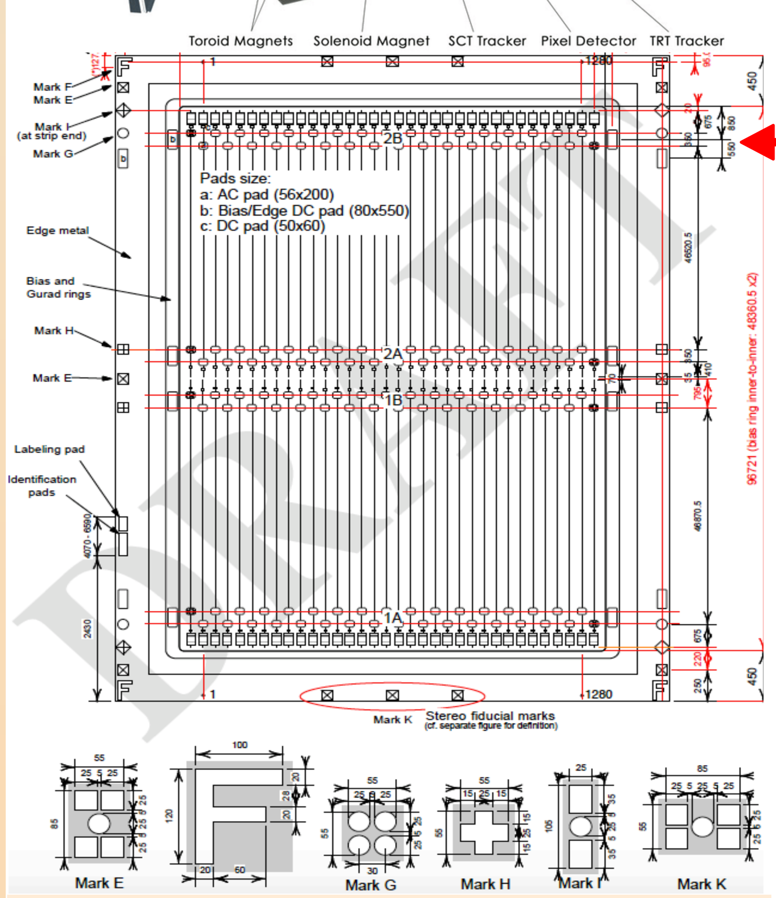


Figure 5: Layout of an ATLAS17LS sensor. Note Fiducial Marks E, F, I and G.

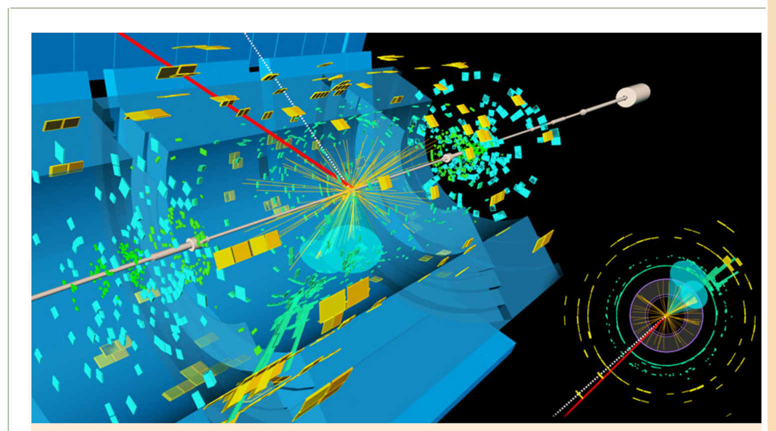


Figure 6: Reconstructed image of a collision in ATLAS.

High-energy collisions result in an explosion of fundamental particles. To precisely reconstruct the trajectory of each particle, sensors must be glued onto the stave with a tolerance of 50 μm. To achieve this goal, image pattern matching in LabVIEW finds the Fiducial Mark positions.

In 2019, a new design of the silicon sensor was adopted and the accuracy and the timing of the pattern matching had to be optimized.

Methods

Variables:

Independent

- Template Size
- Minimum Match Score (MMS)
- Rotation Angle Range (RAR)

Dependent

- Resolution – Standard Deviation
- Accuracy – Mean
- Time to Pattern Match

Tested: Marks F, E, I, and G, on two different sensors

Developed a program that:

1. Takes pictures of the sensor[1]
2. Cuts templates of varying heights[2]
3. Pattern matches with these templates on the sensor pictures[1]
4. Analyzes the efficiency of templates[2]

[1]using Python

[2]using LabVIEW

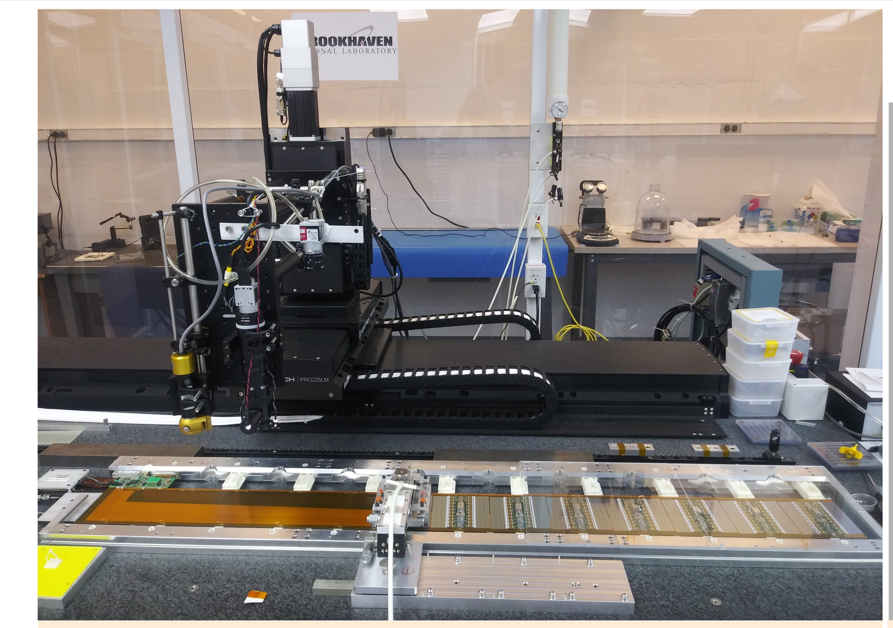


Figure 7: The module assembly robot at BNL

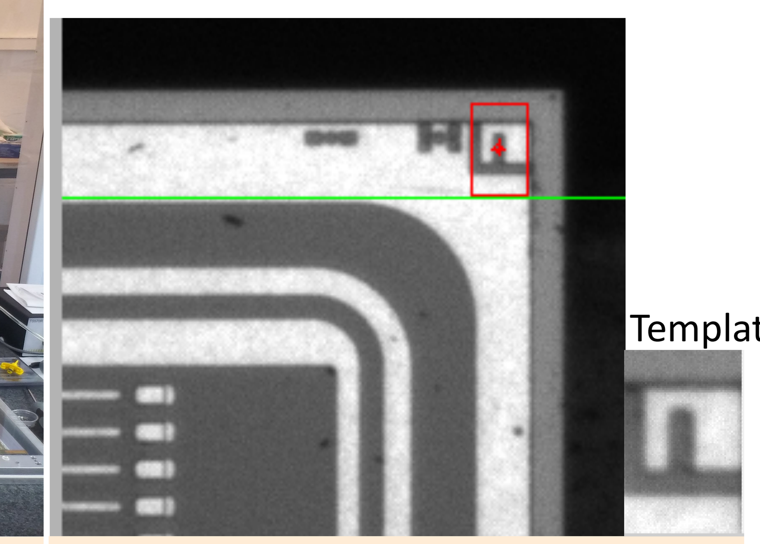


Figure 8: Pattern Matching Mark F in the upper right corner of the sensor.

Results

Analysis of Mark F and Mark E

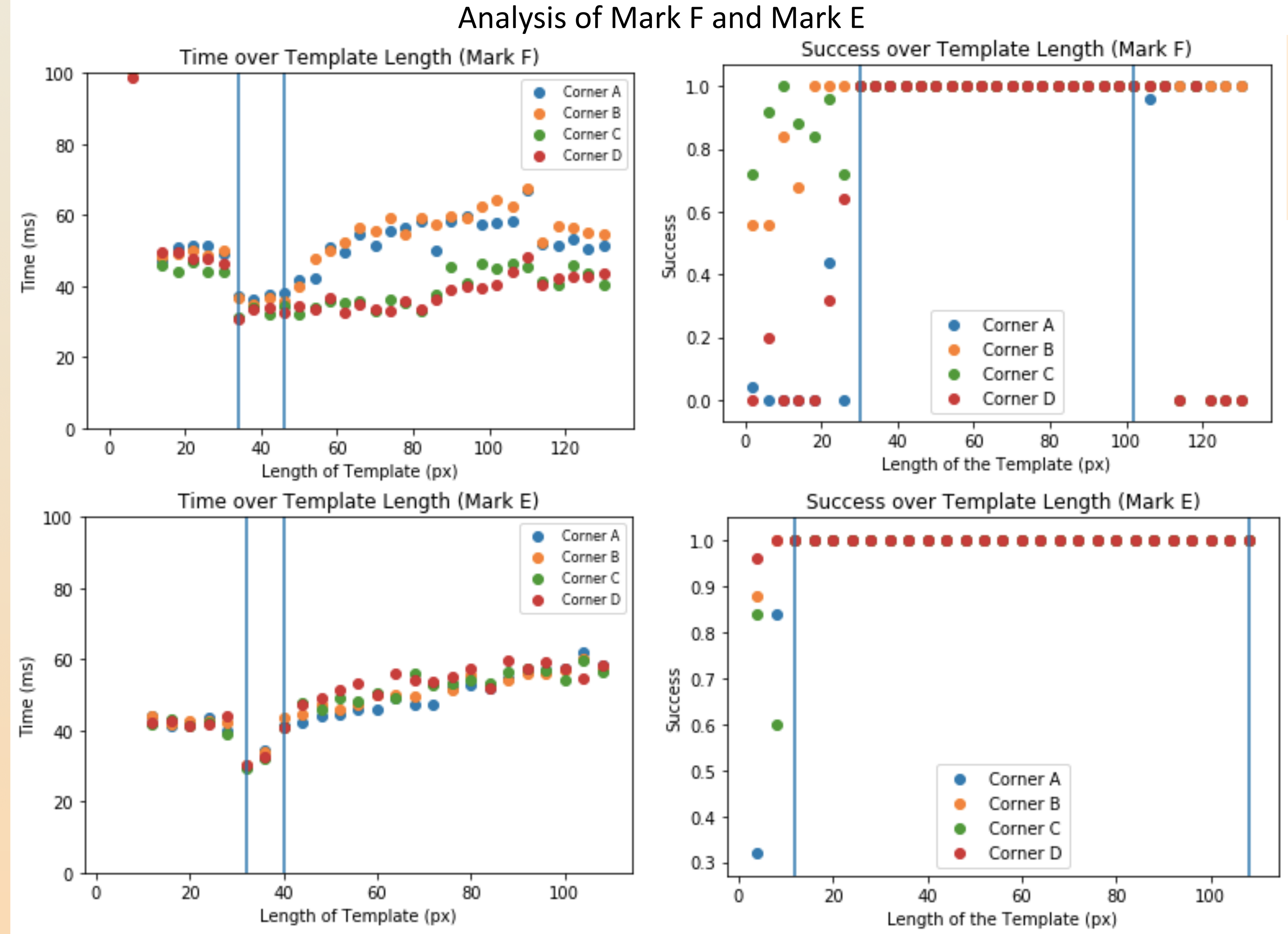


Figure 9: Analysis of Marks F and E. "Success" is defined as the fraction of pattern match positions within 2 μm of the expected. Marks I and G are similar to Mark E.

Template Length: Graphs

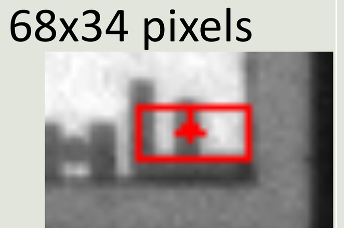
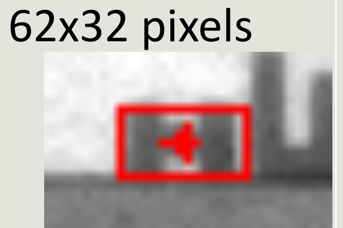
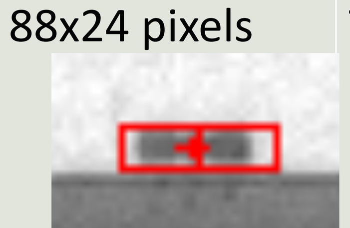
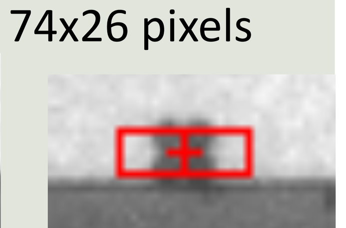
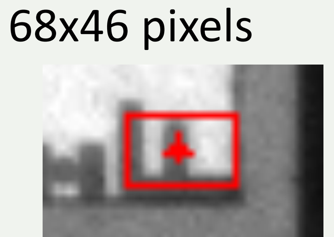
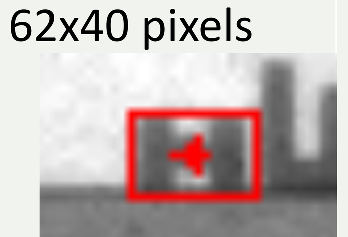
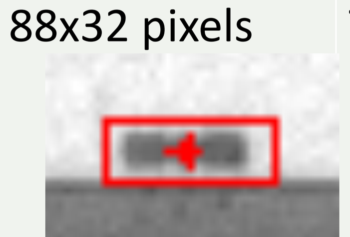
- Mark F – 100% Success for templates with a height 30-100 pixels
- Mark E, I, G – 100% Success for template height >15 pixels
- Among those with 100% Success, shorter templates pattern match faster

MMS/RAR Test Results:

- << 800 MMS likely to match incorrectly
- >> 800 MMS likely to not find a match
- Using RAR function increases the time by 4x

Repeatability: Same results were obtained testing on different sensors

Pattern Matching with the Ideal Templates

	Mark F	Mark E	Mark I	Mark G
Min. Ideal length	68x34 pixels 	62x32 pixels 	88x24 pixels 	74x26 pixels 
Max. Ideal length	68x46 pixels 	62x40 pixels 	88x32 pixels 	74x34 pixels 

Conclusions

Pattern matching is most efficient with 800 MMS and no RAR. For each mark, these is a range of template sizes that maximize accuracy and efficiency.

Starting August 2019, the templates I selected will be used in the assembly of the ITk. They will ensure accuracy and efficiency when finding sensor positions, reducing the uncertainty in the pattern matching procedure.

The majority of this project involves developing software to define the optimal template used for pattern matching. Pattern matching is used throughout the ITk assembly and testing process. My software will be reused to find the ideal template in other parts of the ITk project.

Acknowledgements

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