Building a Computer Board Visual Inspection Pipeline

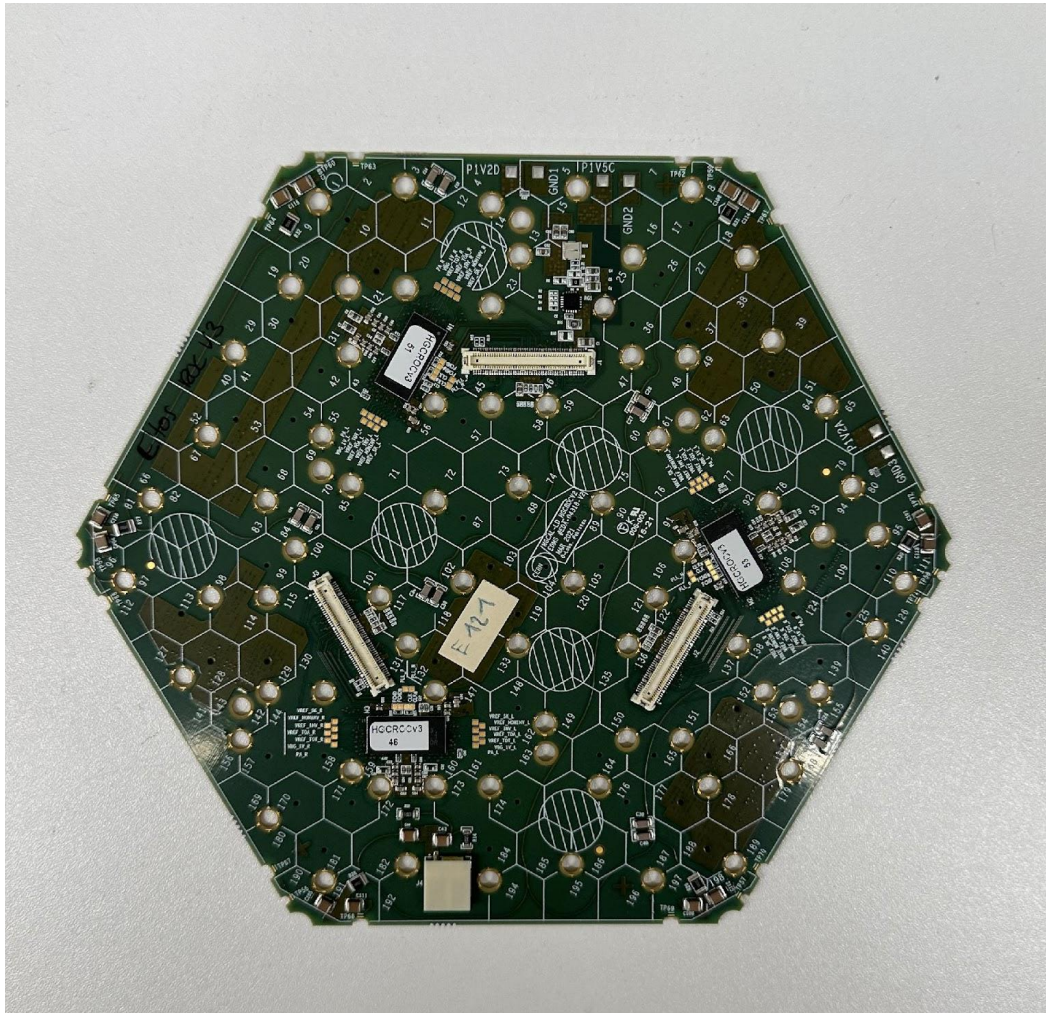
Frederick White
Dr. Gleyzer and Dr. Usai

INTRODUCTION

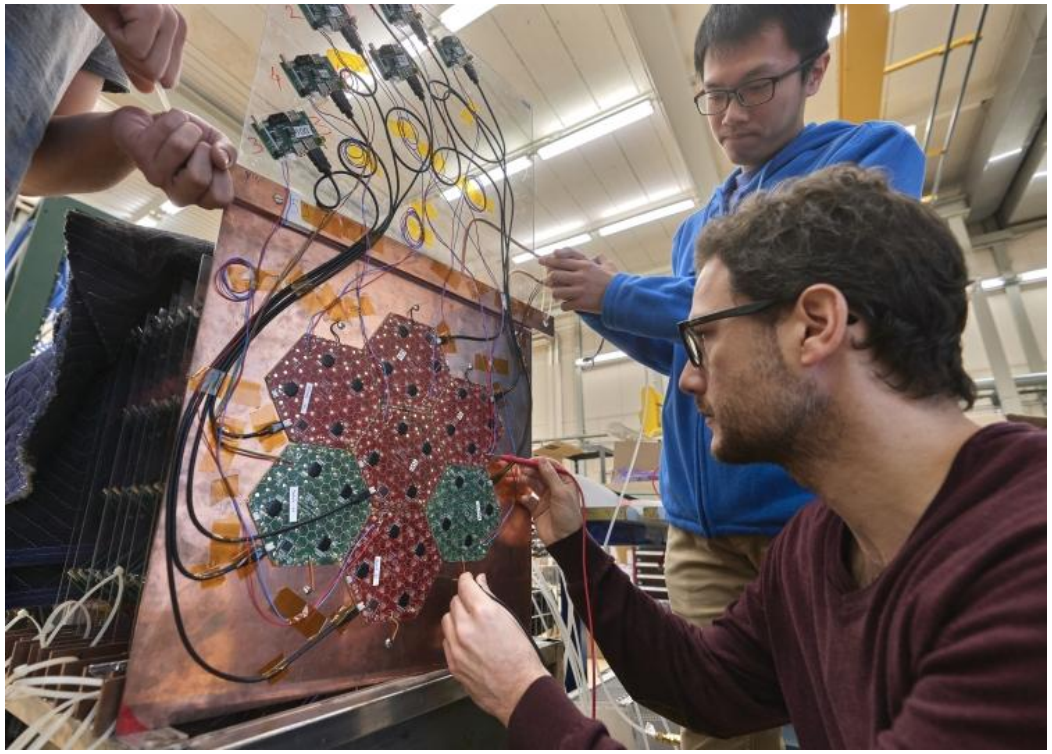
- The High-Granularity Calorimeter (HGCAL) is a significant upgrade for the CMS detector.
- HGCAL ensures excellent performance during the High-Luminosity LHC (HL-LHC) operations.
- It features high readout and trigger granularity to handle the harsh radiation environment in the CMS endcaps.

WHAT ARE HEXABOARDS

- Hexaboards are hexagonal circuit boards used in the CMS detector.
- These boards contain essential electronic components such as sensors, readout chips, and connectors.
- They are designed to fit together seamlessly within the CMS detector, forming a crucial part of its data acquisition system.



WHY VISUAL INSPECTION



- Ensuring the integrity of hexaboards is critical for the accurate functioning of the CMS detector.
- Visual inspection helps in identifying defects and damages that might not be detected through automated tests alone.
- Regular inspection maintains the reliability and performance of the detector components.

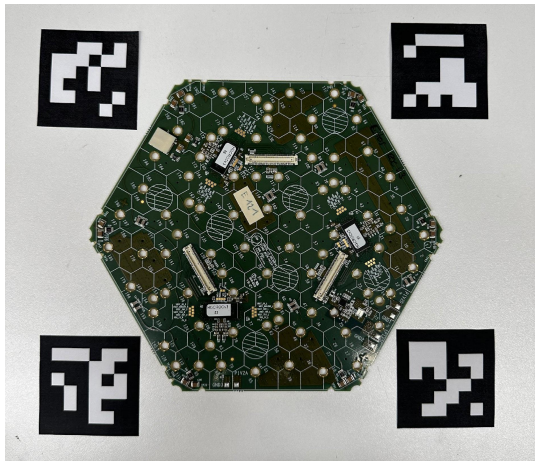
MOTIVATION FOR AUTOMATION

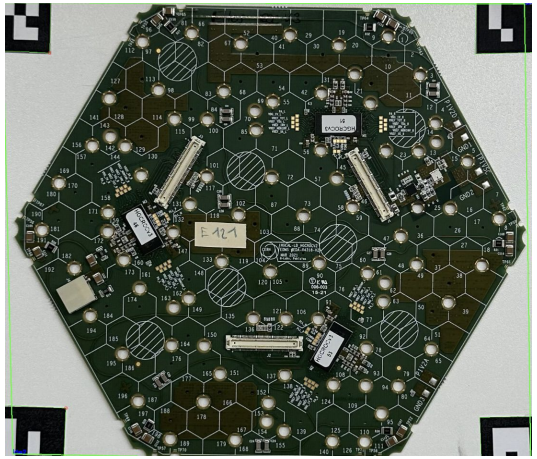
- Manual inspection of hexaboards is time-consuming and labor-intensive.
- Human inspectors may miss subtle defects due to fatigue or inconsistencies in judgment.
- The process lacks uniformity, leading to potential variations in quality assessment.

METHODS


Board Image Isolation and Warp Check
Board Image Segmentation
Pixel-wise Comparison
Anomaly Detection via Convolutional Autoencoders
Two-Method Cross-Comparis on

BOARD IMAGE ISOLATION

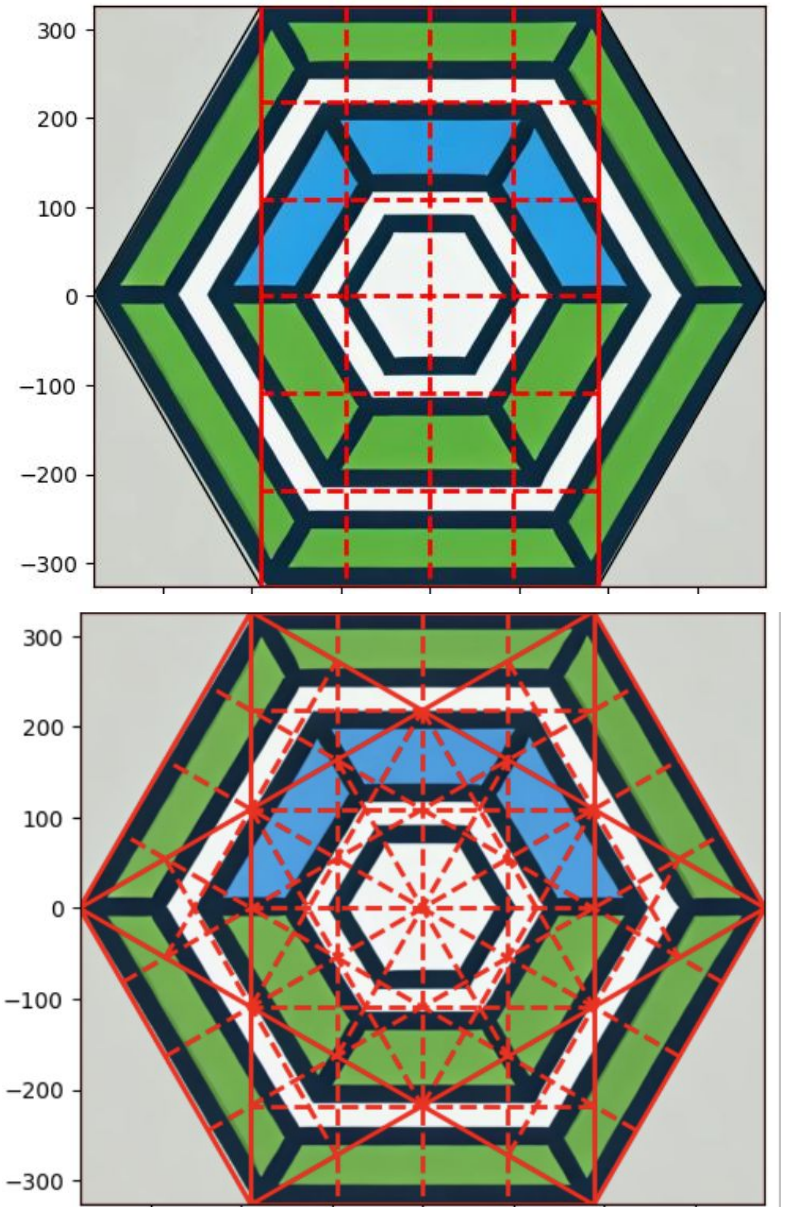


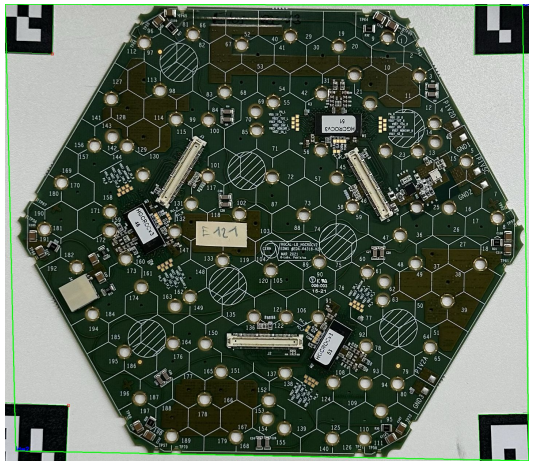


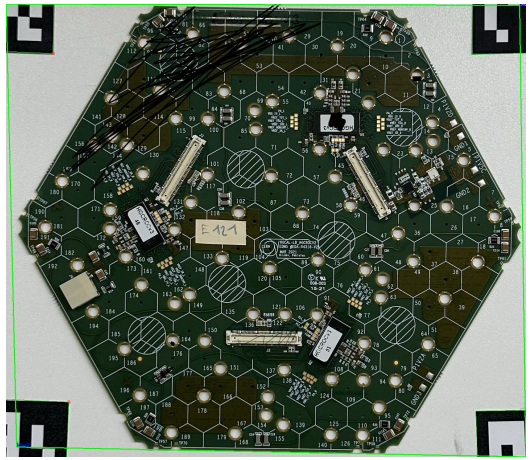
- **Use of ArUco Markers:**
- ArUco markers are placed in fixed positions within the scanning frame to facilitate accurate image isolation.
- These markers help in creating a precise bounding box around the hexaboard, ensuring consistent image capture.
- **Warp Check:**
- After isolating the board image, the distance from the ArUco markers' bounding box to the edges of the board is measured.
- This measurement is used to detect any warping or bending of the board, which could indicate potential defects or damage.
- The bounded image of the board is resized and standardized for further inspection processes.

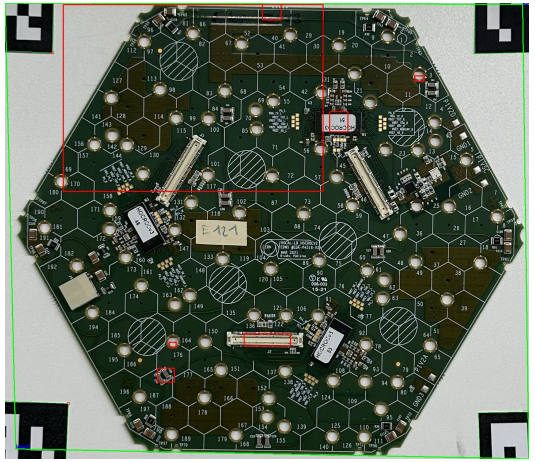
BOARD IMAGE SEGMENTATION

- Once a bounding box is drawn, boards can be broken down into segments using geometry.
- The segmentation is done in three rectangles across the length of the hexagon.
- There is a total of 720 segments in one image.







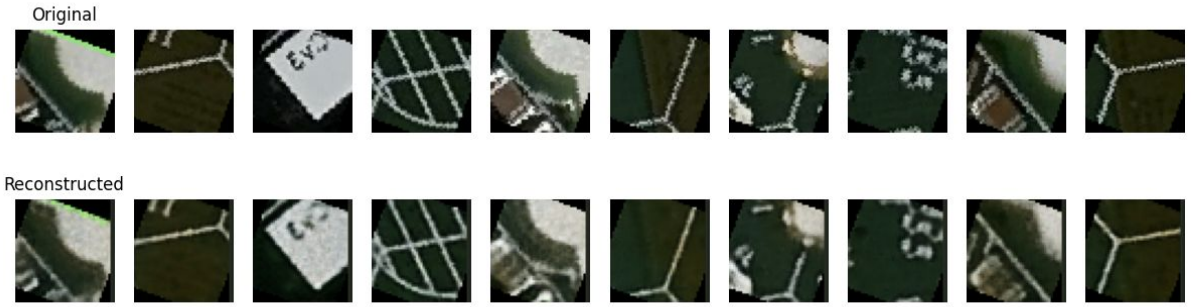


PIXEL-WISE COMPARISON

- A human-approved, damage-free hexaboard is scanned to create a baseline image, which serves as a reference for identifying anomalies in new board images.
- Using the OpenCV framework, each pixel of the new board image is compared to the corresponding pixel in the baseline image.
- Differences that indicate defects or damage, such as scratches, missing components, and other anomalies, are flagged for further inspection
- This process ensures even minor deviations from the norm are identified and addressed.

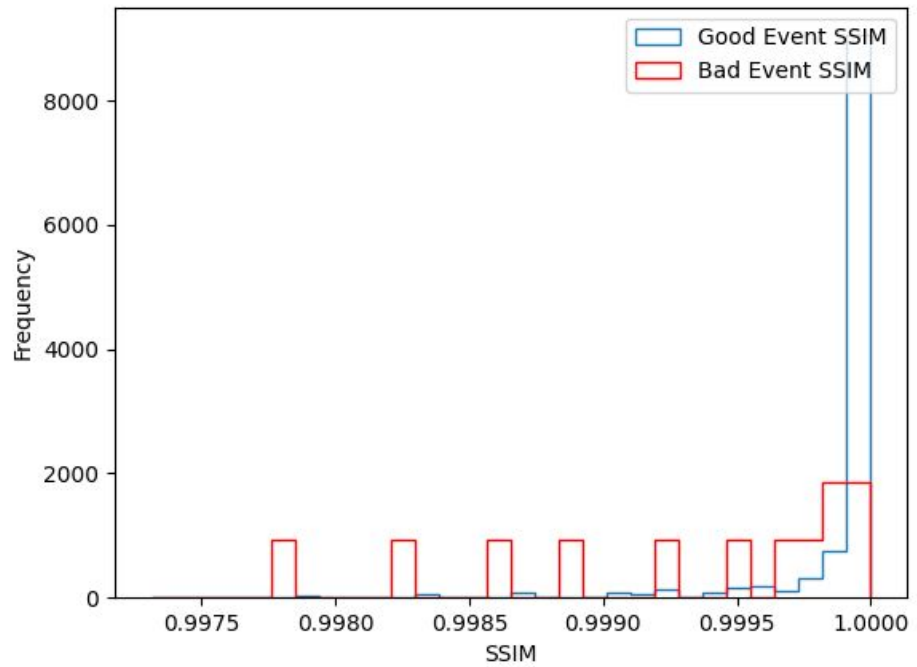
ANOMALY DETECTION

- Autoencoders reduce the number of features of an input image down to low number of parameters (compression)
- They then attempt to take the low number of parameters and reconstruct the original image
- We train convolutional autoencoders on the same image segments as are used in pixelwise comparison
- The autoencoders are only ever trained to images of a human-approved, damage-free board so we expect them to have higher image reconstruction error rates on damaged boards



EXAMPLES

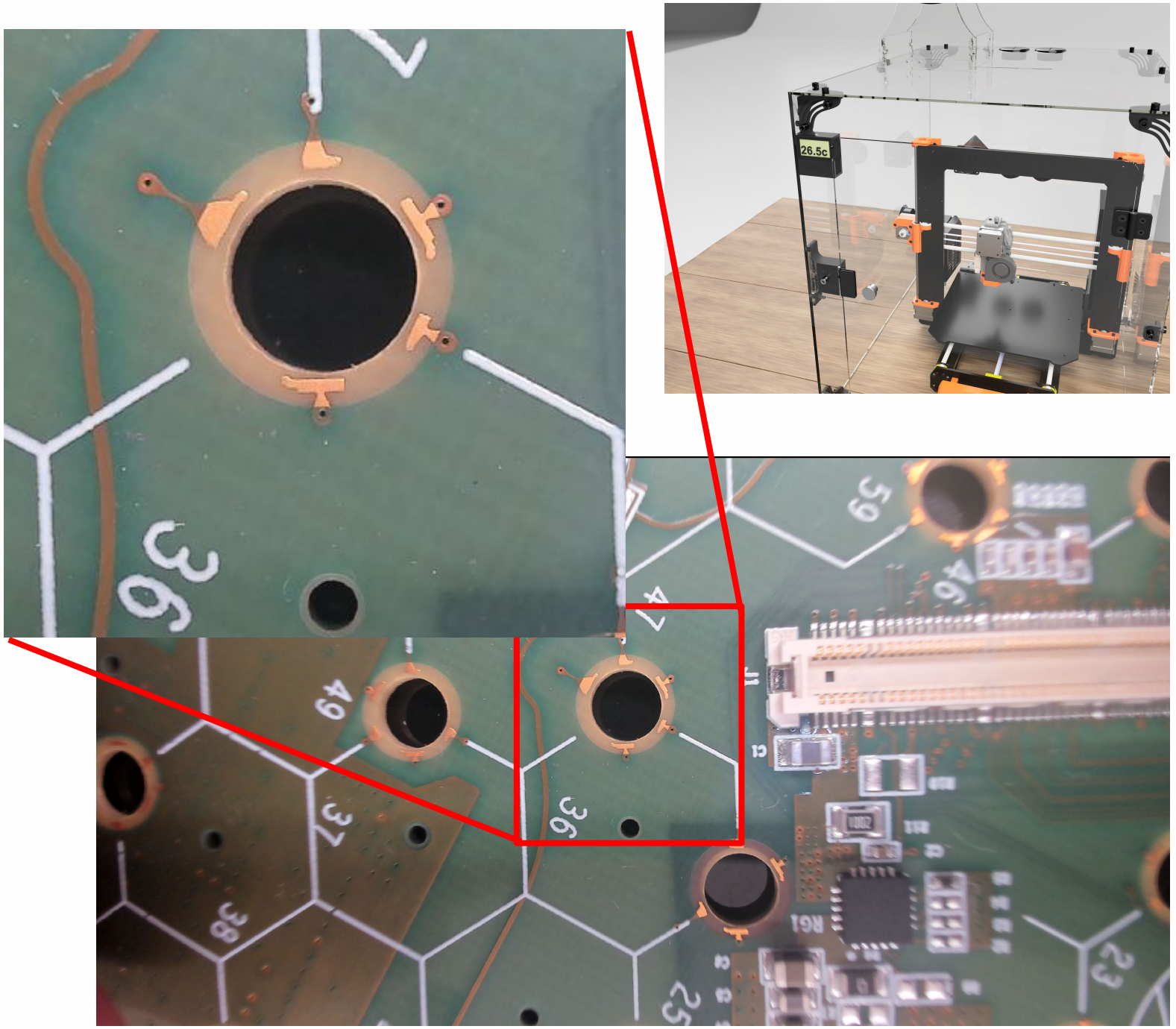
TWO-METHOD CROSS-COMPARISON



- Because we have two different visual inspection techniques which are broken down into segments, we can set thresholds for each inspection software separately, and combined
- For the autoencoders we use Structural Similarity Index Measure (SSIM) which quantifies the similarity between two segments based on luminance, contrast, and structure on a scale of -1 (completely dissimilar) to 1 (completely similar)
- Optimal threshold based on Response Operating Characteristic for SSIM is calculated to minimize the False Negative Rate
- If the threshold is passed for anomaly/damage in a segment, that segment gets highlighted on the board image and flagged for human visual inspection

Future work will use a modified 3D printer scanner

- 3D printer design allows us to move the camera with precise control
- A 4096x2160 (4K) resolution webcam captures high-quality images at a high depth-of-field
- Images can be quickly captured, cropped and stitched together to avoid parallax effects
- Total apparatus is 20 to 100 times cheaper than comparable industrial scanners



WHAT'S NEXT FOR CMS AT UA

- Completing and calibrating scanner system.
- Enhancing the accuracy of the anomaly detection algorithms.
- Expanding the automated inspection system to handle larger volumes of hexaboards.
- Developing more scalable infrastructure to support the growing demand for inspection.

CONCLUSION

- In conclusion, this project underscores the critical role of visual inspection in ensuring the reliability and functionality of hexaboards within the CMS detector. Through the development and implementation of an automated inspection pipeline, significant advancements have been made in enhancing the accuracy, efficiency, and scalability of the inspection process.
- By leveraging advanced technologies such as ArUco markers for precise image isolation, segmentation algorithms for detailed analysis, and machine learning techniques like convolutional autoencoders for anomaly detection, we have established a robust system capable of identifying defects
- The automation of the inspection process not only reduces the time and labor involved but also ensures uniformity and precision, minimizing human error and increasing the overall quality of the inspection. As we continue to refine and expand this system, the future work will focus on integrating more sophisticated machine learning techniques, enhancing the scanner system, and scaling up the process to handle larger volumes of hexaboards.

THANKS / Questions

-