SMART VISION+: ARCHITECTURE FOR AUTOMATING INSPECTION

Alma O. Aragoncillo
Melanie A. Marfa
Mary Rose D. Micua

Manufacturing Engineering Department
Western Digital Philippines Corp. Special Export Processing Zone, Laguna Techno Park, Binan, Laguna, Philippines
alma.olvida@wdc.com, melanie.marfa@wdc.com, maryrose.deocampo@wdc.com

ABSTRACT

In today's fast-paced industrial landscape, the demand for higher production efficiency and uncompromised quality control has driven the adoption of intelligent automation technologies. Traditional manual inspection methods are often time-consuming, inconsistent, and prone to human error, making them unsuitable for modern high-throughput environments. To address these challenges, SmartVision+ or auto visual inspection tool using pattern recognition emerges as a cutting-edge solution that leverages advanced imaging to revolutionize the inspection process. By automating visual inspection tasks, SmartVision+ not only accelerates production lines but also ensures systematic and repeatable quality assessments across diverse manufacturing sectors.

SmartVision+ is an advanced automated inspection system designed to enhance manufacturing throughput and ensure consistent product quality through systematic image-based analysis. By integrating high-speed machine vision with pattern recognition, SmartVision+ enables real-time detection, classification, and evaluation of defects across production lines. The system leverages high-resolution imaging algorithms to perform inspections, reducing reliance on manual checks and minimizing human error. Its scalable architecture supports various industrial applications, offering improved efficiency, accuracy, and traceability in quality control processes. This innovation represents a significant step toward smarter, more autonomous manufacturing environments.

1.0 INTRODUCTION

In modern manufacturing environments, maintaining high product quality while meeting increasing production demands is a persistent challenge. Traditional or manual visual inspection methods, which rely heavily on human operators, are often inefficient, inconsistent, and prone to error—especially in high-throughput settings. Human inspectors can suffer from fatigue, subjective judgment, and limited scalability, leading to missed defects and compromised quality assurance.

As industries move toward digital transformation and smart manufacturing, there is a growing need for automated solutions that can perform inspections with greater speed, accuracy, and repeatability. However, many existing automated systems lack the intelligence to adapt to complex or variable inspection tasks, and they often require extensive manual configuration and oversight.

This gap has created a demand for intelligent visual inspection systems that can not only detect defects in real time but also learn and improve over time. These systems must be capable of handling large volumes of image data, providing systematic analysis, and supporting traceability and collaboration across quality control teams. SmartVision+ addresses these challenges by integrating advanced imaging technologies to deliver a scalable, efficient, and intelligent inspection solution tailored for modern industrial needs.

2.0 METHODOLOGY

The SmartVision+ employed in this project is designed to systematically detect anomalies in objects of consistent type through repeated, high-precision observation. This methodology is structured into several key stages, each contributing to the overall accuracy and efficiency of the inspection system.

2.1 Tool Logic Concept

2.1.1. Image Acquisition
The process begins with the imaging of the product to be inspected using one or more high-resolution camera(s). These cameras are strategically positioned to capture comprehensive visual data from multiple angles, ensuring that all relevant surfaces and features of the product are visible. This step is critical because the quality of the image directly affects the accuracy of feature extraction and defect detection. The imaging setup may include controlled lighting conditions to minimize shadows, reflections, and other visual noise that could interfere with accurate analysis and ensure comprehensive coverage of the product's surface [1].

Figure 1 illustrates the image acquisition setup used in the inspection process.

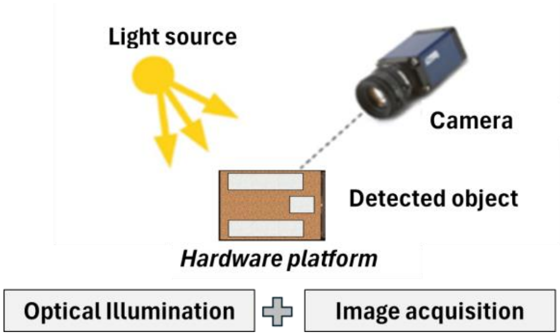

Figure 1 Illustration of image acquisition

In this project, the product under inspection—**a hard disk magnetic slider head**—has extremely small dimensions, measuring approximately **900 × 700 microns**. Due to this microscopic scale, precise imaging is essential to ensure that even the smallest defects or surface anomalies are detectable during inspection.

Refer to Figure 2 for a visual comparison of the slider's size relative to a standard hard disk drive.

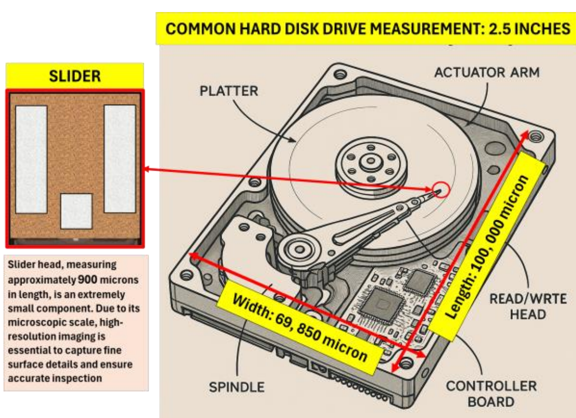

Figure 2: Visual comparison of slider's size relative to a standard hard disk drive.

2.1.2 Preprocessing

Once the images are captured, they are transmitted to a central processing unit. A computer system performing the processing tasks including image resizing, grayscale conversion, noise reduction, and edge detection. These steps are essential to ensure the input data is clean and consistent for the machine learning [1, 2]. Refer to Figure 3 for an overview of the preprocessing workflow and its operation. Figures 4 to 7 provide task-specific illustrations for each stage of the process.

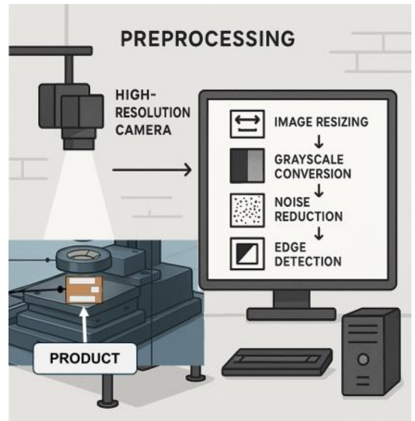

Figure 3 Illustration showing the preprocessing tasks, the image shows under a microscope, with a high-resolution camera capturing detailed images. A computer system shown performing preprocessing tasks including image resizing, grayscale conversion, noise reduction, and edge detection.

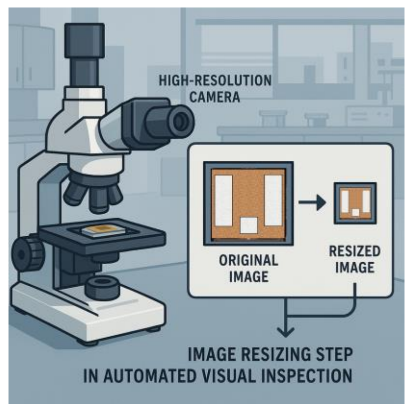

Figure 4 Illustration of Image Resizing Step

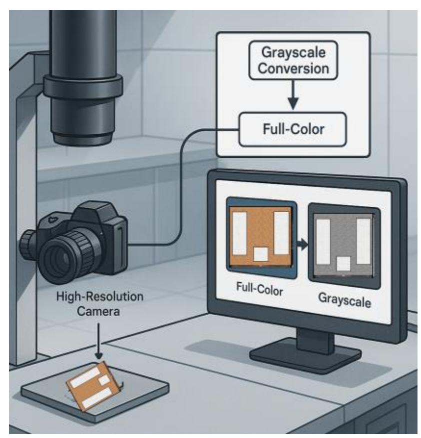

Figure 5 Illustration of Grayscale Conversion

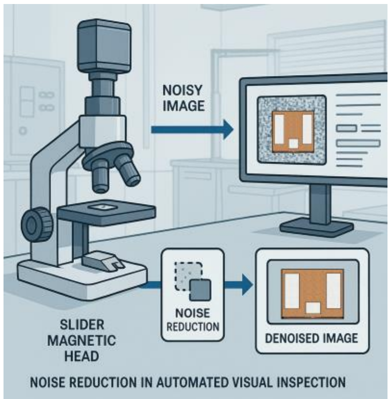

Figure 6 Illustration of Noise Reduction

Figure 7 Illustration of Edge detection with no good and good image

2.1.3 Feature Extraction

In this stage, the system identifies and extracts key visual features from the product. These features may include edges, textures, shapes, contours, and color patterns that are relevant to the inspection criteria. Advanced image processing techniques are often used to automatically learn and extract relevant features from the image data [1]. See below figure 8 for the illustration.

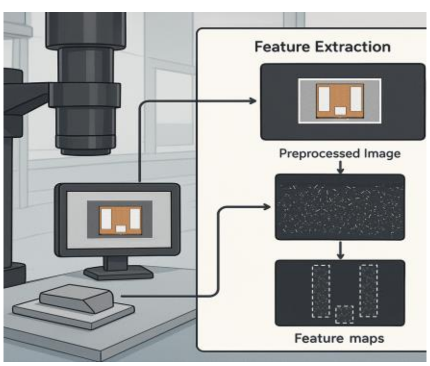

Figure 8 Feature Extraction Illustration

2.1.4 Pattern Matching

The extracted features are then compared to a predefined reference learned image patterns using a specified sensitivity value and threshold criteria. This recipe represents the ideal or defect-free version of the product and serves as the benchmark for inspection. The system checks for presence of known defect patterns and deviation from expected features. This step is the core of pattern recognition, where the system determines whether the object conforms to the standard or exhibits anomalies [2].

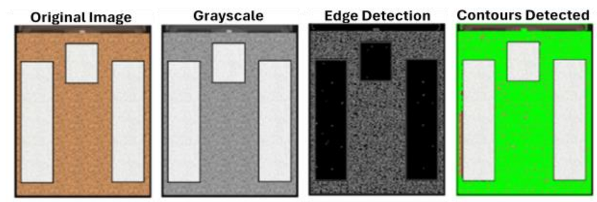

Figure 10 Step-by-step simulation of pattern matching and inspection

2.1.5 Classification

If discrepancies are found during the matching process, the system proceeds to classify the product based on the result of pattern matching as compared to predefined reference learned image pattern [3]. See below figure 9.

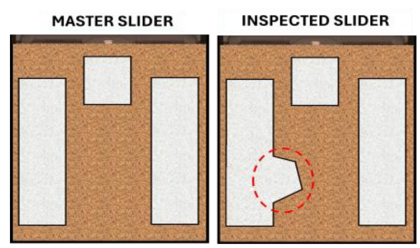

Figure 9 Sample Image of Classification

2.1.6 Decision Making and Output

Based on the classification result, the system decides; PASS: Object meets quality standards, FAIL: Object has a defect and should be rejected, REVIEW: All defined FAIL judgement will undergo manual inspection for final decision. See below Figure 10 for the flow chart.

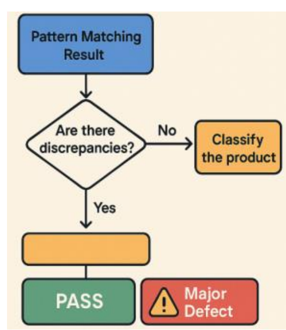

Figure 10 Flow Chart

2.1.7 Data Logging

All inspection results, including images, feature data, and classification outcomes, are stored in a database. This enables:

2.1.7.1 Traceability for quality audits
2.1.7.2 Trend analysis for process improvement
2.1.7.3 Recipe optimization for future updates [1]

2.1.8 Feedback and Continuous Learning

To enhance long-term performance, the system incorporates a feedback mechanism where human inspectors can review and validate the automated decisions. This feedback is used to correct misclassification and improve future performance. This continuous learning loop enhances the system's adaptability and accuracy over time [2 3].

Refer to Figure 11 below for an illustration of the tool logic flowchart.

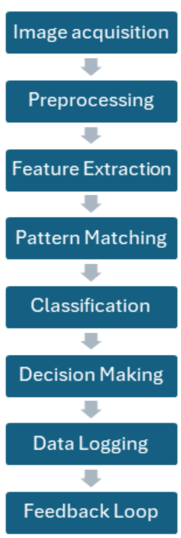

Figure 11: Flowchart of tool logic concept

2.2 System Architecture

SmartVision+ is a high-precision visual inspection system that uses real-time imaging to detect and classify surface defects in manufactured products using OKANO tool software[8]. An industrial camera captures images synced with production flow, and preprocessing is performed using tools like OpenCV and TensorFlow. Products are labeled as OK or NG, with results and metadata sent via API and stored for traceability. A web dashboard provides real-time monitoring and reporting. The system is modular, scalable, and supports adaptive learning for continuous quality control.

Refer to Figure 12 for the detailed schematic of the complete system architecture.

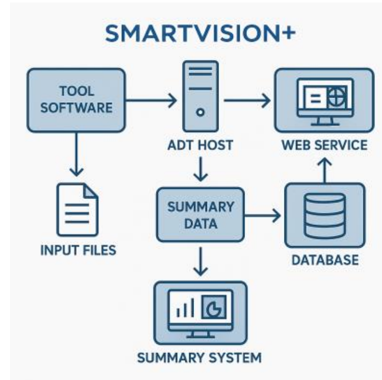

Figure 12: System Architecture

2.3 SmartVision+ Special Features or Applications

In manufacturing, data collection is a fundamental step that ensures both accurate defect detection and continuous system improvement.

2.3.1 Summary System

SmartVision+ features a web-based system that provides comprehensive access to inspection job details—all processed directly on the inspection tool itself, including data from other process steps that use the same tool such as prime yield, UPH, defect map, defect count, image, timestamp, defect category and tool traceability.

Web-based system collects data via a built-in web service or internal API, displays all inspection and production data on a single interface and accessible via browser from PC, tablet, or factory HMI. Refer to figure 13 for example of summary system.

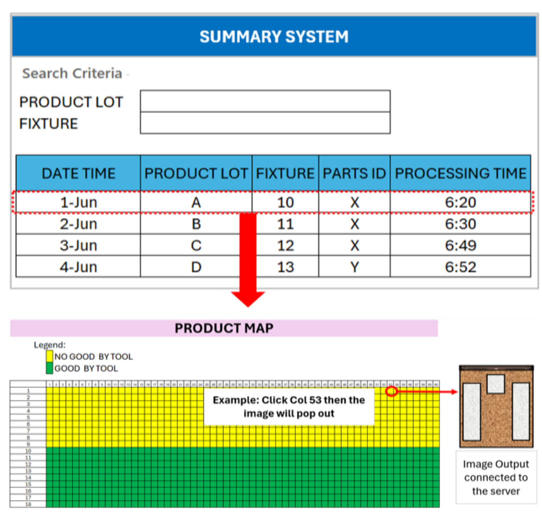

Figure 13 The figure shows that selecting a product lot (e.g., Lot "A") reveals detailed inspection data and images for that lot.

2.3.2 Product Heatmap

The Product Heatmap is an advanced visual tool in automated inspection systems that shows the spatial distribution and frequency of defects on product surfaces. By aggregating defect data, it helps engineers identify recurring problem areas, aiding process optimization—especially in precision industries like semiconductors and electronics. Heatmaps highlight high-defect zones in red and low-defect areas in cooler colors, enabling targeted improvements. These heatmaps update in real time, supporting predictive maintenance and continuous quality improvement.

See below figure 14 for the example of slider heatmap in the product.

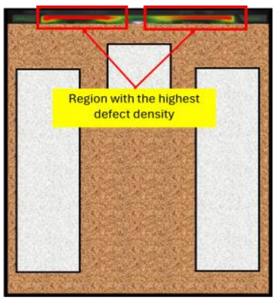

Figure 14: Sample Slider Heatmap with mechanical defects

2.3.3 Stored images that improved the Failure Analysis TAT (turnaround time)

A key feature of SmartVision+ is its ability to store high-resolution images of inspected products, especially those with defects. This greatly speeds up Failure Analysis (FA) by eliminating the need to retrieve physical units, which can be slow or impossible if products are shipped or scrapped[6].

Stored images include metadata like defect type, location, timestamp, and classification, allowing engineers to perform root cause analysis remotely and efficiently. Centralized access supports collaboration across teams and enables quick comparisons across lots to spot recurring issues.
This image archive improves decision-making, reduces downtime, and helps implement corrective actions faster—ultimately enhancing production quality and continuity.

See below figure 15 for the illustration of failure analysis

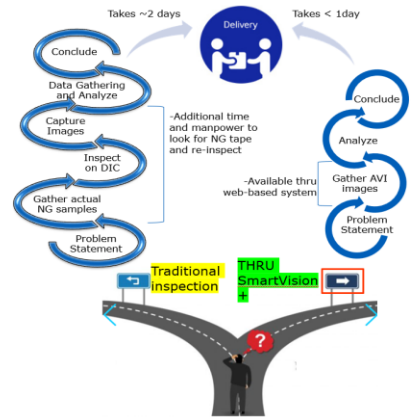

Figure 15: Failure Analysis TAT (Turn Around Time)

2.3.4 Dashboard

The SmartVision+ dashboard provides real-time KPI monitoring, visualizing data like defect counts, UPH, NG rate, and false detections through clear graphs and tables. It helps users quickly identify issues, analyze trends, and improve efficiency. See Figure 16 for a sample dashboard showing Prime Yield and UPH.

Figure 16: Prime Yield and UPH Dashboard

2.3.5 Productivity

SmartVision+ uses pattern recognition and machine learning to provide faster, more accurate, and cost-effective inspections than manual methods. With high-resolution imaging and 24/7 operation, it detects tiny defects consistently on high-speed lines. By automating inspection, it boosts productivity, reduces errors, and lowers waste and costs. Integrated analytics support quality assurance and process improvement, delivering strong ROI and improved product reliability. See Figure 17.

Figure17 : Sample illustration of productive inspection

3.0 RESULT AND DISCUSSION

This section highlights the results of SmartVision+ implementation in a high-throughput manufacturing setting, showcasing its performance, reliability, and impact on data-driven quality assurance. Quantitative gains include improved inspection accuracy, faster cycle times, higher UPH, and increased defect detection. Qualitative benefits include better workflow integration, traceability, and ease of use.
Comparisons with manual inspection reveal significant productivity gains and reduced errors through automated pattern recognition. The system also enhances failure analysis via image archives, heatmaps, and real-time dashboards, enabling quicker decisions and root cause identification.
Overall, SmartVision+ proves to be a scalable digital solution that boosts operational efficiency and manufacturing intelligence.

These instances demonstrate the effectiveness of SmartVision+, particularly in its ability to detect defects accurately, which plays a crucial role in preventing quality issues:

Last January 2025, the inspection process experienced a low in productivity, primarily driven by several jobs exhibiting low prime yield. Prime yield is the ratio of units that meet all quality criteria without requiring reinspection, divided by the total number of units processed. So, when prime yield is low, it means a significant portion of products are failing the initial inspection—either due to actual defects or overly strict inspection parameters.

See below Figure 18 that illustrates the sample map of a single lot, highlighting the tool's judgment results with low prime yield.

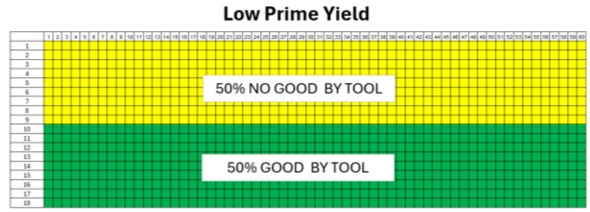

Figure 18: Illustration of sample map highlighting tool judgment

Initial analysis pointed to abnormal pattern defects as the key contributor. SmartVision+ detected consistent defect patterns across the job map, with approximately 50% of the units affected. The defect heatmap further revealed a high concentration of anomalies at identical positions across all impacted parts.

See below figure 19 for the comparison of the abnormal pattern.

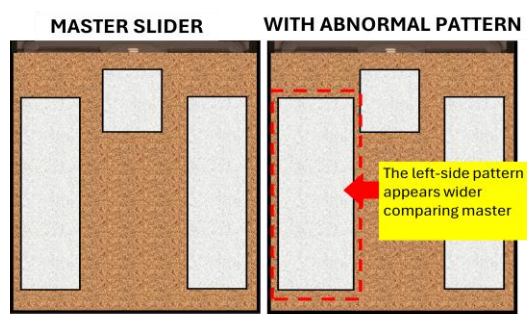

Figure 19: Sample Image Comparison of Abnormal Pattern

SmartVision+ significantly enhanced in-process defect detection by identifying issues in real time through advanced imaging and analytics. Its high-resolution maps and heatmaps enabled quick visualization of defect trends, allowing for immediate action and job segregation. This proactive approach improved quality control and reduced the risk of defective units continuing in the production line. The following table summarizes key performance, efficiency, and value-driven benefits aligned with the study's objectives, demonstrating the system's practical impact.

Table 1: Summary of Benefits

Category	Details	% Gain
Capacity	Tool Capacity	Increased by 72%
Manpower	Manpower Reduction	Reduced by 72%
FA TAT	Faster FA analysis	Decreased by 50%

4.0 CONCLUSION

SmartVision+ has significantly improved manufacturing inspection by enhancing accuracy, productivity, and traceability. Using pattern recognition and image-based analysis, it ensures consistent defect detection across product types—particularly effective for subtle issues like mask misalignment often missed by manual inspection.
Its real-time image storage, defect mapping, and web-based dashboard enable faster root cause analysis and data-driven quality control. Case studies confirm its success in containing defects and preventing faulty units from progressing.
Overall, SmartVision+ is a scalable, intelligent solution that boosts yield, minimizes risks, and supports continuous improvement in modern manufacturing.

5.0 RECOMMENDATION

Based on SmartVision+ implementation insights, the following recommendations aim to boost automated visual inspection effectiveness and scalability:

1) Expand Coverage Early in the Process: Deploy SmartVision+ at key upstream stages to catch defects sooner, reducing rework, waste, and improving yield.
2) Integrate with MES: Connect SmartVision+ to Manufacturing Execution Systems for seamless data logging, lot tracking, and real-time quality management.
3) Continuous Model Training: Regularly update and validate pattern recognition models using new image data and operator feedback to maintain accuracy and minimize false positives.
4) Enhance Operator Training: Provide structured training to ensure effective use of dashboards, heatmaps, and inspection data for faster, informed decisions.
5) Standardize Escalation Protocols: Establish clear procedures for anomaly response to ensure quick, consistent containment and investigation across shifts and sites.

Implementing these steps will help SmartVision+ adapt to evolving production demands, sustain high accuracy, and deliver lasting quality and operational gains.

6.0 ACKNOWLEDGMENT

The author(s) extend heartfelt thanks to all who contributed to the success of the SmartVision+ system. Special appreciation goes to Process Engineering and Quality Assurance for their collaboration and support during development and evaluation.
Thanks also to the SmartVision+ development team for their innovation and technical input, and to Operations and Production for enabling on-site trials and providing valuable feedback.
Lastly, gratitude is given to the management team for supporting the project and promoting a data-driven approach to digital transformation.

7.0 REFERENCES

1: Beyerer, J., Puente León, F., & Frese, C. (2015). Machine Vision: Automated Visual Inspection – Theory, Practice and Applications. Springer.
2: Malarvel, M. (Ed.). (2022). Machine Vision Inspection Systems, Image Processing, Concepts, Methodologies, and Applications. IGI Global.
3: Wang, K. (2018). Smart Inspection Systems: Techniques and Applications of Intelligent Vision. Elsevier.
5: Corallo, A., Del Vecchio, V., & Di Prizio, A. (2024). Advanced AI-Based Solutions for Visual Inspection: A Systematic Literature Review. Proceedings of the 26th International Conference on Enterprise Information Systems (ICEIS 2024), 656–664. https://www.scitepress.org/Papers/2024/126180/126180.pdf
6: Anomaly Detection Expands Use of AI in Defect Inspections. PhotonicsMedia. https://www.photonics.com/Articles/Anomaly_Detection_Expands_Use_of_AI_in_Defect/a65771
7: Lakha, M. V., RajaManohar, S. P., Reddy, K. C., & Sattar, A. (2017). Advanced Image Processing Technique for Failure Analysis. International Journal of Advanced Engineering Research and Science (IJAERS), 4(4). https://ijaers.com/uploads/issue_files/40%20IJAERS-MAY-2017-8-Advanced%20Image%20Processing%20Technique%20for%20Failure%20Analysis.pdf
8. OKANO Electric Co., LTD (2016): ABS and POLETIP Inspection Software, https://okano-denki.co.jp/english/index-eng.html.

8.0 ABOUT THE AUTHORS

Alma Aragoncillo is a Manufacturing Engineer at Western Digital with 19 years of experience, specializing in slider fabrication and inspection within Process Engineering

Mary Rose Micua is a Staff Engineer at Western Digital with 17 years of experience, focused on slider fabrication and inspection in Process Engineering.

Melanie Marfa is a Manufacturing Engineer at Western Digital with 26 years of experience, specializing in slider cleaning within Process Engineering. Engineering