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By:
Etiosa Samson Raymond
Supervisors:
Nicolas Pipard

THESIS DEFENSE

Coil ID Legibility Assessment of Hot-Rolled Coils Using Image Processing, Scene Text Detection and Deep Learning at Tata Steel DSP

Conducted in: TATA STEEL

University: Hanze University of Applied Science Groningen

2025

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ABSTRACT

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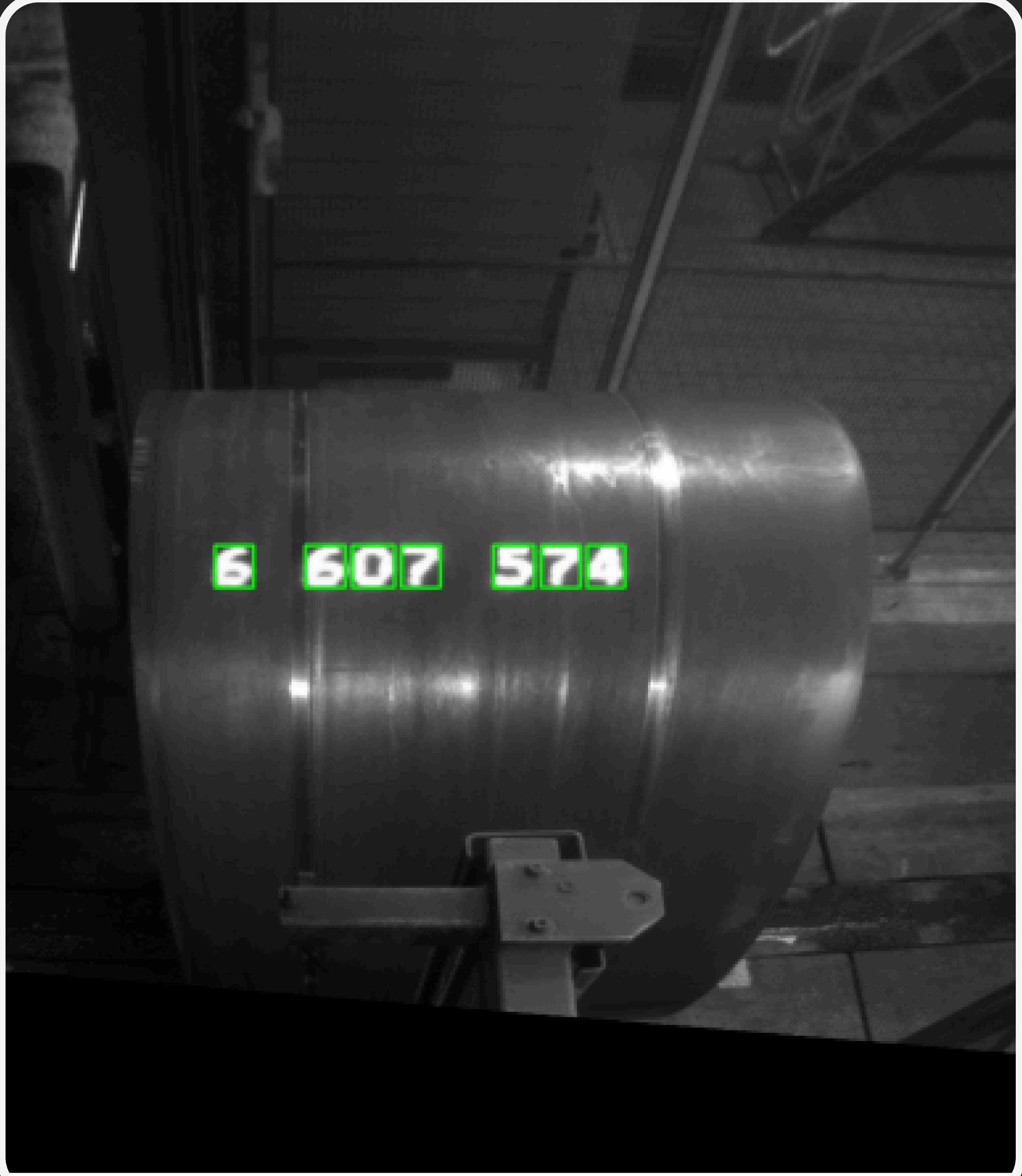
This research explores the development of a modular system utilizing Scene text detection, image processing and machine learning to assess the legibility of Coil IDs on hot-rolled coils specifically at Tata Steel's Direct Sheet Plant (DSP).

The Goal was to localize, detect and classify Coil ID digits in challanging environments in within some specific range of time at the DSP plant.

The main findings were EAST scene detector failures reliably indicated severe legibility issues, highlighting its potential as a readability indicator in the pipeline. Digit detection achieved excellent performance (99.4% precision, 99.5% recall), but legibility classification struggled (44% precision, 73% recall) due to data imbalance as the system was validated with the DSP unseen data.



INTRODUCTION

Steel manufacturing is central piece to many industries such as Construction and automation sectors.

Yearly, Tata Steel Direct Sheet Plant(DSP) produces around 1.4 million tons of steel sheets which equates to about 70,000 coils, in the process of manufacturing a critical aspect is identification of the coil for accurate logistic operation.

For this, a unique ID is spray-painted on each Coils called Coil IDs.

However, this identification technique comes with print legibility issues, and this is why this research is embarked on to automate the print legibility assessment.

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PROBLEM STATEMENT

Automated printing robot

Coil ID legibility errors are rare, the consequences are severe when they occur:

- Misidentified coils can lead to incorrect deliveries to customers
- Wrong deliveries can cause safety hazards or damage machinery
- A single incorrect delivery can cost thousands of euros
- Lose of competitive edge over other steel manufacturers who have better identification systems in place.
- Replacement of the misidentified coils wastes resources and causes a sustainability issue for the environment

The Challenge: Develop an automated system to assess Coil ID legibility with ≥80% recall and ≥70% precision using computer vision.

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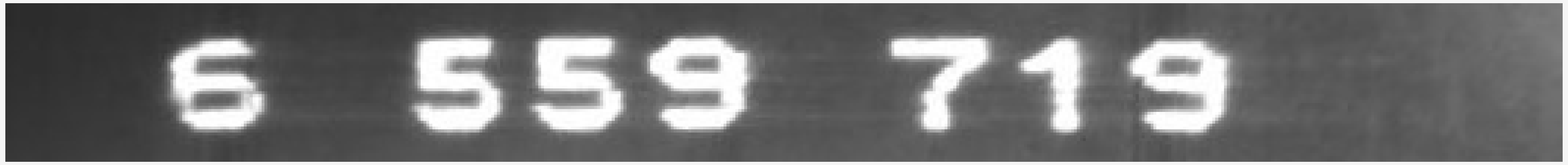
COIL IDS



The Coil ID consists of 7 digits and is typically written at the top and sides of the hot-strip coil.

It is spray-painted in white ink on the steel surface, serving as a unique identifier for tracking and logistics.

However, in this project, the readability assessment will focus solely on the Coil IDs located at the top of the coil, as these are the primary identifiers used by crane operators during transportation.

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PROBLEM STATEMENT

OVERVIEW

After a Coil is produced with the Coil IDs painted on it, it is sent directly to the area where a crane operator will pick it up. Currently, crane operators manually read these IDs from distances of 5-10 meters, which can be prone to human error as the crane operator might misidentify a Coil ID, this Legibility assessment development is crucial as it will eliminate the manual intervention.

How?

Operators at the DSP will get the alert if the Coils are readable or unreadable to make decisions like repainting before going out to the crane operator.

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WHY COMPUTER VISION?

OVERVIEW

At the DSP, alternatives like QR codes, bar codes, and changing the current robotic printer have been looked into, and after final considerations, they were rejected due to

1. High cost of system modification that would occur.
2. Disruption of current operations at the DSP.

After final consideration, computer vision seemed to be the most cost-effective.

why is this?

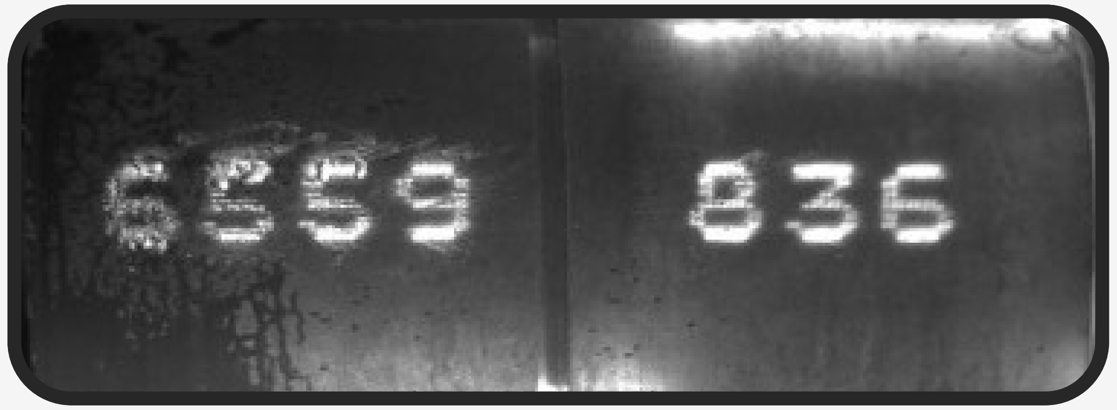
1. Using existing infrastructure, which is the surveillance camera in an optimal position to capture the image of the Coils for evaluation.
2. Minimal or no disruption to production operations in the DSP plant.

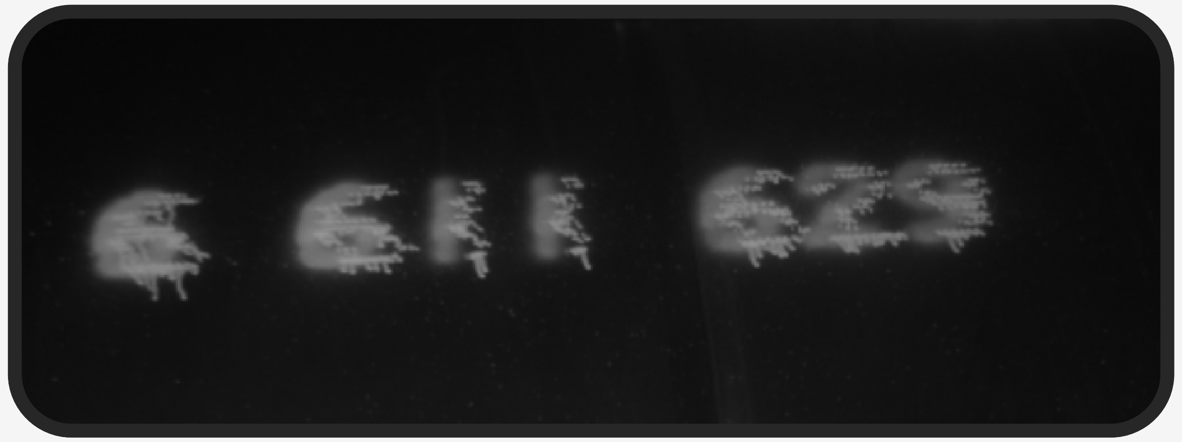
LEGIBILITY PROBLEMS

In the DSP there are 3 usual cause of legibility problems

ENVIRONEMENTAL CONDITIONS

Low temperatures cause the coil's surface to remain wet, which prevents the paint from drying quickly and adhering properly. This leads to smudged and faded digits on the Coil IDs.





PAINT APPLICATION

The Automatic Robot spray painting is prone to nozzle blockages, distorting characters and causing smearing of the Coil IDs, the problem can be continuos leading to multiple Coils having this problem consecutively till the nozzles are unblocked.

STRAPS OBSTRUCTION

Coils are often secured with straps, and sometimes the Coil ID ends up printed on the strap instead of on the coil itself. When a strap moves or breaks, parts of the Coil ID can disappear, making accurate identification difficult.

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RESEARCH-QUESTION

RESEARCH-QUESTIONS

How can image processing and machine learning be used for Coil ID localization, recognition, and extraction to assess print legibility with at least 80% recall and 70% precision, while accounting for environmental variations and completing evaluation within 5 minutes?

SUB-QUESTIONS

SUB-QUESTIONS

1. What technique is effective for localizing Regions of Interest (ROIs) in Coil ID images?

2. Which image recognition algorithm are most effective for processing Coil ID images under varying environmental conditions?

3. How can machine learning algorithms be applied to assess Coil ID print legibility, and which models offer the best performance in terms of recall and precision?

4. What are the common environmental factors affecting Coil ID print legibility, and how can the evaluation system be adapted to tackle it?

5. How can the evaluation system be optimized to deliver accurate legibility assessments within a 5 minute timeframe?

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REQUIREMENTS

REQUIREMENT - 1

Detecting unreadable prints with at least 80% recall and 70% precision.

REQUIREMENT - 2

Employing data augmentation to address dataset imbalance.

REQUIREMENT- 3

Localization of the Coil ID Region of Interest

REQUIREMENT - 4

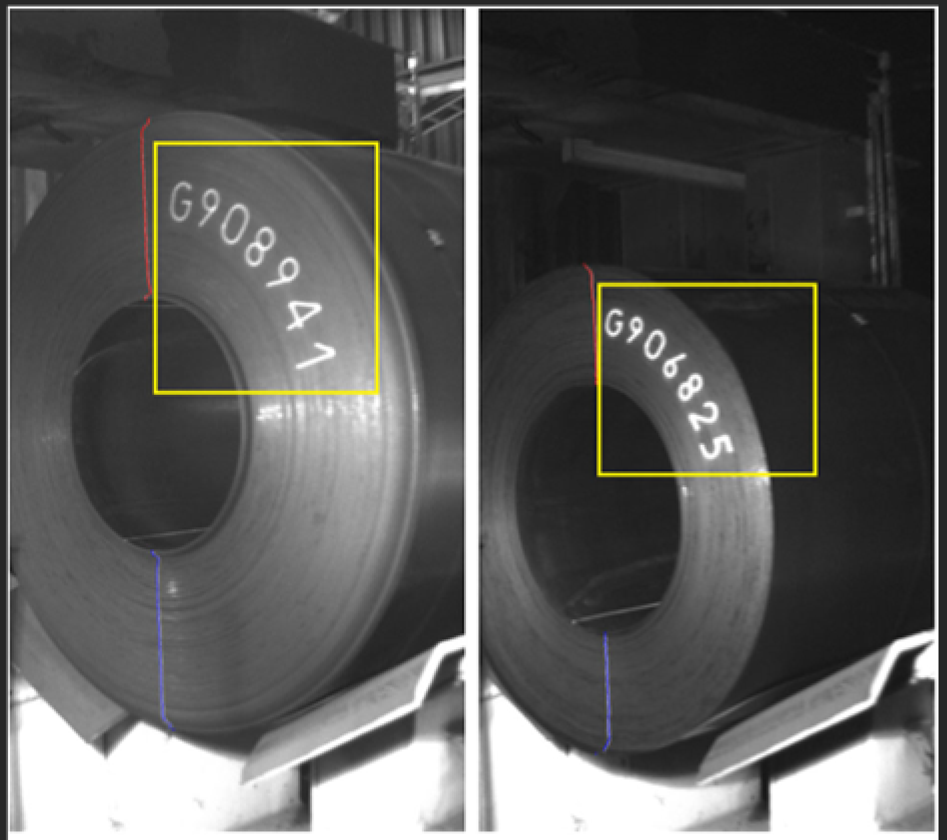
Coil ID Digit Recognition

REQUIREMENT - 5

Process within 5 minutes time frame.

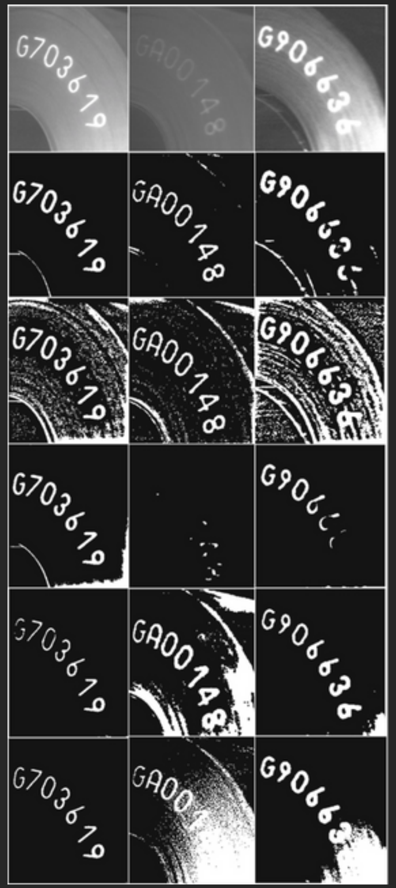
LITERARY REVIEW : RELATED WORK

1 ROI Extraction

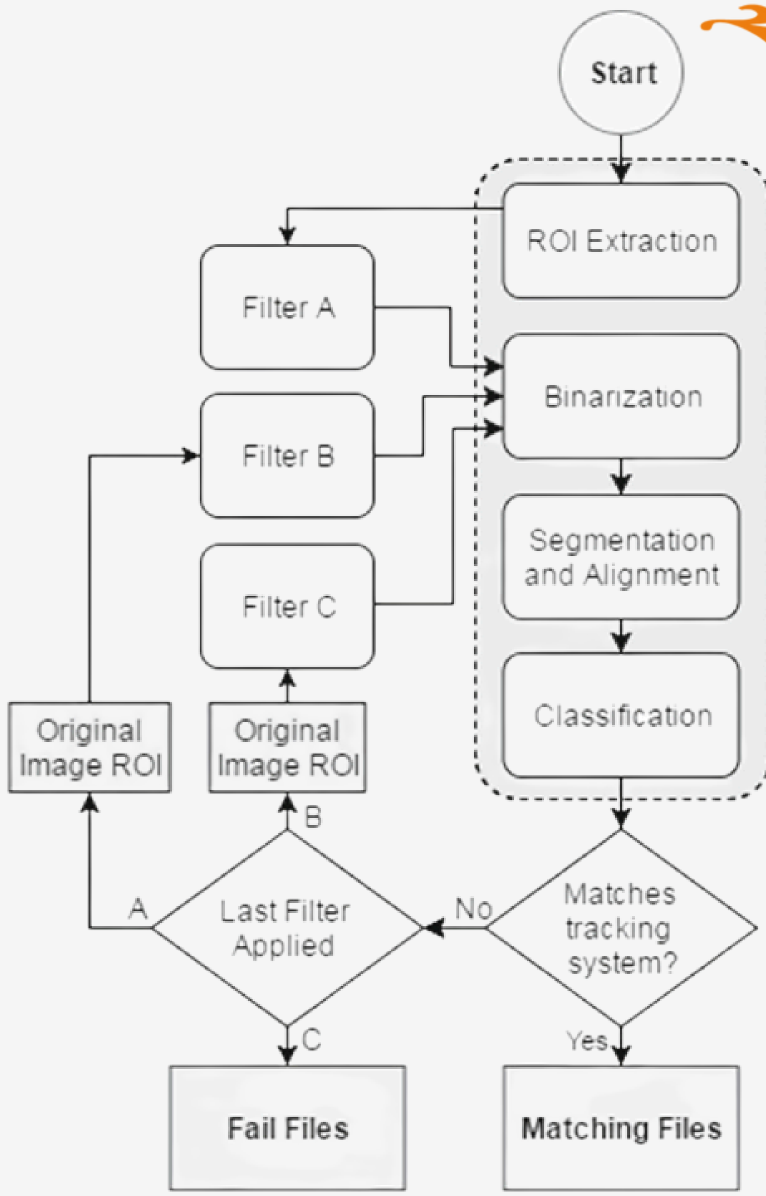


(a) ROI in large coil (b) ROI in small coil

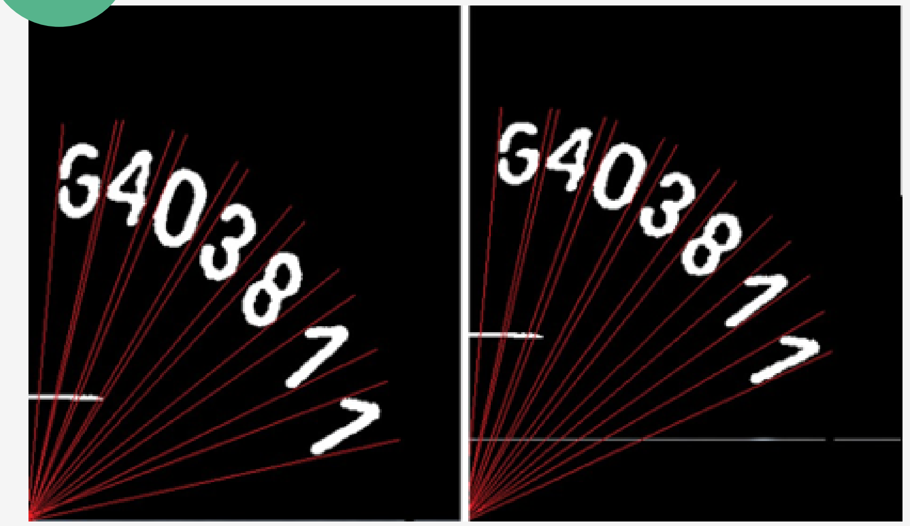
2 Binarization



Calderia pipeline approach



3 Segmentation



4 Classification

Output

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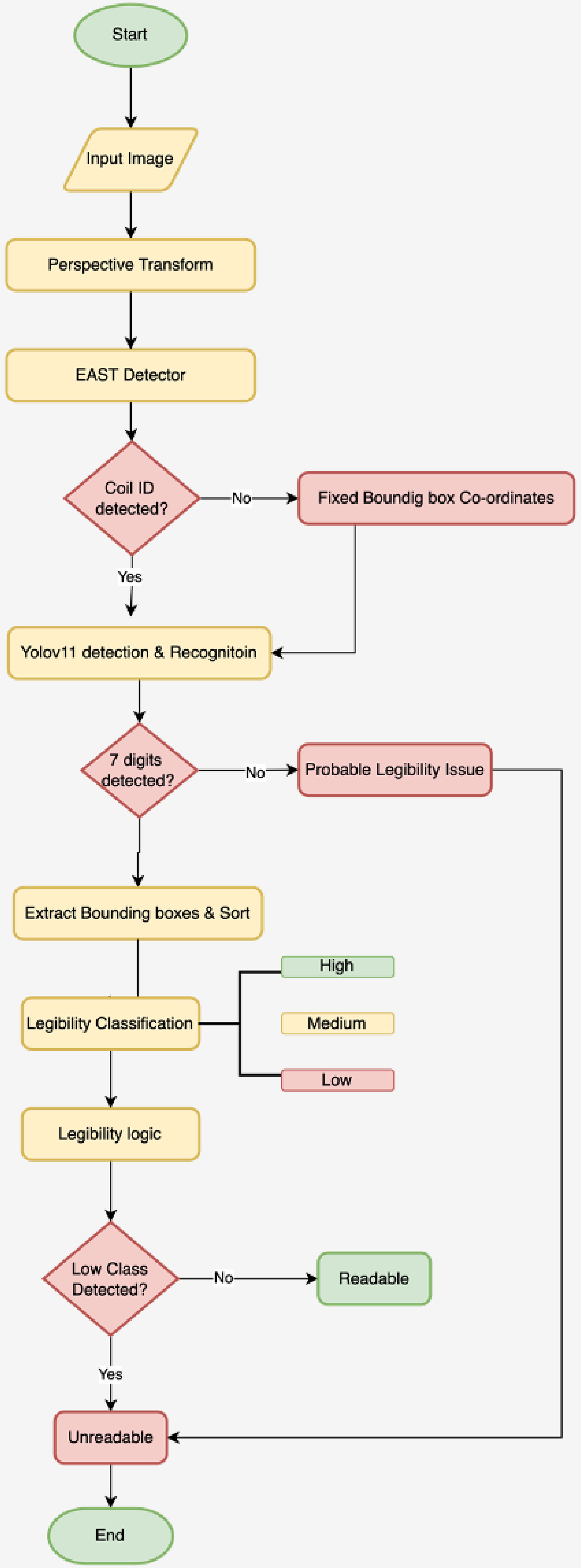
Proposed Pipeline Logic



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RESEARCH DESIGN

Data Acquisition

Camera Setup

Data Processing

Annotation, Augmentation
and Image processing

ROI Localization and Extraction

EAST Scene Text Detector
utilization

Classification and Evaluation

Digit Detection with YOLOv11
and Legibility Assessment

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DATA ACQUISITION

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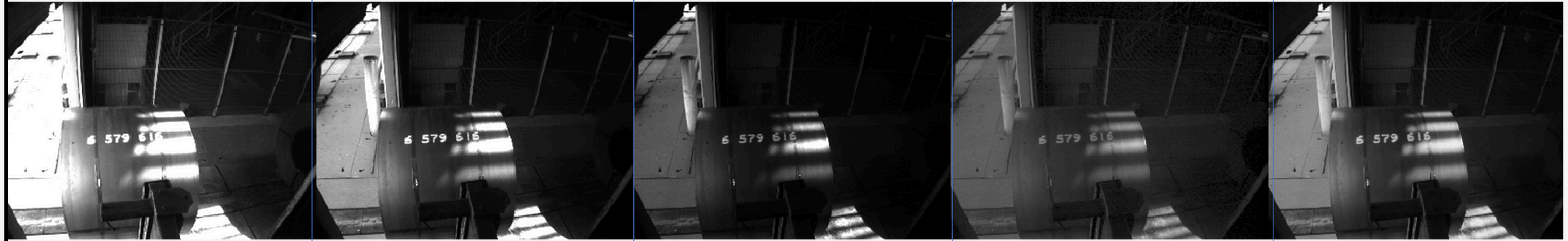
DATA ACQUISITION

Data was collected at DSP using a Basler Scout 1400 camera with a multi-exposure technique

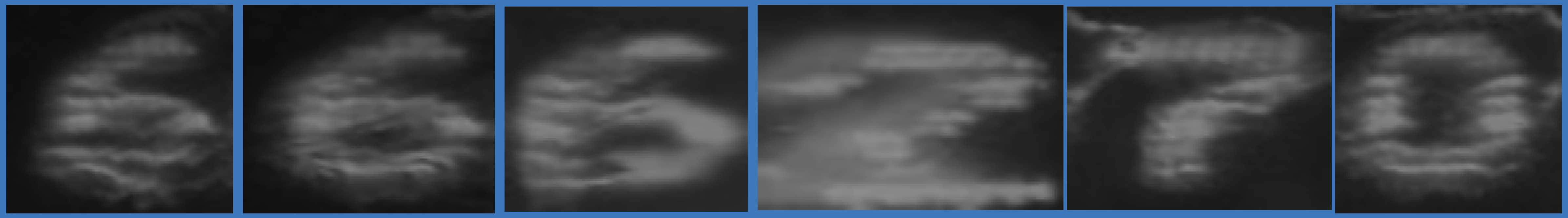
Multi exposure was used to capture images under different exposures, combining them to create an optimal image . This approach minimizes shadows and ensures consistent standard image quality critical for accurate Coil ID detection through out the project.

1.Shuttertime X	2.Shuttertime X/a	3. huttertime X/b	4.Shuttertime X/b	5.Combined result



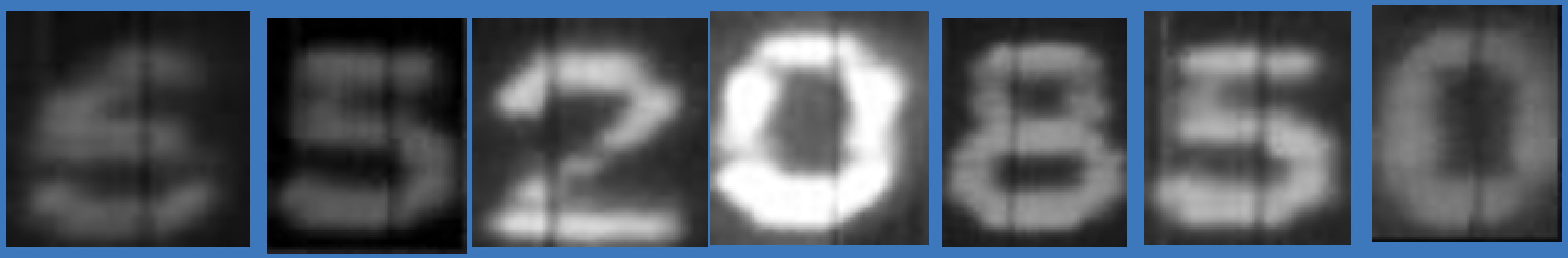
DATA PROCESSING: ANNOTATION

Criteria for the annotation process used to train the Legibility model



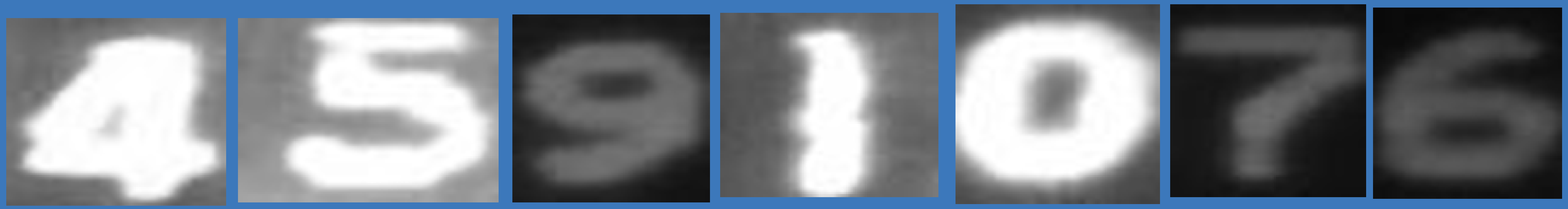
Low Readable class

Digits where smudging and paint irregularities are present



Medium Readable class

Digits with visible straps attached

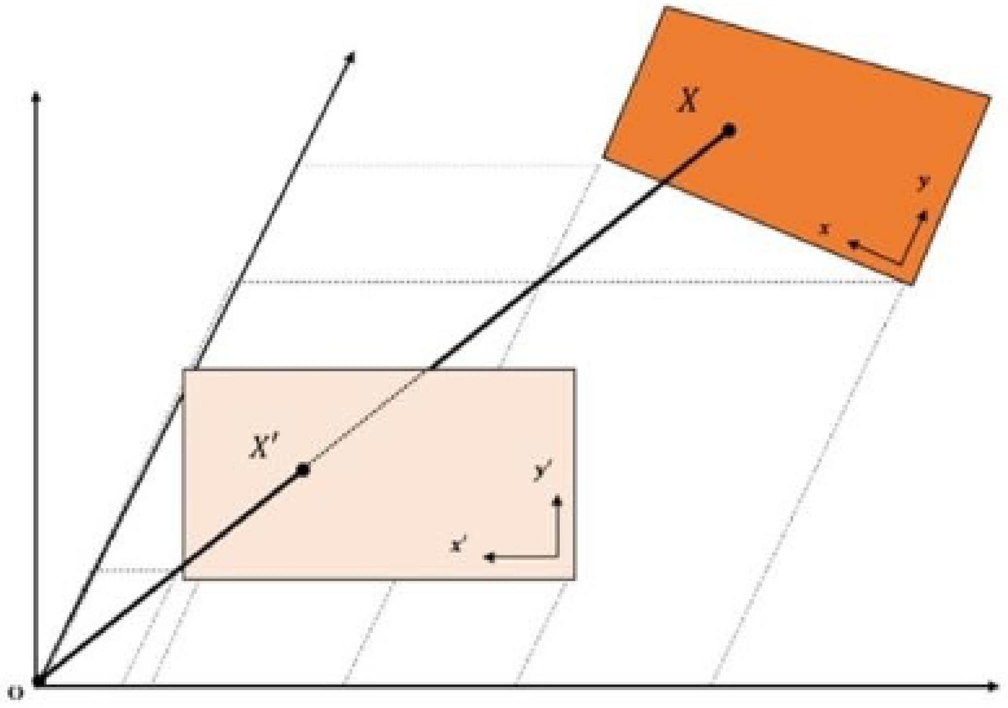


High Readability class

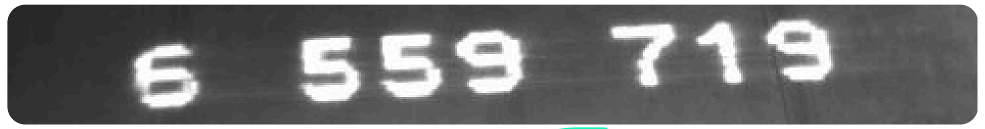
Pristine or clear Digits

IMAGE PROCESSING

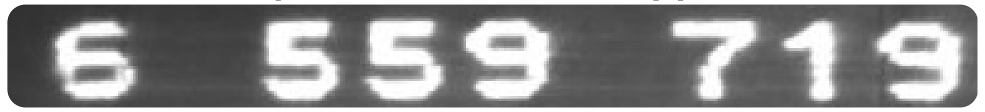
IMAGE PROCESSING: PERSPECTIVE TRANSFORMATION



Input Image(Original)



Perspective Transform applied



THEORETICAL FRAMEWORK

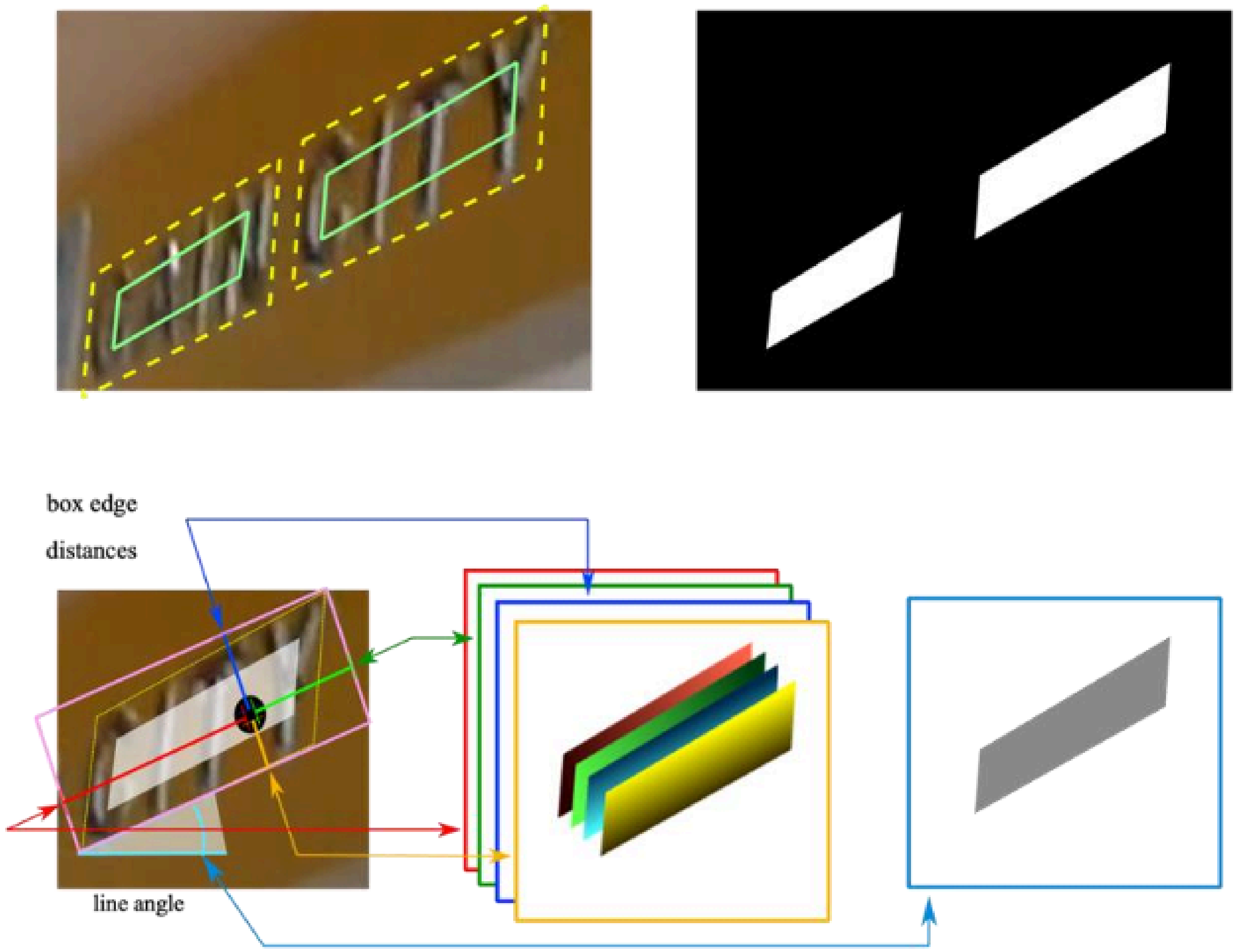
OVERVIEW

Image Transformation: A preprocessing technique that modifies or corrects geometric properties of an image.It was used to standardize coil ID images by correcting perspective, scaling, and orientation.

The camera position captures the coil in a skewed or angled position, and this can be very vital when trying to use a character recognition algorithm, this aids the Scene text algoritm in better prediction.

LOCALIZATION

SCENE TEXT DETECTION: EAST



Output Layer: A score map to indicate where text is located. Geometry information for bounding boxes, including rotation angles and coordinates for text regions.

THEORETICAL FRAMEWORK

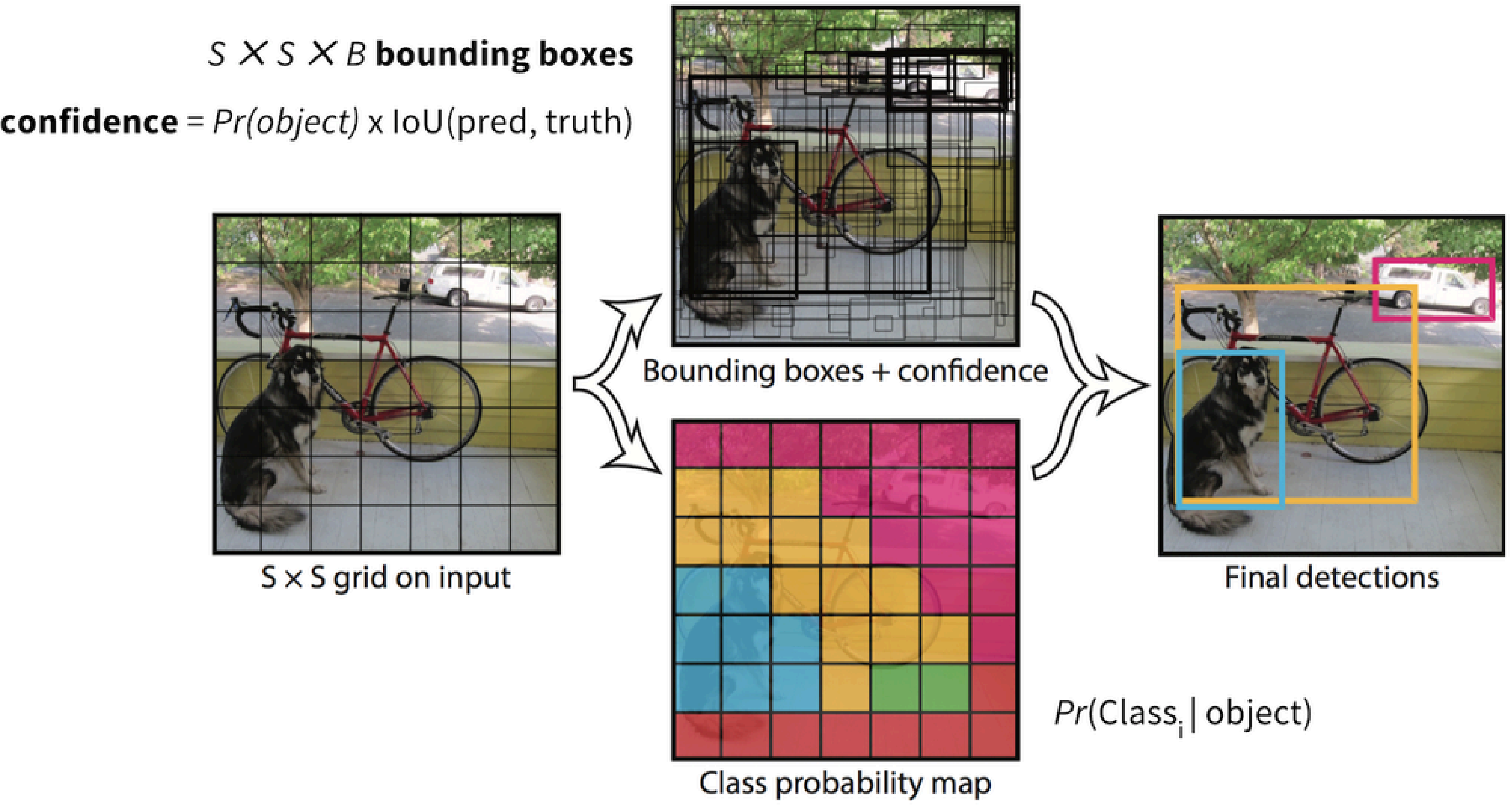
OVERVIEW

The Efficient and Accurate Scene Text Detector (EAST) model, presented by Zhou et al , establishes a simple yet efficient pipeline for detecting text in natural scene images. EAST directly outputs text regions from full images using a fully convolutional network (FCN), producing two types of bounding box geometries rotated rectangles (RBOX) and quadrangles.

WHY CHOSEN: This algorithm was chosen due to its ability to handle arbitrary text in complex environments and also to eliminate the rigid traditional technique from the base pipeline of fixed co-ordinates.

DETECTION & CLASSIFICATION

DIGIT DETECTION: YOLO



THEORETICAL FRAMEWORK

OVERVIEW

YOLO, which stands for 'You Only Look Once,' is designed to detect objects in a single glance. Unlike traditional object detection methods that process images in multiple steps, YOLO uses a single neural network to identify objects and their locations in one pass.

In contrast with the alternative technique of filtering and then using connected component analysis which is prone to noise as used by Caldeira, YOLO has a better edge because instead of splitting the process into seperate segmentation and classification it does this in a single pass and speeds up the process.

MODEL RESULTS

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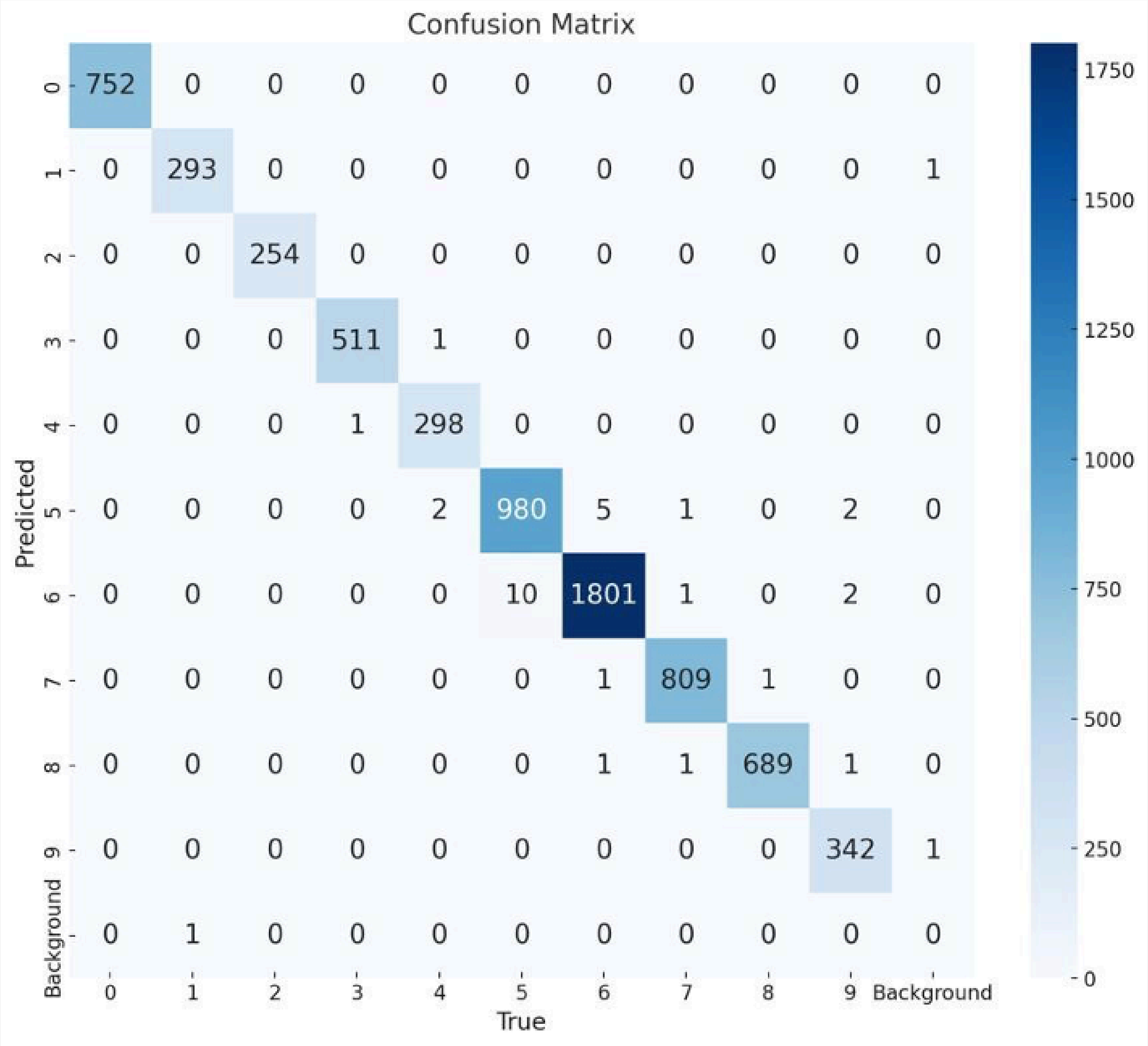
DIGIT DETECTION RESULT

For the training of the digit detection model, YOLOV11 was used and augmentation was applied to the dataset to improve variability across different enviroment

Trained on 100 epochs and to avoid overfitting a drop out layer was incoperated, this is to reduce overfitting by randomly deactivating the neurons during training.



The model achived a precision of 99.4% and a recall of 99.5%

A notable key finding was the the minimal missclassification of 6 as 5 which was misclassified 10 times

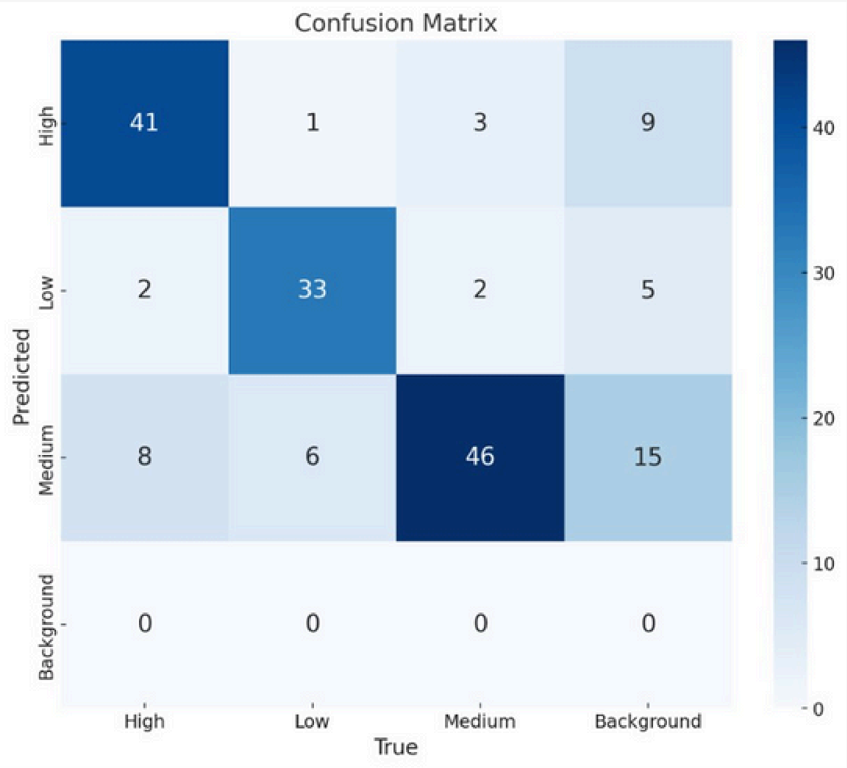
LEGIBILITY CLASSIFICATION RESULTS

This model was trained with YOLOV11 based on the DSP legibility criteria which was High, Medium and Low class and also importantly on a balance data set

Key Findings were:

The precision dropped after augmenting the data set, how ever the recall and accuracy improved on the Augmented model.

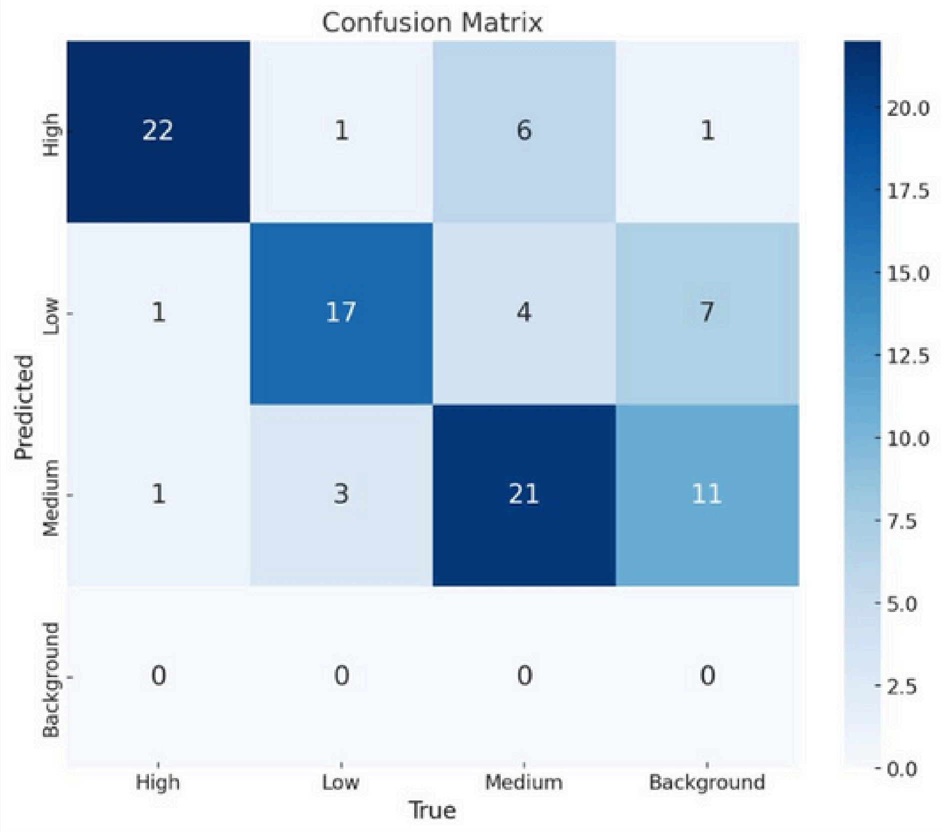
AUGMENTED



Firstly, Non-Augmented data was trained and achived an ;

Accuracy of 85%
Precision 70%
Recall : 84%

NON AUGMENTED



Firstly, Non-Augmented data was trained and achived an ;

Accuracy of 79%
Precision 84%
Recall : 79%

MODEL TEST PERFORMANCE

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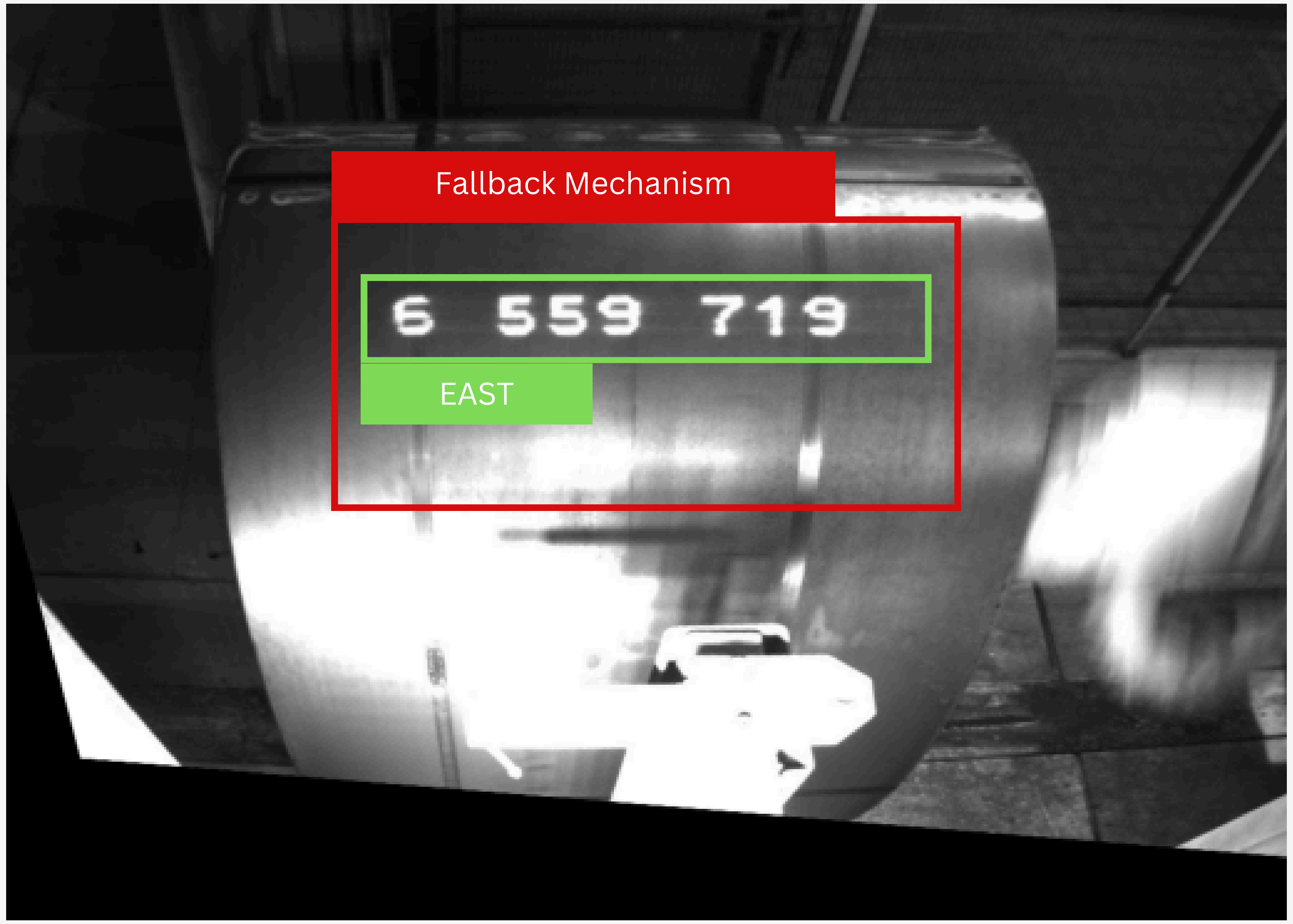
LEGIBILITY ASSESSMENT RESULTS

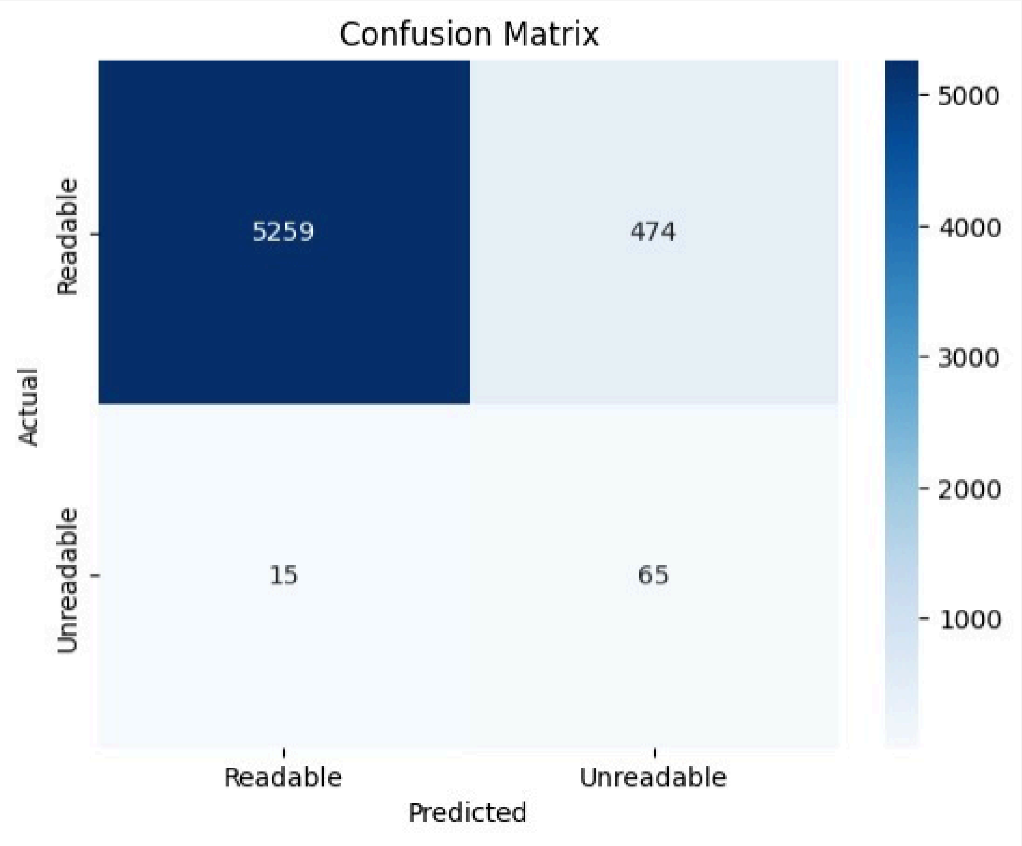
To evaluate the model for Industrial settings, a monthly data that consisted of 5,834 images was collected from the DSP.
The legibility assessment module decides if a whole Coil ID was readable based on the algorithm of the overall system as shown in pipeline previously. The rule was simple: if any digit was classified as Low, the Coil ID was marked as Unreadable.



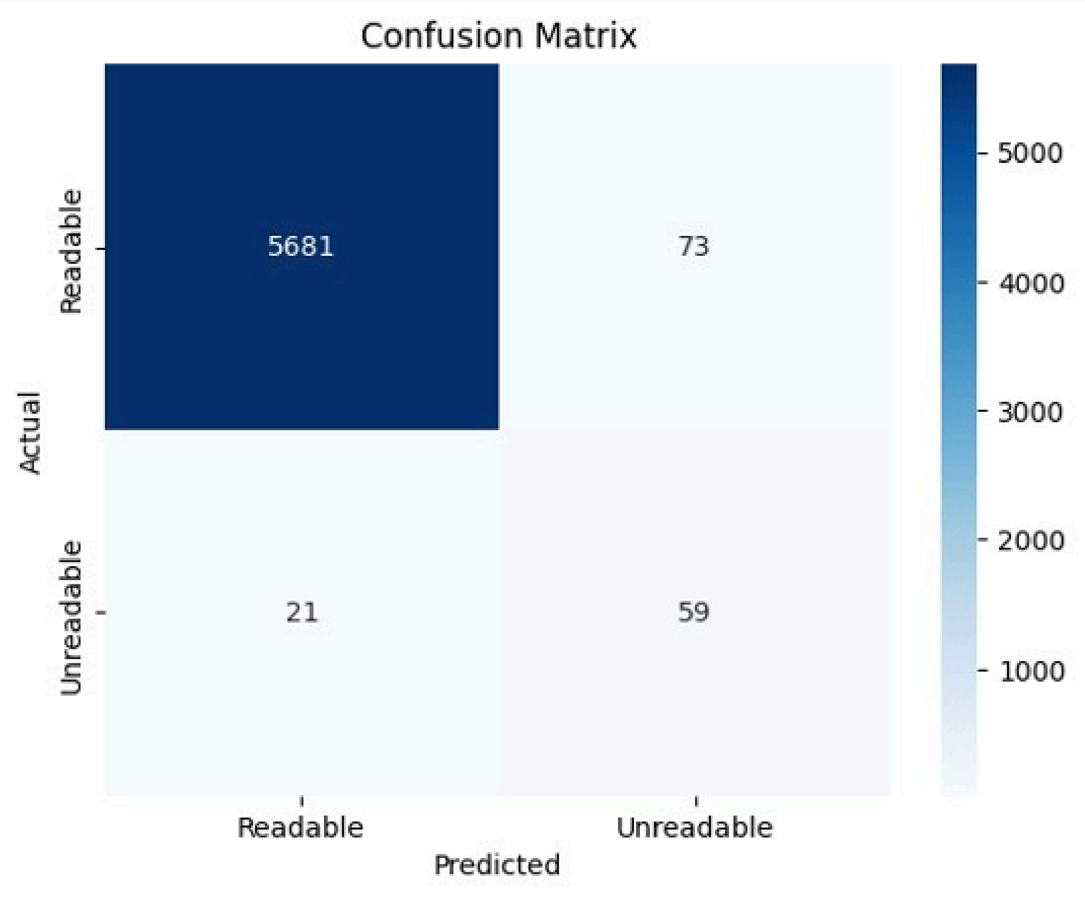
EAST was tested on the Legibility Assessment Test Set to measure how often it successfully detected the Coil ID. Out of 5,834 images, EAST detected the Coil ID in 5,813 cases, **giving a 99.64% success rate**. In 21 images, EAST did not detect the Coil ID, so the fallback method was used.

Detection Outcome	Number of Images	Percentage
Coil ID detected by EAST	5,813	99.64%
Coil ID not detected (fallback used)	21	0.36%

NON-AUGMENTED



AUGMENTED



After the an impressive recall of 81%; however, the precision struggled and it was 11%.

Inference time: Each image took **6.3** seconds to process an image

Another test to compare the result the augmented model, and the precision achieved is 0.44 and the recall is 0.73

ETHICAL AND SUSTAINABLE ASPECT

ETHICAL ASPECT

- **AI Transparency**
- **Reliability**
- **Bias Mitigation**
- **Accountability**

SUSTAINABLE IMPACT

- Reduces reliance on manual inspections, lowering energy consumption and minimizing waste.
- Enhances operational efficiency to prevent costly misidentifications and production delays.
- Aligns with environmental, economic, and societal sustainability goals, promoting improved quality control and safety.

KEY FINDINGS

MAJOR FINDINGS

- EAST failed to detect Coil IDs in 21 images, all of which had severe readability issues, showing its indirect role in identifying problematic prints.
- YOLO achieved 99.4% precision and 99.5% recall in digit detection, proving its reliability for Coil ID recognition.
- Data augmentation increased recall (73%) but introduced more false positives, lowering precision to 44%, highlighting the challenge of balancing accurate detection with minimal errors.
- The system processed images in 6.3 seconds, meeting industrial real-time requirements.
- Limited unreadable Coil IDs in the dataset affected model performance, highlighting the need for better data collection.

LIMITATIONS

HIGH POSITVE RATE

The biggest issue is readable Coil IDs being marked as unreadable. While the model successfully detects unreadable prints, it overcompensates by flagging prints that a human operator would still consider legible.

DATA AUGMENTATION

Augmenting the dataset helped increase recall (catching more bad prints), but it also introduced more mistakes in classification. The model learned to expect certain types of defects that might not always exist in real world conditions.

LIMITED DATA

The dataset lacked enough samples of Coil IDs that were severely degraded, smudged, or partially missing. As a result, the model struggles with extreme cases that happen less often but matter the most when they do.

CONCLUSION

Though, the legibility classification model struggles with low precision (44% due to data imbalance), we can still detect unreadable Coil IDs by processing data effectively and selecting the right machine learning models.

This research proved that the YOLO-based digit detection model shows excellent performance by achieving 99.4% precision and 99.5% recall, while EAST localization reliably identifies coil IDs with a 99.64% success rate.

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RECOMMENDATIONS

ACTIVE LEARNING

Active learning can be implemented to enhance the system's overall performance by identifying uncertain Coil IDs, and requesting operators annotation for these cases.

DATASET EXPANSION

Increase the variety and number of images, particularly for unreadable Coil IDs, to better capture the full range of conditions encountered in production. This will help the model generalize better and reduce bias.

GAN EXPLORATION

Alternative methods, such as GAN based synthetic data generation, to create more realistic training samples without excessive variability

THANK YOU

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