AUV SIMULATION FOR UNDERWATER PIPELINE INSPECTION

DEEP INSIDE

MEET THE TEAM!

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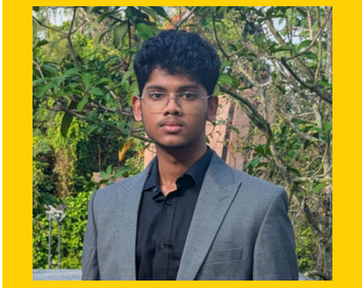

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INTRODUCTION

Importance of Subsea Pipelines:

- Subsea pipelines transport vital resources like oil, gas, and water across underwater distances.

Need for Inspection:

- Maintaining pipeline integrity is crucial to prevent leaks, environmental hazards, and costly downtime.

Limitations of Traditional Methods:

- Human divers and ROVs face constraints like depth, weather conditions, and high operational costs.

Advantage of AUVs:

- Autonomous Underwater Vehicles (AUVs) offer reliable, efficient, and scalable inspection alternatives.

Role of Sensors:

- AUVs are equipped with sonar and visual sensors for autonomous navigation and data collection.

Machine Learning Integration:

- ML enables real-time detection, classification, and localization of pipelines and defects from sensor data.

PROBLEM STATEMENT

- Pipeline inspection is essential for subsea infrastructure safety and efficiency.
- Traditional methods (divers/ROVs) are costly, labor-intensive, and weather-dependent.
- There's a need for autonomous, real-time, and scalable pipeline monitoring.
- This project proposes an ML-enabled AUV system for pipeline detection and localization using visual/sonar data.
- Goal: Reduce manual inspection, increase reliability, and improve operational efficiency.

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BUSINESS CASES

1. Oil and Gas
   - Pipeline inspection and maintenance
   - Subsea infrastructure monitoring
   - Leak detection and corrosion assessment
2. Marine Research & Oceanography
   - Deep-sea exploration
   - Environmental monitoring
   - Seafloor mapping and sampling
3. Defense & Military
   - Mine detection and disposal
   - Surveillance and reconnaissance
   - Harbor and ship hull inspection
4. Underwater Archaeology
   - Wreck exploration
   - Artifact recovery
   - Site mapping without human intervention
5. Telecommunications
   - Submarine cable inspection
   - Route planning and burial
   - Fault detection and repair support

GLOBAL IMPACT

May 6, 2023

U.S. pipeline regulator takes aim at methane leaks

Area guardsmen in fight against oil spill

By Matthew Hamilton
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Each day this week guardsmen from northeastern Louisiana will take a 20-mile helicopter flight from Venice to build the last best hope for preventing the Deepwater Horizon oil spill from spoiling more wetlands.

About 300 soldiers from Monroe's 528th Engineer Battalion are constructing and anchoring an inflatable dam across 21 miles of vulnerable shoreline to keep storm surges from dumping oil blobs into nearby marshes. When not constrained by thunderstorms, the soldiers work long hours in marshy terrain to finish the line, even as plumes of oil wash ashore in points east.

AP

Members of the Louisiana National Guard build a levee Friday to protect inland waterways from the Deepwater Horizon oil spill on Elmer's Island in Grand Isle.

Capt. Joshua Culp said the 528th Engineer Battalion was mobilized April 30, moving from Belle Chase to Marrero and then finally to Venice where the unit has set up its headquarters of air-conditioned tents and trailers.

By May 11 Black Hawk helicopters began airlifting all-terrain vehicles and small front-end loaders over Cocodrie Bay, where beaches are accessible by air alone and the shore rests against a spoke of marshland that extends into Louisiana's southernmost point.

Since May 14, soldiers have been setting up "Tiger Dams," 50-foot tubes anchored into the ground, filled with water and stacked in two layers to form a two and half-foot barrier. The inflatable berms are set up on the shoreline and act as a second line of defense if oil, by storm surge or other means, makes its way past the boom line in the water.

Culp said the battalion will have completed about two miles of inflatable dam by Thursday. The guardsmen

See GUARD 8A

Tug sinks, oil spills

31,000 gallons spread after accident

FOURCHON (AP) — Ships were stowed to a crawl Friday to keep from stirring up oily water while crews cleaned up a 31,000-gallon spill near Louisiana's southernmost deepwater port.

"It's a medium-sized spill," said Roland Guidry, Louisiana's oil spill coordinator. A spill of about 1,000 barrels - 42,000 gallons - would be considered large, he said.

Guidry and the Coast Guard said no birds or animals got caught in the spill, so far as they knew, and only a small amount got to the beach.

About 5,000 gallons of oily water had been removed by about noon Friday, and the cleanup was expected to take several days, Coast Guard Petty Officer Jeff Crowley said.

Most of the oil rose from a 12-inch pipeline broken Tuesday night by a striking tugboat.

Divers Friday were making plans to check the pipeline and prepare salvage operations on the towing vessel Stone Fueler, Crowley said.

One of their first jobs will be to mark other nearby pipelines, so that the salvage barge coming to lift the tugboat doesn't push an anchor leg into one of them, Guidry said.

Although storms kept divers from checking the damage Thursday, they actually helped by churning the water, aiding evaporation and breaking up the oil, he said.

The Stone Fueler leaked an undetermined amount of its 8,000 gallons of diesel fuel, the Coast Guard said.

The pipeline was shut until repairs could be made.

Most of the fuel had been recovered, evaporated or dispersed by late Thursday, the Coast Guard said.

The accident occurred in about 20 feet of water about one-half mile northeast of the Belle Pass jetties. The port was closed to traffic after the accident but was reopened to inbound traffic Thursday morning.

Ships using nearby West Bell Pass were required to proceed slowly through the channel so the cleanup would not be interrupted, the Coast Guard said.

More than 36,000 feet of containment boom had been deployed Thursday.

State and federal officials, and commercial interests set up a post at the Fourchon Volunteer Fire Station to monitor the cleanup.

A preliminary inspection of shorelines in the Elmer's Island, Fourchon and Grand Isle areas reportedly did not find any oil on the beaches or shoreline. The oil spill response vessel OSRV Edison G was dispatched to aid in the recovery of spilled material.

The sunken vessel's owner contracted with Oil Mop Inc. to assist in spill containment and cleanup. The Stone Fueler was towing an empty tank barge at the time of the accident.

World • August 27, 2023

Pipeline leaks on southern Iran's coast

January 29, 2022

Oil spill reaches shoreline in eastern Thailand

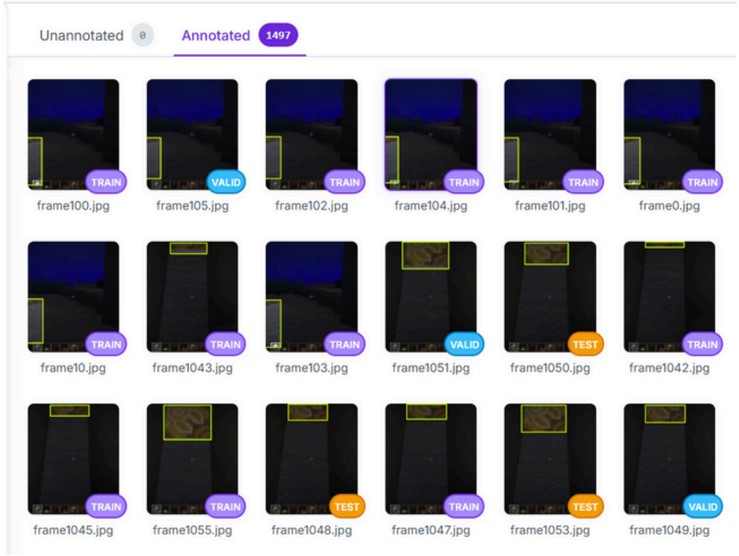
COMPANIES INVESTING IN PIPELINE AUVS

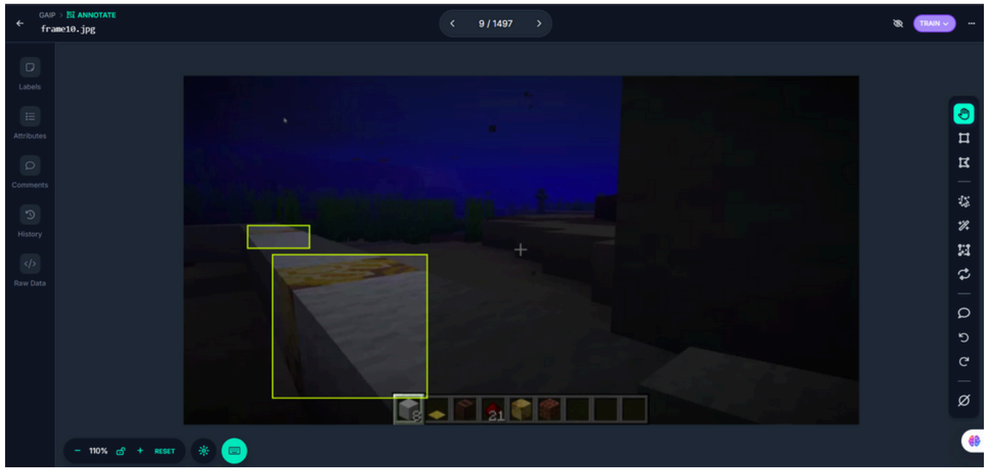
Company Name	Purpose	Investment
Nauticus Robotics	Autonomous underwater robots (AUVs), AI, and teleoperation for pipeline inspection and repair	$12 million investment in 2024 for Aquanaut commercialization
Kawasaki Heavy Industries	AUV with robotic arm for deepwater pipeline inspection	Ongoing R&D investments, government/industry support
Oceaneering International	ROVs, AUVs, and advanced subsea inspection	Collaboration with University of Houston, Chevron, BSEE grant ($960,493)
University of Houston	Smart Touch ROVs for subsea inspection	$960,493 BSEE grant, Chevron collaboration
BeeX	Oil & Gas Pipeline Inspection and Monitoring	$2 million dollars investment in collaboration with Earth Venture Capital and ShipFocus Ventures

DATA OVERVIEW AND EDA

1. Dataset Description

- Total images (original): 1,775 frames extracted from screen recordings of a simulated underwater pipeline environment in Minecraft.
- Augmented images: Increased to approximately 3,500 using rotation augmentation at +15° and -15°.
- Annotation tool: Roboflow was used for manual labeling of corrosion regions.
- Classes:
  - Corrosion – the only class of interest, defined by visible rust patches on pipeline surfaces.





DATA OVERVIEW AND EDA

2. Data Distribution

- Train/Val/Test Split:
  - Training: 70%
  - Validation: 20%
  - Testing: 10%
- Distribution ensured a balanced spread of angles and corrosion types to help the model generalize across scenarios.

DATA OVERVIEW AND EDA

3. Exploratory Data Analysis (EDA)

- Class Frequency:
- As only one class exists, EDA focused on bounding box density and positioning rather than class balance.
- Bounding Box Analysis:
  - Corrosion patches mostly appear in the lower half or center of the frame, consistent with pipeline placement in the simulation.
  - Box sizes vary, indicating both small specks and large rust patches.
- Augmentation Effects:
  - Rotation helped introduce slight variations in pipeline angle, mimicking AUV orientation drift.
  - Resulted in improved model robustness during evaluation.
- Image Quality & Diversity:
  - Despite being game-rendered, the lighting, pipeline color, and background variability introduced enough visual diversity for model training.
  - HSV color histograms were used to verify pipeline distinguishability for segmentation.
- Sample Visualizations:
  - Random image samples were plotted with bounding boxes to confirm annotation accuracy.
  - Histogram plots of bounding box sizes and image brightness levels were used to assess consistency.

METHODOLOGY

Simulation Environment Setup

- Used Minecraft to simulate an underwater pipeline due to its customization and visual control.
- Constructed a virtual pipeline with distinct rust patterns to replicate real-world corrosion.

Data Collection

- Captured a screen recording while navigating the pipeline environment.
- Extracted ~1,775 frames from the video, showing various views and corrosion conditions.

Annotation and Dataset Preparation

- Manually annotated frames using Roboflow, marking visible corrosion.
- Created a labeled dataset with bounding boxes for object detection model training.

METHODOLOGY

Data Augmentation

- Applied rotation-based augmentation (+15° and -15°) to each image.
- Doubled the dataset size to approximately 3,500 annotated images for better generalization.

Corrosion Detection Using YOLO

- Trained a YOLO object detection model on the augmented dataset.
- YOLO was used to detect and localize corrosion on underwater pipelines in real-time.

Navigation Assistance via DeepSORT

- Integrated DeepSORT for real-time object tracking.
- Enabled consistent tracking of corrosion patches across frames.
- Improved inspection path planning and reduced redundant detections.

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METHODOLOGY

Pipeline Detection via HSV Thresholding

- Used HSV color thresholding to segment and isolate the pipeline from the environment.
- Enabled focused analysis by distinguishing the pipeline from the background.

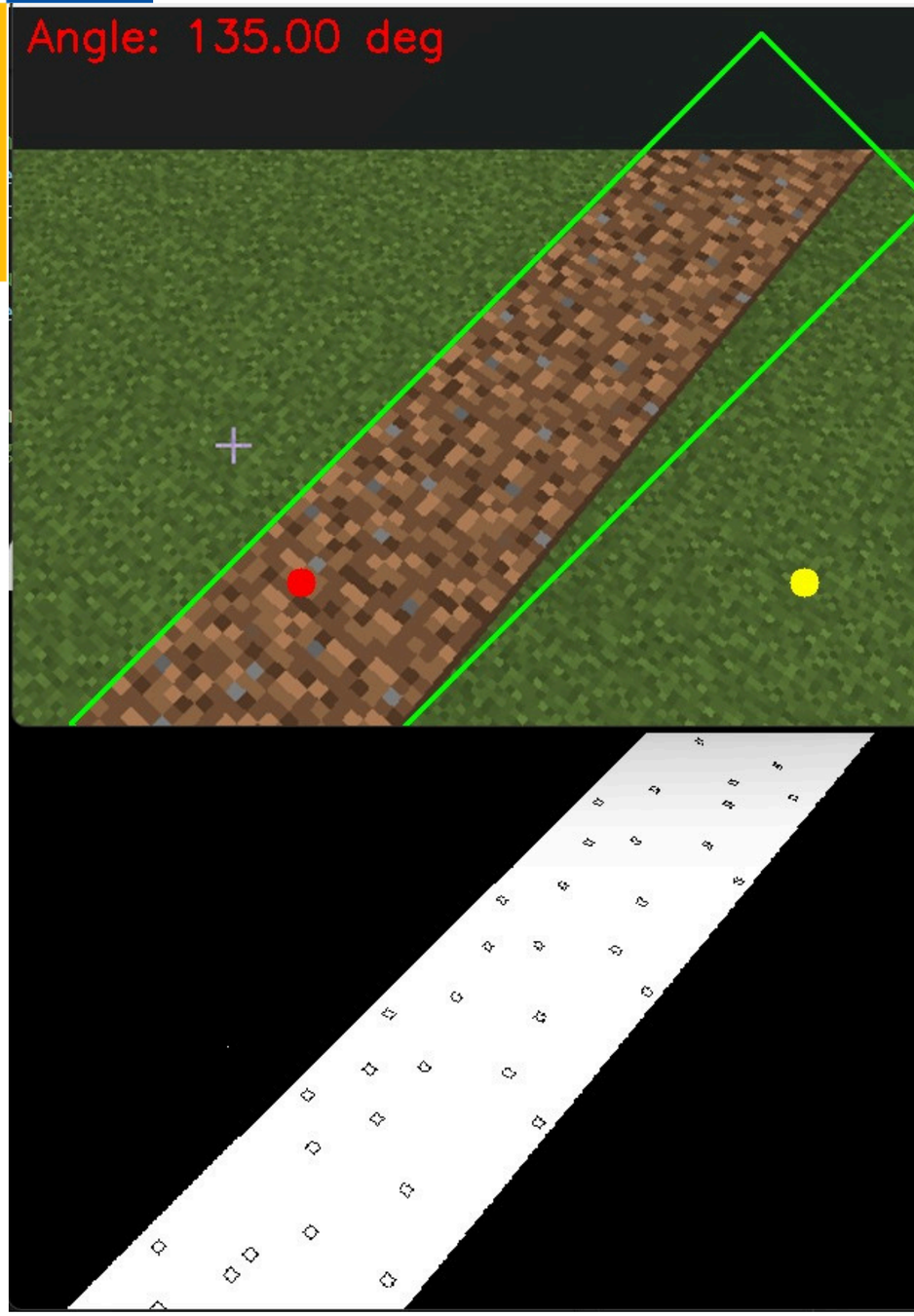
System Integration

- Integrated YOLO corrosion detection, DeepSORT tracking, and HSV pipeline segmentation.
- Created a unified vision-based system simulating an AUV's real-time perception.
- Enabled autonomous detection and tracking of pipeline corrosion in the simulated underwater environment.

RESULTS AND ANALYSIS

HSV Thresholding – Pipeline Segmentation

- The method performed well under consistent lighting and clear simulation textures.
- Challenges:
  - Minor false positives occurred when rust patches had similar hues.
  - Performance decreased slightly when shadows or texture noise was present.



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RESULTS AND ANALYSIS

Autonomous Tracking – DeepSORT Integration

- Consistent ID tracking was maintained for corrosion patches across sequential frames.
- The system helped simulate a realistic AUV navigation path, responding dynamically to object movement and occlusions.
- It enabled direction correction when corrosion points drifted in-frame, mimicking how an AUV would correct its course underwater.

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RESULTS AND ANALYSIS

Results and Analysis – YOLOv8 Corrosion Detection

- Model: YOLOv8s
- Epochs: 120 (early stopped at 78)
- Dataset: ~3,500 images (with rotation-based augmentation)
- Input Size: 640×640
- Batch Size: 16

Key Metrics (at Epoch 78)

Metric	Value
Precision	1.055
Recall	0.5042
mAP@0.5	1.131

Summary

- High precision indicates accurate detections with few false positives.
- Moderate recall shows some corrosion spots were missed.
- Good mAP confirms the model performs well across IoU thresholds.
- Model converged by epoch 78, reducing risk of overfitting.

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FAILURES

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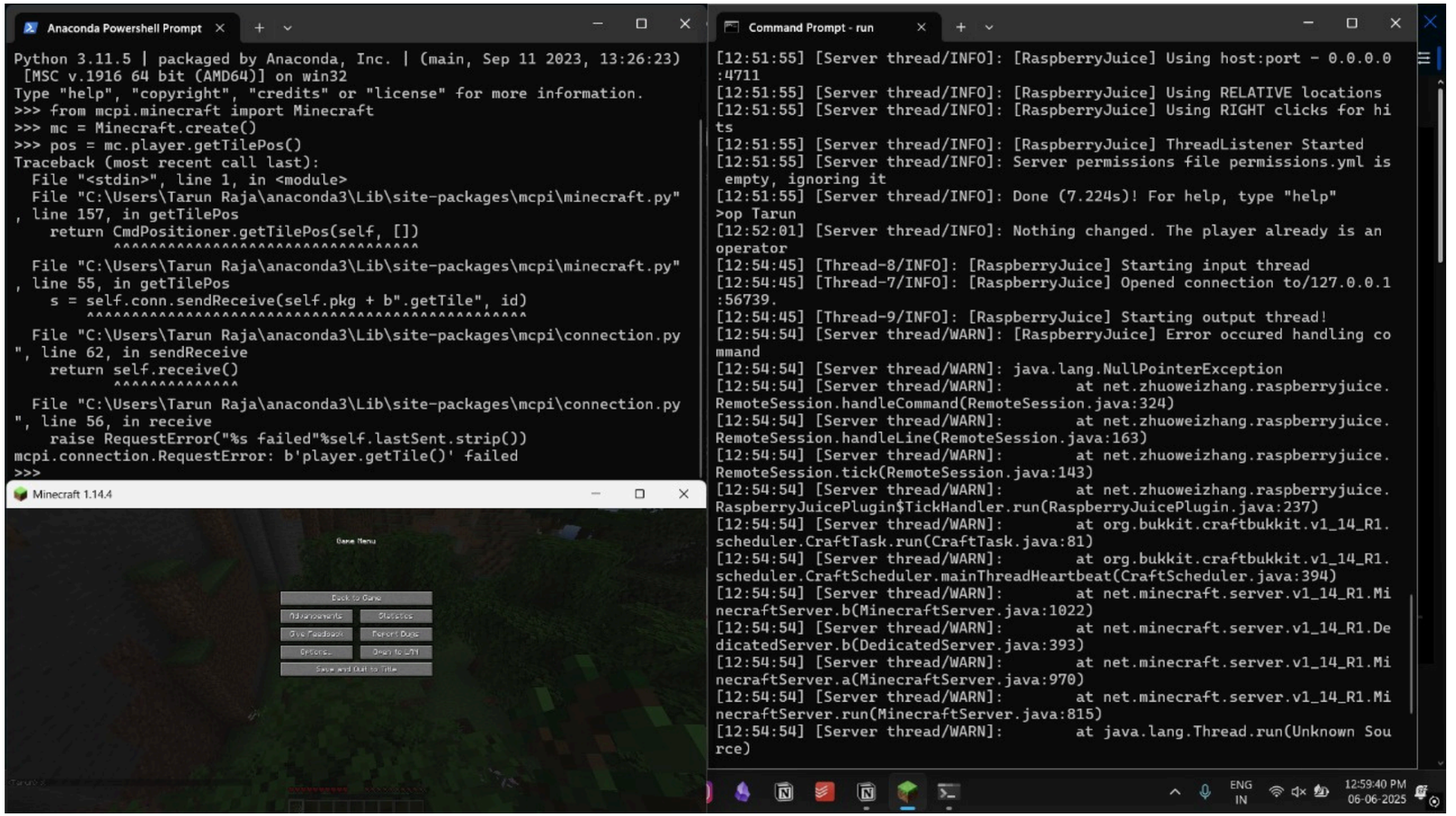
-Minecraft Server and Python Code incompatibility



FAILURES

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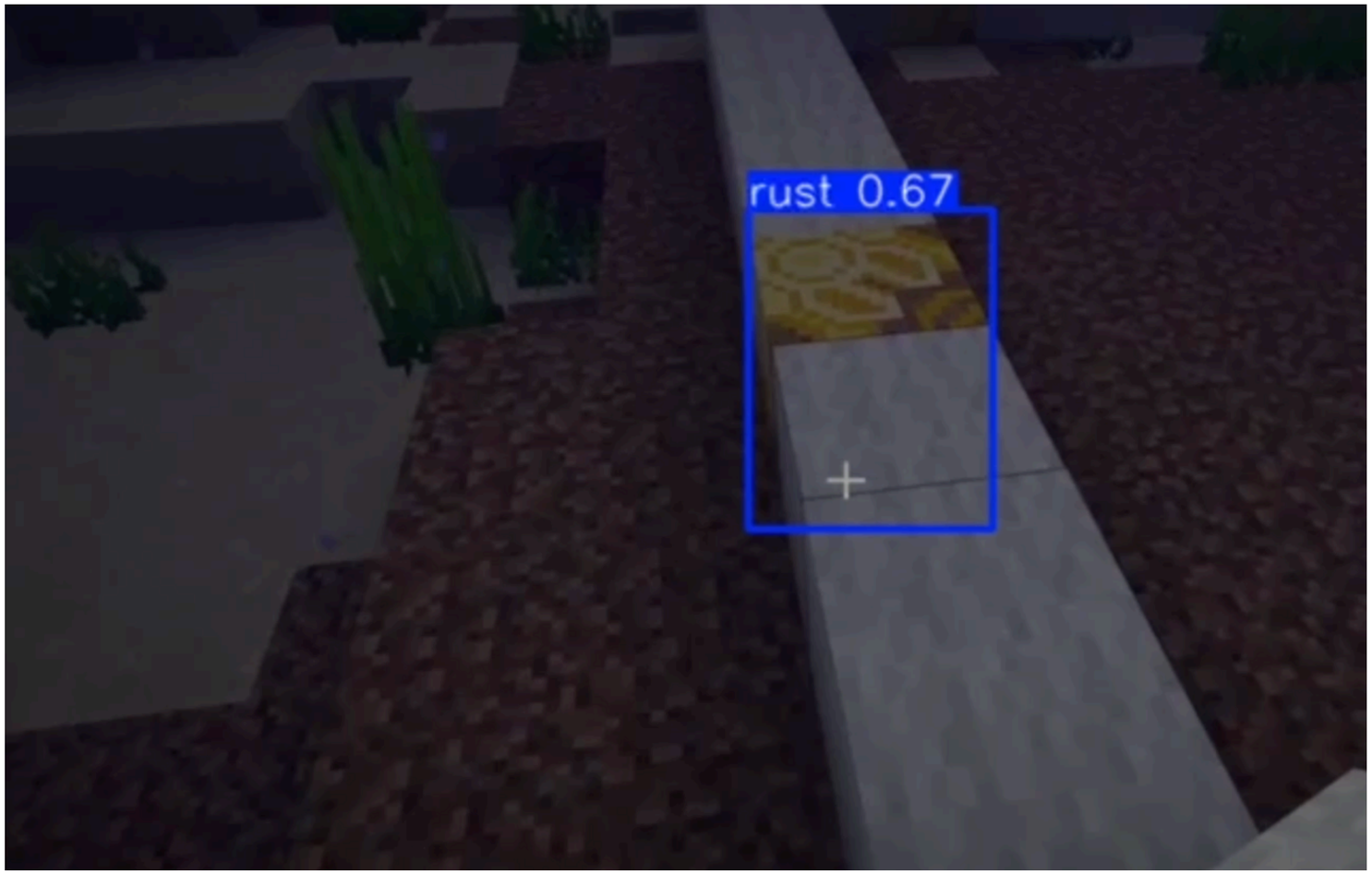
-Data Loss



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DEMO

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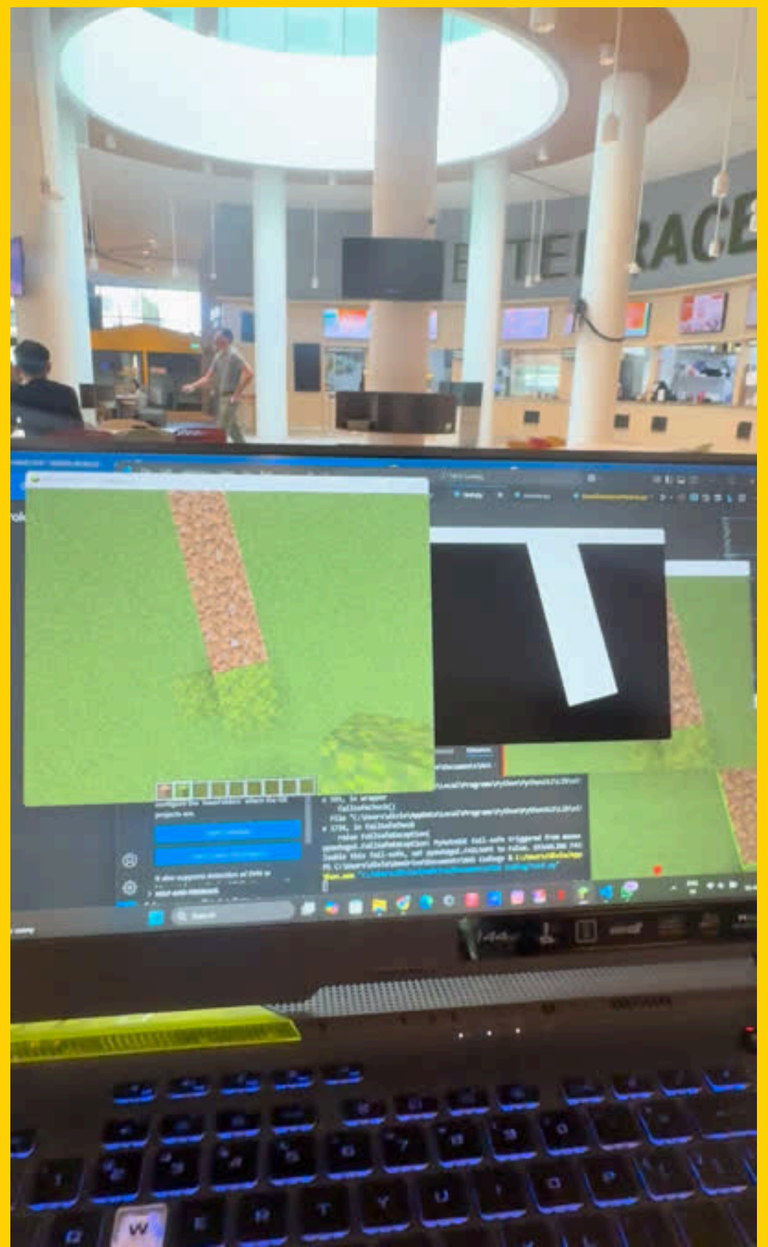


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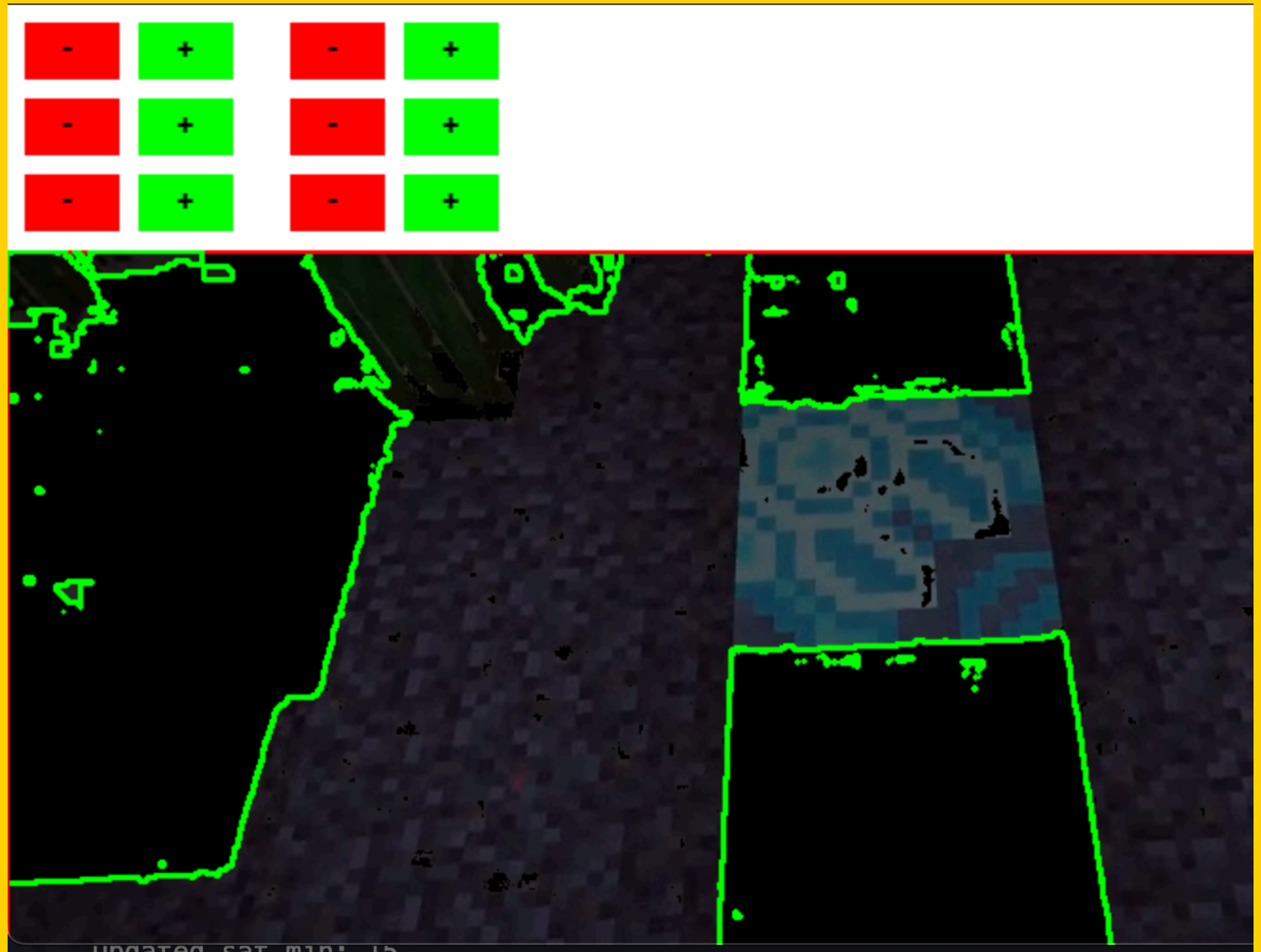

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THANK YOU!