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The 22nd International Asset, Facility & Maintenance Management Conference

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Automating Subsurface Utilities Detection and Visualization using Deep Learning and Augmented Reality

Mahmoud Hamdy Safaan & Mohamed Marzouk

26-28 January 2025
The Ritz-Carlton Jeddah, Kingdom of Saudi Arabia

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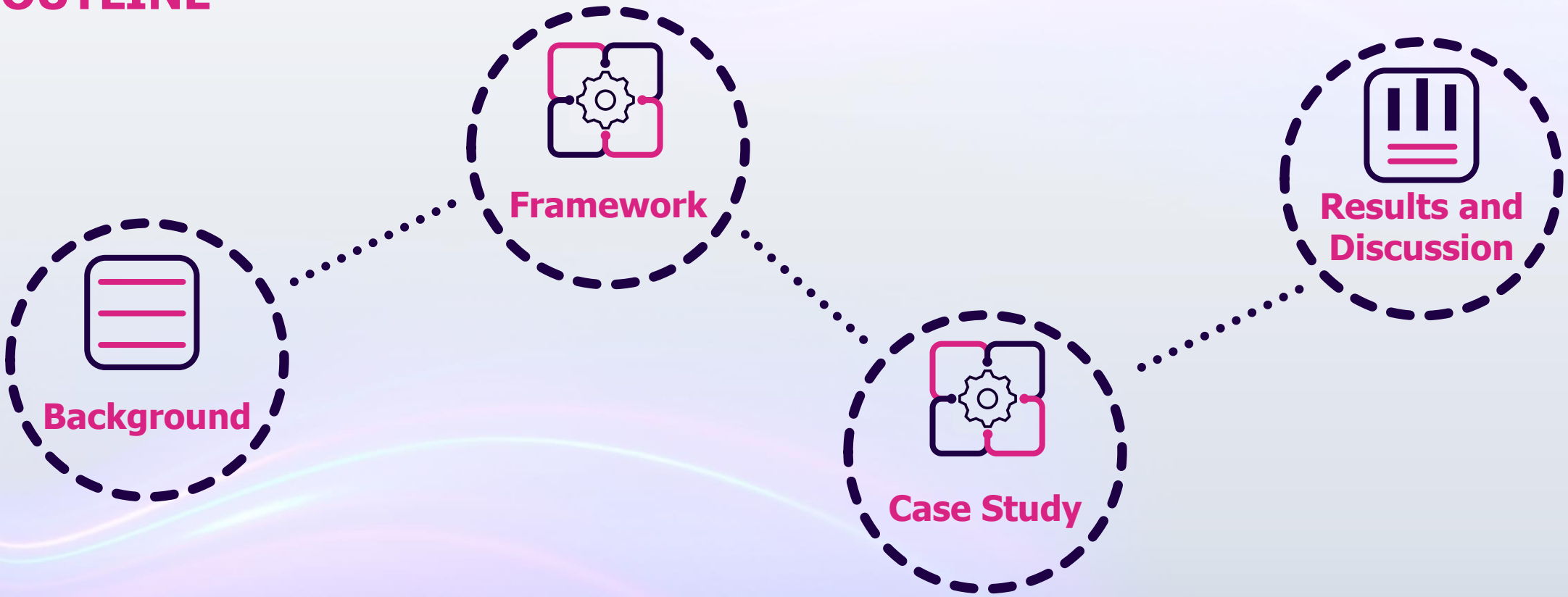
OUTLINE



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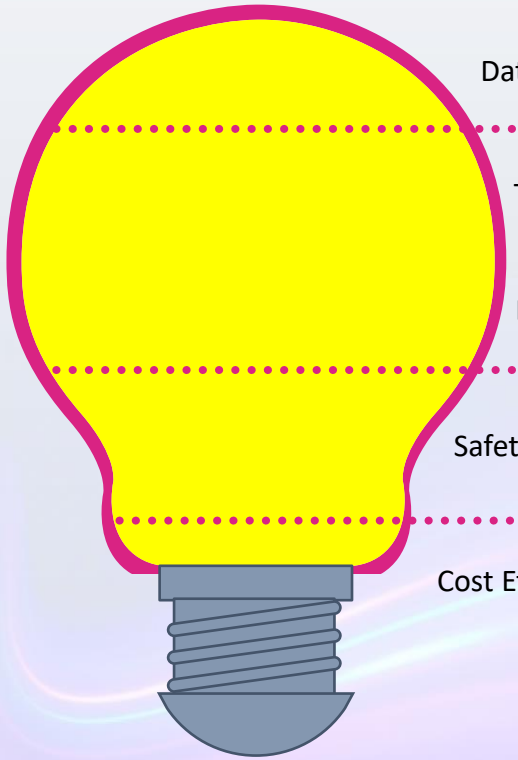
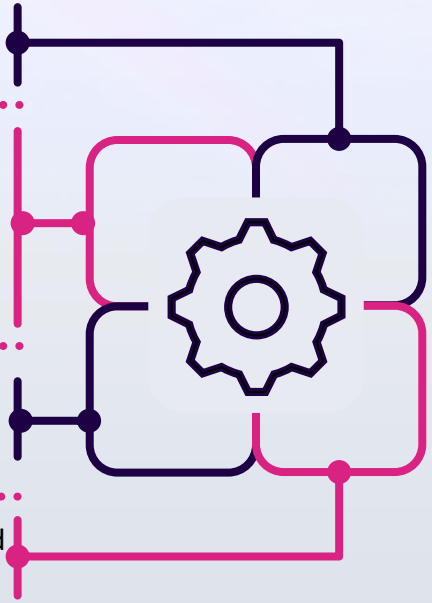
BACKGROUND



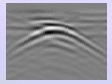
Data Acquisition	Missing existing utilities.	Utilizing **GPR** for utilities detection and simplifies the interpretation process.
Time Consumption & Detection Accuracy	Manual and traditional methods are time-consuming and often lead to inaccuracies in detecting and mapping subsurface utilities.	Utilizing **Mask R-CNN** to automates the detection process **Enhancing detection accuracy** & significantly **reducing the time** required for subsurface utility detection.
Safety Hazards & Service Disruptions & Regulatory Compliance		Integration of **Augmented Reality (AR)** offers an innovative way to visualize detected utilities, improving **comprehension** and **decision-making.**
Cost Efficiency	Inefficiencies in traditional methods often lead to higher costs.	Reduce overall project costs by providing informed decision making



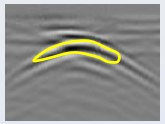
FRAMEWORK

Data Collection & Processing

- Data Collection
- Data Decryption and Preprocessing
- Data Fusion and Processing
- B-Scan Images Dataset with Various Filters per Profile



Model Training and Inference



- Data Preparation

- Model Preparation, Training, and Test Data Inference

- Masks Map for Each Profile Filter Configuration

Detection Post-processing

- Data Post-processing
- Model Evaluation
- Spatial Point Cloud

AR Visualization

- Application Development
- Application Testing and Deployment
- Data Visualization

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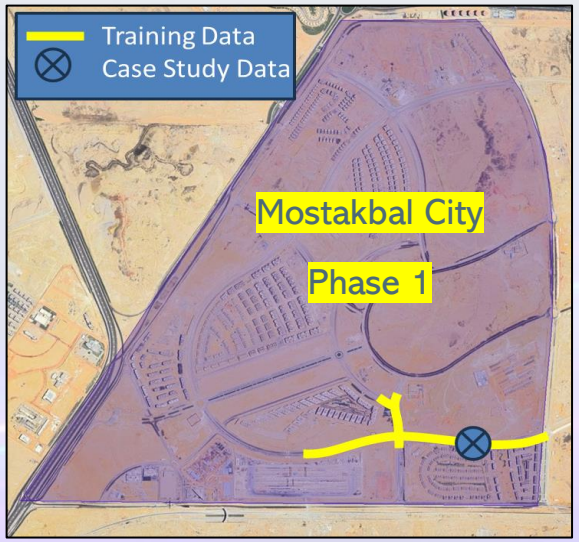
CASE STUDY

Data Collection & Processing — Data Collection

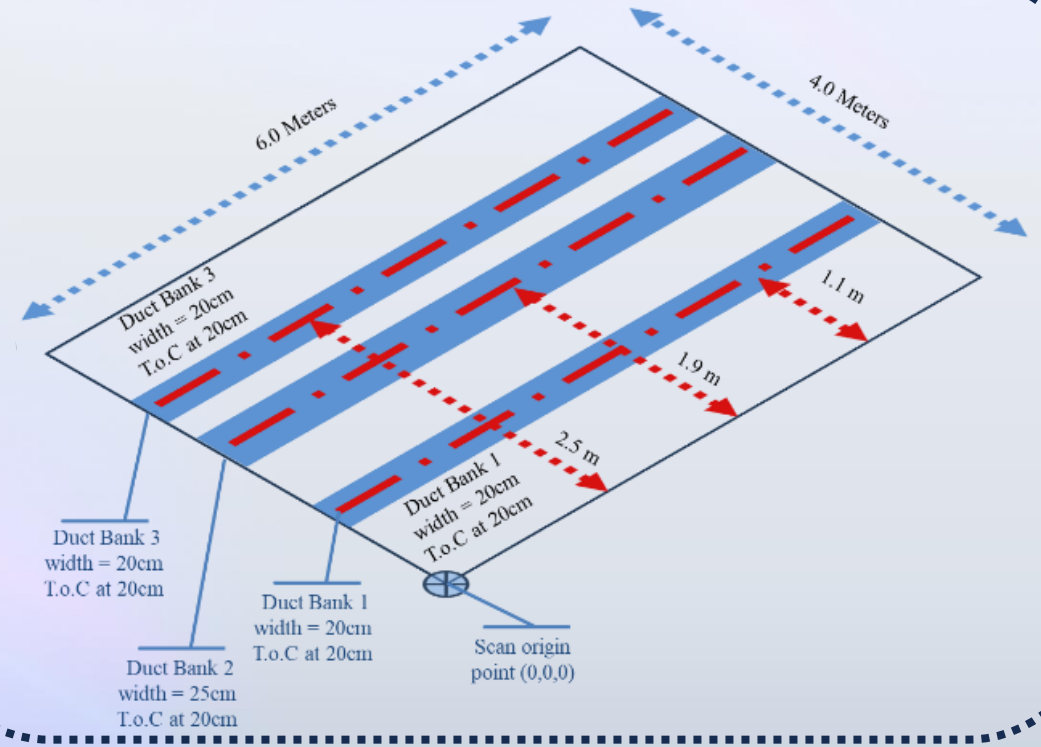
Location



Hardware

IDS ris mf hi-mod (2000MHz&400MHz)

Case Study



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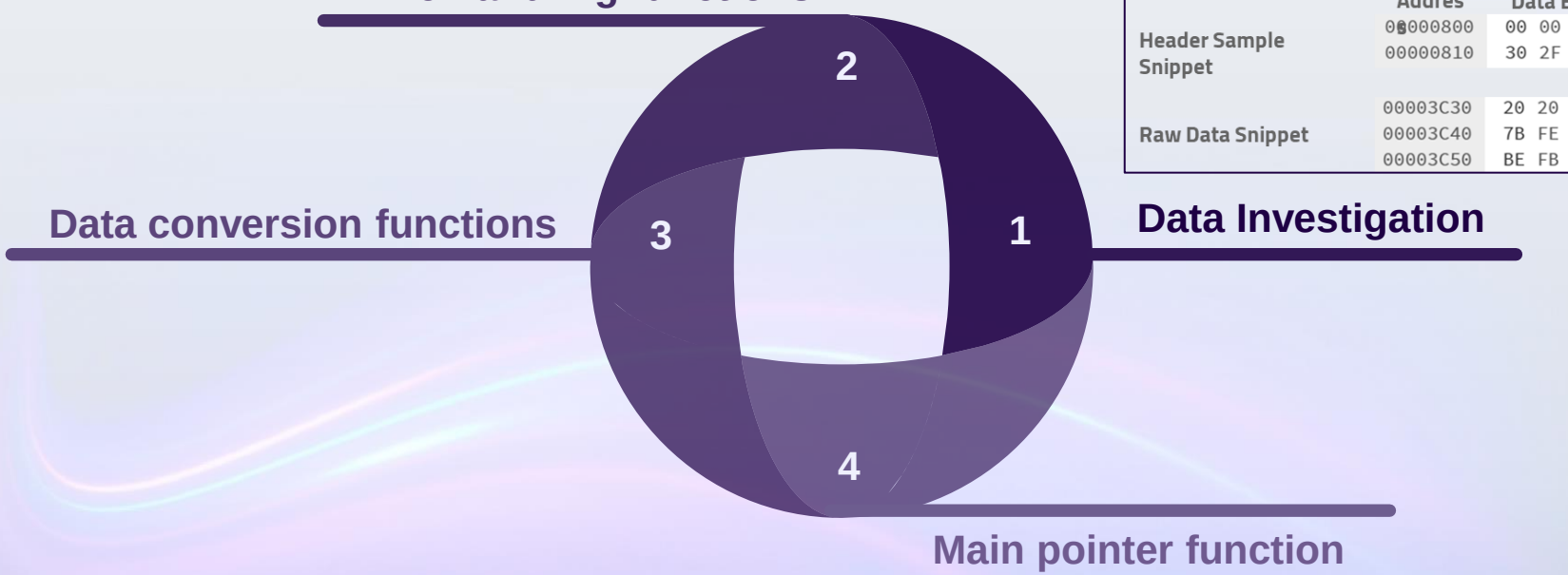
CASE STUDY

Data Collection & Processing — **Raw Data Decryption**



	Addres	Data Bytes															Hexadecimal converted to ASCII
Header Sample Snippet	00000800	00	00	00	00	00	00	00	00	43	00	00	00	30	35	2F	32	.....C...05/2
	00000810	30	2F	32	33	20	20	31	31	3A	34	32	3A	34	33	00	00	0/23 11:42:43..
Raw Data Snippet	00003C30	20	20	20	20	20	20	20	20	20	20	20	20	52	00	00	00	R...
	00003C40	7B	FE	8F	FE	BA	FC	D8	FB	C5	FB	BE	FB	C3	FB	BF	FB	{▪Å▪‖ⁿ╪√┤√╣√├√┐√
	00003C50	BE	FB	BE	FB	BF	FB	BF	FB	C0	FB	C1	FB	C0	FB	C1	FB	╛√╛√┐√└√┴√└√┴√

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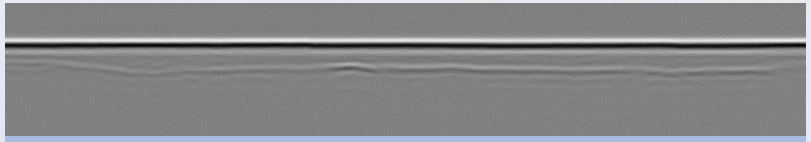
CASE STUDY

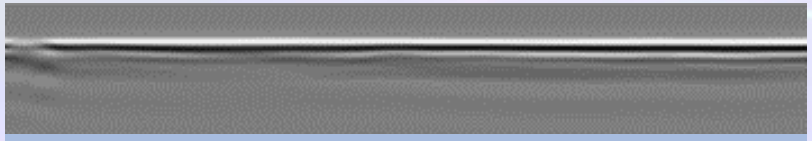
Data Collection & Processing — **Data Fusion**

- Data Resampling
- Spectral Forecast

Input



Raw data from 2000MHz sensor

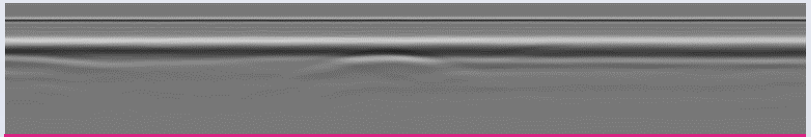


Raw data from 400MHz sensor

Process

1-Check data direction based on file structure.
2-Perform a paired processing at each iteration.
3-Compute each dataset's parameters.
4-Calculate Fused Data.

Output

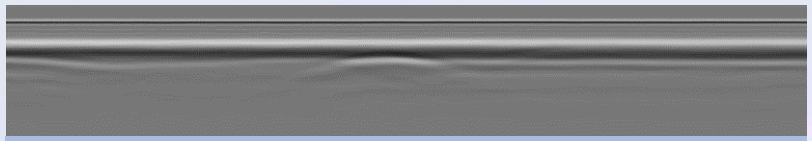


Fused Data

CASE STUDY

Data Collection & Processing

Input



Fused Data

Data Preprocessing & Processing

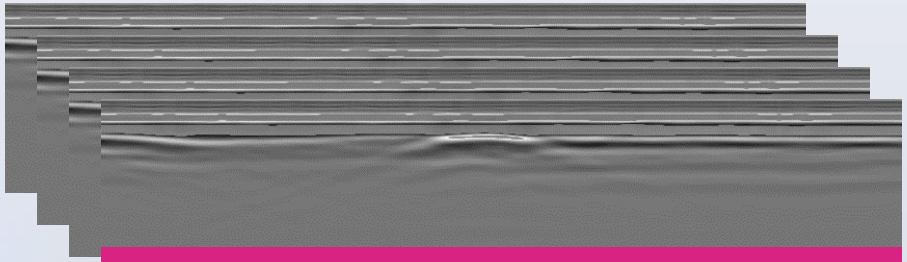
Process

1-Applying multiple filters each with its own configuration.
2-Performing SNR to filter out datasets.
3-Performing Zero-time correction.

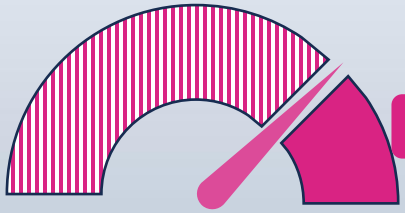
	Min. Range	Max. Range
Low Amplitude (GHz)	0.3	2.1
Dewow (window)	2	10
Signal Gain (Factor)	1.05	1.3

Output

- Low Pass Filter
- Power Gain
- Dewow
- Signal-to-Noise Ratio (SNR)
- Zero-Time Correction



A set of filtered data configurations



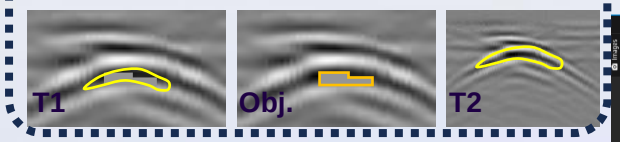
Best 15%

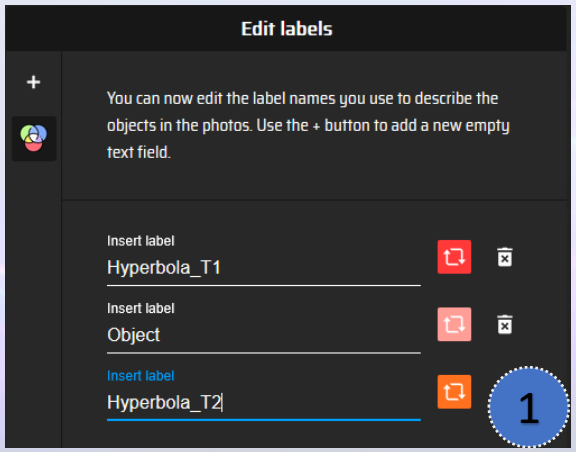
Selection Criteria Based on SNR value

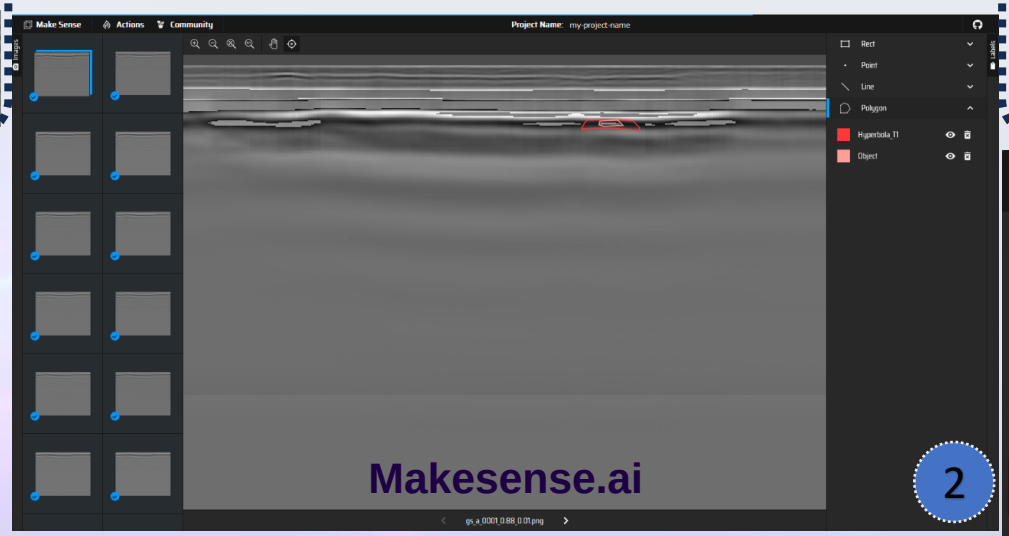
CASE STUDY

Deep Learning Model Training — **Dataset Preparation**

Input

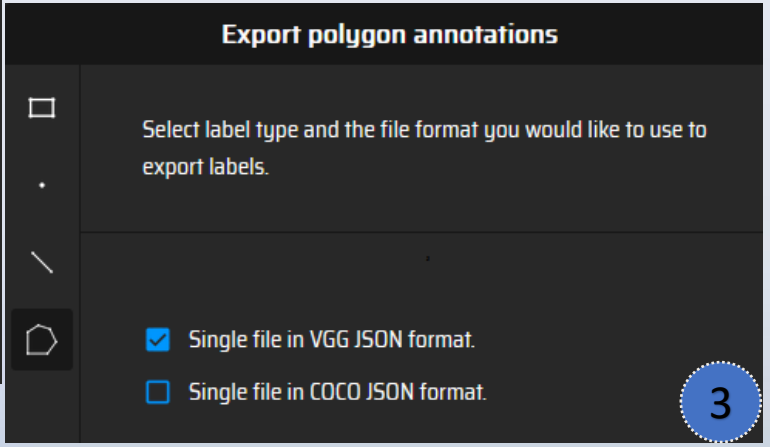






Output

Database of:



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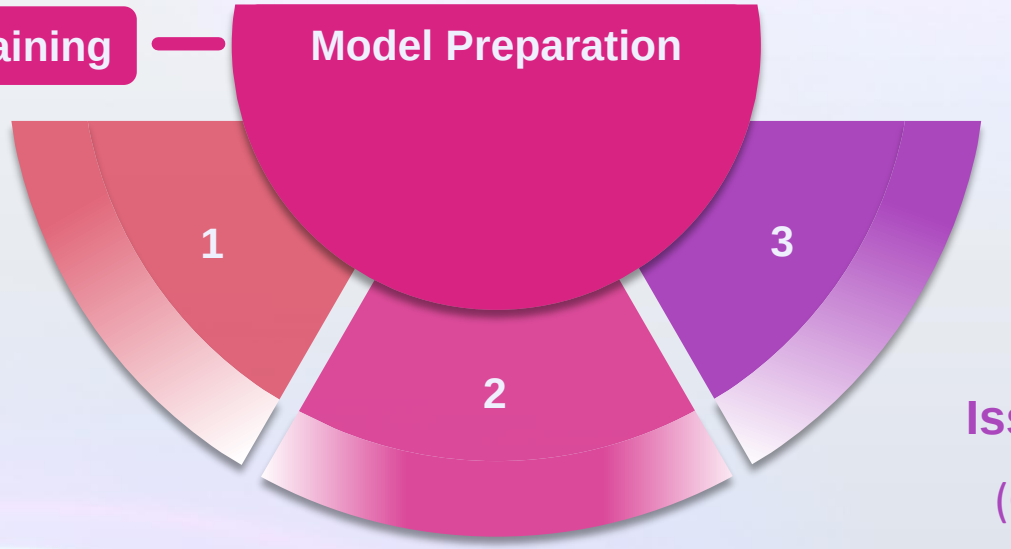
CASE STUDY

Deep Learning Model Training



Model Architecture Selection

(ResNet-50)

Matterport Mask R-CNN

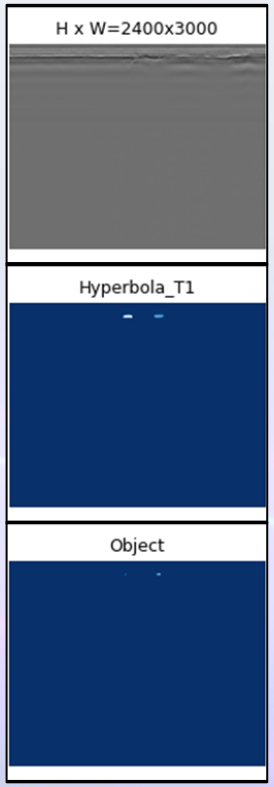
Integration Issues and Bugs

(Google Colab)

CASE STUDY

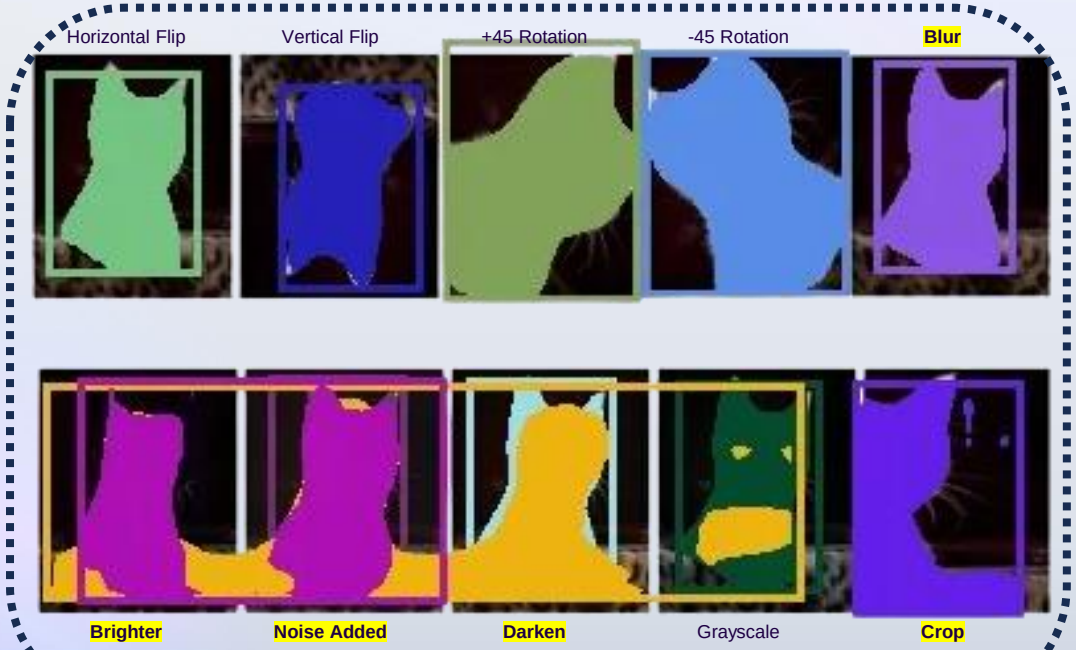
Deep Learning Model Training — Model Preparation — Integrating Database to the Model

Hyperparameter	Configured Value
GPU Count	1
Images per GPU	4
Steps per epoch	500
Validation steps	15
Backbone	ResNet-50
RPN Anchor Scales	[32, 64, 128, 256, 512]
RPN Anchor Ratios	[0.5, 1, 2]
RPN_NMS_Threshold	0.70
Minimum Image Size	800
Maximum Image Size	1024
Image Channel Count	3
Detection Minimum Confidence	0.80
Detection NMS Threshold	0.3
Learning Rate	0.001
Learning Momentum	0.9
Weight Decay	0.0001
Number of Classes	4 (3 classes + background)
ROI Positive Ratio	0.33
Pool Size	7
Mask Pool Size	14



Original Image

Data Augmentation



Augmented Images

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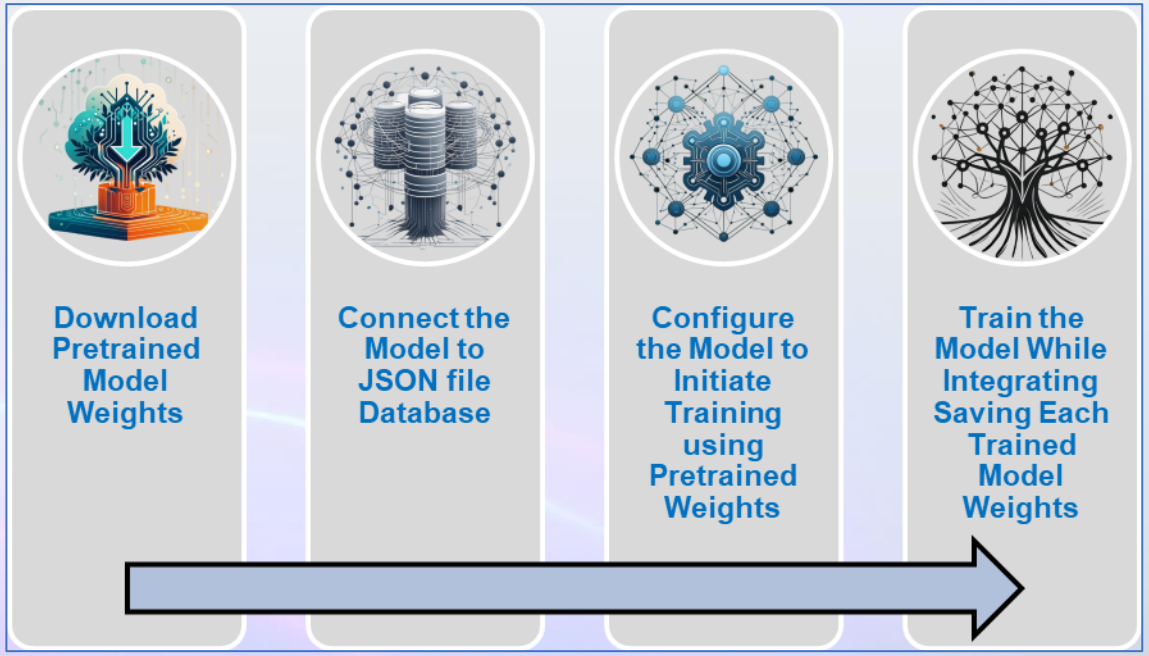
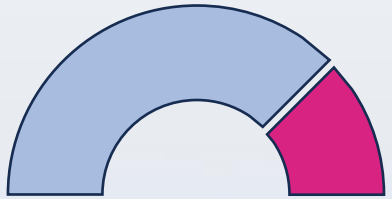
CASE STUDY

Deep Learning Model Training — **Model Preparation** — **Transfer Learning**



CASE STUDY

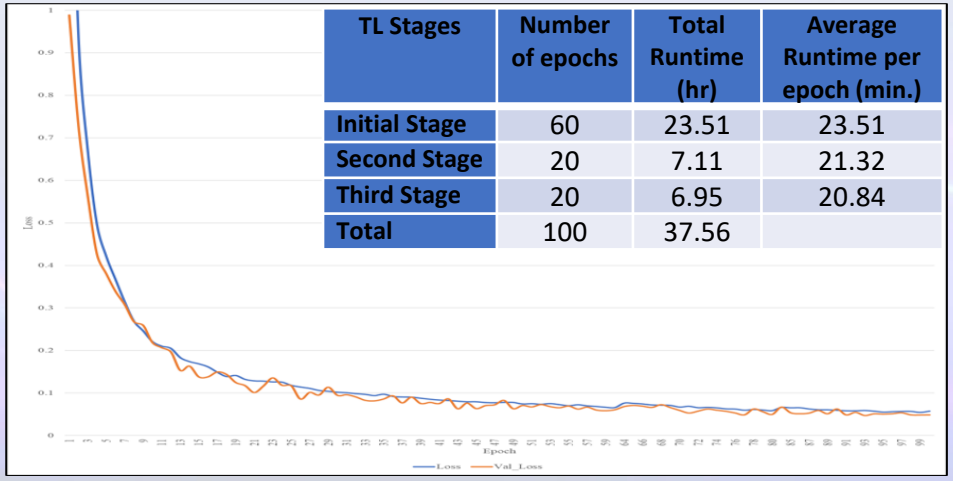
Deep Learning Model Training — **Model Training**



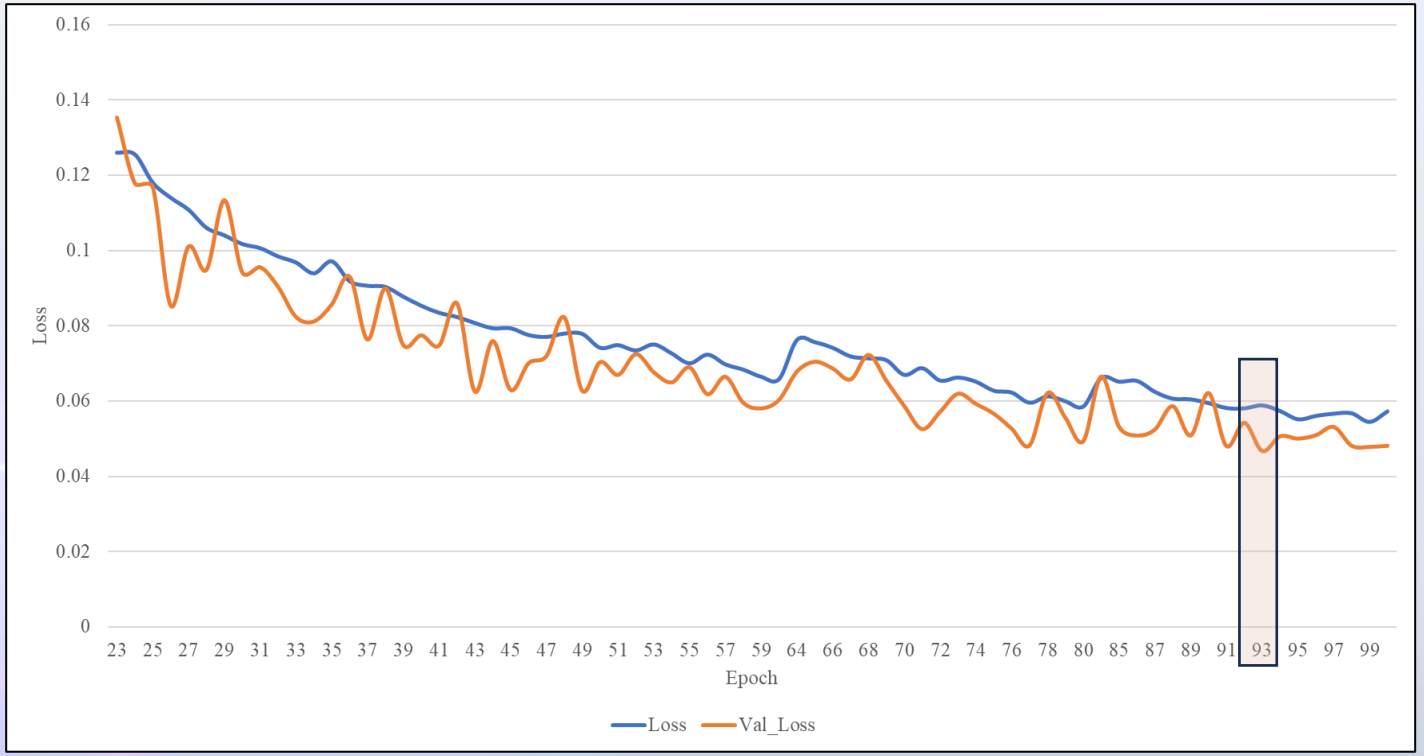
80% Training

20% Validation

Dataset Split



TL Stages	Number of epochs	Total Runtime (hr)	Average Runtime per epoch (min.)
Initial Stage	60	23.51	23.51
Second Stage	20	7.11	21.32
Third Stage	20	6.95	20.84
Total	100	37.56	



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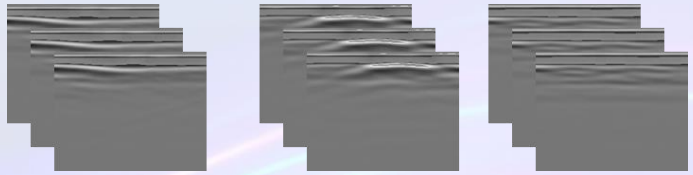
CASE STUDY

Deep Learning Model Training — **Inference**

Input

***.h5 Best Trained Models**



Set of filtered data

Process

1- Load trained model.
2- Load B-Scan images.
3- Get detections per an image while checking for overlapping masks.

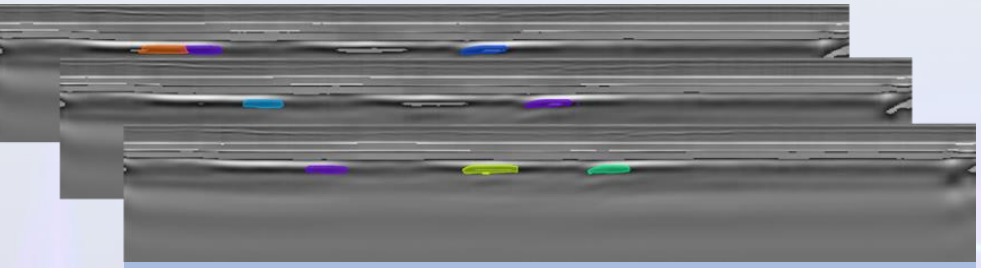
Output

Set of detections per each profile filtering configuration.

CASE STUDY

Detections Post-processing

Input



Set of predictions per each profile filtering configuration.

Process

Keeping Regions with 85% Occurrence on all Filtering Configurations for Each Profile

Output

Refined predictions for each profile.

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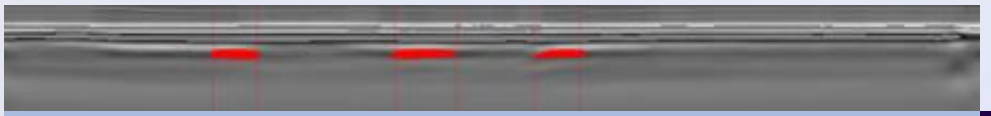
CASE STUDY

Detections Post-processing

Input

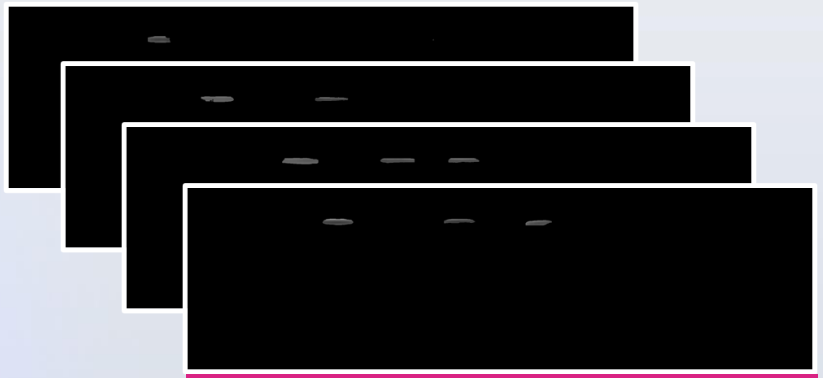


Refined predictions for each profile.

Process

1- Cross reference each profile's for proper alignment.
2- Check masks occurrence and keep masks that meet the threshold.
3- Get a binary array of masks for each profile.

Output



Binary masks for each profile

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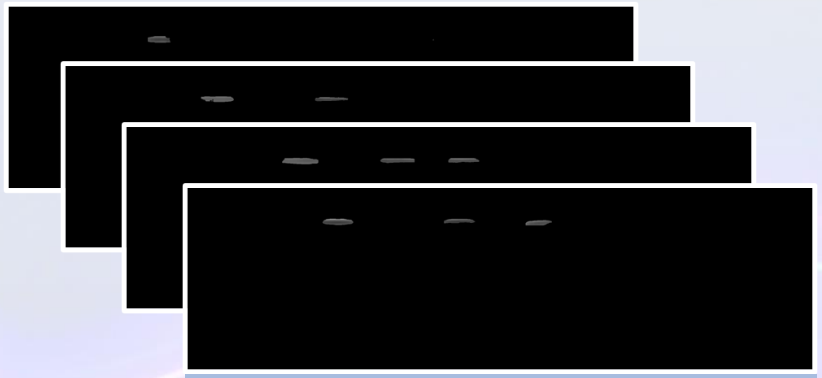
CASE STUDY

Detections Post-processing

Input



Binary masks for each profile

Process

1- Perform pixel reduction.
2- Convert each pixel location into a point in a 3D space.

Output

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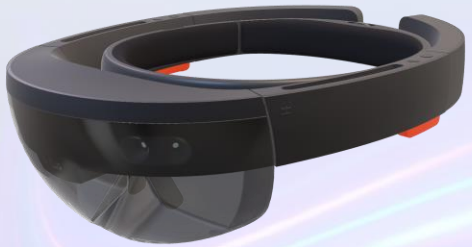
CASE STUDY

Augmented Reality Visualization — **Anchoring and Tracking Modules**

Hardware

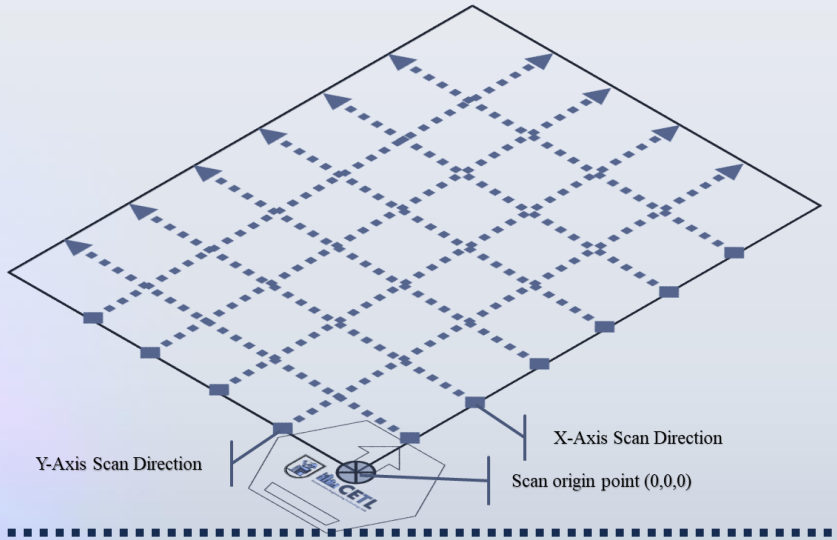


HoloLens 1st Generation

Technique

Vuforia VuMark developed using Adobe Illustrator

Implementation



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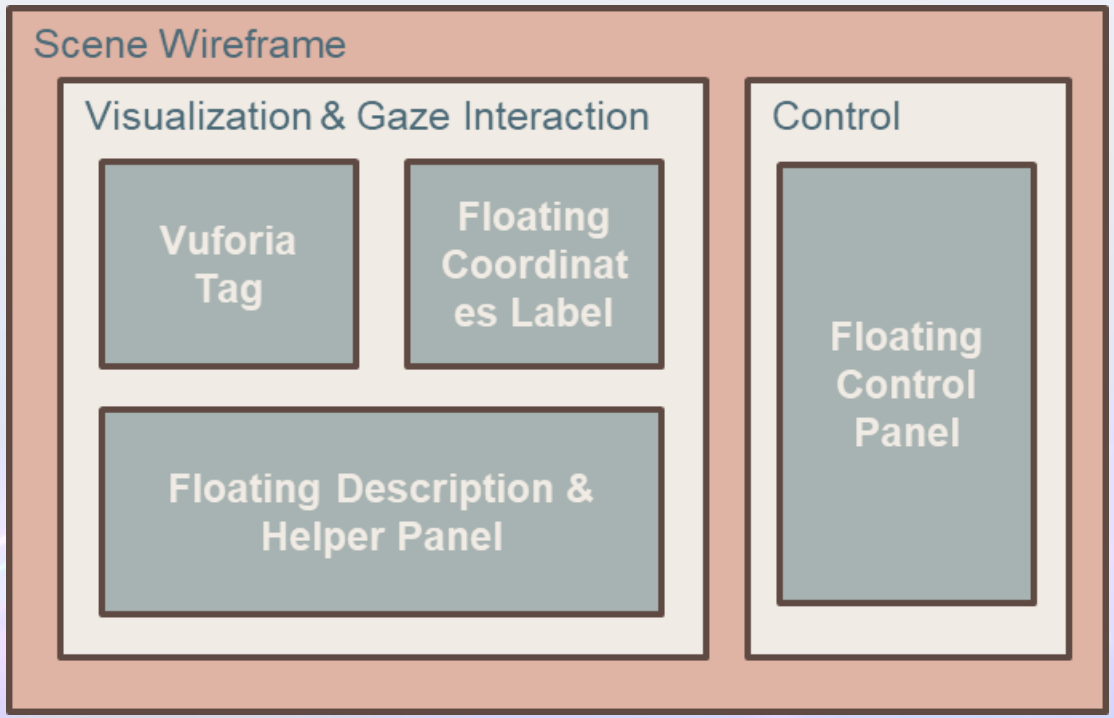
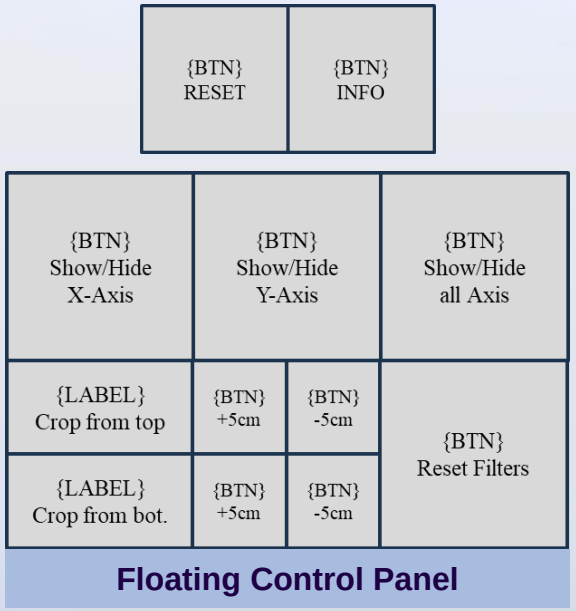
CASE STUDY

Augmented Reality Visualization — **Scene & User Interface Design**





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CASE STUDY

Model Visualization

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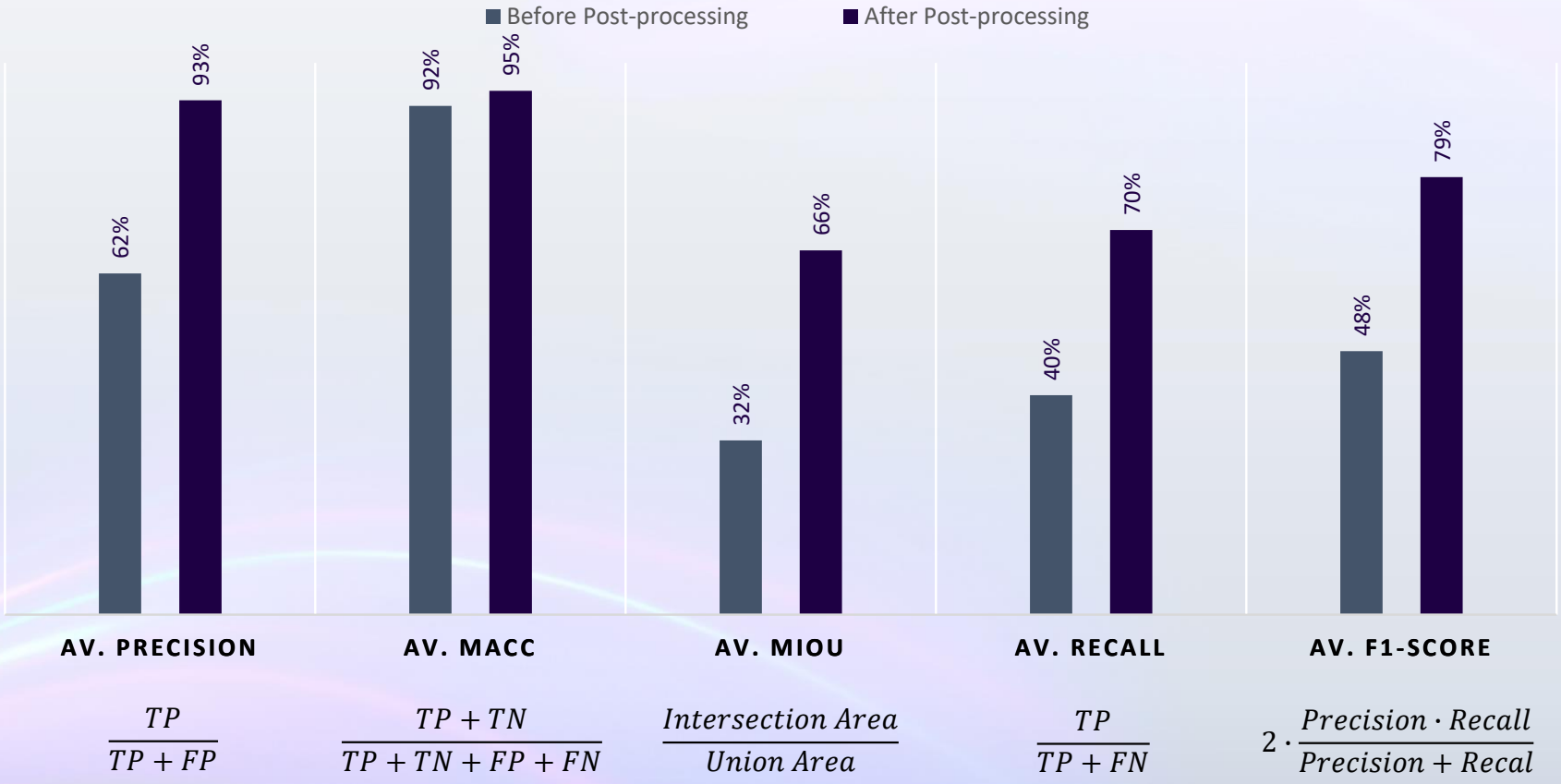
RESULTS

$\frac{TP}{TP + FP}$	$\frac{TP + TN}{TP + TN + FP + FN}$	$\frac{Intersection\ Area}{Union\ Area}$	$\frac{TP}{TP + FN}$	$2 \cdot \frac{Precision \cdot Recall}{Precision + Recal}$
AV. PRECISION	AV. MACC	AV. MIOU	AV. RECALL	AV. F1-SCORE

RESULTS


Before Post-processing
After Post-processing
62%
93%
92%
95%
32%
66%
40%
70%
48%
79%
AV. PRECISION
AV. MACC
AV. MIOU
AV. RECALL
AV. F1-SCORE
$\frac{TP}{TP + FP}$
$\frac{TP + TN}{TP + TN + FP + FN}$
$\frac{Intersection\ Area}{Union\ Area}$
$\frac{TP}{TP + FN}$
$2 \cdot \frac{Precision \cdot Recall}{Precision + Recal}$

CONCLUSION

Novel Framework Integration

- Deep learning and augmented reality integration for GPR data interpretation.

Research Objectives

- Validating records of existing utilities as-built.
- Demand for precise detection of subsurface utilities.
- Minimize service interruption and socioeconomic impacts.

Framework Stages

- Data Collection and Processing: GPR data collection, decryption, fusion, and processing.
- Training Mask R-CNN Model: Pixel-level instance segmentation, transfer learning, and data augmentation.
- Post-Processing: Enhance model predictions and generate point cloud.
- Visualization: Deploying an AR application for HoloLens.

RECOMMENDATION FOR FUTURE RESEARCH

Generalizing Machine Learning Algorithms:

- Explore different network architectures, training strategies, and data augmentation.
- Training the model on data of different soil and material.

Utilizing Cloud Computation:

- Streamline post-processing phase.
- Reduce computational time and enhance prediction efficiency.

Geolocation Integration:

- Combine GPR data with other geospatial information for improved mapping accuracy.

Shape Generation Deep Learning Models:

- Develop 3D model and integrate with the framework.

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