ROBOTICS FOR INSPECTION AND MAINTENANCE

ERF2022 ROTTERDAM 28-30 JUNE

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TERRAPIN Project
28/6/2022

TERRAPIN

roboTic undERgRound wAterPipe INspector

Domain: Water Supply and Sanitation

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THE TEAM

Problem: Damages of wastewater networks & water supply networks

- Leaks in wastewater networks inflicts heavy environmental pollution (pollution of the ground as well as groundwater contamination)
- Globally, water loss amounts to 126 billion cubic meters per year
- 20% of water is lost due to leakages
- Water main breaks can cost from $100 to $500.000 [1]
- There are 240,000 water pipe breaks in the US alone every year [2]
- Every year, around 900 billion gallons of untreated sewage escapes aging wastewater systems in the U.S. alone

[1] https://waterfm.com/the-economics-of-water-main-failures/
[2] https://www.jamesdysonaward.org/en-US/2018/project/lighthouse/

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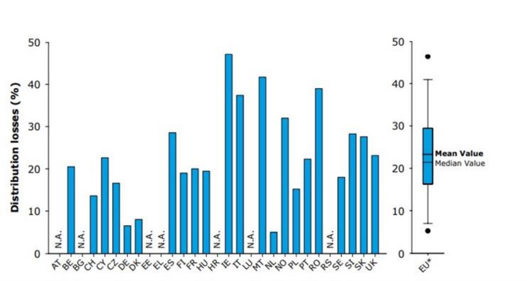
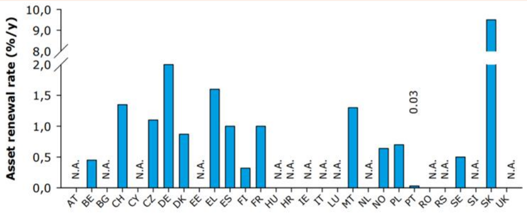
Water Leakages in Europe

- Drinking water distribution network losses on average are 23% of water volume for Europe
- Old network with assets renewal only at ~1% rate [3]
- Updating the infrastructure will take decades and cost hundreds of billions of Euros. Other solutions are urgently needed, such as modelling to predict leakage



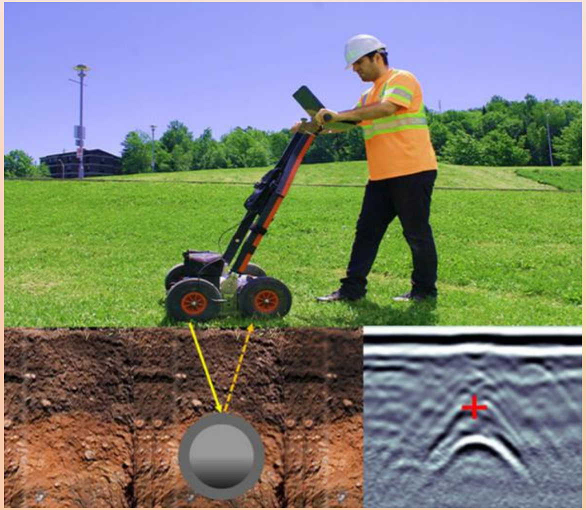


[3] https://www.danva.dk/media/3645/eureau_water_in_figures.pdf

Challenge for underground pipe inspection

Current Practices are expensive and time consuming:

- manual handling/driving of a ground penetrating radar (GPR) sensor above the subsurface inspection area of interest
- manual detection & condition estimation and annotation of detected underground utilities in the collected GPR data
- inability to accurately identify defects and overall water pipe material condition



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TERRAPIN Solution

Objective: Integration of a surface operating rover with a GPR antenna

- ❖ HW integration of Rover with GPR antenna
- ❖ Development of a driver for GPR data collection with rover
- ❖ Rover localization fusing stereo-based visual odometry, GPS and IMU measurements
- ❖ Incremental georeferenced metric mapping based on rover localization

☑Rover ☑GPR Antenna

Integrated HW approach

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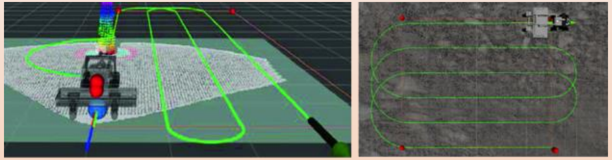
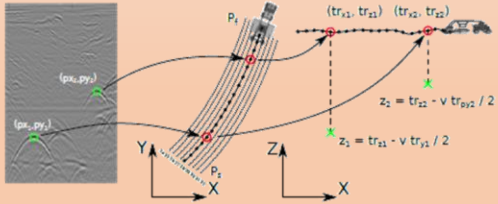
TERRAPIN Solution

Objective: Subsurface utility and defect mapping with structured rover navigation

- ❖ GPR data collection
- ❖ Rover structured navigation based on Boustrophedon-like motions (Dubins Paths) for optimal surface coverage with towed GPR antenna
- ❖ Integration of the detected utilities (pipes, leakages etc.) on metric map
- ❖ Utility semantic mapping including georeferenced leakages detection



Calculated Dubins paths in simulation

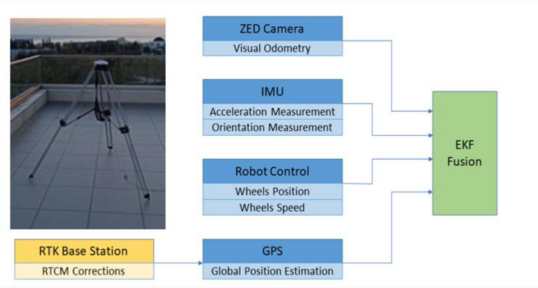


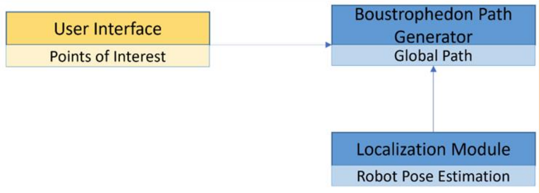
Registration of rover motion with detected utilities

TERRAPIN Solution

Rover localization

- ❖ Kalman Filter approach has been selected
- ❖ Multiple sensors are utilized to estimate the global position
    - ➢ ZED stereo camera (incremental motion estimation)
    - ➢ IMU (acceleration and relative orientation measurements)
    - ➢ Robot Hardware (wheel odometry)
    - ➢ GPS (with RTK corrections)





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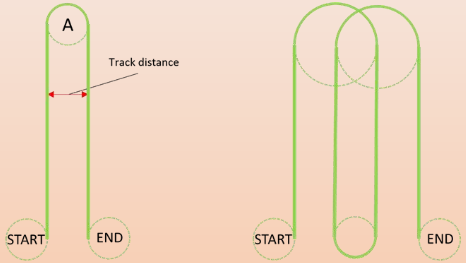
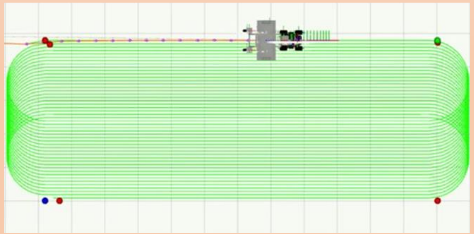
Rover navigation

- ❖ Dubin's path variation of the boustrophedon cellular decomposition (BCD) has been selected
- ❖ Global path generation based on the area of interest
- ❖ Dubin's path is generated which respects the rovers minimum turning radius and the coverage density
- ❖ The generated path differs from the traditional boustrophedon path by involving unidirectional turns
- ❖ The rover scans dense and in parallel over the underground utilities
- ❖ Time-Elastic Band (TEB) local planner path following controller proved to be the most efficient one

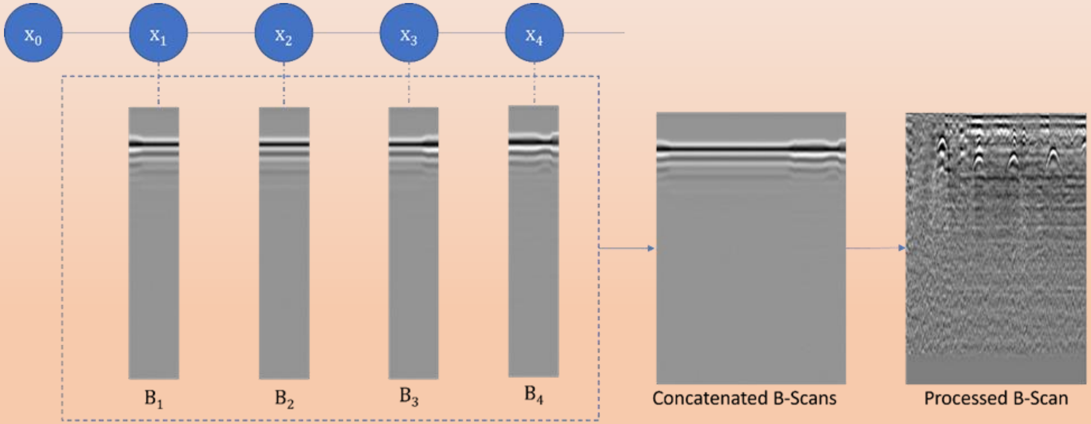




TERRAPIN Solution

Rover mapping

- Graph-based approach
- Each node represents the current robot's pose
- Nodes are being added every 2m
- GPR data are associated with each node
- A-Scans are aggregated between consecutive nodes to a B-Scan representation
- B-Scan associated with a node is representing the underground infrastructure between two nodes (2m)
- When rover reaches the end of a straight line B-Scans are concatenated to a single B-Scan representation



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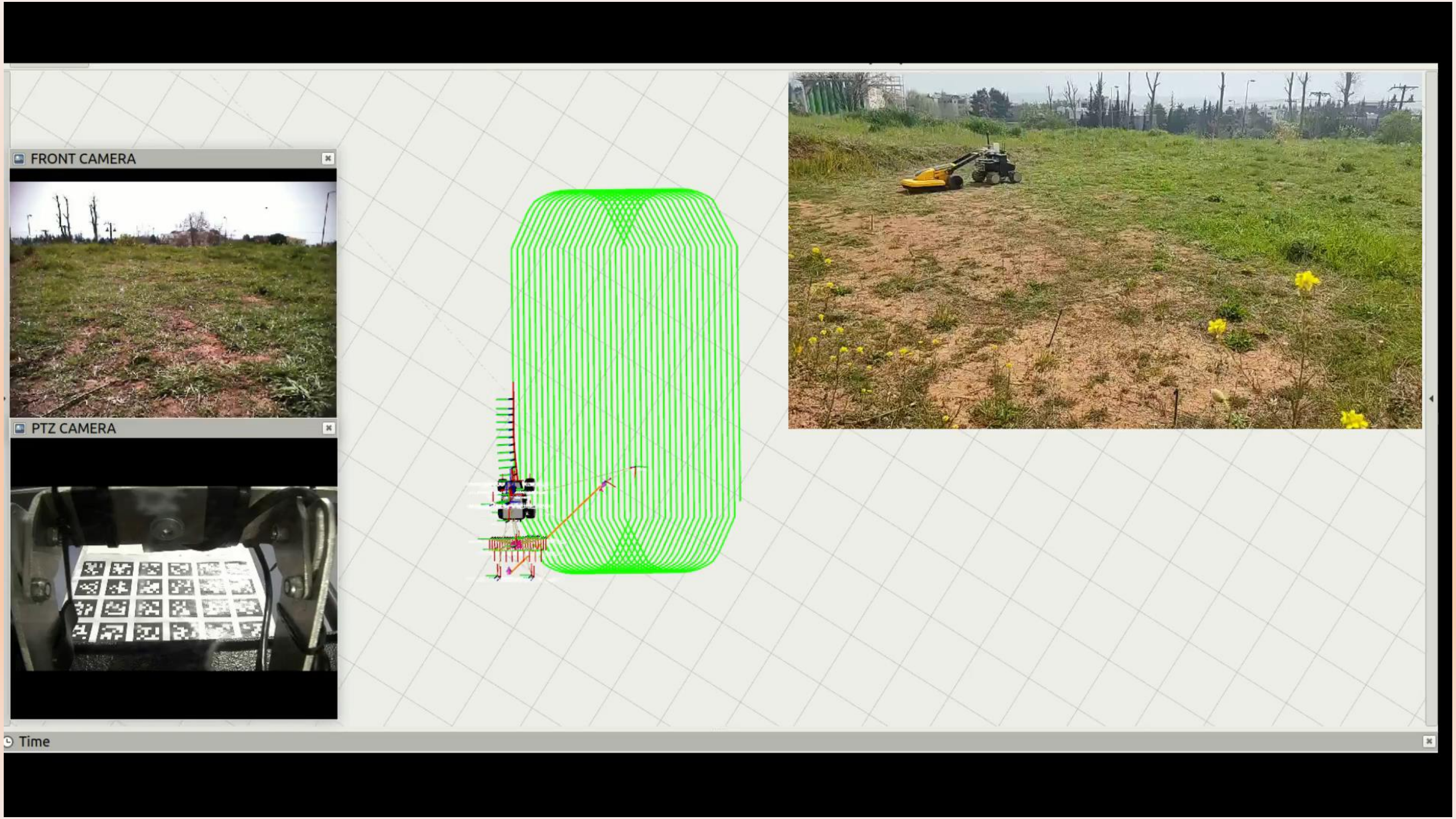
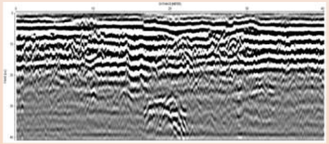
Demo Video



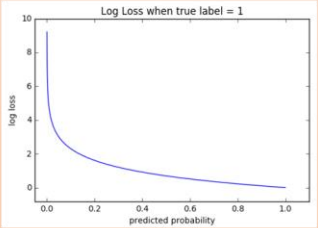
TERRAPIN Solution

Objective: The automatic detection of water pipes and leakages in the underground space

- ❖ Tool of study: The proposed approach will be based on artificial neural network models, e.g. Convolutional Neural Networks (CNNs), which are appropriate to analyze visual imagery.
- ❖ Input: 3D images, from GPR data, that include labels based on whether depict water pipe or not.
- ❖ Output: Classification of 3D images for the increase of our model accuracy.
- ❖ Loss function: The Cross-entropy loss is used for the classification of 3D images.
- ❖ Next step: The parameters, such as the material, the length and the diameter of pipe will be used for the modeling of pipe material degradation.



B-Scans

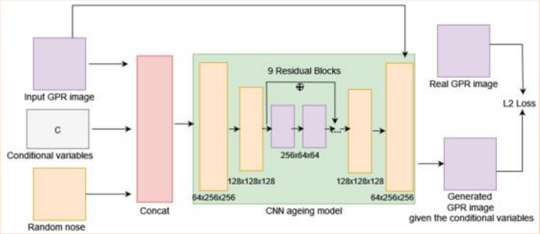


Example of possible loss values through the cross-entropy function

TERRAPIN Solution

Objective: The modeling of the pipe material degradation

- ❖ Tool of study: The proposed approach will be based on machine learning frameworks, e.g. Generative Adversarial Network (GAN), in which two neural networks contest with each other.
- ❖ Input: 3D images from GPR data, random noise and conditional variables such as the material, length and diameter of pipe.
- ❖ Output: The degraded image in many snapshots in time.
- ❖ Loss function: L1 Loss Function will be used as is not affected by outliers that may arise.
- ❖ Details: The simulation of the proposed approach on different materials, lengths and diameters of pipes contributes to the estimation of the pipeline lifespan and urgency of its maintenance.



Proposed GAN Generator network architecture.

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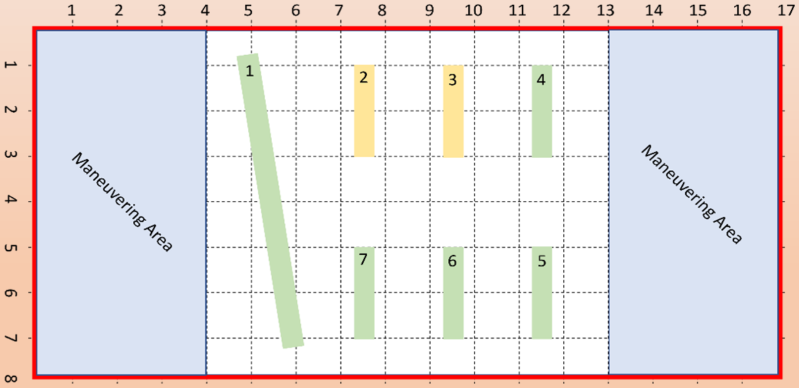
Results
Data Collection

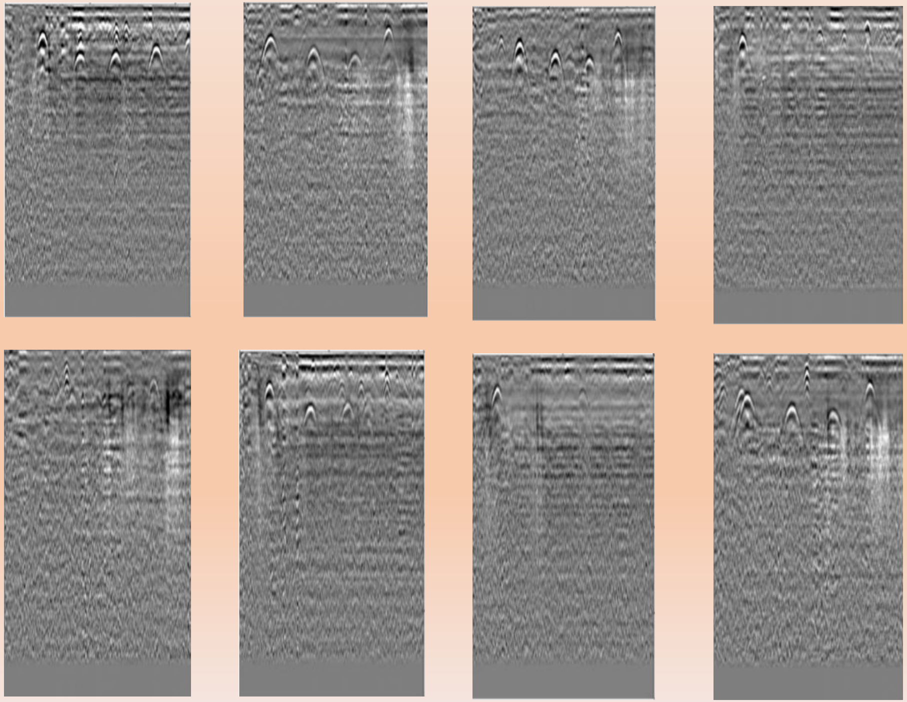


No	Material	Depth (m)	Φ (mm)	Length (m)
1	Metal	0.2	50	6.5
2	PVC	0.3	200	2
3	PVC	0.2	150	2
4	Metal	0.3	200	2
5	Metal	0.2	100	2
6	Metal	0.35	100	2
7	Metal	0.3	200	2

Experimental Area

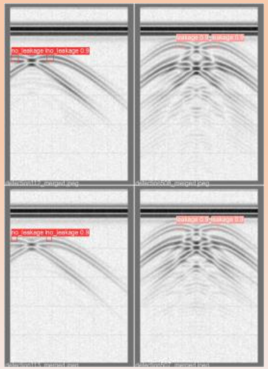
Results
Data Collection

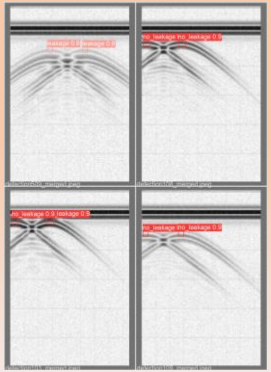
Collected B-Scans



Simulated B-Scans

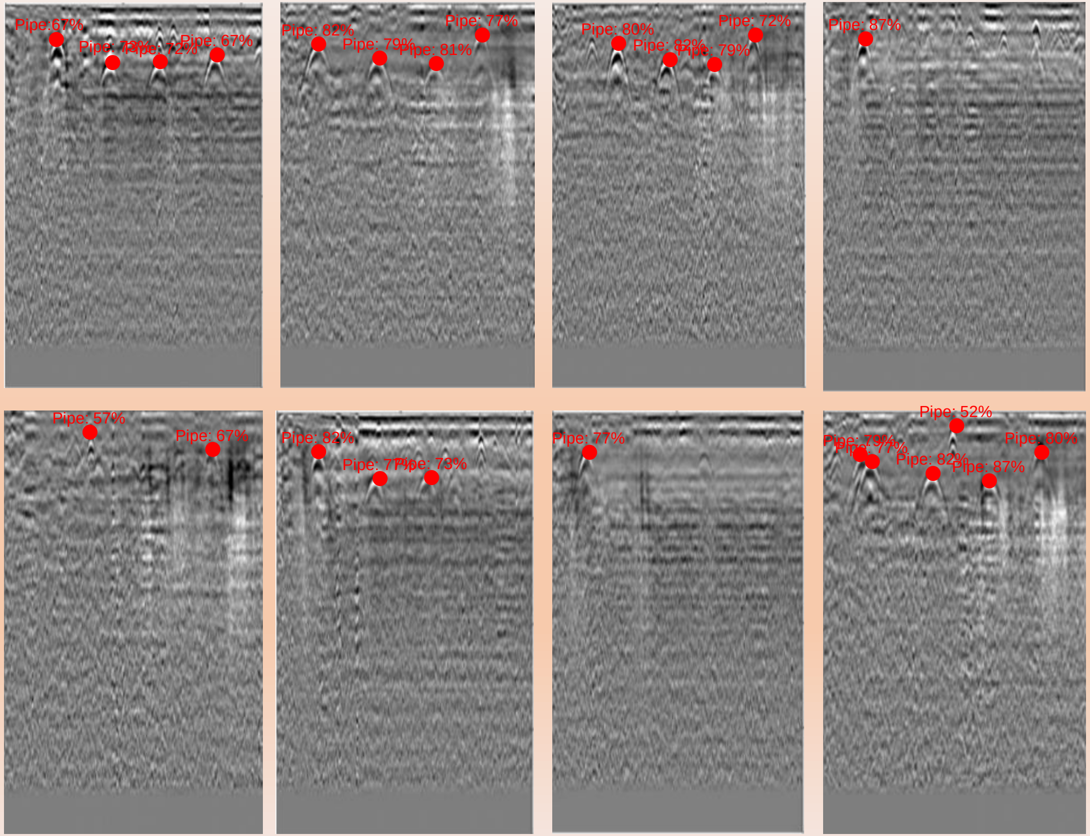
- Utilization of the GprMax: open source SW that simulates E/M wave propagation.
- Modelling details:
  - pipe leakage: the pipe which presents leakage is covered by another pipe which has water.
  - pipe corrosion: the soil layer mixed with corrosion products is simulated as a cylindrical shell of thickness δ around the pipe.
  - The GPR images which are generated simulate pipes with various scenarios regarding their material, diameter and depth which are buried.





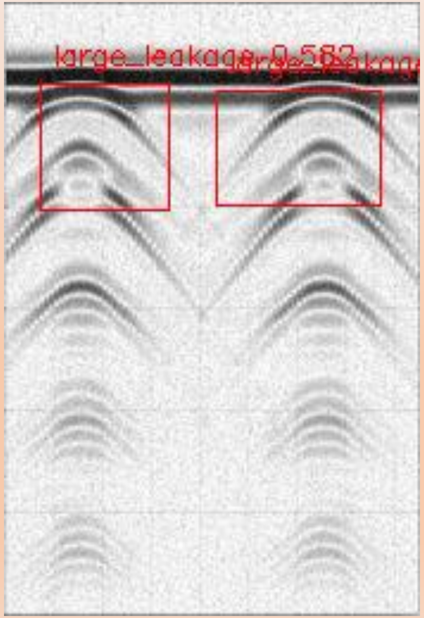
Results
Pipes Detection

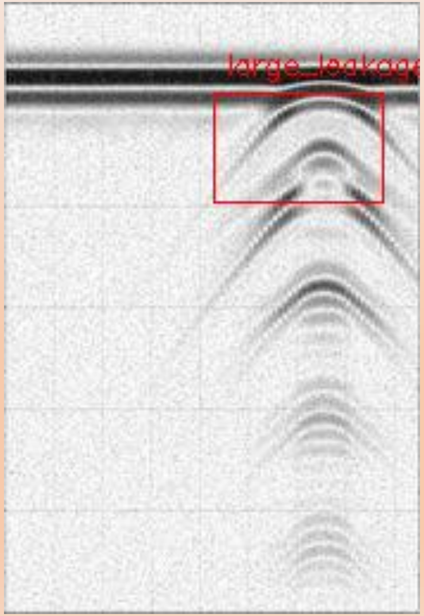
Collected B-Scans



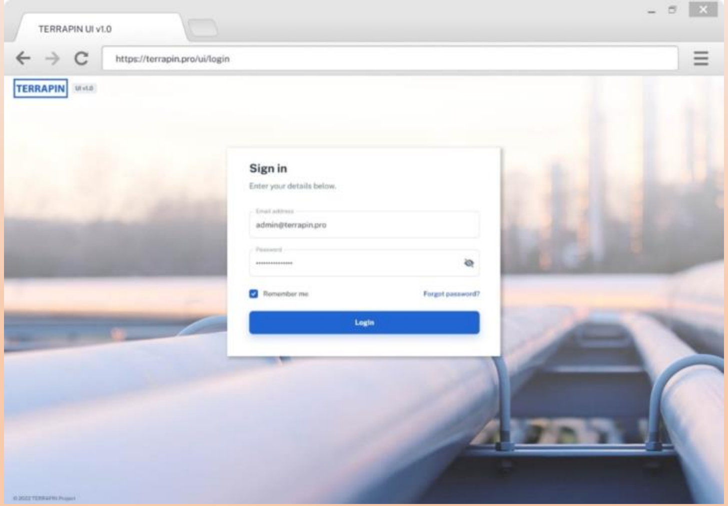
● Detected Pipe

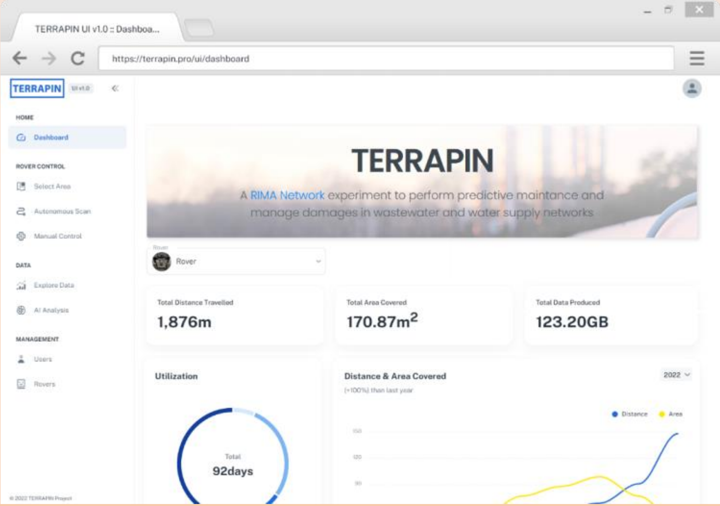
Results
Leakage Detection on Simulated Data





User Interface





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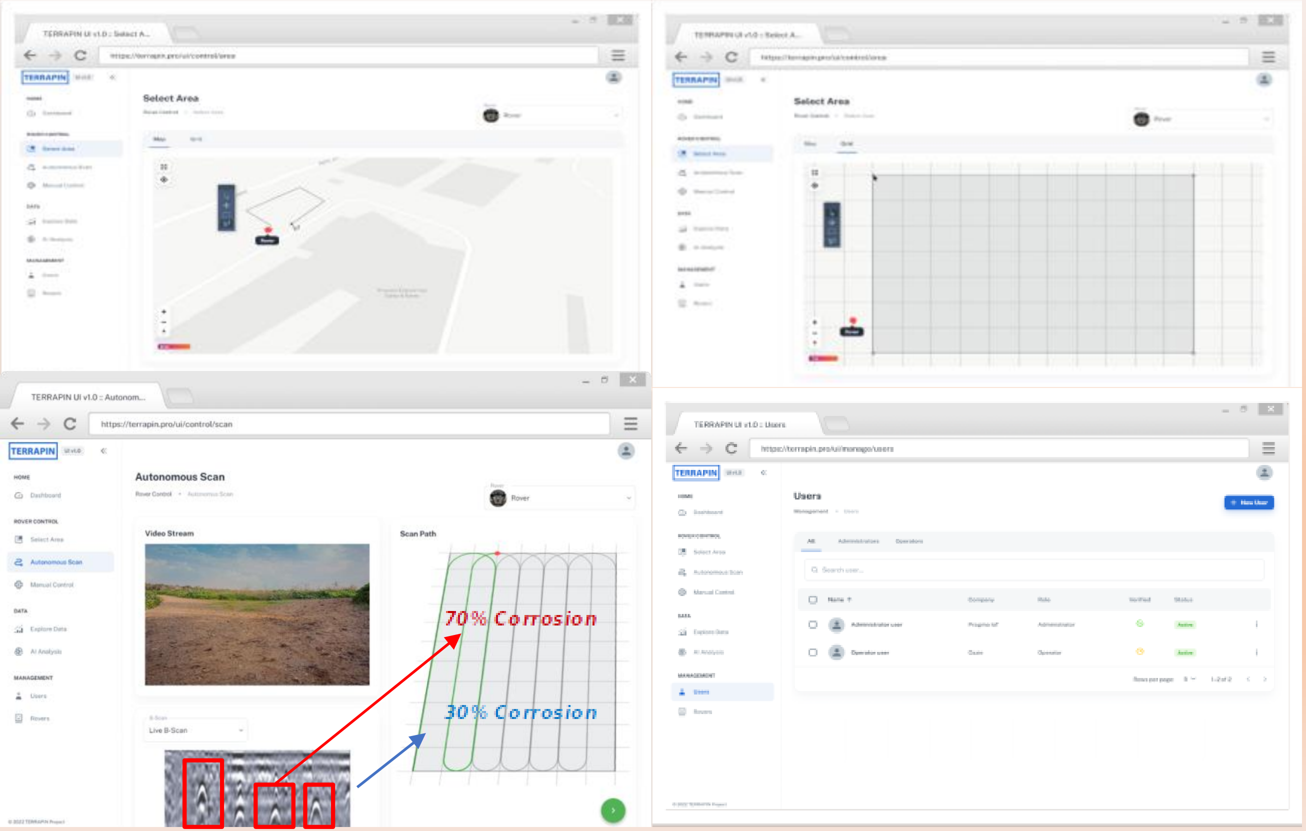

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THANKS FOR YOUR ATTENTION

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