TERRAPIN

roboTic undERgRound
wAterPipe INspector

Domain: Water Supply and Sanitation

10/10/2022

The TEAM

Hypertech

OZZIE
robotics

pragma.

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

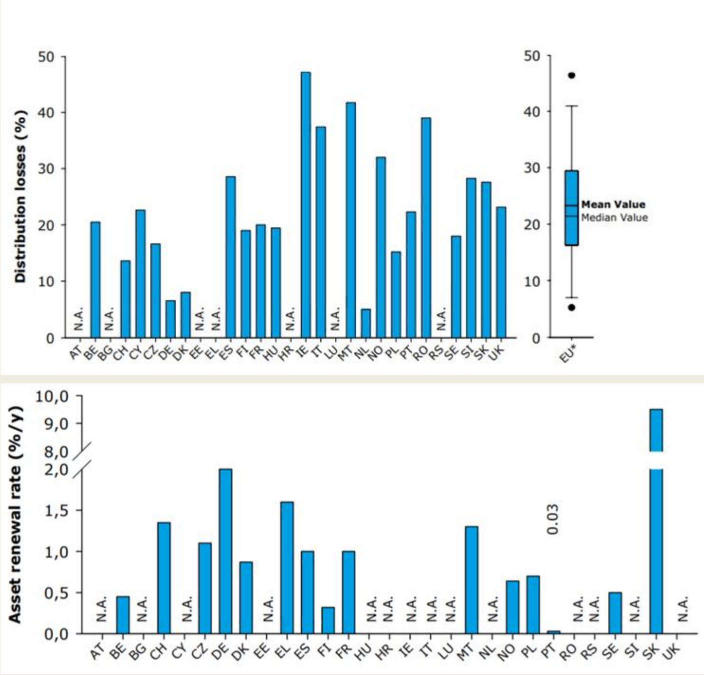
[1] https://waterfm.com/the-economics-of-water-main-failures/

[2] https://www.jamesdysonaward.org/en-US/2018/project/lighthouse/

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

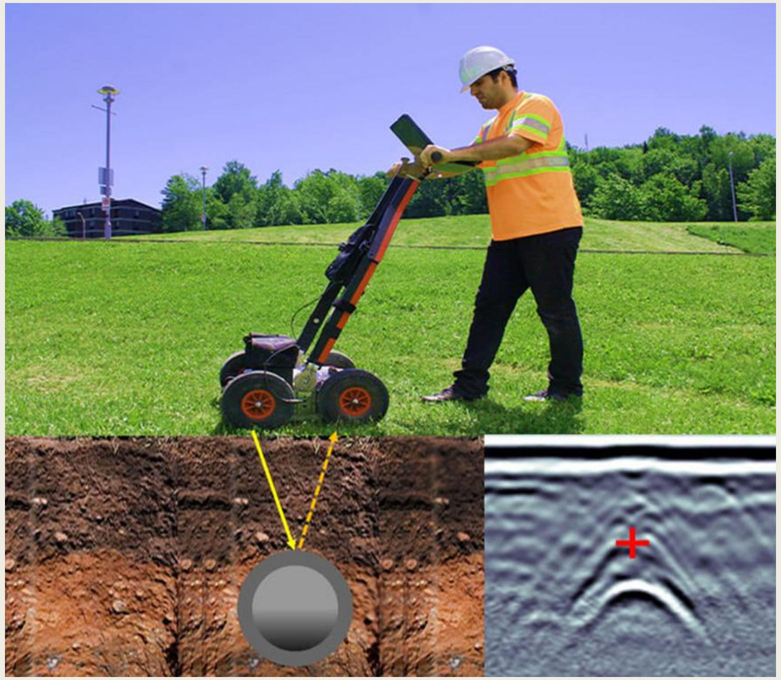
[3] https://www.danva.dk/media/3645/eureau_water_in_figures.pdf



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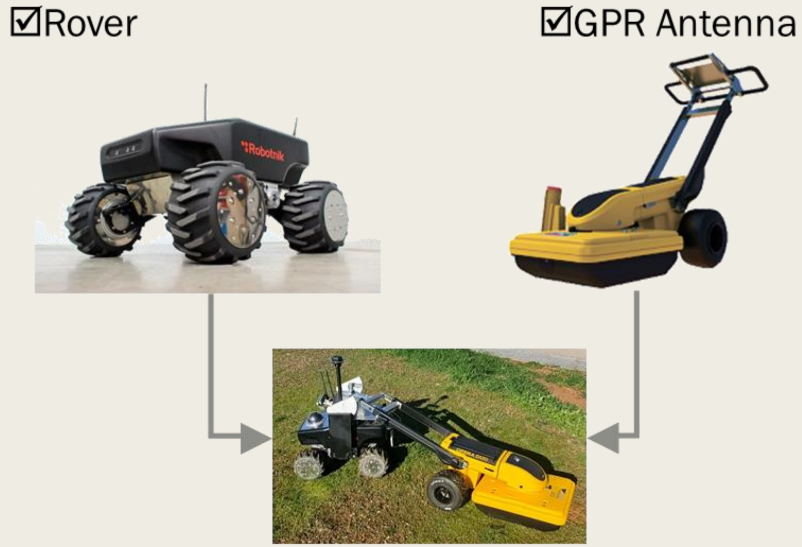
Objective: Integration of a surface operating rover with a GPR antenna

- 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



Integrated HW approach

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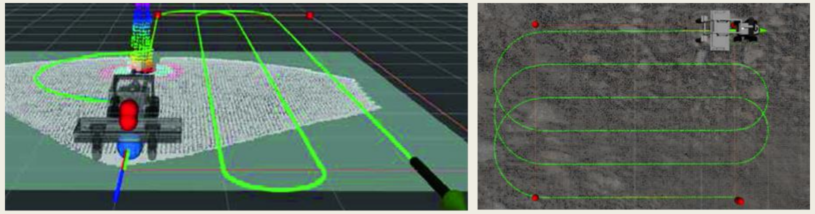
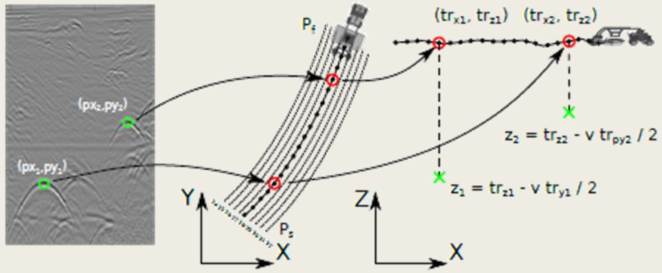
Objective: Subsurface utility and defect mapping with structured rover navigation

- 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

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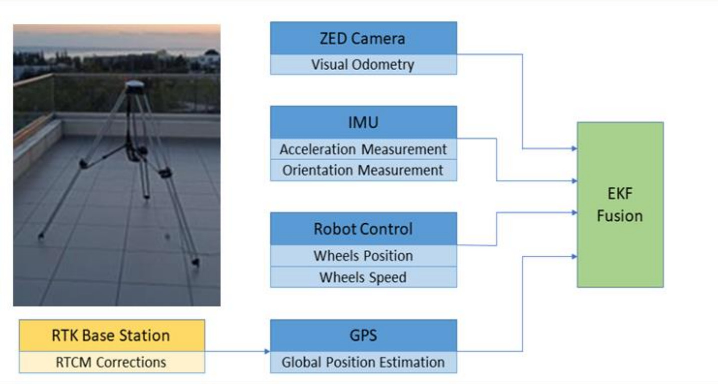
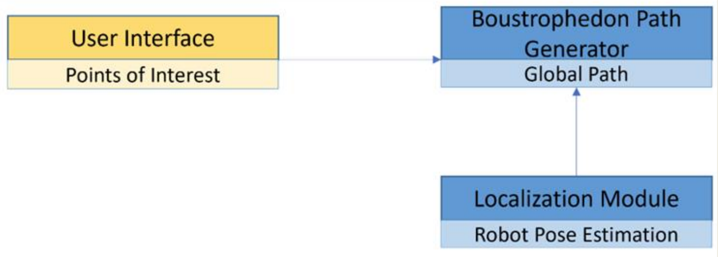
Rover localization

- ❖ 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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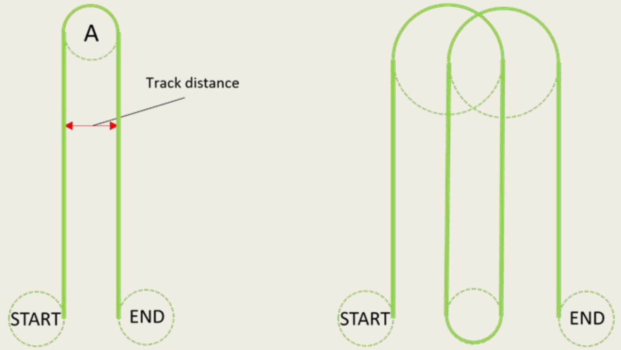
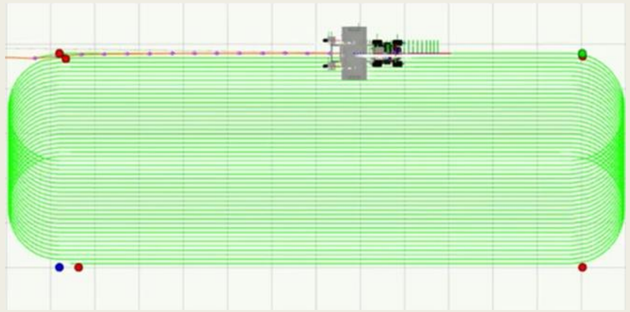
Rover navigation

- 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





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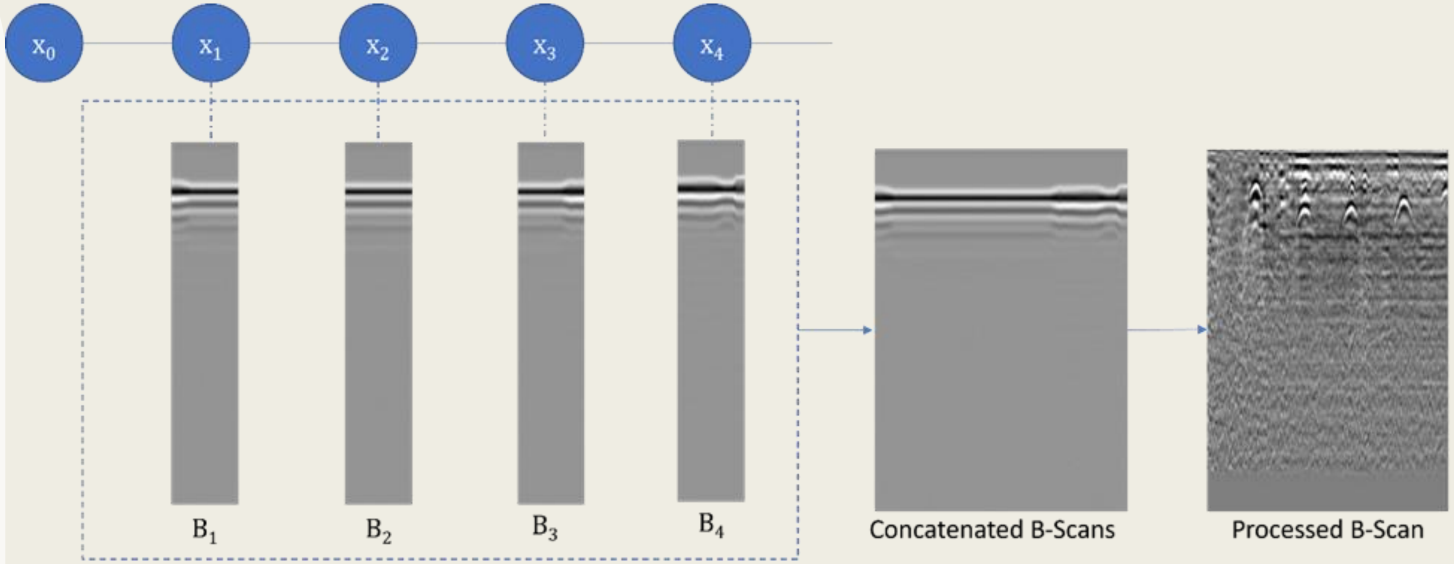
Rover mapping

- 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

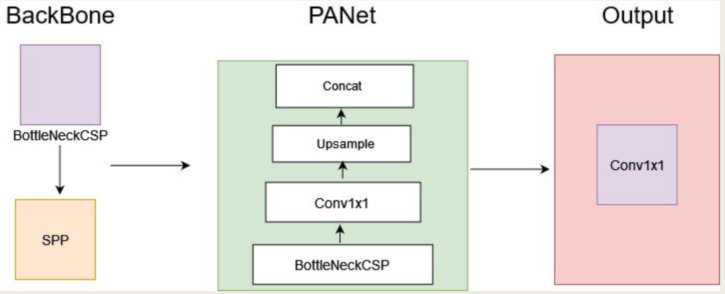


Demo Video

TERRAPIN Solution

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

- Approach: The leakage detection of underground water pipes through GPR data is based on Convolutional Neural Network (CNN) and namely using the YOLOv5 algorithm
- Tool: The YOLOv5 algorithm can directly learn features from GPR images in a supervised learning mode and classify images of different categories based on their features (e.g. GPR images with or without leakage)
- Input: GPR images with different number of pipes of different material and diameter. The annotation include labels based on whether each pipe depicts leakage or not
- Output: The output includes the classification of pipes (i.e. if present leakage or no) and their location



YOLOv5 Architecture

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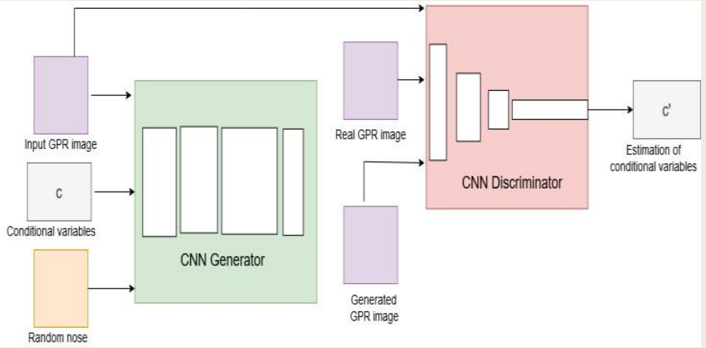
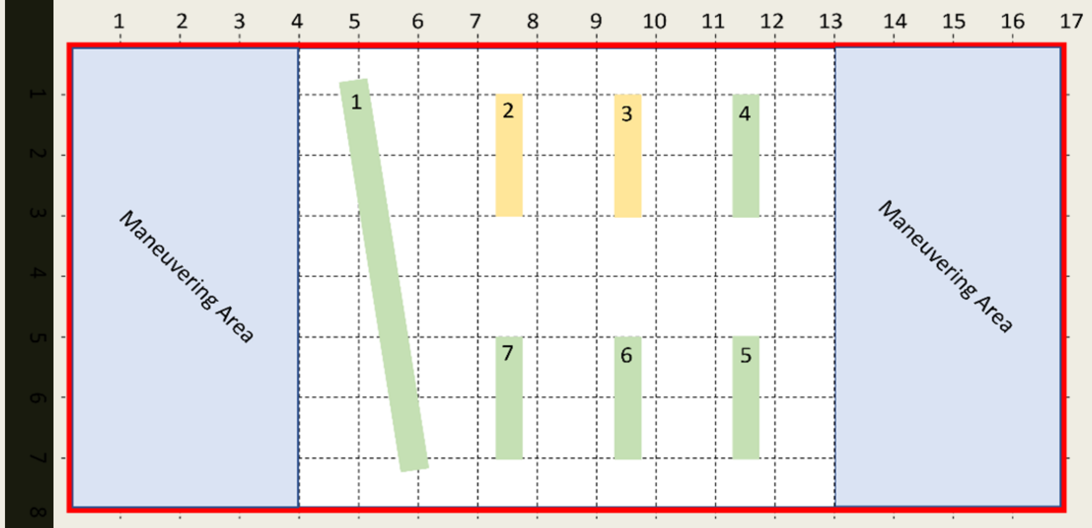
Objective: Simulation for pipe material degradation

- ❖ **Problem definition: The investigation of water pipe material degradation**
- ❖ **Approach: The investigation of water pipe material degradation through GPR data is based on the proposed Generative Adversarial Network (GAN)**
- ❖ **Simulation: on different materials, diameters & depths of pipes contributes revealing the extent and severity of the evolving defect of pipeline, as well as its lifespan.**
- ❖ **Input: The conditional inputs are the GPR image and a target degradation time**
- ❖ **Output: The output is a GPR image of the pipe material, as it would have degraded at the target time**

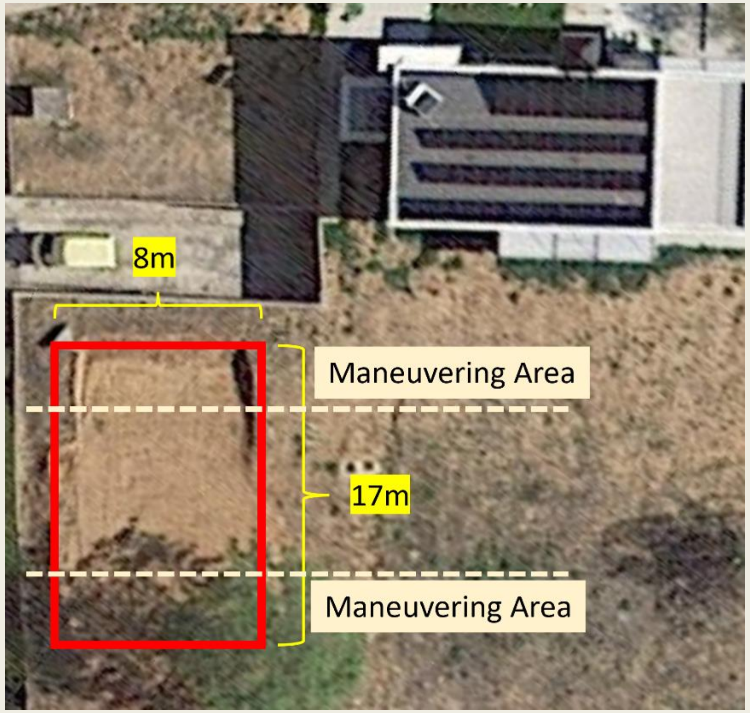


Proposed GAN Generator network architecture

Results
Data Collection



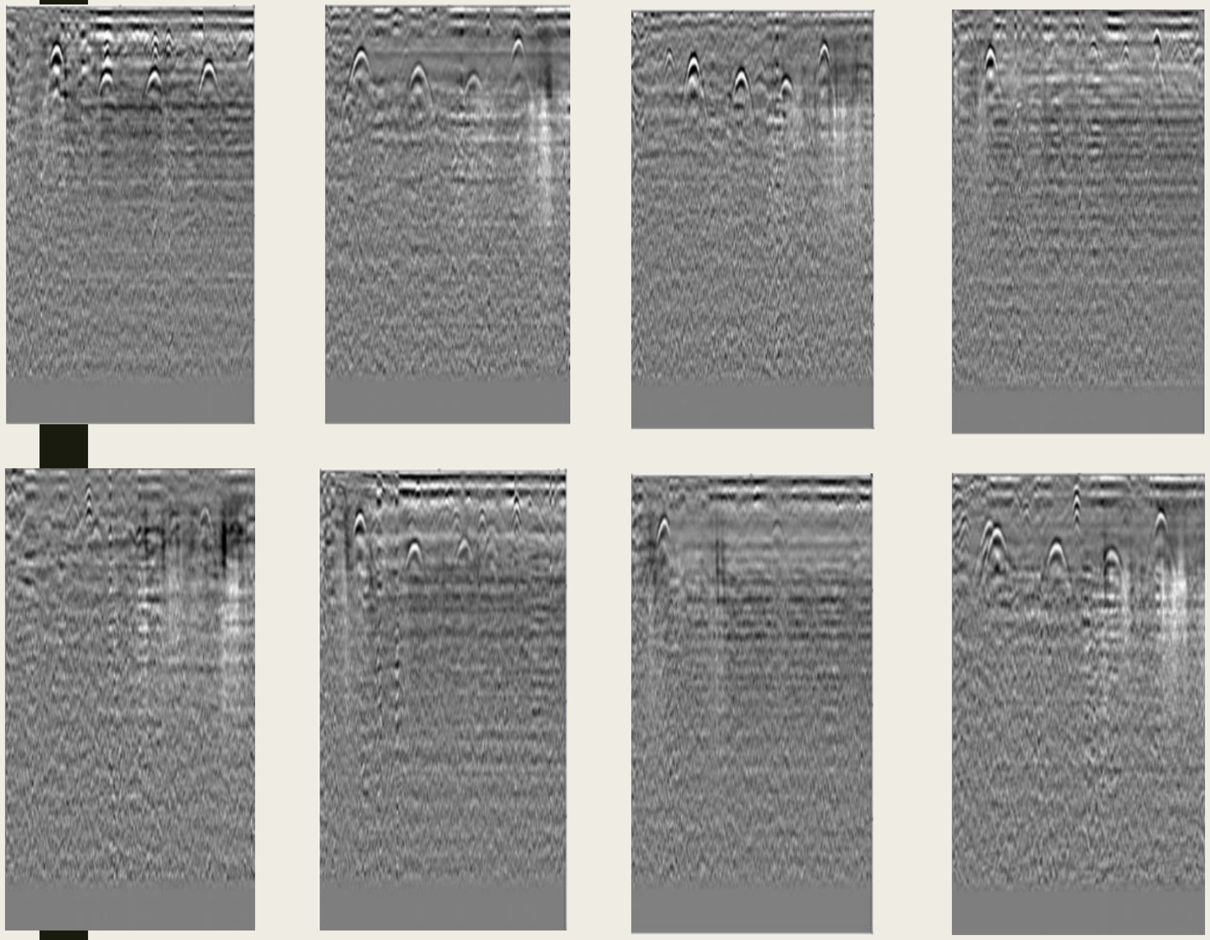
No	Material	Depth (m)	Φ (mm)	Length (m)
1	Metal	0.2	50	6.5
2	PVC	0.3	200	2
3	PVC	0.2	150	2
4	Metal	0.3	200	2
5	Metal	0.2	100	2
6	Metal	0.35	100	2
7	Metal	0.3	200	2



Experimental Area

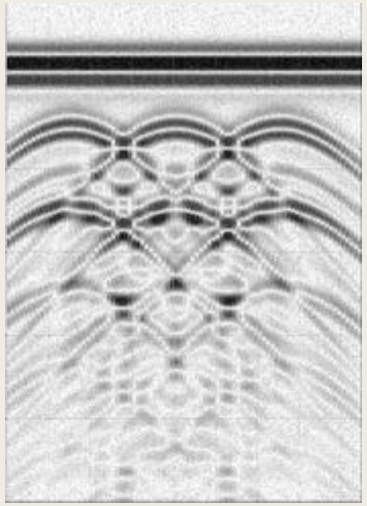
Results
Data Collection

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*



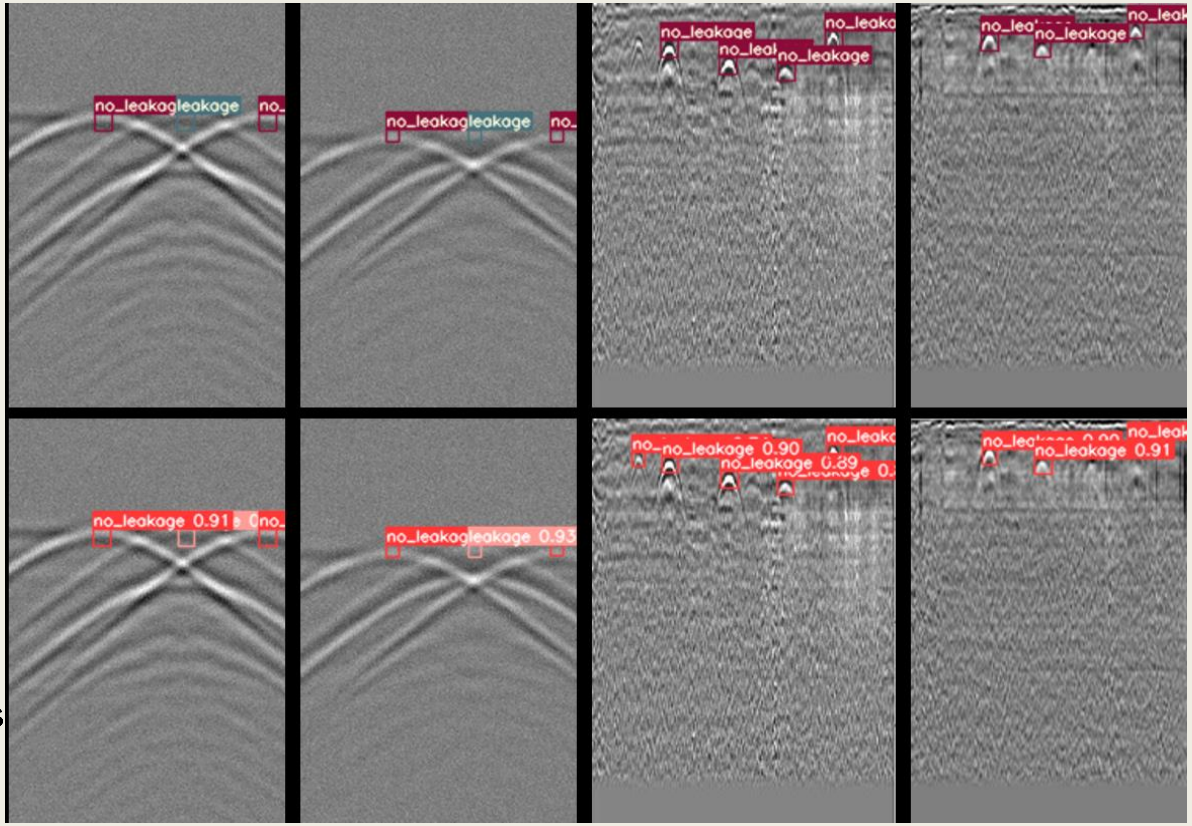
GPR image shows the b-scan which resulting from 3 pvc pipes that present leakage

GPR image shows the b-scan which resulting from 3 pvc pipes without leakage

Results
Pipe & Leakage detection

Ground truth

YOLOv5 predictions

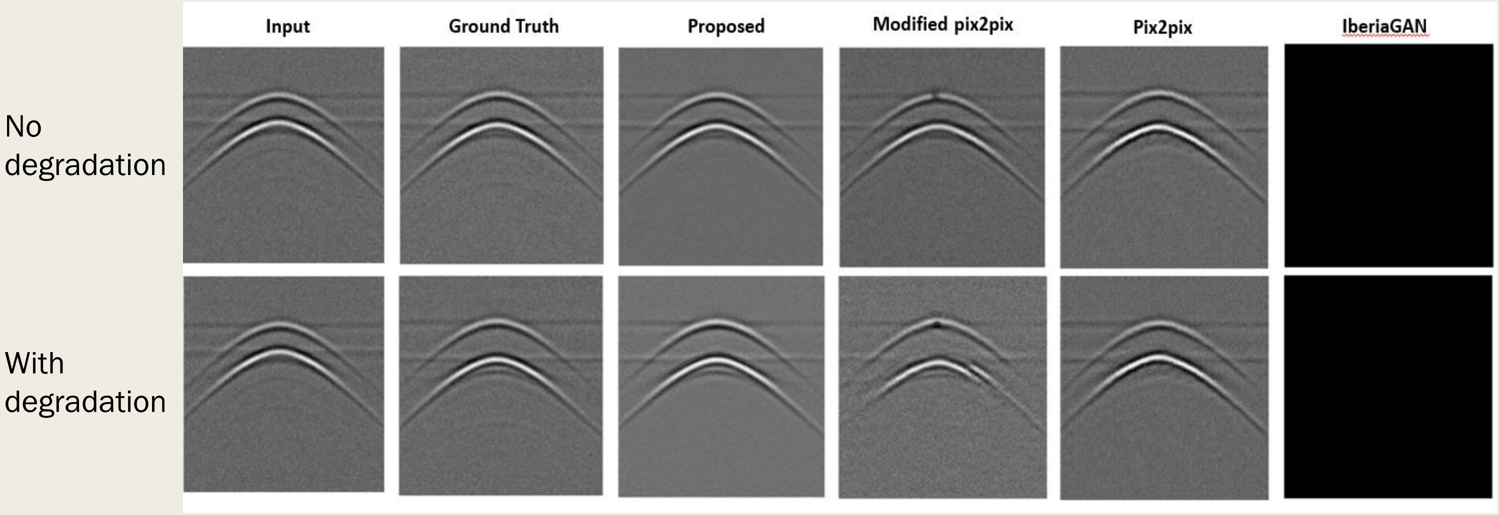


- The **red boxes** present the **estimation** of the **algorithm** regarding the **detection** of each **pipe** location.
- Given the **probability** for the **classification** of each pipe depending on its label (e.g. **leakage** and **no leakage**).
- The **YOLOv5** is more **suitable** model **than Faster R-CNN.**
- The results of **YOLOv5** model **satisfy** the **requirements** of **TERRAPIN** project.

Model	Precision	Recall	mAP@.5 (%)	mAP@.5:.95 (%)
YOLOv5	**99.7**	**99.6**	**99.2**	**86.1**
Faster R-CNN	65.2	50.4	94.8	50.1

Table: Summary of the results of pipe detection based on four performance metrics.

Results
Pipe Material degradation detection

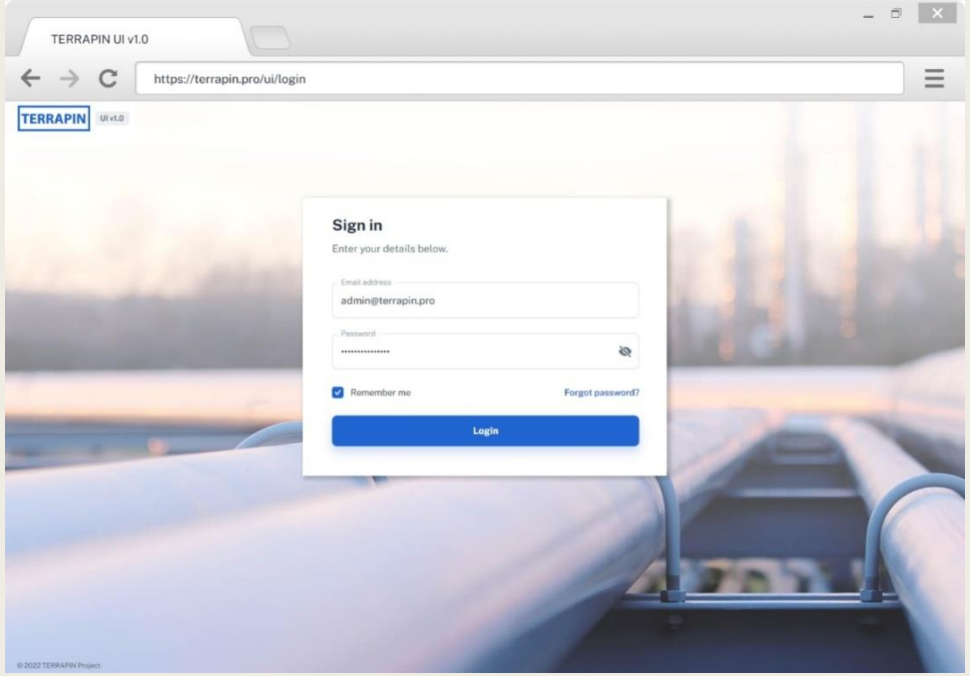


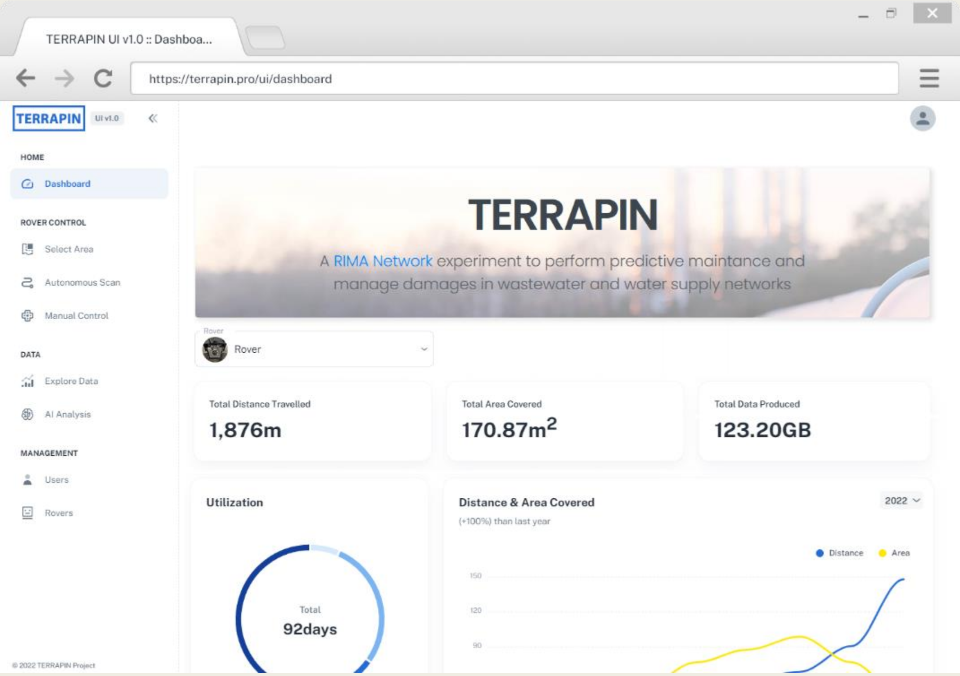
Model	FID	MSE
Proposed cGAN	**101.216**	**0.00228**
Pix2pix	168.903	0.01112
modified Pix2pix	190.617	0.00758
IberiaGAN	524.822	0.26190

Table: Results of pipe material degradation experiments based on two performance metrics.

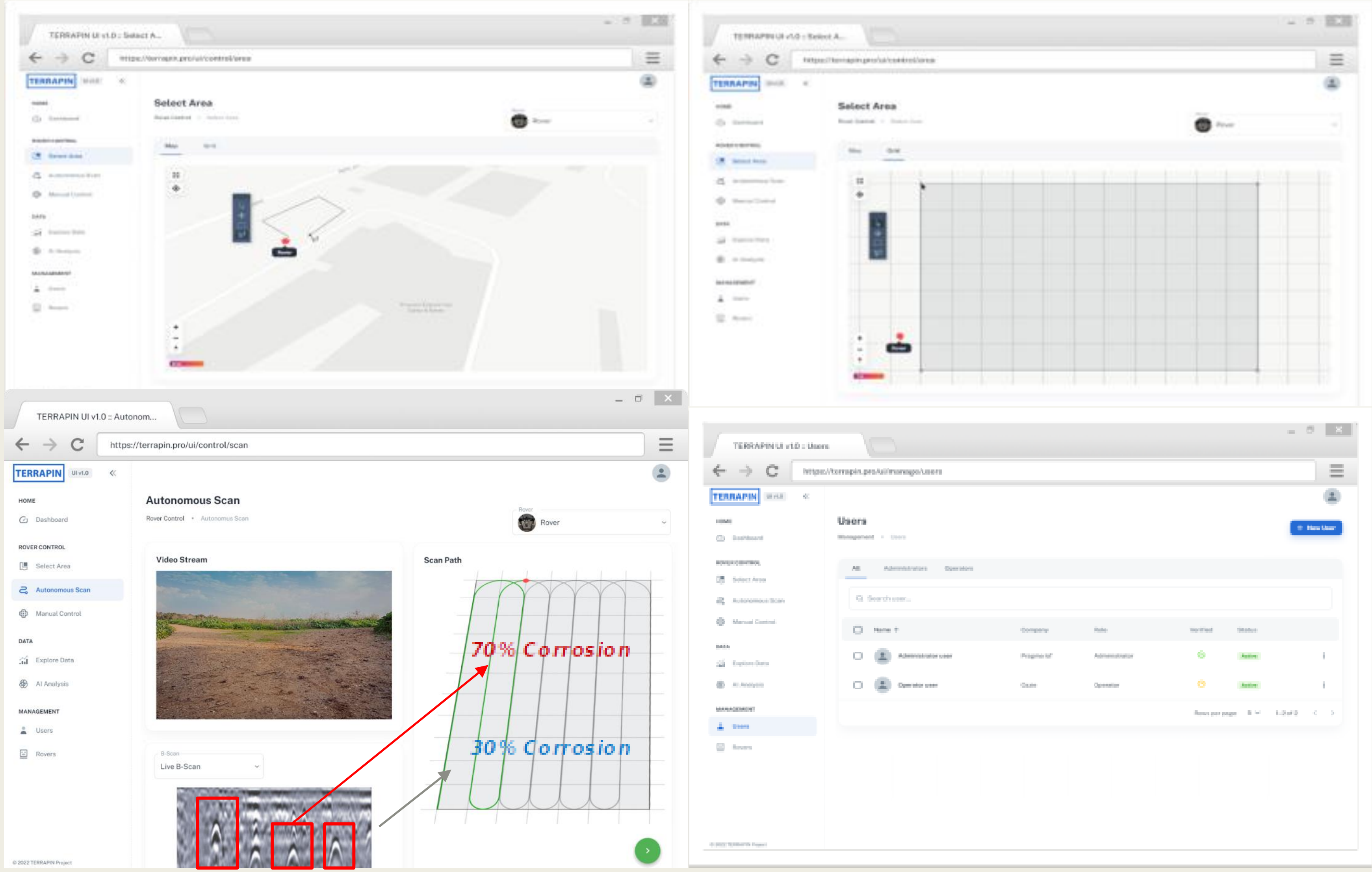
- The **first column** of figure includes the **simulated GPR images**, the **second column** the **ground-truth GPR images** and the **other columns** show the **degraded GPR images** based on **models.**
- The **proposed GAN model** is able to **efficiently capture** the **content** of the **input images** and **model** their **degradations** accordingly.
- The **results** of proposed cGAN **satisfy** the **requirements** of **TERRAPIN project.**

User Interface

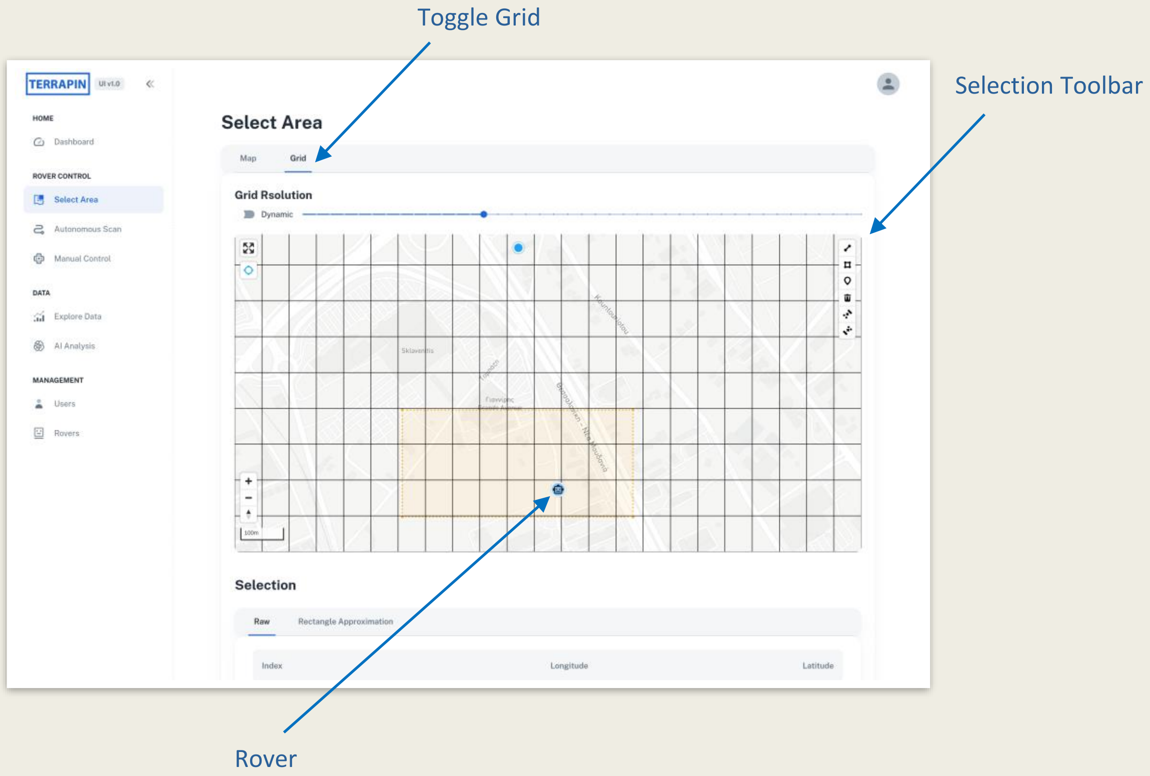


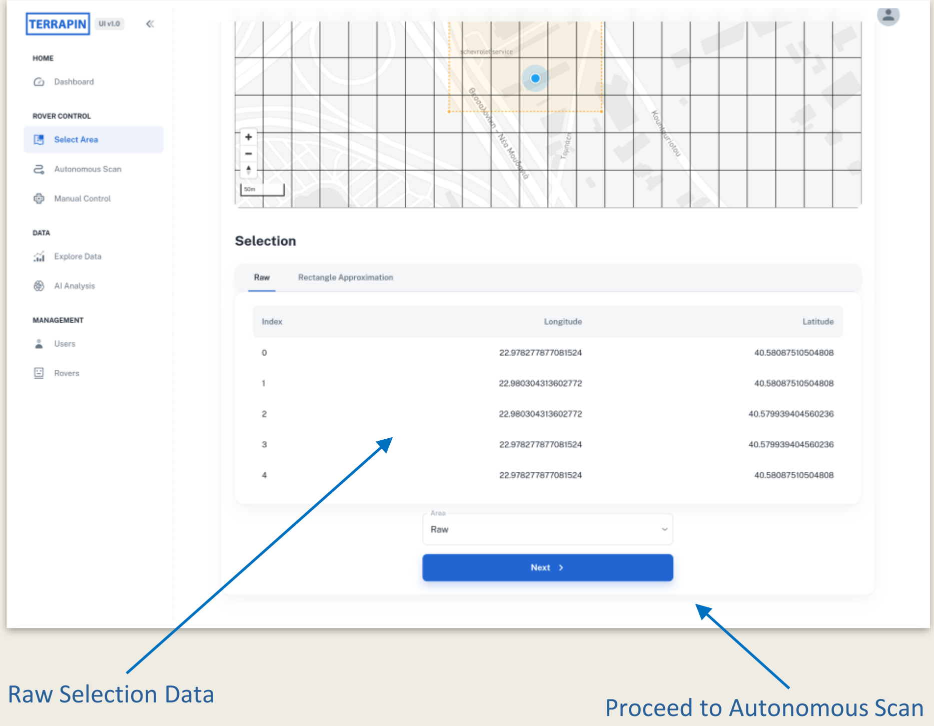


User Interface



User Interface





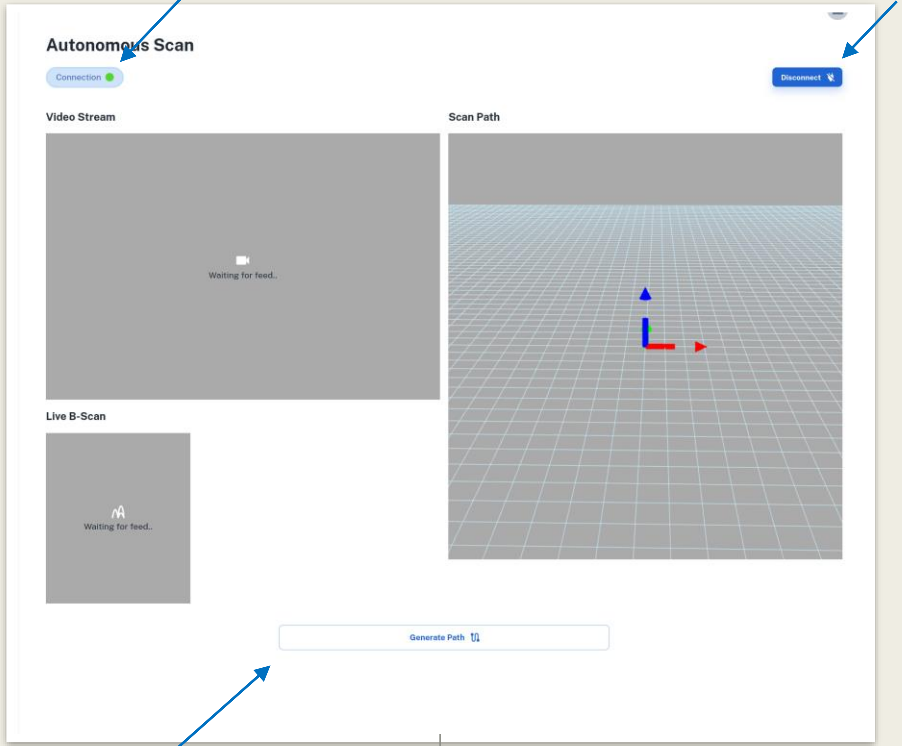
- Enable and adjust gird, for precise selection
- Select area from map

- Verify selection data
- Proceed to Autonomous Scan

User Interface

Connection Status

Manual Disconnect



Send Selection data to Rover

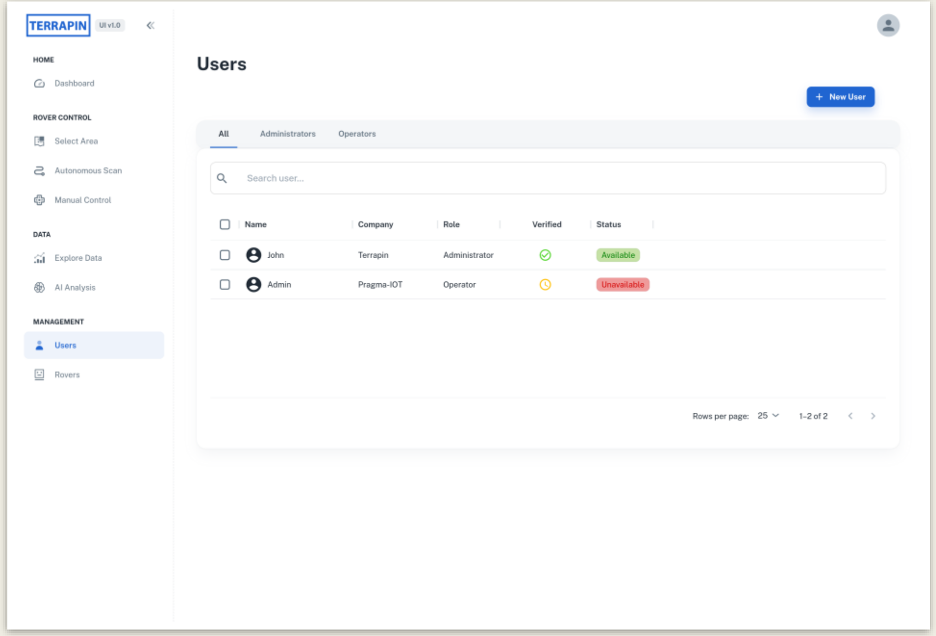
Scanning Process

1. Connection established with rover.
2. Selection sent to rover for path calculation.
3. Rover initiates scan process.

Begin Scan Process

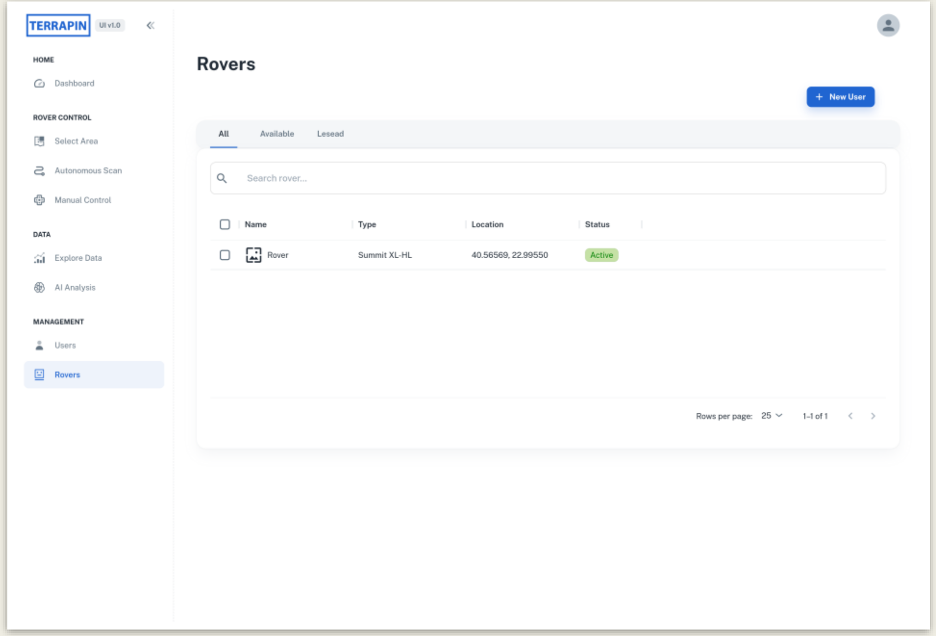
Optimised path

User Interface



- **Administrators:** can create, edit and delete the user accounts.
- **Operators:** can access data for rovers that are assigned to them.

User Interface



- Status overview for all rovers.
- Store rovers with specific their configurations.
- Assign rovers to operators.

Contact Us

– *https://terrapin.pro/*