PONTI

POSITION **N**AVIGATION **T**IMING FOR VIADUCTS MON**I**TORING

S4L
SPACE FOR LIFE

FINAL PRESENTATION

Teleconf, 02nd Oct 2025

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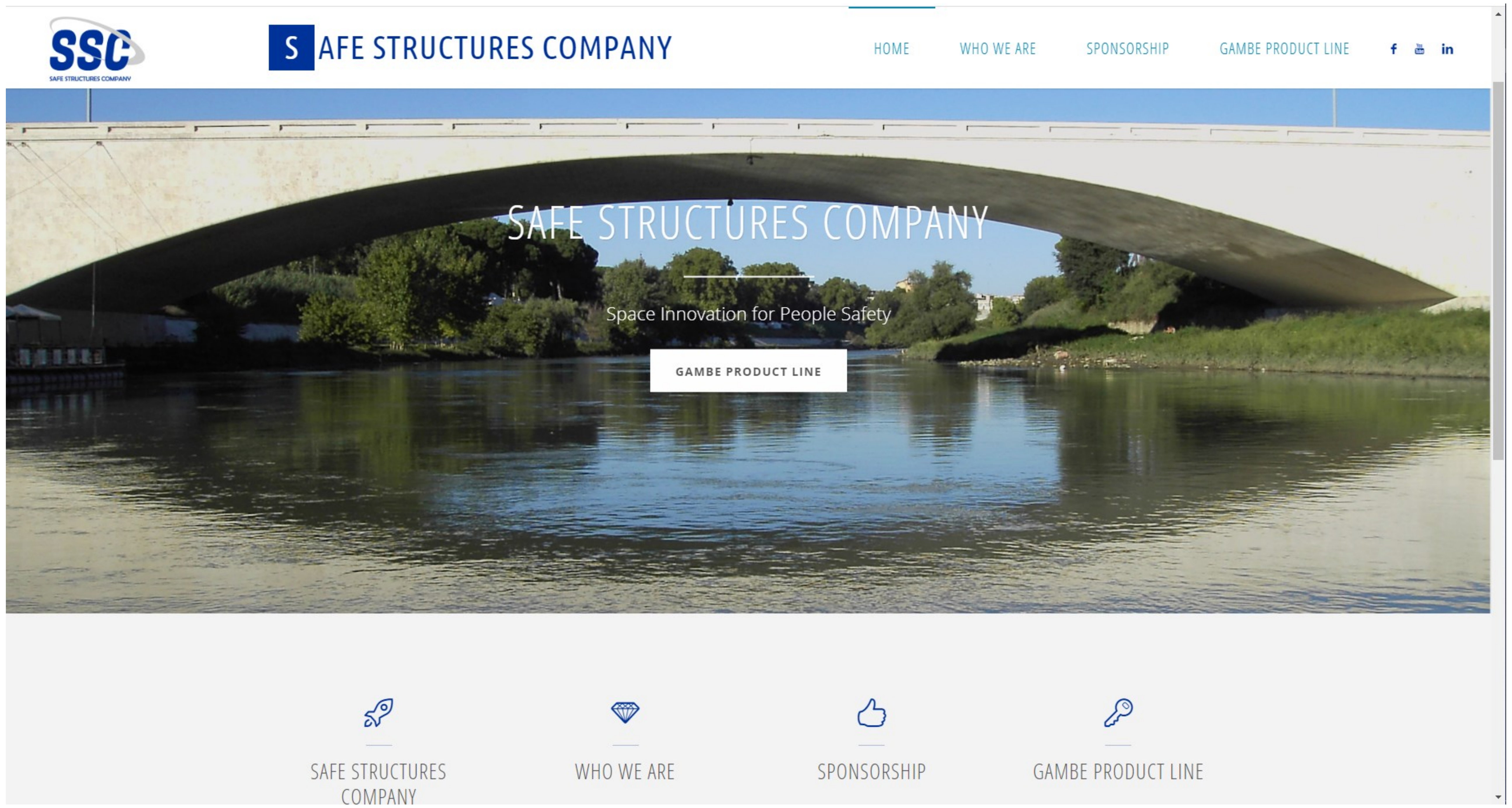
The Company

Space for Life (S4L), formerly **Safe Structures Company** (SSC), is a start-up founded in 2019 and consecrated to innovation. Its founders (Leonardo Gagliardi, Fabio Gerace and Paolo Di Scanno), coming from Space and Ground markets, joined to share their experiences and to merge their competences in electronics, structures and information technologies to solve industrial problems with lateral thinking.

Its first innovation project has been **GAMBE** – **G**NSS **A**nd **M**obile data for **B**ridg**E** monitoring – with the objective to monitoring healthy of highway bridges by using IoT and Big Data paradigms.

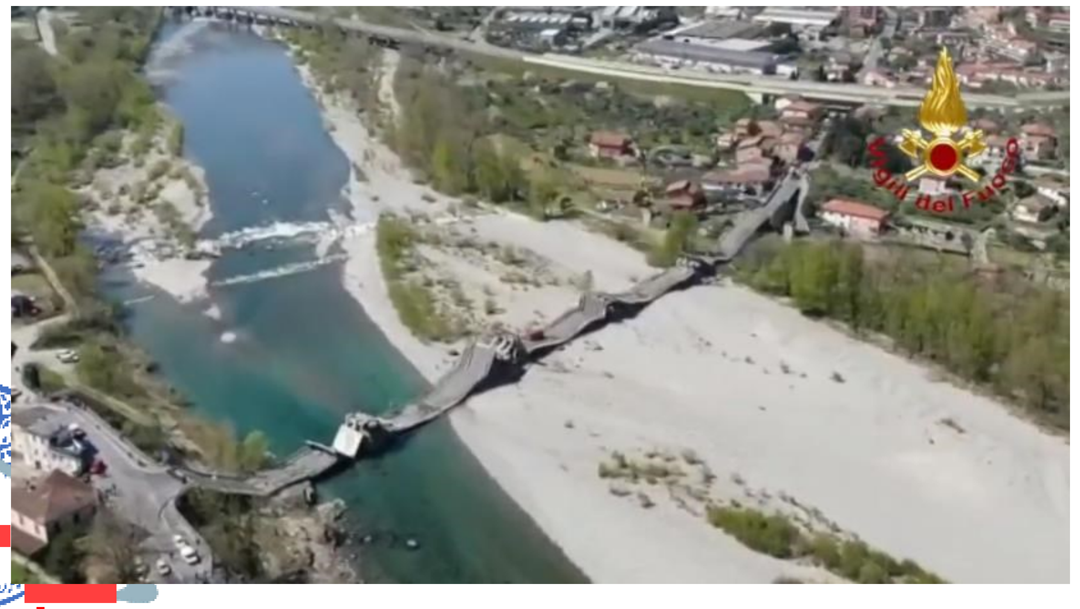


PONTI PROJECT – NEED

Ponte Morandi – Genova

Cavalcavia – Annone

Viadotto – Licata



Ponte in Albiano – Massa Carrara

The ageing of structures such as bridges and viaducts has recently dramatically shown the level of dangerousness of the possible collapse of these structures. Thus, for motorway companies and for the audit and control authorities, it has become a priority to equip themselves with systems which will enable economic efficiency to improve monitoring and compliance verification to rules and regulations.

In Italy, 'expired' and to be revised bridges are thousands; i.e. the number of bridges and viaducts present on 5.700 km of the AUTOSTRADE network are respectively 1866 and 1751.
Same numbers could be scaled for European countries and USA; i.e. American Highway network, referring only to the interstate, is 77.017 km with 55.512 bridges.

The GAMBE project was aimed to realize **a cost-effective system for bridges and viaducts monitoring by using accelerometers data of drivers' smartphones, georeferenced by means of satellite navigation systems** (GNSS). PONTI adds to GAMBE a dedicated box to overcome verified issues as:

1. it is intended to integrate GAMBE approach with a more targeted approach, using fleets that run through pre-established routes; the collection of mobile phone data supplied to drivers of particular fleets: public transport, police, maintenance equipment, etc., makes it possible to speed up the collection of data on routes of particular interest;
2. it foresees also to develop a dedicated low-cost mobile system to acquire the necessary data, interfaced with an evolved version of the APP and the Cloud Services that allows better analysis of structures health status.

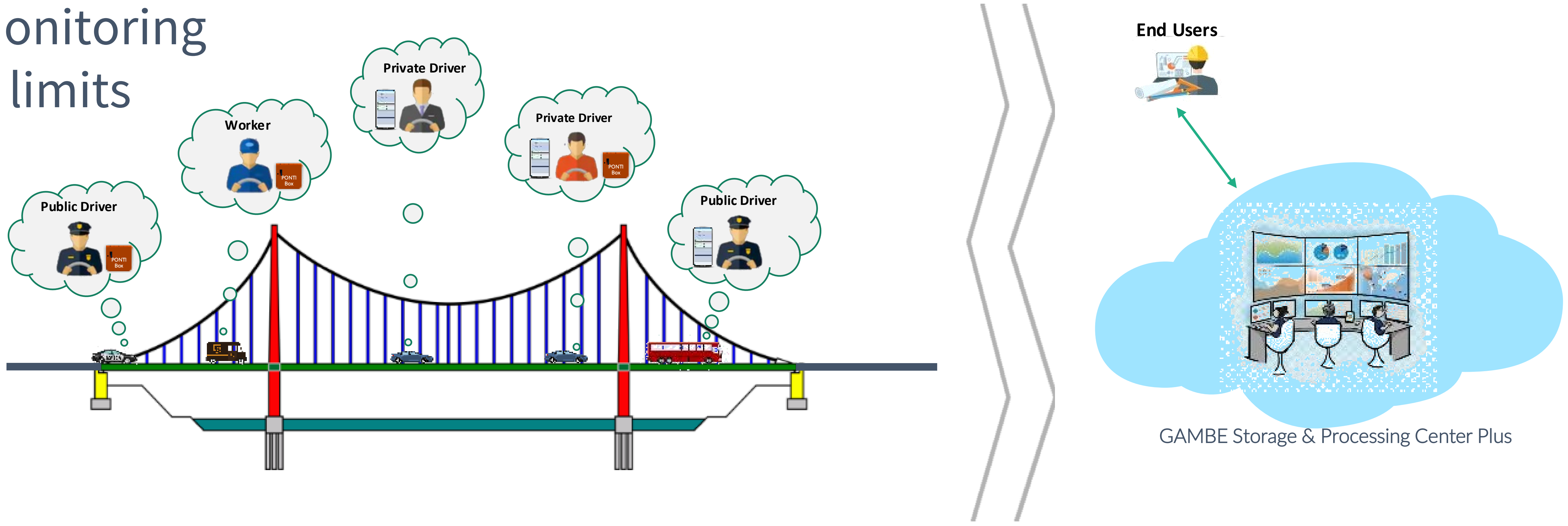
The savings in economic terms is evident as well as the greater effectiveness and efficiency.
Solutions such as that proposed by S4L are currently not present on the market. In the literature are reported experiences of using the data of the accelerometers of smartphones at the level of university research, which at the time, have not produced operating systems.

The S4L strategy is to arrive soon on the market, aiming exclusively at the engineering of the system.

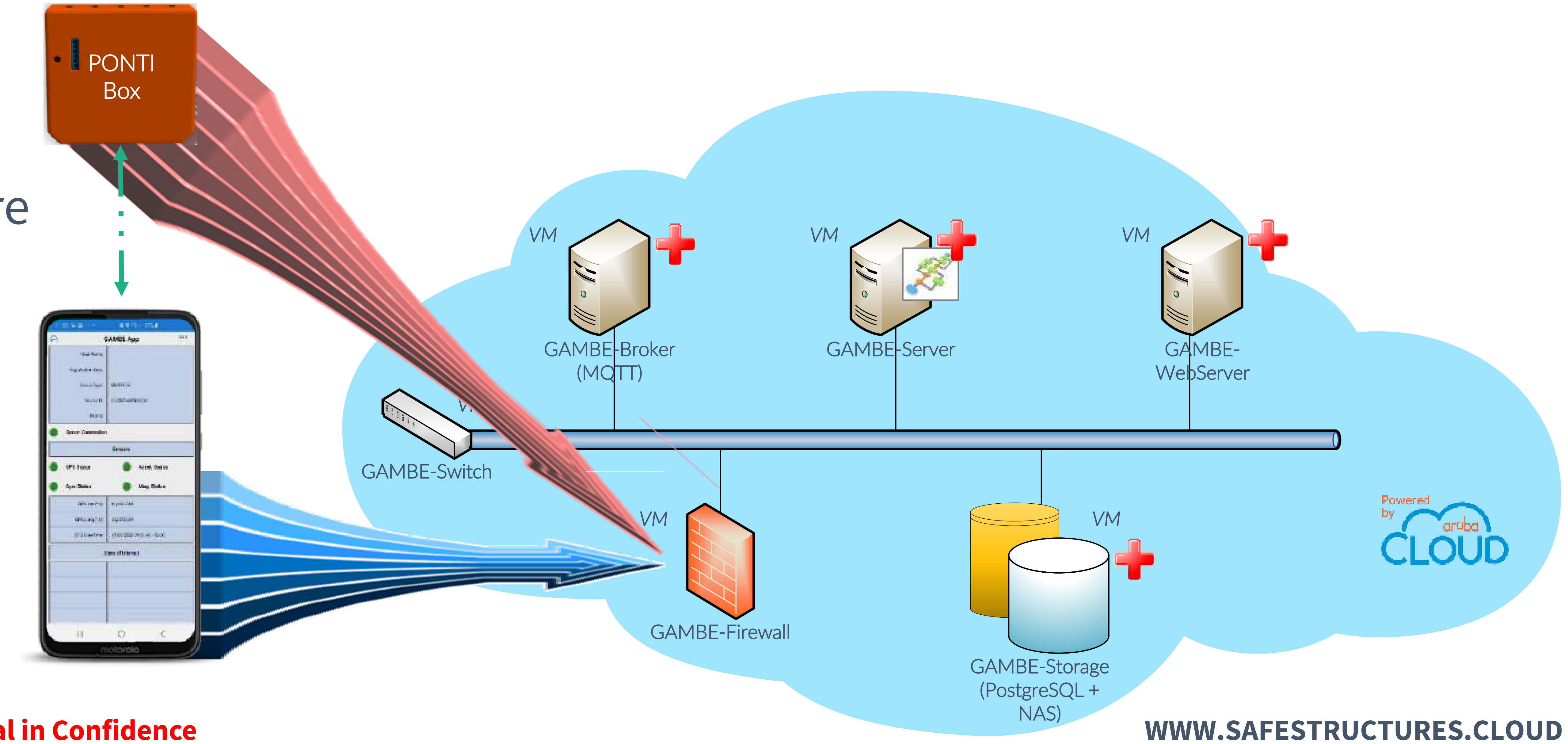
PONTI System Objective

PONTI System born with the objective to respond to the Bridges monitoring need of Institutions and Highway Concessionaries overcoming the limits of GAMBE:

- the acquisition frequency of smartphones' accelerometers is unstable and sometimes insufficient for the characteristics of typical Italian motorway structures (viaducts) that structurally are formed by several (4÷25) simple aligned structures that should be singly analysed;
- the social approach for the use of the APP, necessary for the collection of data, requires a long time to diffuse the APP itself to reach the necessary density of information on a single structure.



It added to the acquisition system a **Box** able to be used **autonomously** and connected with a mobile phone, having a more accurate, even if low cost, accelerometer.
The system also improved the Storage and Processing Center (SPC+) to be used in any acquisition conditions (Box alone, Box via mobile phone, mobile phone alone) in all its modules.



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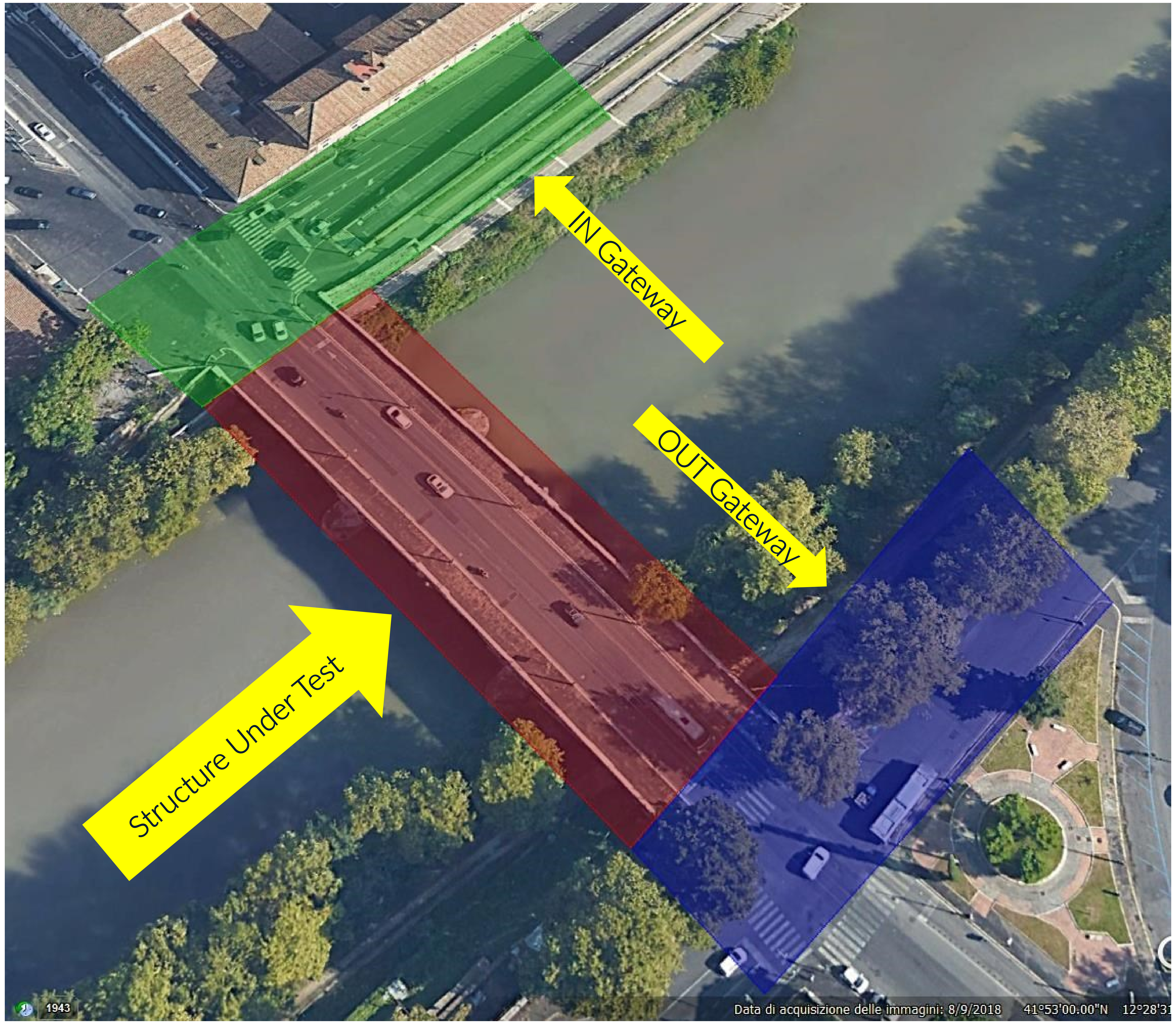
Zone of Interest

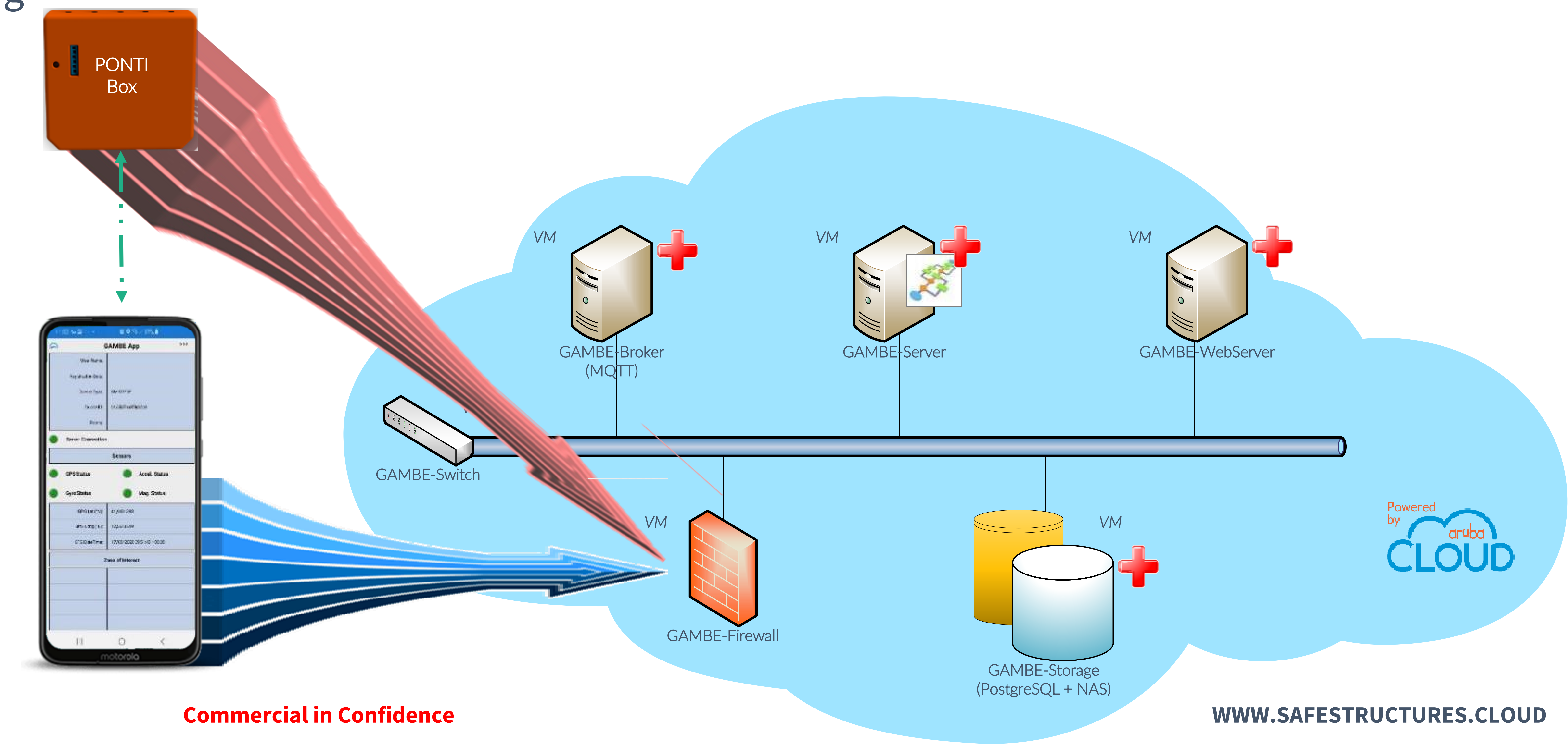
Using GNSS, sensors data are acquired in Gateways
(G-IN and G-OUT) and in Structure Under Test (SUT).



DEVELOPED PRODUCTS

PONTI System is formed by the following products:

- **PONTI-Box**
  It is a dedicated sensor box: designed and tested according to automotive standards; powered by vehicle battery; equipped with a high accuracy accelerometer and a PNT receiver for data localization and timing, able to exchange data and synch via Bluetooth with the smartphone running PONTI-App or autonomously with PONTI-SPC+ using mobile networks.
- **PONTI-App**
  It is a mobile phone application able: to acquire data both from smartphones sensors and from PONTI-Boxes using internal PNT receiver for data localization and timing; to transmit them to PONTI-SPC+.
- **PONTI-SPC+***
  It is the Storage & Processing Centre integrating in the Broker and in Storage the acquired data of PONTI and in Server the processing algorithms.

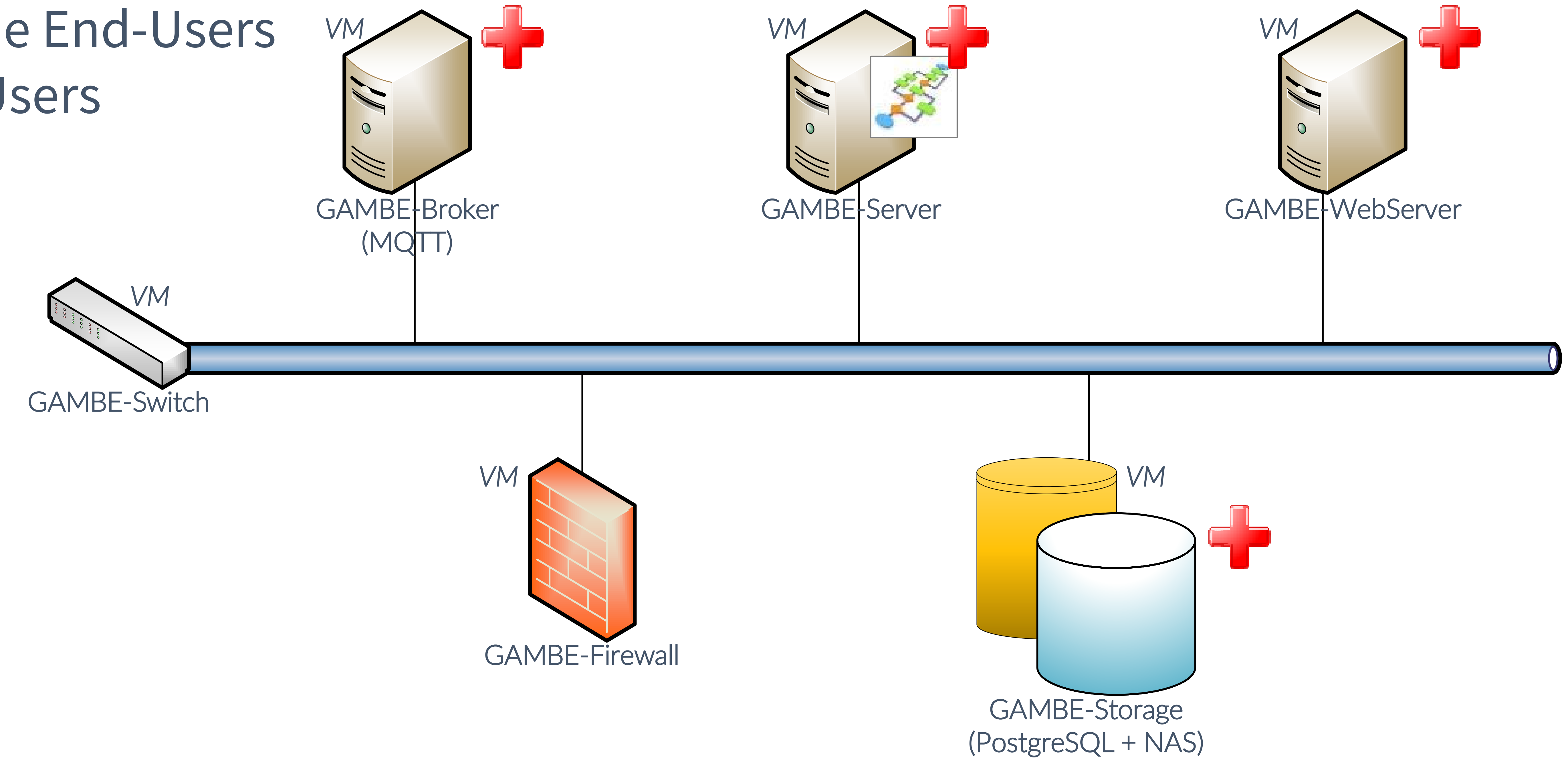


**Note that the '+' indicate an important evolution from previous GAMBE product.*

PONTI-SPC+ ARCHITECTURE

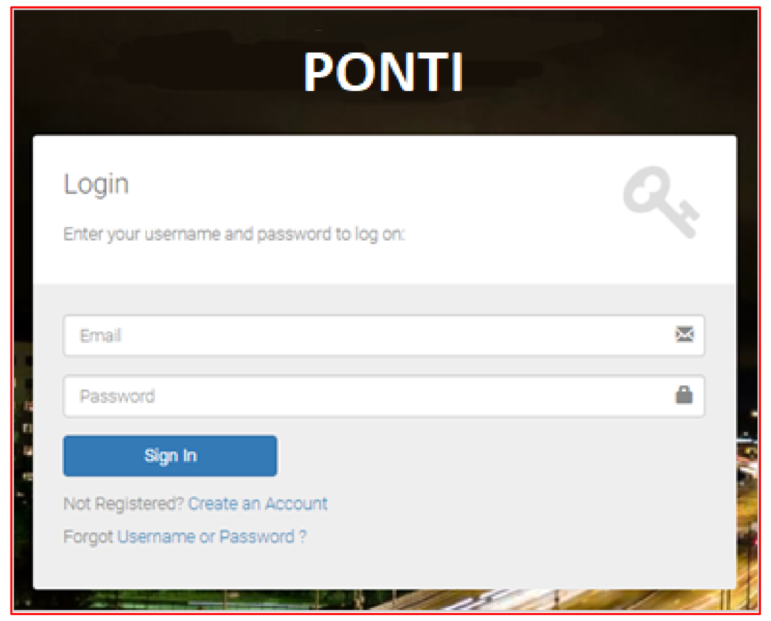
PONTI-SPC+ is a complex SW system based in cloud and completely scalable adding, in the virtual network managed by **GAMBE-Switch**, multiple instance of the functional 5 VMs:

- **GAMBE-Firewall**, not evolved from the previous project, is the only VM that expose an IF to WAN (for Boxes, Apps and End-Users) and guaranty the security of the infrastructure;
- **GAMBE-Broker+** accepts connections from devices (Apps and Boxes) using Mosquitto MQTT server providing acquired data to the Server+ via the DBs services offered by Storage+;
- **GAMBE-Storage+**, provide the IF to the DBs to the other VMs;
- **GAMBE-Server+** is aimed to provide the Zone of Interets (ZoI) required by devices, to collect, to process and to prepare data received along the time by all devices;
- **GAMBE-WebServer+** provides high-level data to the End-Users exposing a web IF; moreover, it manages the End-Users configuration data.



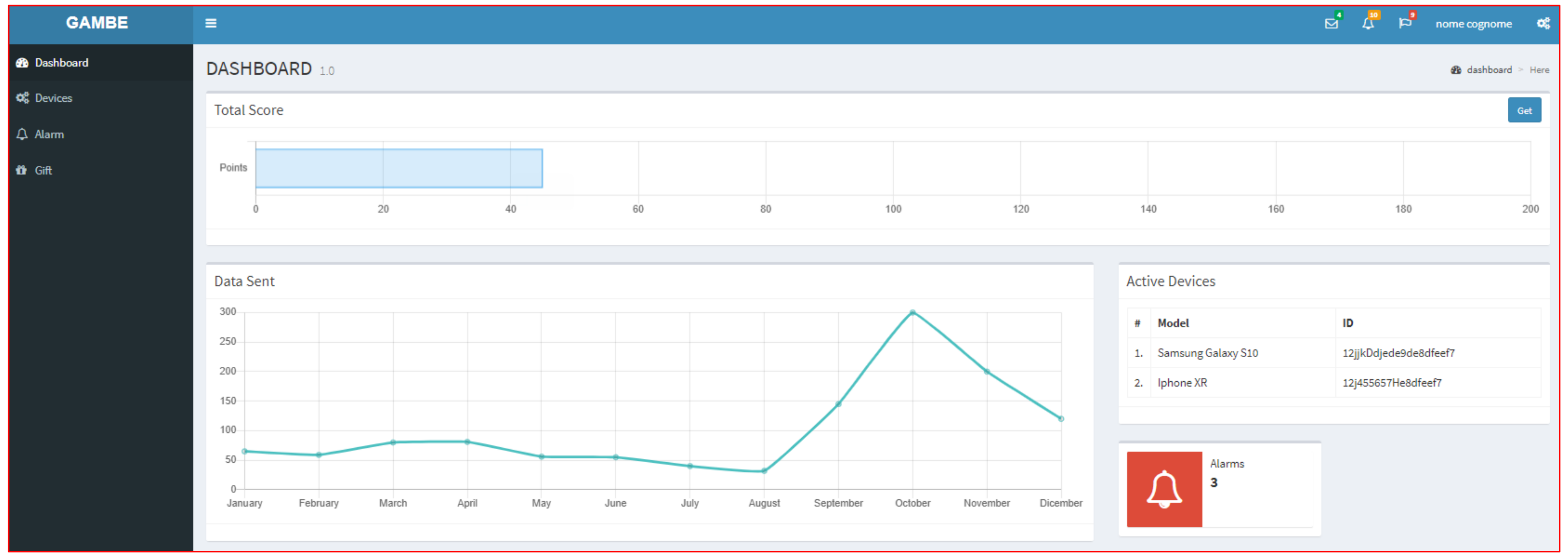
PONTI-SPC+ WEB SERVICES PANELS

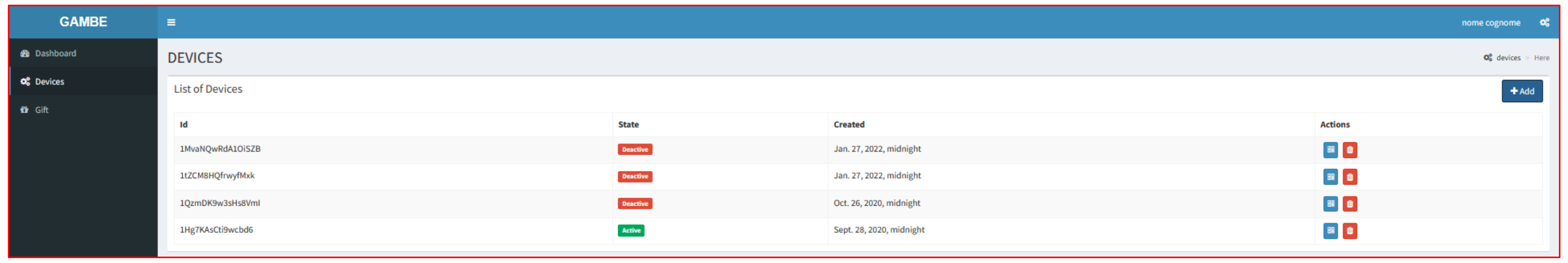
User Profile



The **registration** of the service can only take place for the User profile.
From the website of access to the portal you will have the opportunity to register for the service through the appropriate FORM accessible via the "Sign In" button.

User Profile Interface shows the GUI for the USER profile of the Web Application. The user profile corresponds to the final user of the service who will use the application (PONTI-App) for smartphones or PONTI-Box to send data to the subsystem (PONTI-Server) which will manage the collected information.
The user, through the "Dashboard" section, will be able to view the points accumulated during the use of the service.

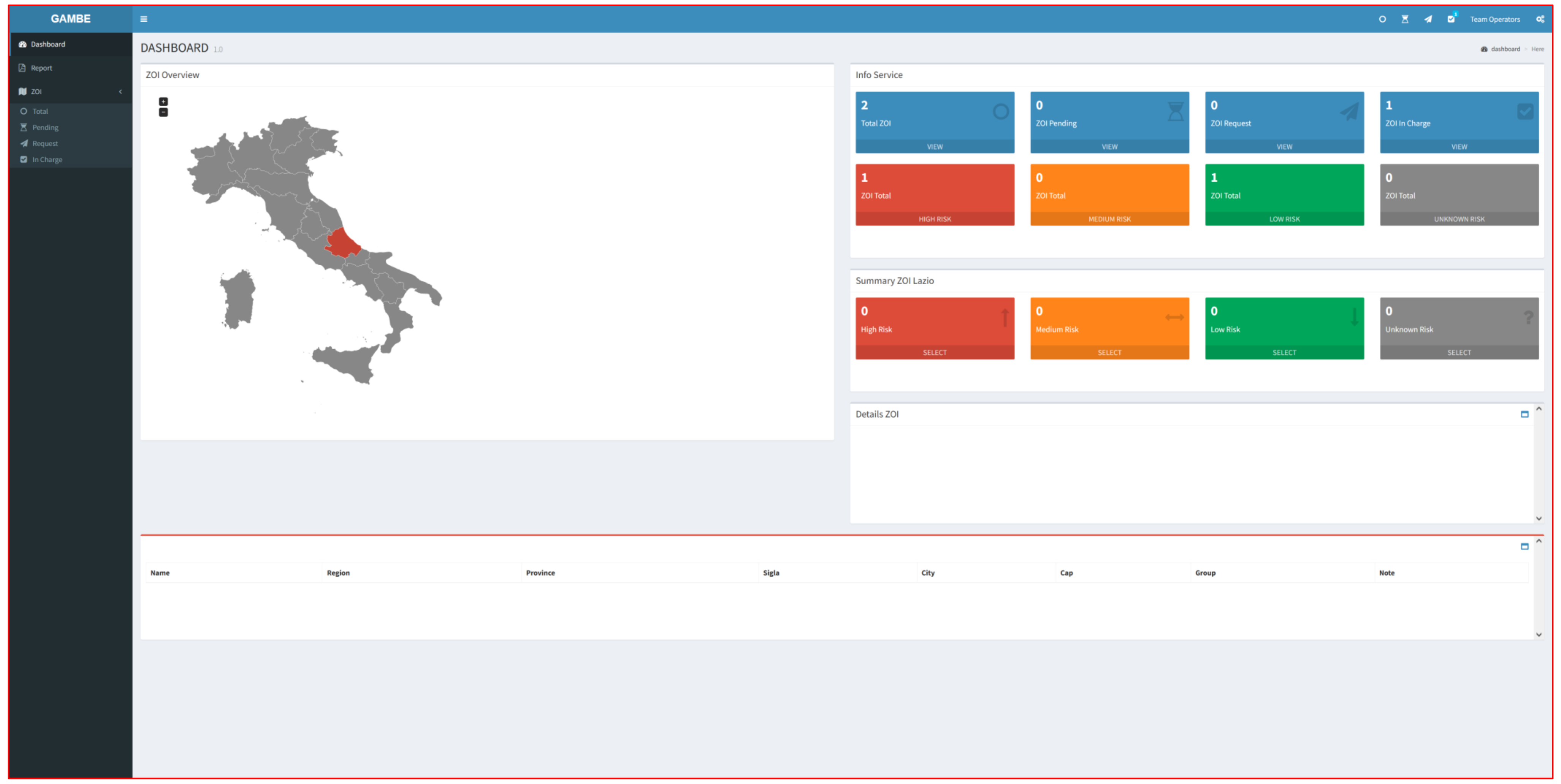




The user will have the possibility to register the device used by the application (PONTI-App) for the collection of data to be sent to the PONTI-Server subsystem.
To register the device, the system will generate a unique code.

PONTI-SPC+ Web Services Panels

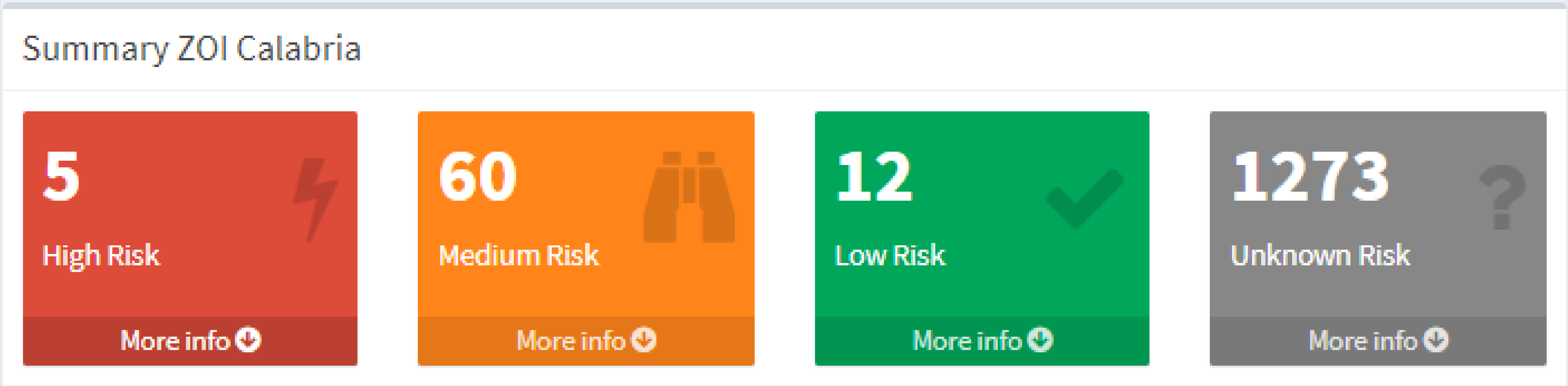
Customer Profile – Main Panel



The operator profile corresponds to the user of the service. The operator will have the opportunity to supervise and manage their areas of interest (ZOI): the monitoring shall aim to determine their health status while the management shall include checks by the administrator of the service and maintenance interventions through the sending of specialist intervention teams, for the maintenance of the ZOI of interest.
Operators shall have read-only permissions on the system but will be able to make requests to the service administrator for further information on the health status of the ZOIs and action on them.

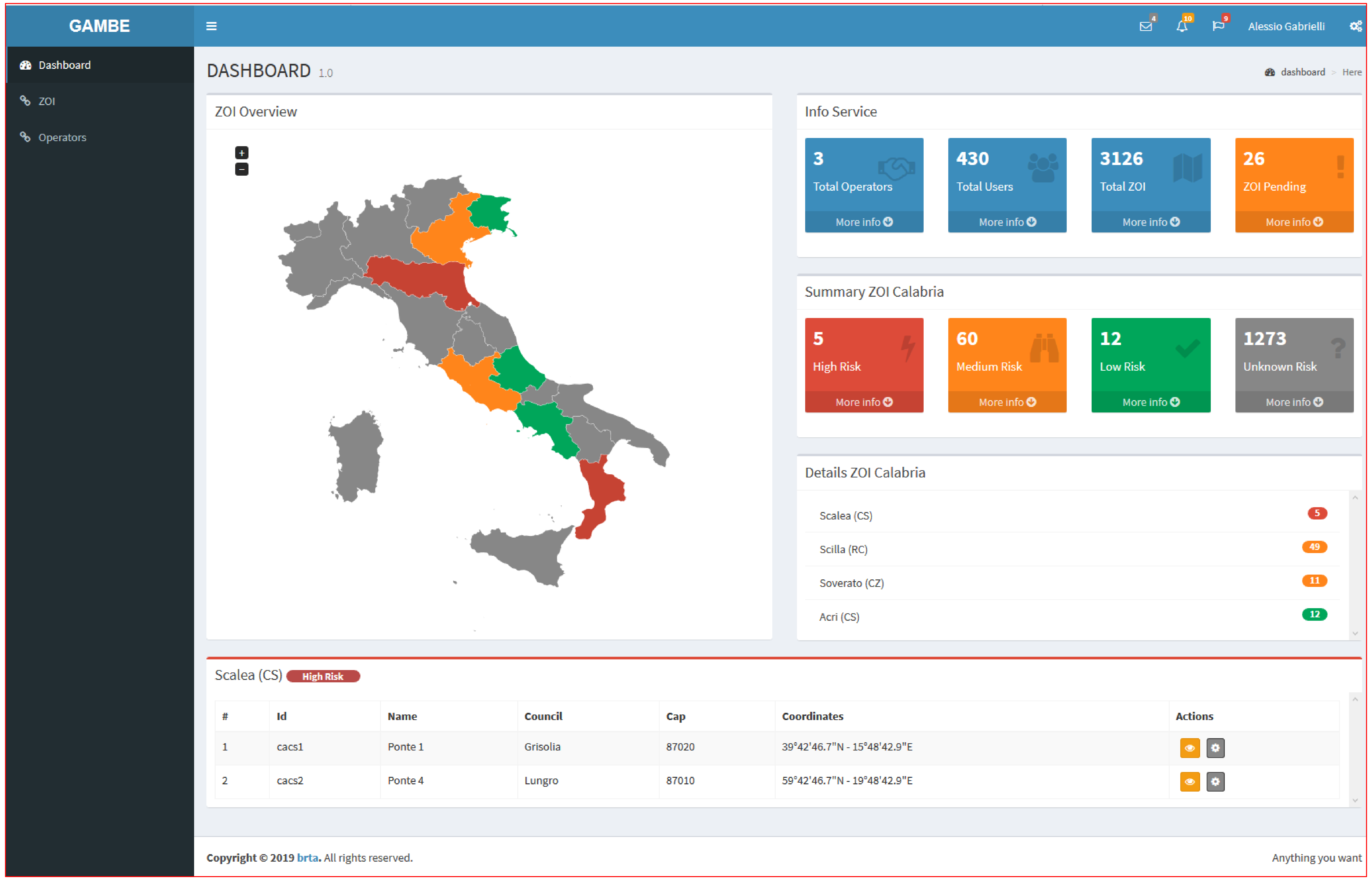
In the right section "Summary ZOI <REGION NAME>" an aggregate data shall be reported in which, for each risk index, the total of the ZOI belonging to it shall be indicated.
This information shall be represented through graphic "widgets", one for each level of criticality. The "Unknown Risk" widget considers the ZOIs for which no data have been received.
For example, the region is represented:

- 5 ZOI with high risk,
- 60 ZOI with medium risk,
- 12 ZOI with low risk,
- 1273 ZOI with absent data (Unknown Risk).



PONTI-SPC+ WEB SERVICES PANELS

Administrator Profile – Overview Panel



Administrator Dashboard shows the interface (GUI) relating to the ADMINISTRATOR profile required by the WSR subsystem. The administrator profile corresponds to the service manager.

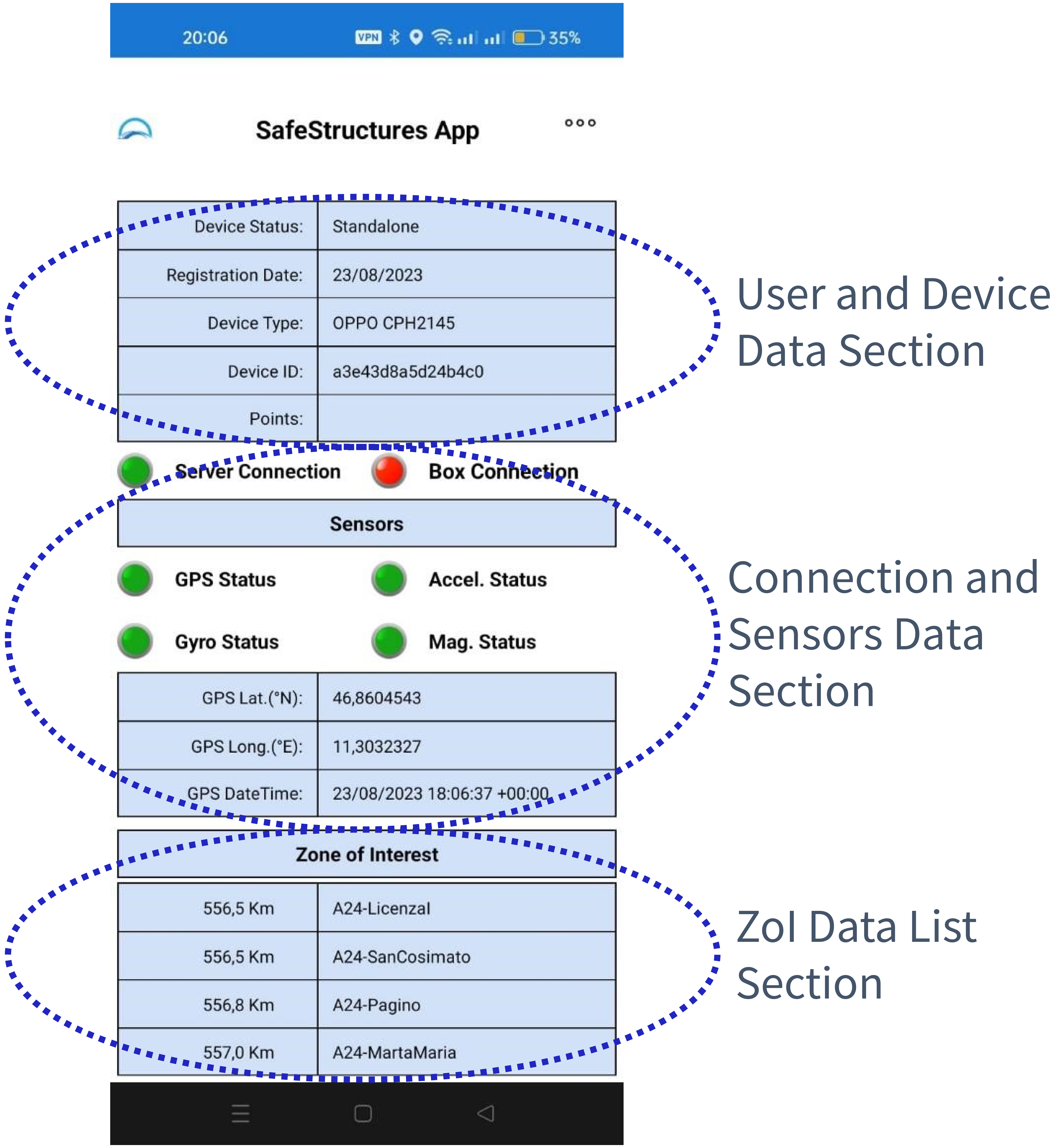
The administrator shall have the possibility through the "Dashboard" section to view information on:

- Total of Operators who requested the Service (activated);
- Number of Users registered for the service;
- Total of the ZOIs managed;
- Total of pending ZOIs (ZOIs not yet taken over by operators).

PONTI-App

The PONTI-App has been designed to collect data provided by onboard sensors:

- GNSS receiver
- Accelerometer
- Gyro
- Magnetometer



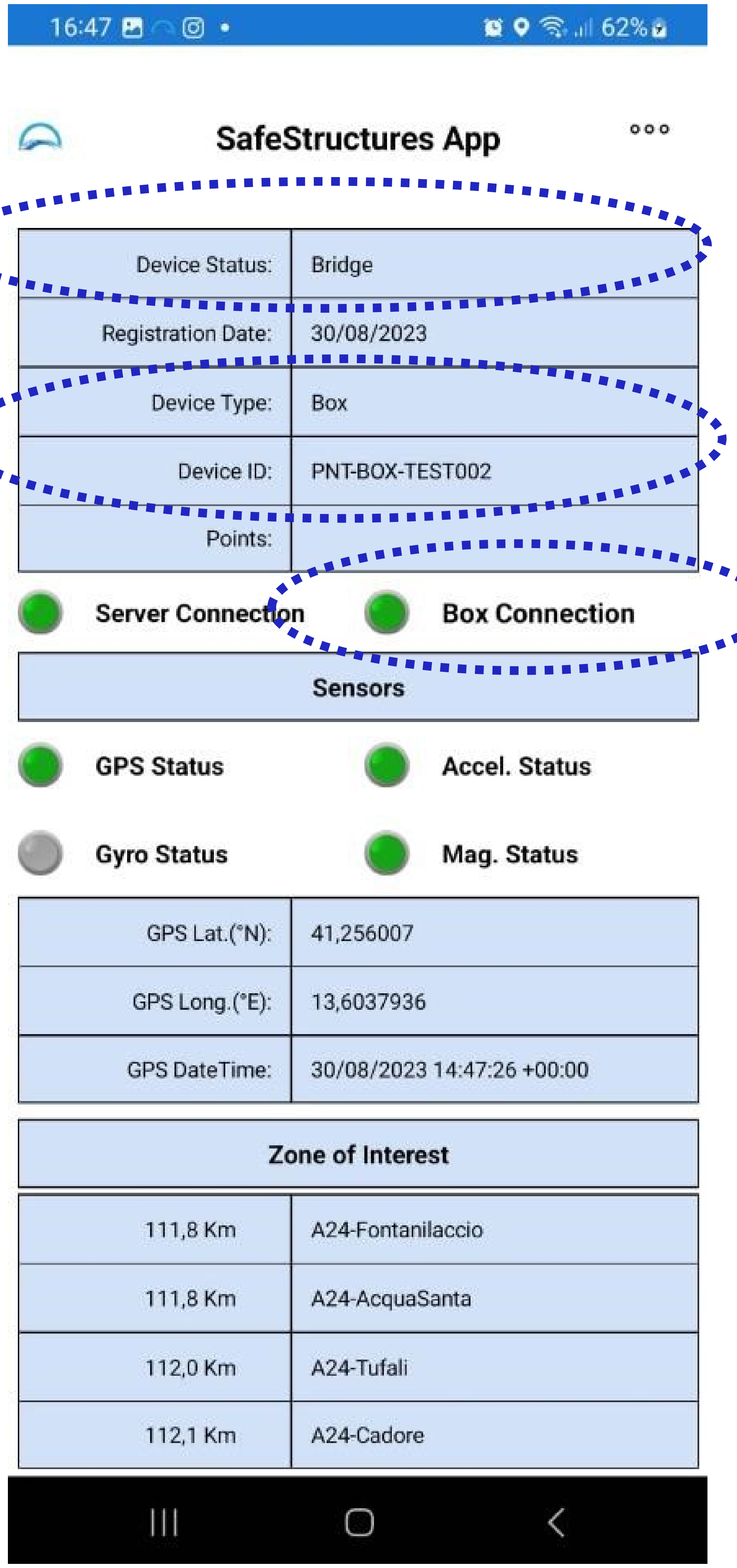
Moreover PONTI-App shall operate in

- Standalone mode: to collect data and interface directly the PONTI-SPC+
- Bridge mode: to act as a bridge to allow a PONTI-Box to interface the PONTI-SPC+. In this configuration PONTI-App present itself to the PONTI-SPC+ as the connected Box

PONTI-APP

Operative mode

Bridge Mode



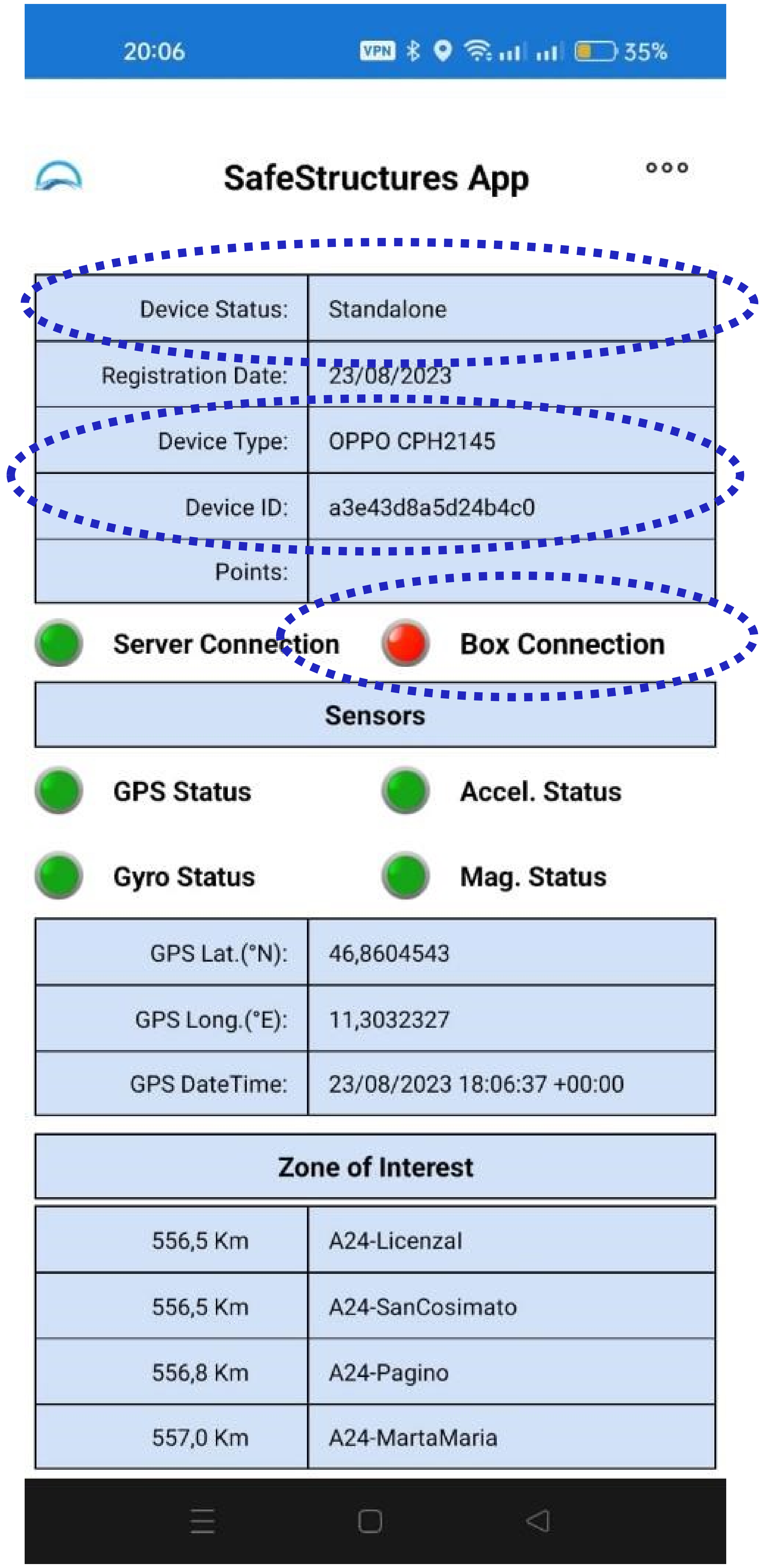
Status

Type & ID provided to SPC+

PONTI-App can operate in two mode:

- Standalone: to ensure a capability of collecting and transfer data to PONTI-SPC+
- Bridge: to ensure the capability to transfer data collected by PONTI-Box

Standalone Mode



Status

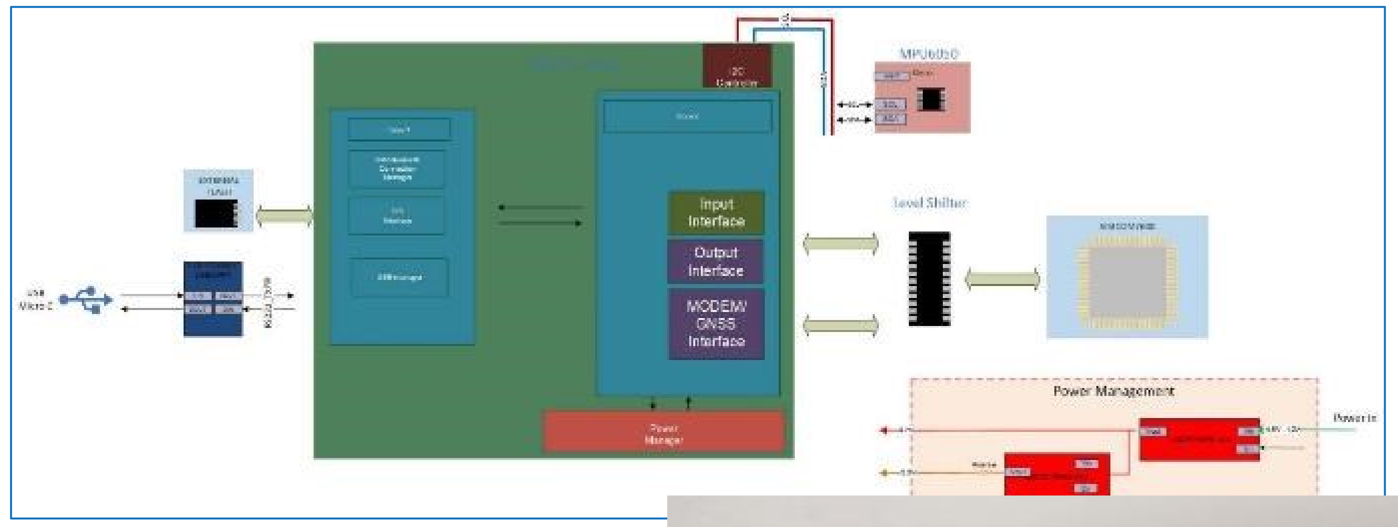
Type & ID provided to SPC+

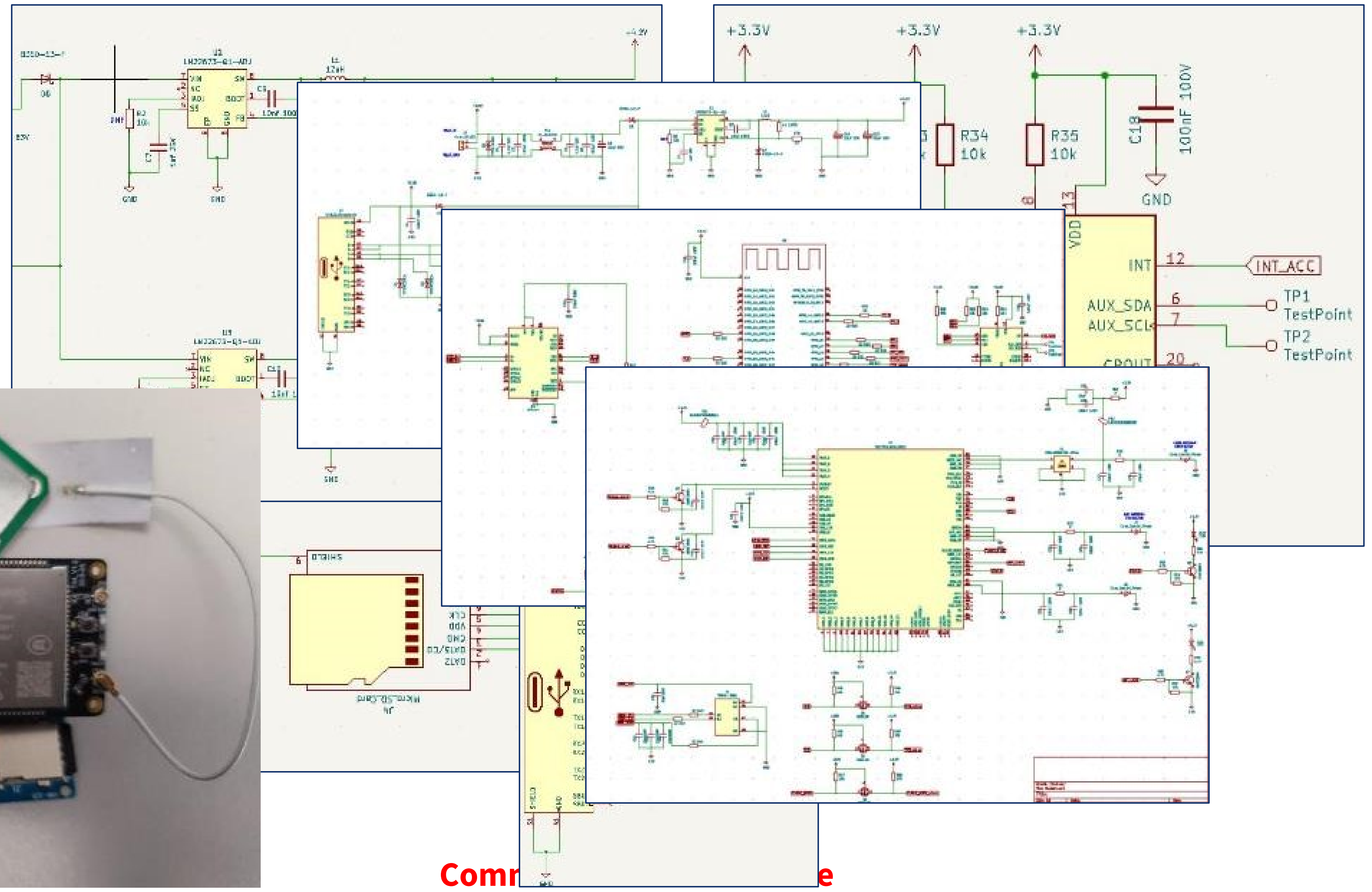
PONTI-Box

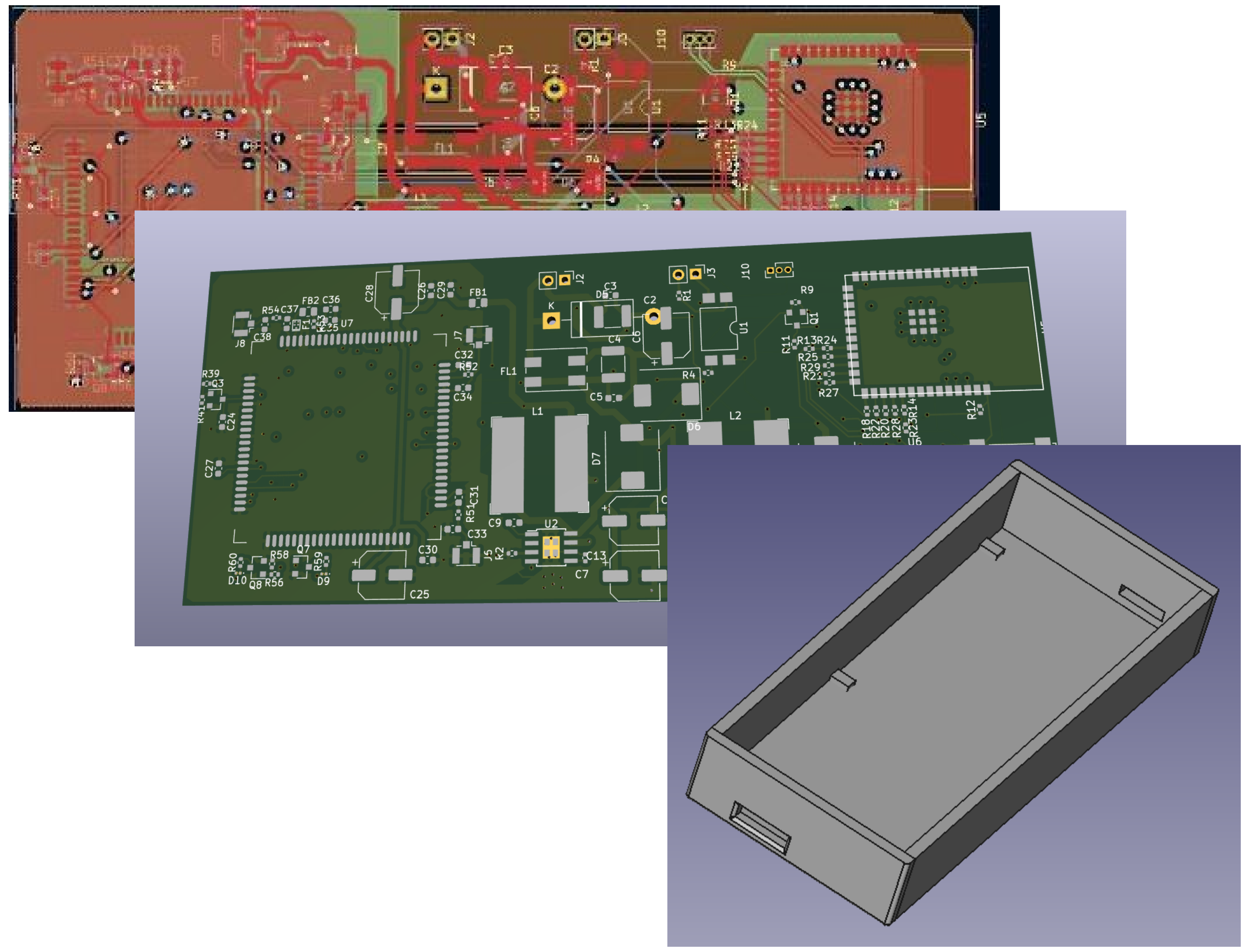
PONTI-Box is one of the new element of the system, designed to autonomously acquire accelerometric data crossing a bridge\viaducts (SUT) and providing them to PONTI-SPC+.
It has been designed with the following characteristics:

- designed and tested for automotive applications
- small form factor: < 16 cm x 6 cm x 3 cm
- small weight: < 150 g
- accelerometers acquisition rate: 1 ksps
- powered by vehicle battery: 5÷34 V
- low-power: < 1.5 A
- low-cost: < 100 € (currently < 200 €)

Design & Development process passed through: PDR → CDR + BB → 1st MAIT → Final MAIT







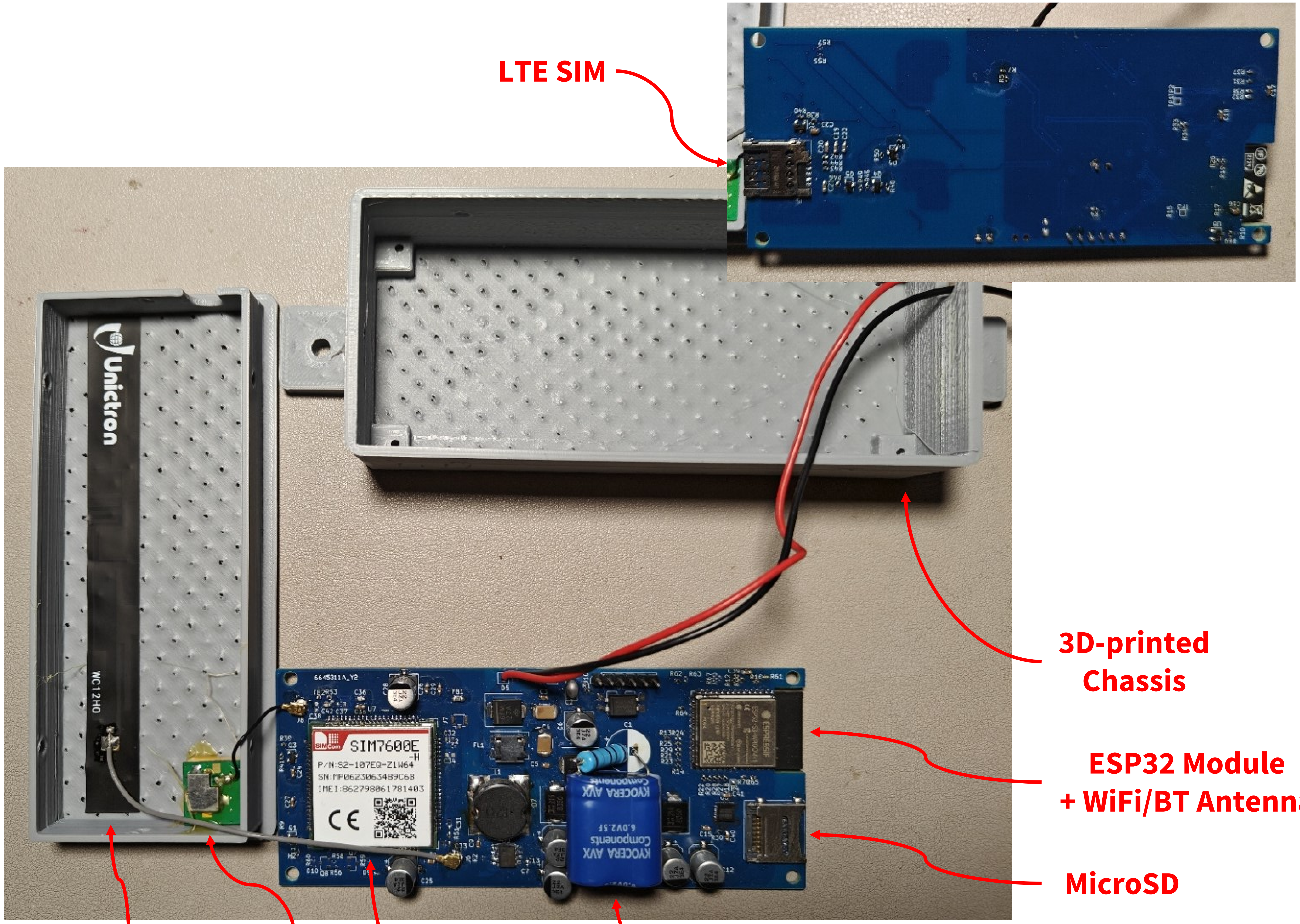
PONTI-Box

PONTI-Box is based on the following main components:

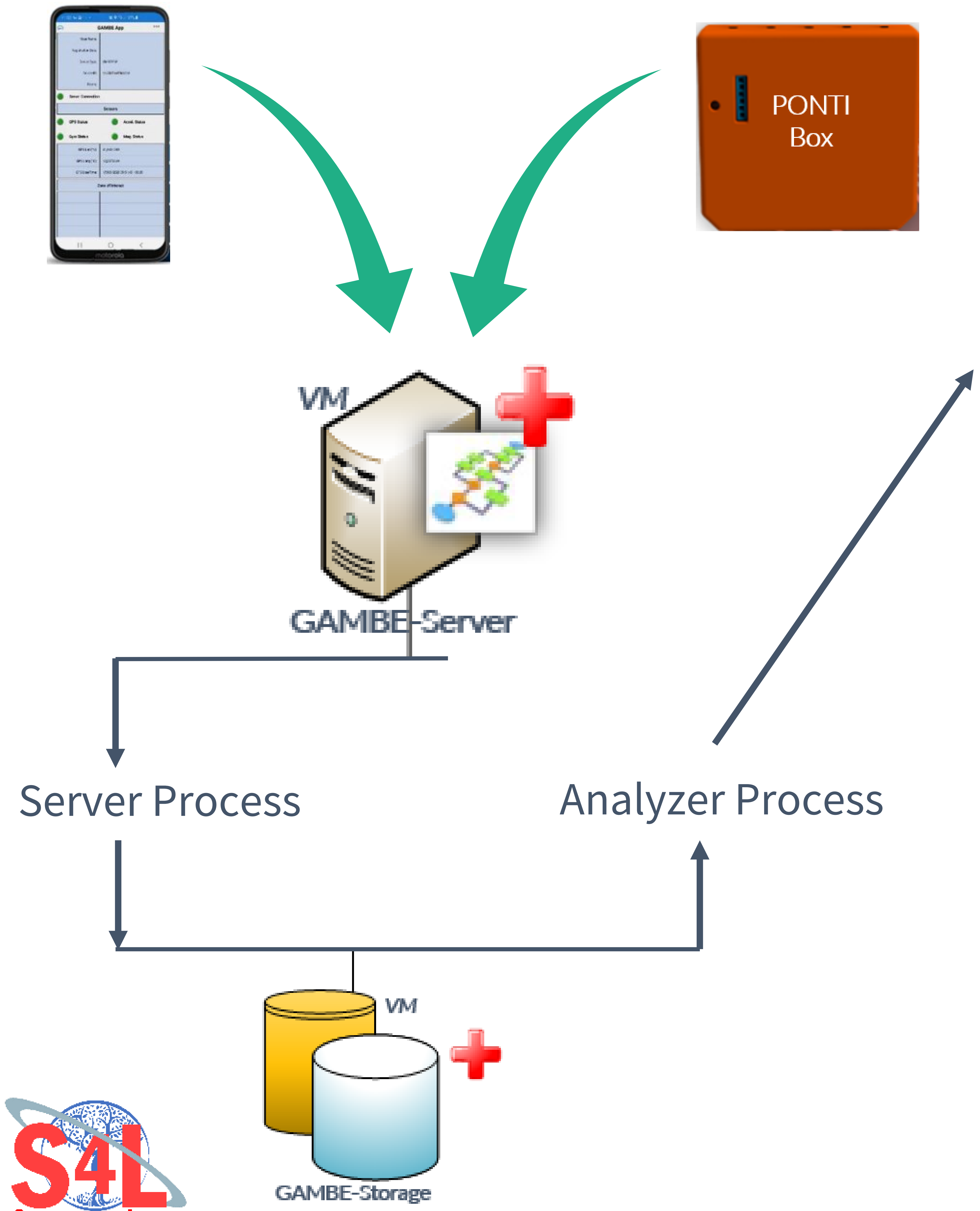
- Expressif ESP32-S3-WROOM-1-N4 Dual-core uController
- SIMCom SIM7600E LTE/GNSS Module
- TDK INVENSENSE MPU-6050 3-axis Gyroscope/Accelerometer

Several test phases:

- laboratory tests
- in-house verification
- debug field tests
- short campaign (Dem. Step 1)
- long campaign (Dem. Step 2)



DATA GATHERING AND PROCESSING FLOW



Level-0 Processing
- Track Building (GNSS+Acc.)
- Track Filtering
- Direction Filtering & Track Interpolation

Level-1 Processing
- Fast Fourier Transform (FFT)
- Short-Time Fourier Transform (STFT)

Level-2 Processing
- Average FFT (aFFT)
- Machine Learning FFT Peak Detection (FFT_Ps)
- Average STFT (aSTFT)
- Machine Learning STFT Peak Detection (STFT_Ps)

Level-3 Processing
- FFT_Ps Change Detection
- STFT_Ps Change Detection

Level 0 Analysis

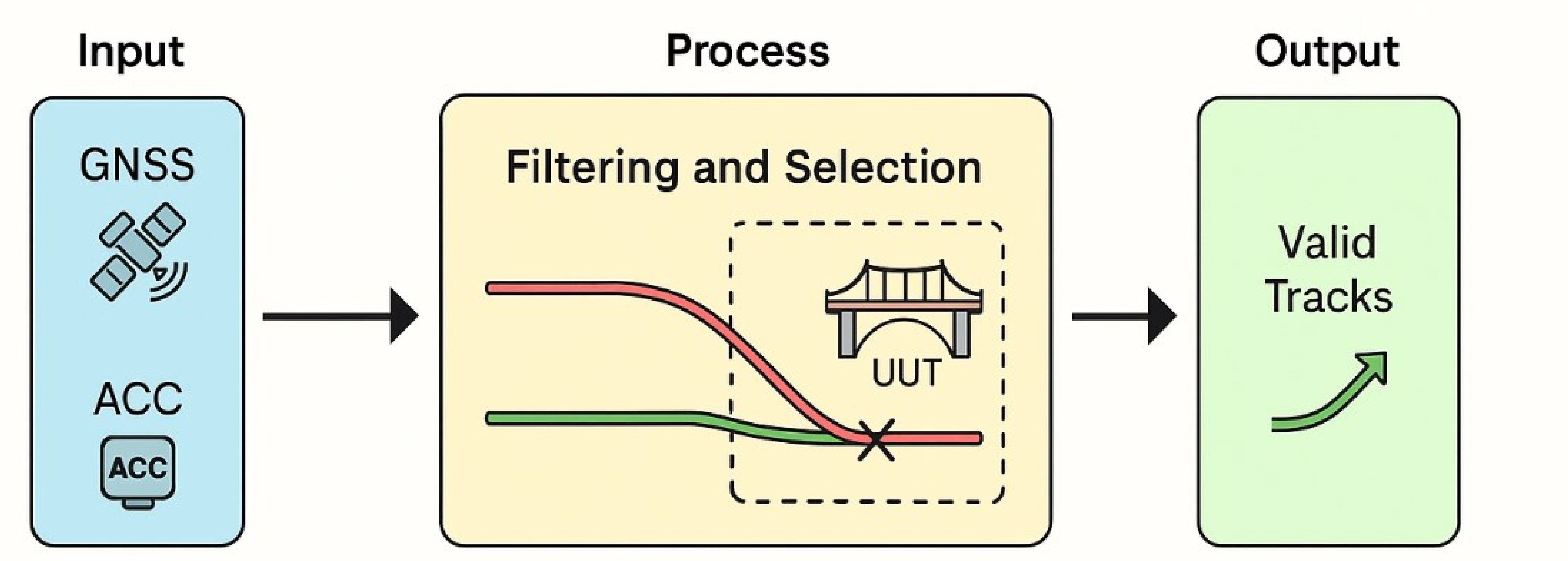
Track Filtering & Selection

This stage processes raw GNSS and accelerometer data, selecting only valid tracks

A track is kept if it fully crosses the viaduct zone (UUT), remains inside its boundaries, and travels within the defined speed range

Moreover time filters are applied

The output is a clean dataset of valid crossings ready for further analysis



Input: raw BOX_GNSS data for each ZOI (Zone of Interest)

Main operations:

- Reading UUT (Unit Under Test) coordinates and defining the viaduct polygon
- Checking UUT crossing (entry from side AD, exit from side BC)
- Discarding tracks with points outside the polygon
- Filtering by speed (V_MIN ≤ v ≤ V_MAX)
- Applying optional time filters

Output: set of “valid” tracks

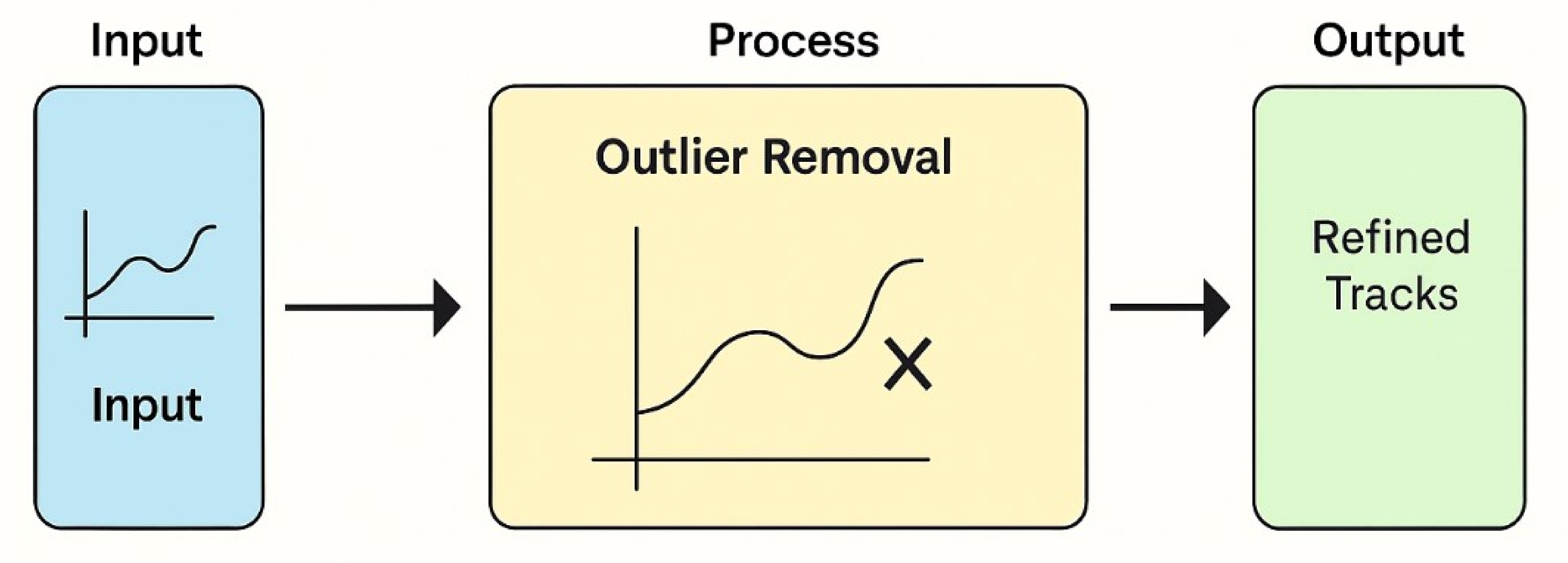
Level 1 Analysis

In this stage, a single validated track is interpolated to refine the GNSS trajectory inside the UUT

Accelerometer data are aligned with each GNSS point to create a continuous dynamic signal

A Fourier Transform is then applied, revealing the frequency spectrum of the crossing and highlighting the key vibration components of the structure

Single Track Accelerometric Analysis



Input: one track validated from Level 0
Main operations:

- Interpolation of the GNSS trajectory
- Identification of the segment inside the UUT
- Alignment of accelerometer data with the trajectory
- Computation of acceleration magnitude
- FFT of the accelerometric signal → frequency spectrum

Output: plot (linear/log FFT and zoom 0–50 Hz) and file with signal and FFT

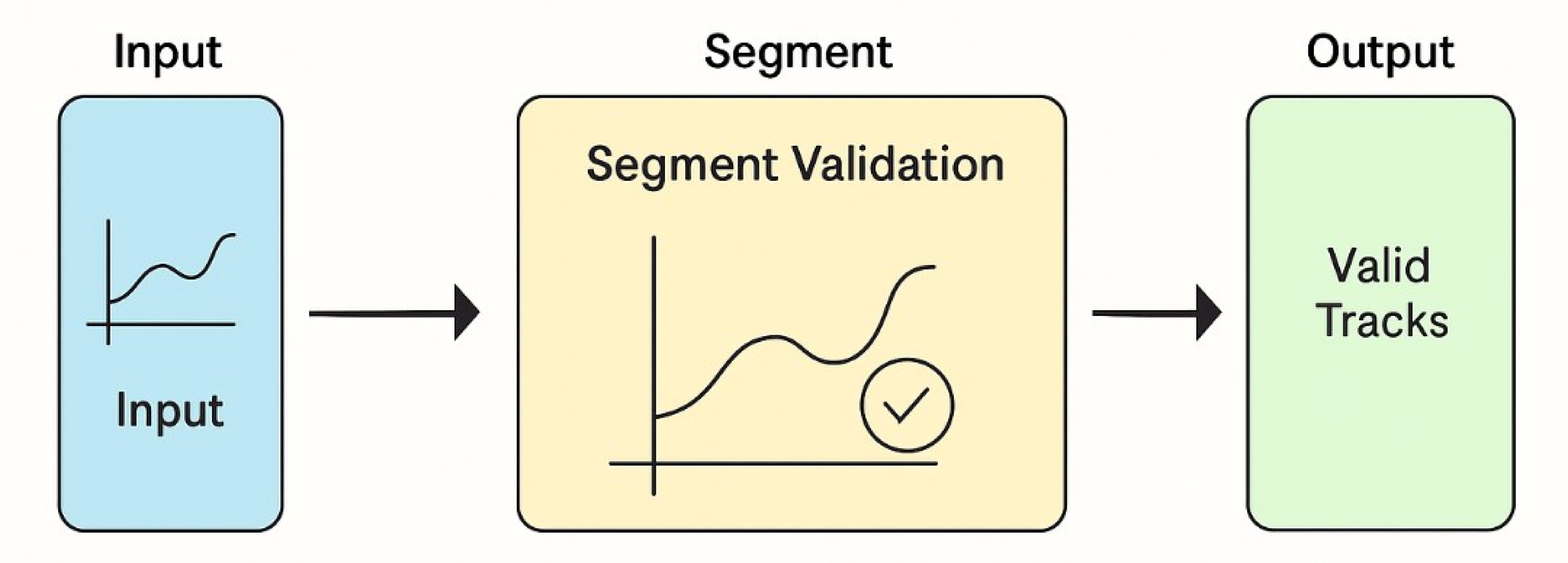
Level 2 Analysis

This stage aggregates data from multiple crossings to build a representative frequency response

The average FFT is calculated, dominant frequencies are extracted using Radial Basis Function Networks, and spectrograms are produced to map how vibration energy evolves along the viaduct

The result is a robust picture of structural behavior across repeated passages

Advanced Multi-Track Analysis



Input: Processed tracks (Level-1).

Main operations:

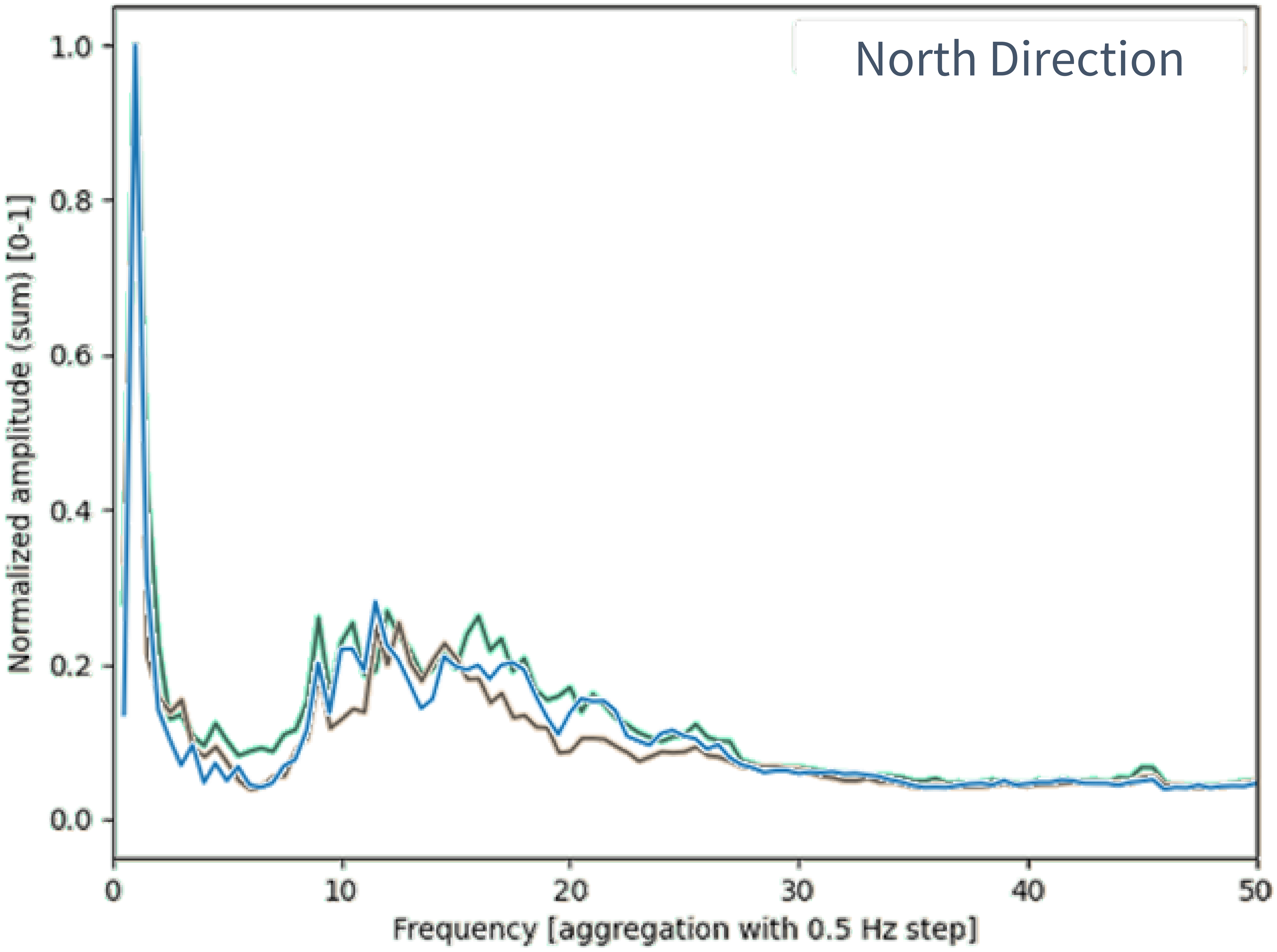
- **FFT Aggregation:** compute normalized FFT for multiple crossings, aggregate with 0.5 Hz step, save data and plots (linear/log, zoom 0–50 Hz)
- **RBFN Regression:** train a Radial Basis Function Network on aggregated FFTs, extract dominant frequencies via peak detection
- **Spectrogram (Lomb-Scargle + Hanning):** time-frequency analysis of accelerometric signals, cubic spline interpolation, normalization, generation of aggregated spectrogram (also zoom 0–50 Hz)

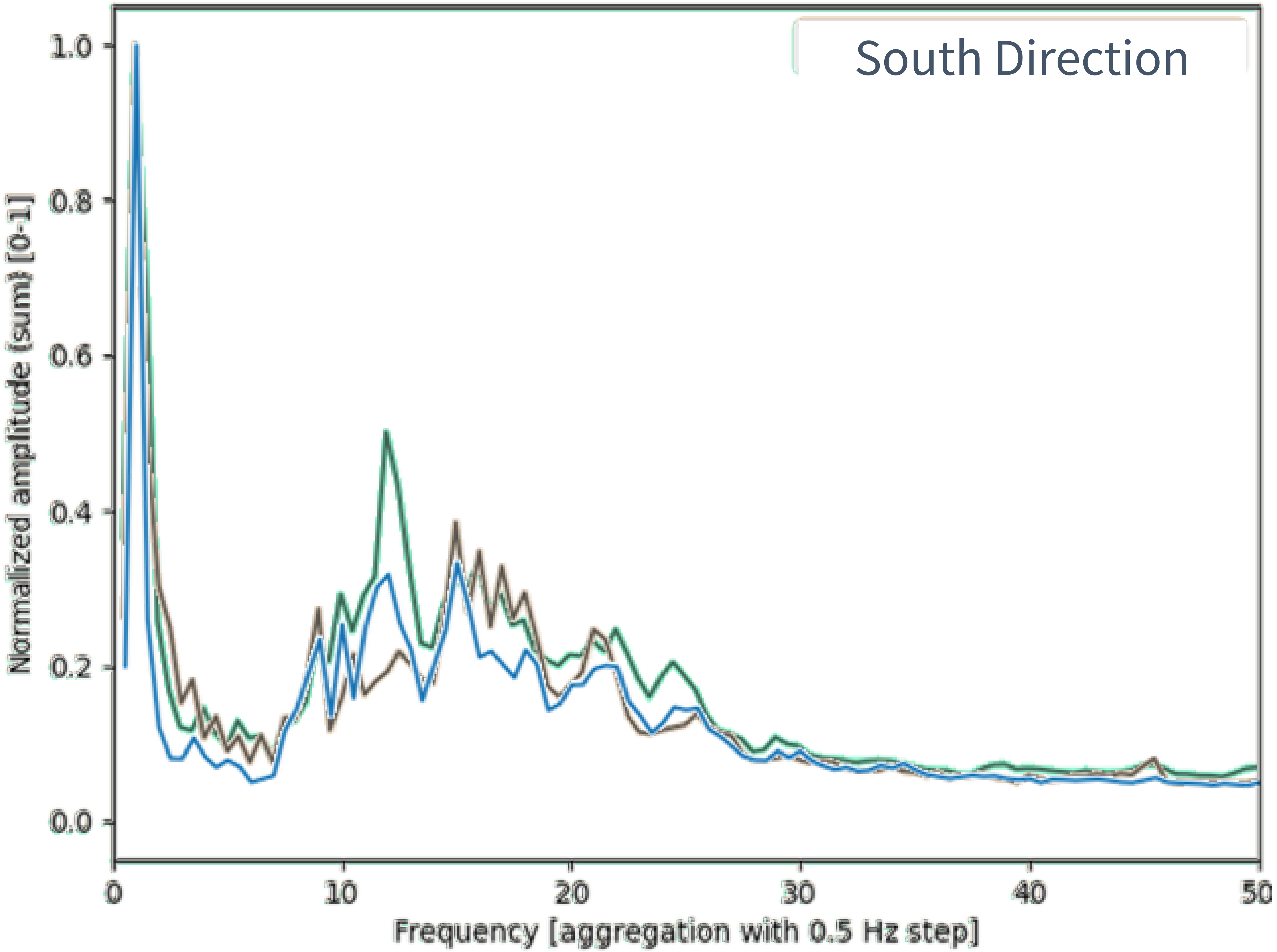
Output:

- Aggregated FFT plots and normalized spectrograms
- Identified dominant frequencies

LEVEL 2 EXAMPLE OUTPUT: ANALYSIS RESULT

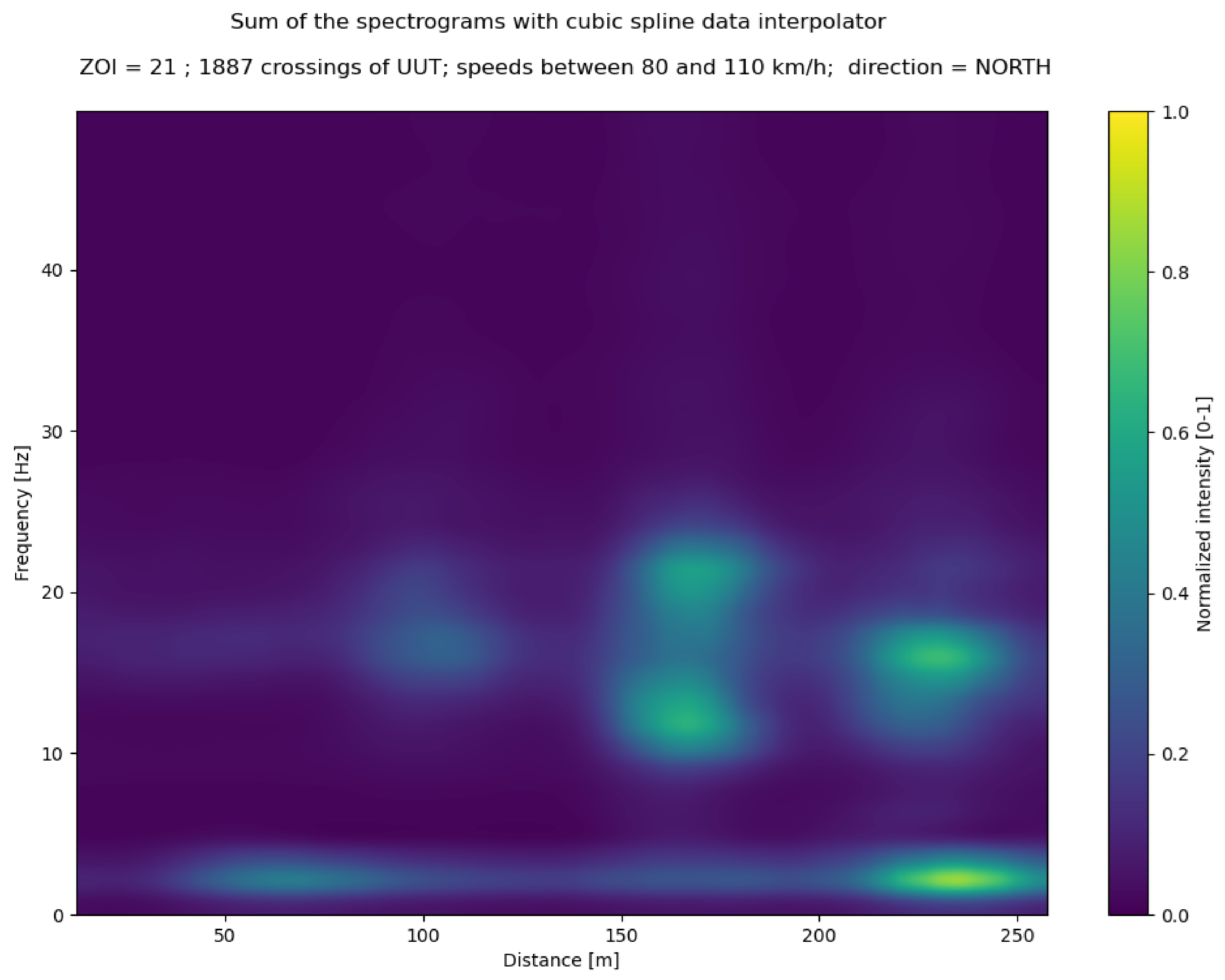
L2: FFT for ZoI 29 Tufali – North 1839 passes, South 2190 passes

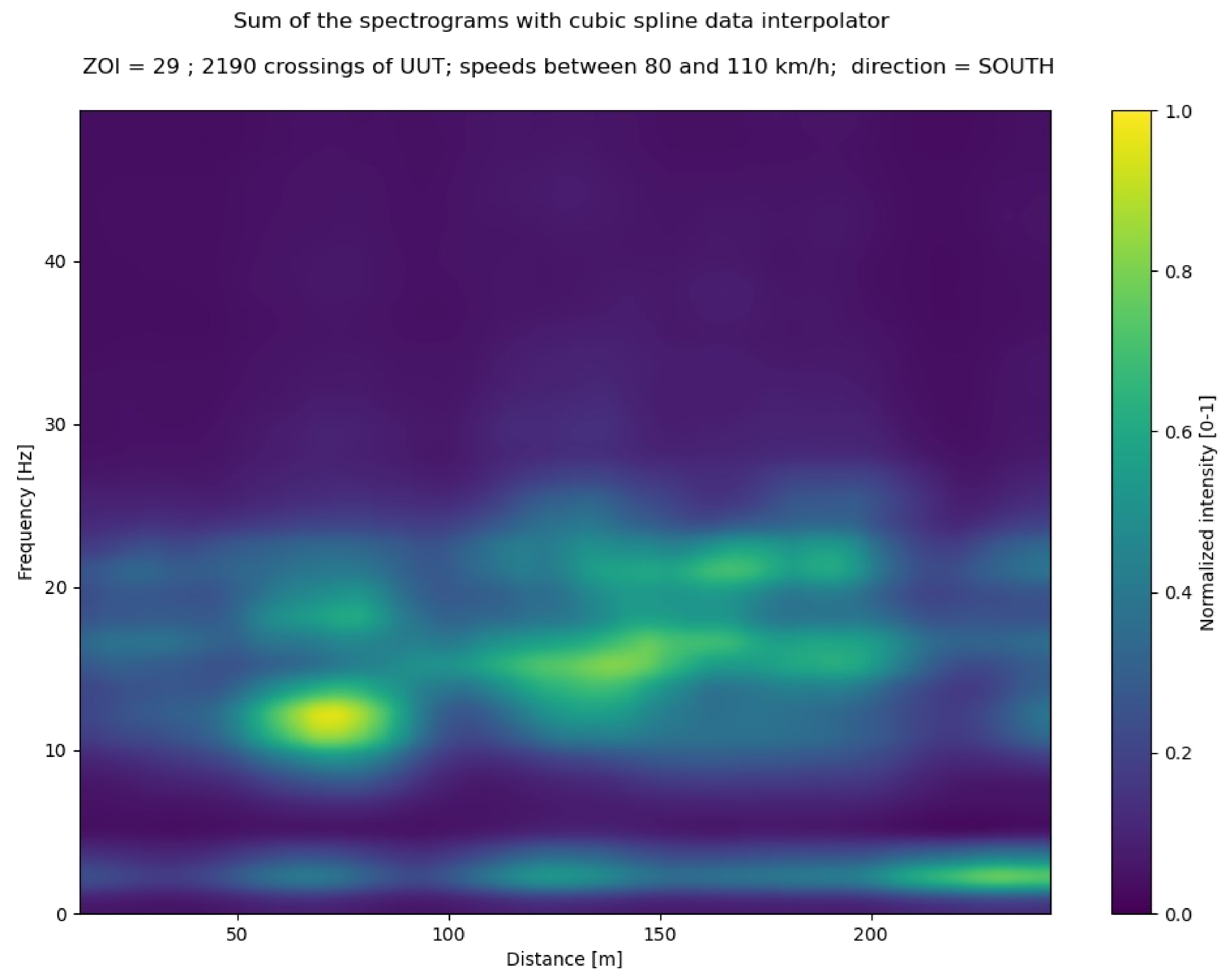




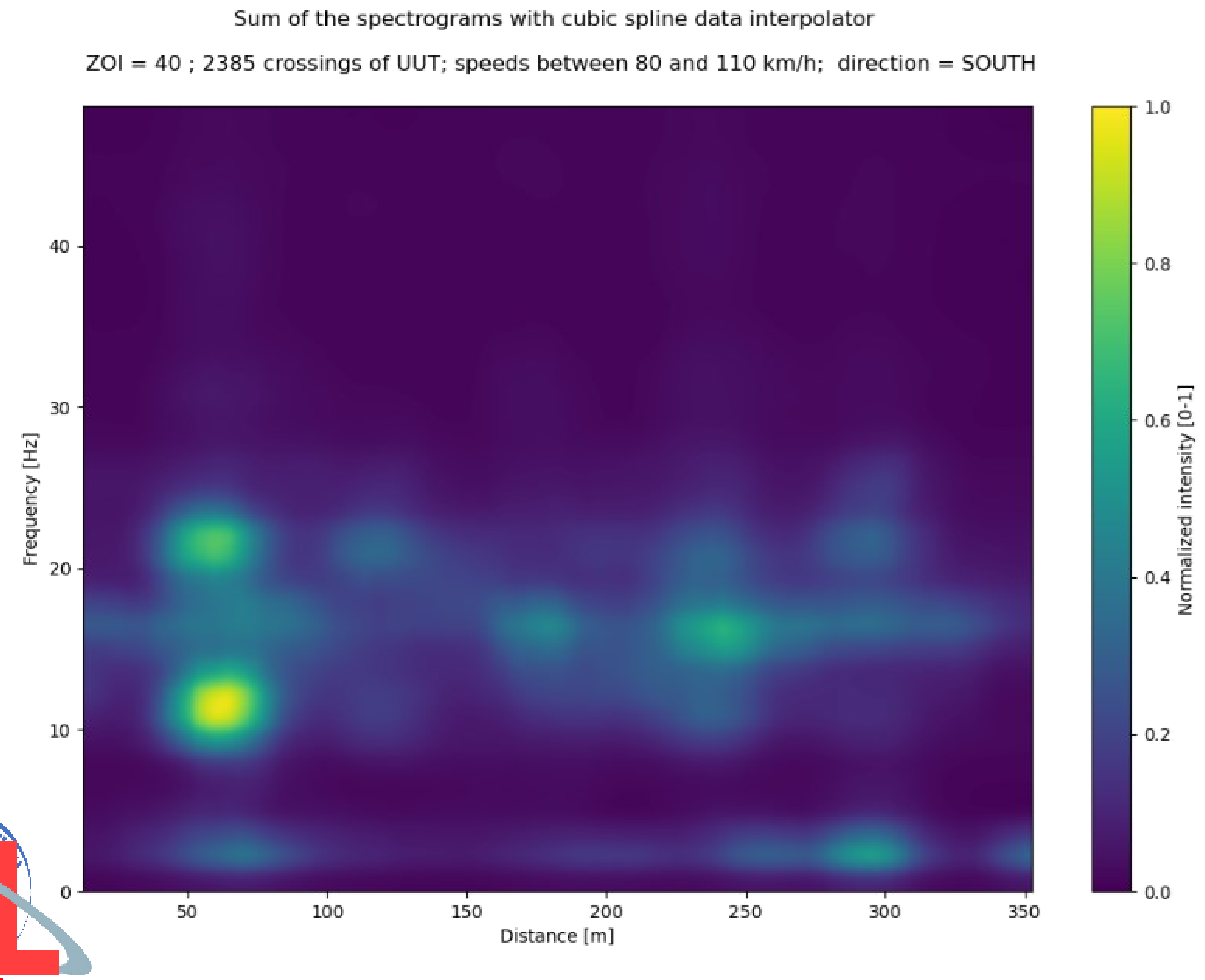
Above graphs show the sum of spectrograms of the same bridge in North direction in the 3 sections of the ZoI: the Entry and Exit Gates (green and red lines considered out of the viaduct) and the SUT (blue line).
Unfortunately, **they cannot demonstrate the presence of bridge modal frequencies** expected to be below 15 Hz.

LEVEL 2 EXAMPLE OUTPUT: STFT FOR 3 VIADUCTS (BEST CASES)





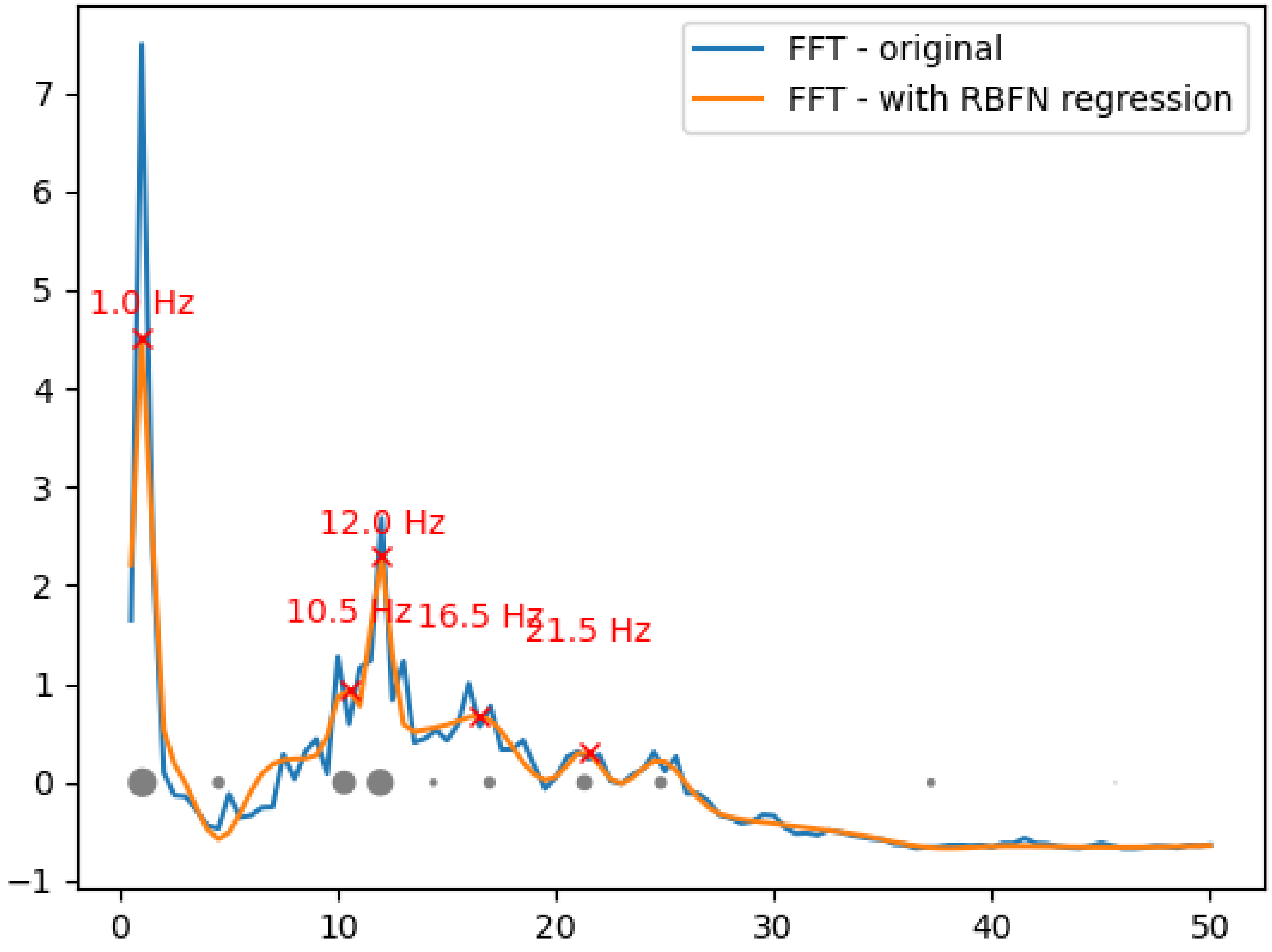
Left graphs show the average of STFT of 3 viaducts in the best cases. Unfortunately, generally speaking (18/21), **they cannot demonstrate the presence of bridge nodes** expected to be periodical.



As side results this analysis shows a weakness of the system: 1kHz sampling rate is not enough to have a good frequency resolution. With this system the frequency resolution is about 2.5 Hz, but 0.5 Hz may be needed.

LEVEL 2: EXAMPLE OF FFT PEAK DETECTION

Right graph shows an example of peak detection on average FFT performed by using Radial Basis Function Network.
In this case, it correctly detected major components of FFT.



Analysis Result on Web Services

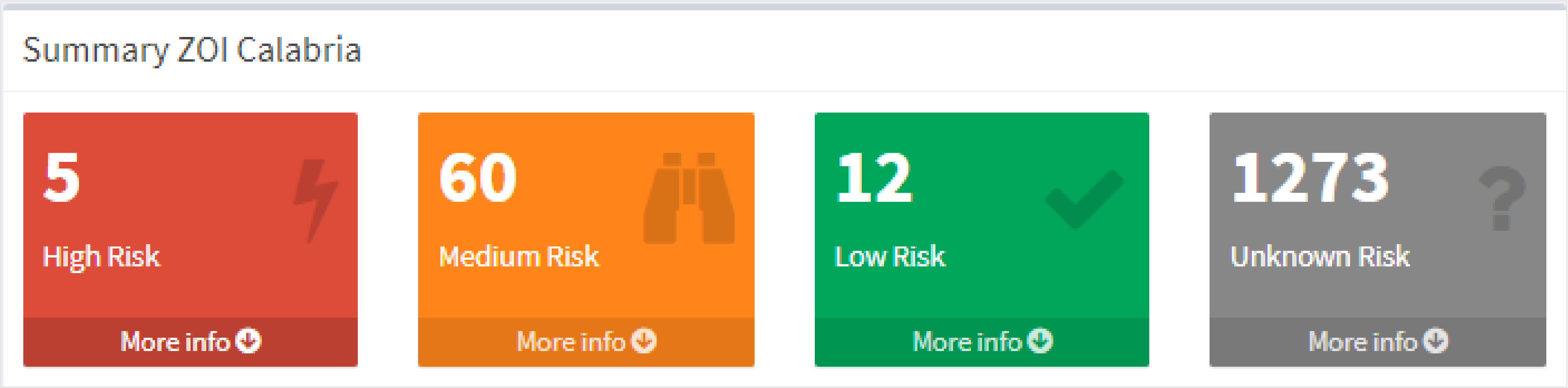
Administrator & Operator

When the Analyzer process has completed its cycle, the outcome is stored in the ZOI database, where the evaluation result is set (e.g., the ZOI is assigned the High-Risk level)

The administrator is notified of the event, and the ZOI appears among those that need to be verified.

At this stage, the operator is not yet aware of the change in risk level

The administrator may carry out additional analyses before notifying the operator of the event



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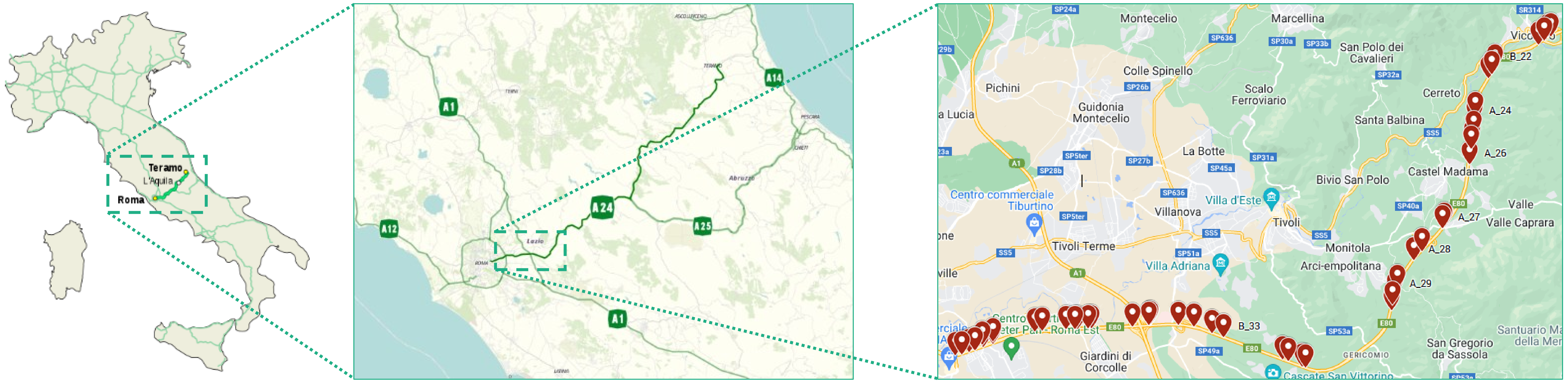
Demonstration Step 2 – Acquired Data

Thousands of data has been acquired!

The system acquired around **62,8k passes** where **21 buses** (13 Solaris InterUrbino 12 and 8 Neoplan Skyliner L) passed above viaducts with a speed from 90 kmh to 110 kmh.



ID	Name	Start (km)	Finish (km)	Length (m)	Passes
45	Aniene I	0,485	0,71	225	NT
44	Aniene II	3,336	3,476	140	NT
43	Cerroncino	3,88	4,2	320	NT
42	Benzone	4,55	4,765	215	4032
41	Montegiardino	5,025	5,235	210	116
40	Dell'Osa	5,58	5,8	220	3415
39	Lunghezza	7,485	7,605	120	4647
38	San Giuliano	8,5	8,8	300	2442
37	Corcolle I	8,88	9,245	365	1
36	Corcolle II	9,4	10,58	1180	2764
35	Freghiza	11,37	11,42	50	0
34	San Vittorino	12,4	12,93	530	2304
33	San Germano	13,7	14,03	330	4497
32	Cisternole	16,29	16,44	150	3164
31	Miandola	16,82	16,9	80	2014
30	Fontanilaccio	21,05	21,21	150	4140
29	Tufali	21,62	21,83	210	4179
28	Cadore	22,99	23,36	370	4845
27	Acqua Santa	24,41	24,56	150	4305
26	Della Noce	26,906	27,466	550	2123
25	Cannuccette	27,666	27,936	270	2605
24	Santo Stefano	28,4	28,58	180	4574
23	Marta Maria	30,02	30,2	180	1194
22	Pagino	30,27	30,42	150	1704
21	San Cosimato	32,165	32,405	240	2038
20	Licenza I	32,54	32,765	225	404

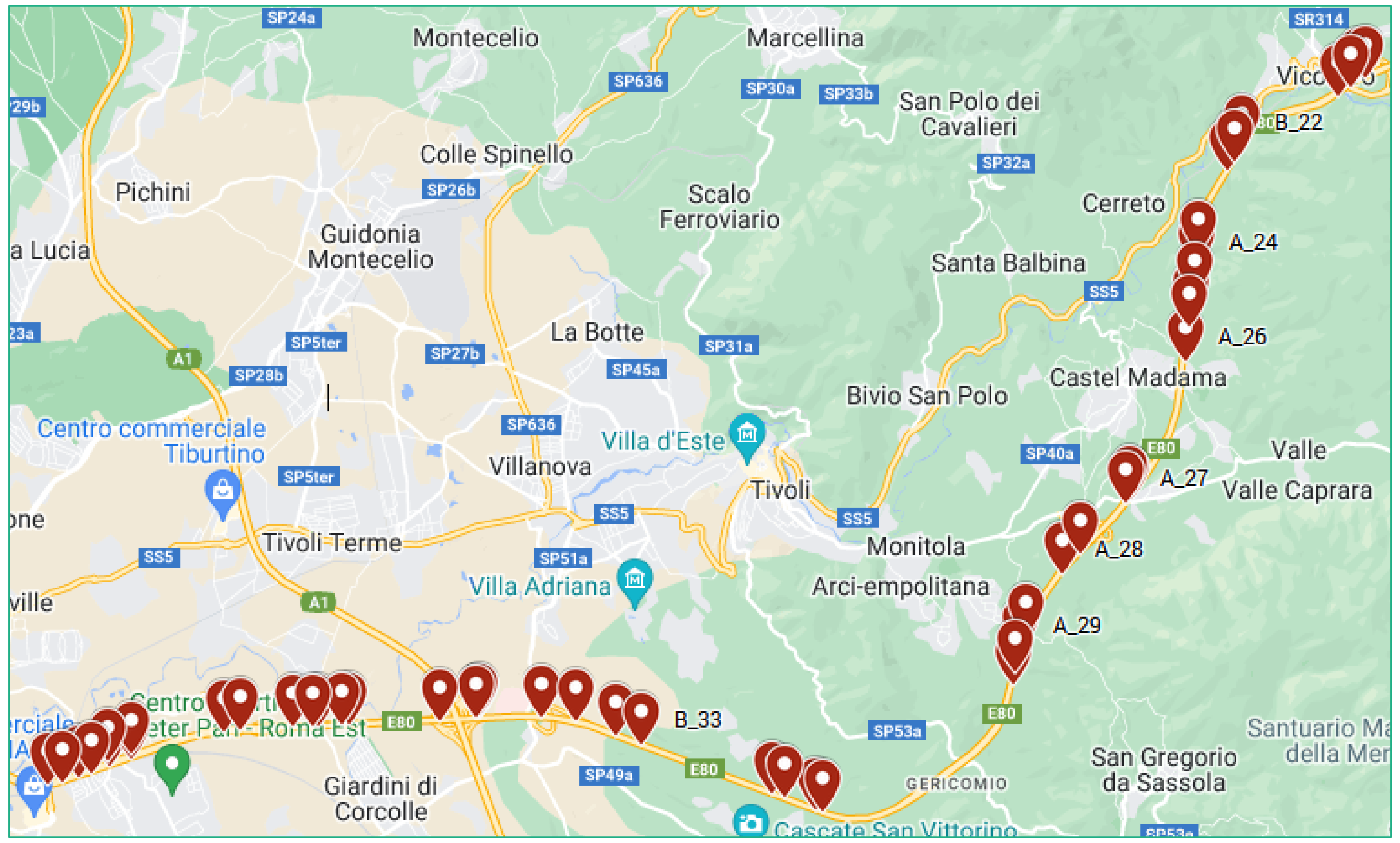
Demonstration Step 2 – Same Acquisition Anomalies

The side table shows the passes considered in the analysis where buses passed above viaducts (in all subZoI) with a speed from 90 kmh to 110 kmh as from Level-0 Filtering.

Considering that only (8) Neoplan Skyliner L buses worked along the whole route and that the others passed only few viaducts as moving locally, the total number of expected passes was not known precisely. The estimated number of passes in any direction was around 4600 (2100÷2500 per direction).

After Level-0 filtering, the percentage of valid passed resulted quite variable.
The acquisition anomalies due to GNSS may be clustered in the following:

1. **too short viaducts**,
2. **too close viaducts**,
3. late GNSS connection due to **route orography** (hills, tunnels, …).



ID	Name	Start (km)	Finish (km)	Length (m)	% of Valid Passes	# of Analyzed Passes (N+S)
45	Aniene I	0,485	0,71	225	NA	NA
44	Aniene II	3,336	3,476	140	NA	NA
43	Cerroncino	3,88	4,2	320	NA	NA
42	Benzone	4,55	4,765	215	73,97 %	2472+1179
41	Montegiardino	5,025	5,235	210	16,89 %	908+193
40	Dell'Osa	5,58	5,8	220	61,64 %	948+2385
39	Lunghezza	7,485	7,605	120	93,61 %	2260+2044
38	San Giuliano	8,5	8,8	300	53,42 %	2189+212
37	Corcolle I	8,88	9,245	365	2,28 %	0+0
36	Corcolle II	9,4	10,58	1180	47,03 %	103+1632
35	Freghiza	11,37	11,42	50	0 %	0+0
34	San Vittorino	12,4	12,93	530	42,01 %	1954+24
33	San Germano	13,7	14,03	330	94,98 %	2247+1982
32	Cisternole	16,29	16,44	150	70,32 %	884+1642
31	Miandola	16,82	16,9	80	90,87 %	2092+1851
30	Fontanilaccio	21,05	21,21	150	90,87 %	1970+2050
29	Tufali	21,62	21,83	210	87,67 %	1839+2190
28	Cadore	22,99	23,36	370	97,72 %	2082+2494
27	Acqua Santa	24,41	24,56	150	94,06 %	1880+2286
26	Della Noce	26,906	27,466	550	48,40 %	1470+39
25	Cannuccette	27,666	27,936	270	48,86 %	93+2147
24	Santo Stefano	28,4	28,58	180	93,15 %	1802+2506
23	Marta Maria	30,02	30,2	180	23,29 %	953+7
22	Pagino	30,27	30,42	150	32,42 %	3+1662
21	San Cosimato	32,165	32,405	240	49,32 %	1887+45
20	Licenza I	32,54	32,765	225	51,14 %	97+365

PONTI Project – Results

Below summarized project outcomes according to the final demonstration campaign

- ✅ The system correctly acquired data
- ✅ The system correctly processed all acquired data
- ✅ The system architecture is designed to be open, scalable, and adaptable in order to accommodate evolving requirements
- ⚠️ ZoIs starting or finishing with tunnels or GNSS issues or too close each other may arise acquisition problem
- ❌ Not having different types of vehicles to acquiring data or the characterization of the vehicle in terms of its frequencies to be filtered in the frequency analysis
- ❌ Frequency resolution is too low

Lesson Learnt

- The system needs some evolution to be validated:
  1. enhancing the acquisition frequency from 1kHz to 15 kHz to improve spectral and spatial resolution (even if partially increasing costs).

- The business model shall be revised:
  1. heavy vehicles result over-damped and probably need too many acquisition to get SUT characteristics useful for end-users (modal frequencies);
  2. heavy vehicles fleets should be avoided as are often of the same type and may require some calibration to cancel vehicles transfer function;
  3. PONTI-Box may be more expensive as expected, but the number of units will be reduced
  4. The PONTI-BOX enhanced (PONTI BOX PLUS) will be on board of a dedicated van, integrated in a sensors set, operated by AI. The van will be characterized in terms of vibrations, to filter the noise, and in operation the van will run at a optimized speed in relation to the type of structure under analysis.

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Way Forward

The concluding results of the demonstration show the need to improve the system. In the previous slide we give a preliminary description of the next activities.

Moreover to improve the impact on the market, S4L will develop a mobile laboratory to be used for roads conditions evaluations (as asphalt damages), to be proposed in partnership with a big company having good contacts with interested end-users;

Phrase of the Day

“Each day is an opportunity It's one thing to say this phrase each day, another to actually apply it. When you're standing in line at Starbucks, remember that this day has never existed before.”