# Decision support system for prediction of earthworks failures

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# Motivation

- Earthworks failures can lead to disastrous consequences, e.g. flooding,
- Remediate of earthwork constructions is highly expensive,
- Asset monitoring of earthworks can provide early intervention and prevention of failures
- Reduce intrusiveness and low cost of monitoring platforms

# Review of earthworks health monitoring

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- Manual walk-through by trained environmental engineers every few months for visual inspection
- soil resistivity surveys and a 3D mapping of the ground using these results
  - provides information about the moisture content of the earthwork non intrusively.
  - ALERTme– system, which maps 3D the resistivity of a railway embankment using a kit designed for this purpose (specifications of 500V/up to 500mA)
- **Limitations:**
  - high voltage and current, which requires expensive voltage transformers, and cabling in order to mitigate health and safety risks during the experiments.
- What should we measure besides resistivity:
  - movement of the ground (vibration, acceleration)
  - pore pressure
  - both are currently are measured using dedicated sensor.

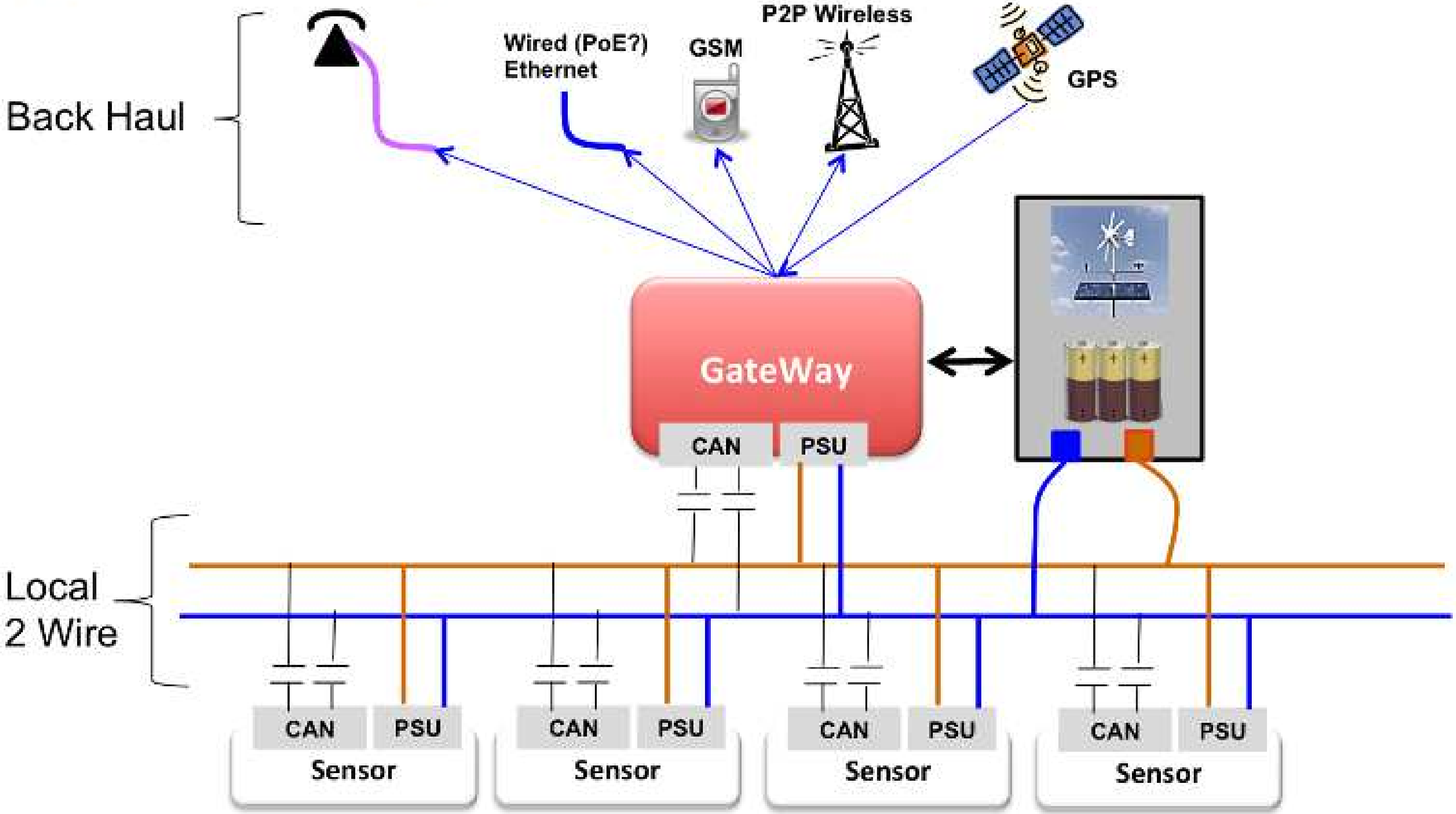
# Contribution

We propose a unique, customized and cost-effective platform for automated monitoring of earthworks through:

i. integration of analogue and digital sensors for measuring pressure and motion,
ii. resistivity sensor that requires low voltage compared to the off-the-shelf resistivity solutions,
iii. variable and on-demand sampling rates that can be dynamically controlled,
iv. a prototype mechanical waterproof design for housing main hardware, resistivity sensor-board and relevant sensors.

- We show initial results for ground movement, pressure and resistivity.

# System Setup



# System Setup

- ***Sensor Nodes*** deployed in arrays: each node is a customised reprogrammable board that was designed and prototyped and is connected with three sensors and resistivity circuitry, and can be enabled for the usage of more sensors.
- ***Sensor Communication Module***: Interfacing the sensor nodes to the gateway node using a ***Controlled Area Network*** (CAN)
- ***CAN network***: The CAN cable has 6 pins. One pin used to power sensor node from the power supply, another is ground and the other two are used for CAN high and CAN low. The fifth pin is used as a ground sense, in order to have a reference for the resistivity measurement .
- ***Hub for data collection*** *:* Interfacing the Gateway with the Cloud through near near white space communication (~433 MHz).
- **Switch Mode Power Supply (SMPS):** The voltage supply used for both main and resistivity boards is an enclosed 12 VDC, 1.3A.

# Prototype Sensor Node

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The **prototype sensor node** consists of

- ➢ a main platform PCB board,
- ➢ a separate PCB board for the resistivity sensor
- ➢ relevant cabling.
- ➢ All the hardware has been integrated in a 32.5 cm tall PVC tube with diameter of 14.5cm and thickness of 80mm, that provides both endurance and waterproof protection.
- ➢ Copper probe at the bottom of the node

Sensor Node

**Main PCB board**: has dimensions 110mm by 37.5 mm and consists of the following off and on-board sensors:

- •***Resistivity board*** for injecting current, sensing voltage, sinking current, sensing voltage with current injection sampling rate of 5 sec
- •***Digital Accelerometer***. This on-board sensor will be able to sense acceleration or vibrations (±2g/±4g/±8g dynamically selectable full-scale) in the soil with sampling rate 12.5 Hz
- •***Analog Pressure Sensor*** that can measure absolute pressure (0 – 200kPa) with sampling rate 1 sec.

Main PCB board

Resistivity board

# Resistivity Sensor Board

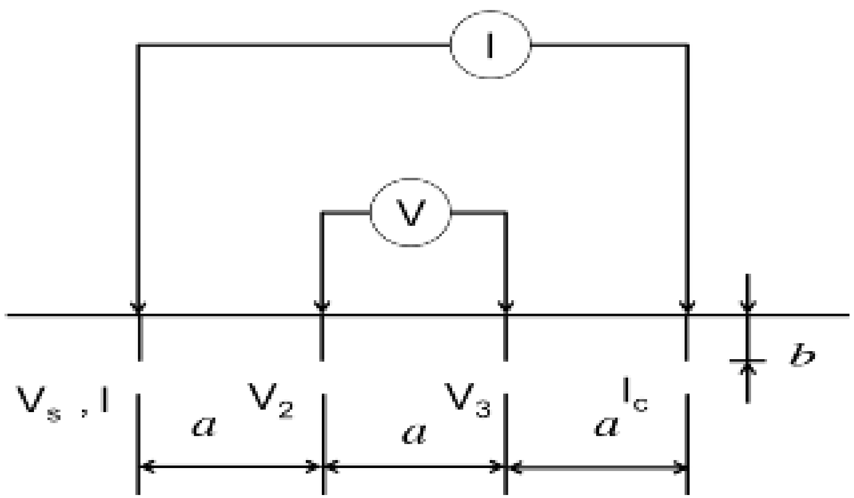
- Resistivity sensor was built on a separate PCB board for safety reasons, as it will have to inject and sink current, which might negatively impair the other hardware parts on the main PCB board.
- Due to the voltage limitations, the global resistivity measurements will have to be redefined, as the maximum distance between the nodes will not exceed 1m.
- Our resistivity circuit will be able to inject much lower currents, which was set for the deployed nodes up to 119mA, and was selected by taking into consideration the common values of resistivity (1-10000 Ωm) and an average spacing of 1 m.
- Every sensor board is connected to a solid copper probe, similar to commercial resistivity kits
- The most common material for these rods is stainless steel, but solid copper rods are also widely used and also due to the voltage limitations of the specific project a solid copper rod would offer higher conductivity compared to stainless steel.

# Resistivity Measurements Specifications

- Resistivity sensor node was built and programmed in order to measure the voltage that is sensed at the two intermediate nodes, namely $V_2$ and $V_3$, the current injected I , the Voltage supply $V_s$ and the sink current at the last node $I_c$ .
- An additional measurement called ground compensation is acquired by using one of the extra leads of the CAN cable. Using ground compensation, we can compensate for power losses that occur due to the length of the CAN cable.
- Wenner(1916) and IEEE(2012), soil resistivity is measured using the 4-pin Wenner method.

$$\rho_w = \frac{4\pi a R_w}{1 + \frac{2a}{\sqrt{a^2 + 4b^2}} - \frac{a}{\sqrt{a^2 + b^2}}}$$

where
$\rho_w$ is the apparent resistivity (Ωm)
$a$ is the spacing between the probes (m)
$b$ is the depth of the probes (m)
$R_w = V/I$ is the Wenner Resistance (Ω)
$V = V_2 - V_3$

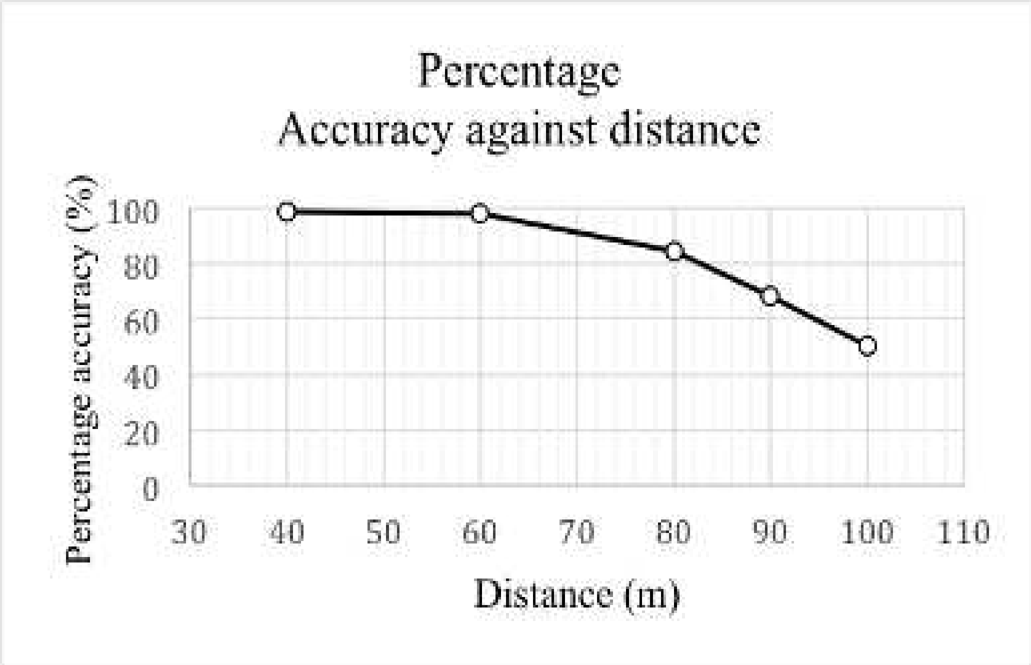


# Low Power Supply

- The voltage supply used for both main and resistivity boards is an enclosed 12 VDC, 1.3A **Switch Mode Power Supply (SMPS)**. The specific type of power supply was selected because of the availability of mains power at site in Falkirk Wheel and also due to its output isolation from mains ground, which could affect the measured data.
- Power is distributed to all nodes using the CAN cable with one lead for power, one for ground compensation, in order to compensate the losses due to the length of the cable and ensure the accuracy of the results for resistivity measurements.
- Resistivity board is also powered directly from the power CAN lead, and not as initially planned, through the regulated 10V from the main board. The main reason for this choice was to reduce the risk of damaging the main board and also to ensure that the maximum voltage available from the SMPS for better accuracy.

# Data Communications from Data Collection Hub to the Cloud

- Usage of near white space RF at 433 MHz.
- Communication requirements: feasibility to operate both indoors and indoors in different weather conditions, ability to operate in high voltage environments




- Feasibility to operate both indoors and outdoors in different weather conditions
- Good system performance, reliability with an 80m trade-off between accuracy and distance.

# Deployment

- Deployment was carried out in Falkirk Wheel at Falkirk, Scotland at an embankment that is maintained by Scottish Canals during late February-beginning of March 2014.
- During the test period the weather at area was close to the average temperatures of the area with no extreme below zero temperatures.
- The spacing between the probes for the deployment was selected to be 1m, and the depth of the probes is 44.5cm, the height of the casing is 32.5 cm and the length of the rod that is placed at the bottom of the tube is 12 cm .

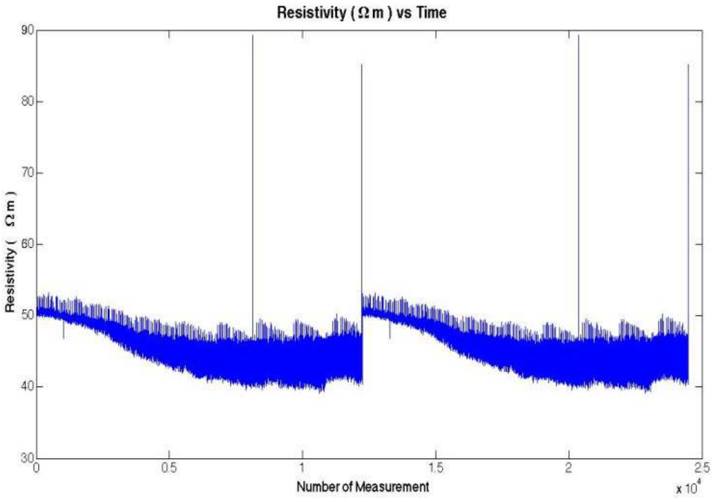
# Resistivity Results

Due to the current setup the sensors are sending directly their measurements to the gateway, where they are receive a timestamp.

**Data Preprocessing:**

(1) Assuming that the data arrive at the gateway with the same order the each sensor receives its measurements

(2) assuming that the data can arrive with a different order but still can be grouped per sensor.

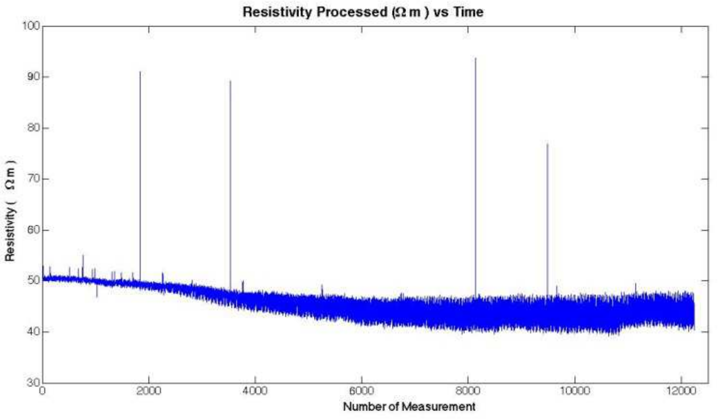



**Results:**

➢average resistivity varies between 40-60 Ωm.

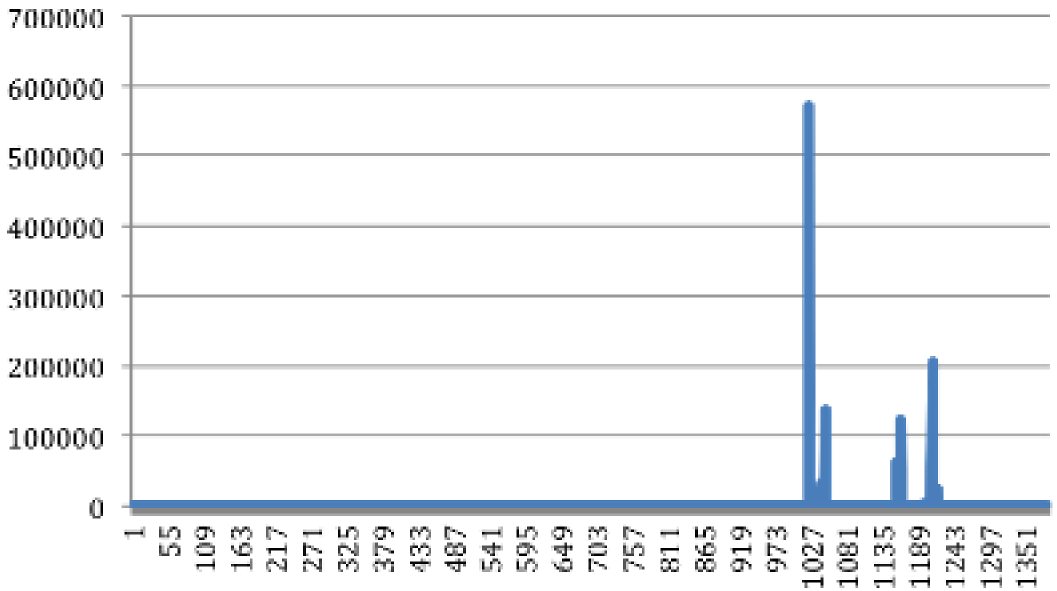
➢there are some higher resistivity values that reach around 90 Ωm,

➢Second assumption provides a more settled graph, without affecting marginally the average resistivity, due to the high sampling rate.




➢According to Nwankwo et al(2013) and Pangonilo, the resistivity measurements that we represent above can be categorised as clay, which is one the most common soil types in Scotland. Pangonilo claims that clay resistivity can be between 2-100 Ωm.

# Accelerometer

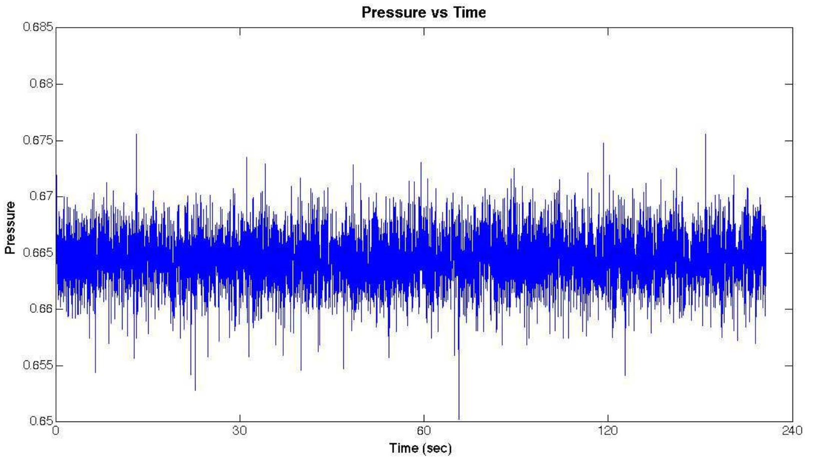


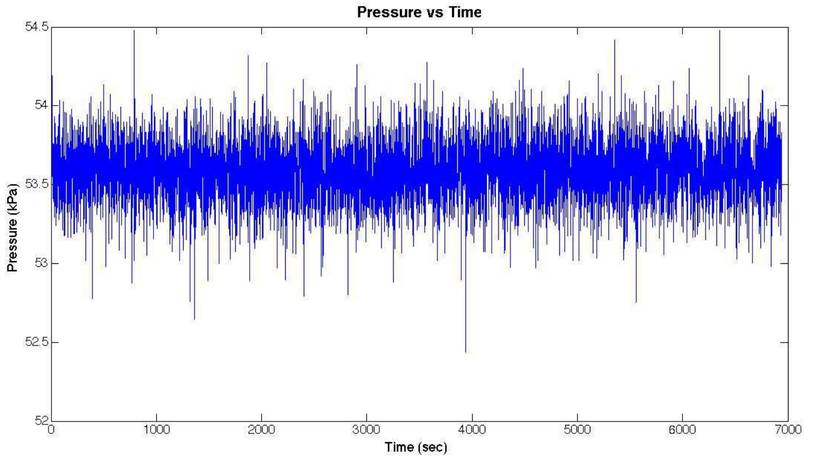

$X^2+Y^2+Z^2$ vs number of samples

While readings do not exceed a sum of squares of 200 to 250, there is a clear peak at 300. This occurred we jumped in the vicinity of the sensor node, which resulted in noticeable ground movement. This indicates the need for destructive testing, further data analytics and the potential to detect clear patterns of embankment failure.

# Pressure

- The deployed pressure sensor is a differential pressure sensor and it provides as an output the differential voltage, which is proportional to the differential pressure applied. (Figure 1)
- This voltage output can be found and it has been amplified by a gain of 62
- Figure 2 the converted voltage output to pressure units by using the sensitivity of the sensor (according to the specific application) S=0.2 mV/kPa and by attenuating for the output gain.
- We can notice a variation of around 2 kPa during a 2 hours sample timespan and the above results translate to almost 0.5 atm.



# Conclusions & Further work

- Proposal of a cost-effective low power prototype sensor solution for monitoring earthworks.
- Current setup can measure soil resistivity, ground movement and pressure, but allows the incorporation of other sensors.
- The obtained results show expected resistivity values for the weather condition and soil material at the deployment site.
- Ground movement sensor sensitivity was proven and can be use in a future non-destructive test that could provide the profile of a healthy and failing earthwork.
- A further calibration of the absolute pressure with a pore pressure sensor would provide a cost-effecting alternative of the current methods of measuring pore pressure.

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# Thank you

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