

User Guide

Tilt90 Wireless Tiltmeter Event Detection Mode

LS-G6-TIL90-X/IE

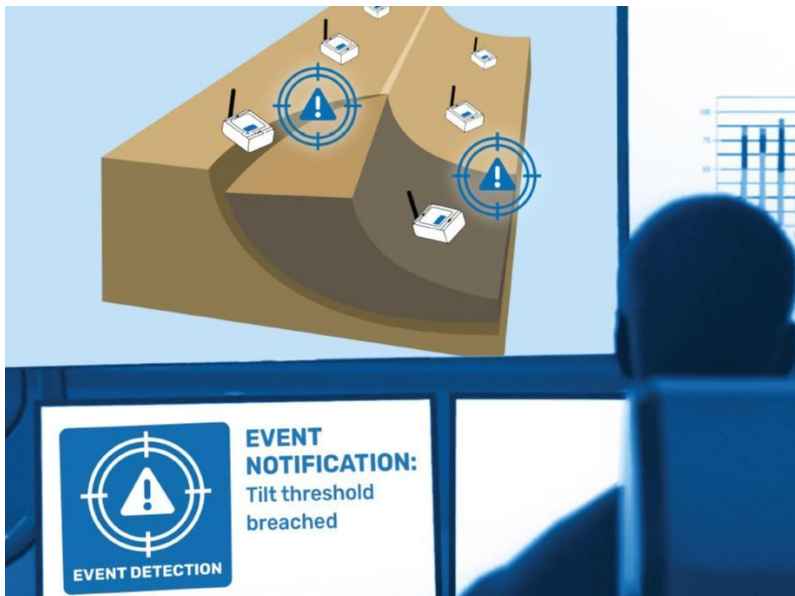


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Glossary

- **Event Detection Solution:** Set of items which work together to offer the features presented in this guide.
- **Event Detection Mode (EDM):** Specific way of operation for a TIL90 which enables real-time alerting when an event occurs.
- **Sample:** One single measurement of the sensor.
- **Sampling rate:** Number of times information from a sensor (sample) is collected per unit of time. In other cases this would be given in Hz, but given that in Loadsensing systems frequencies are small (for example, 0.00027 Hz is once every hour), it is used interchangeably as Sampling period.
- **Sampling period:** Time between two sensor information collections. ($1/\text{Sampling rate}$). It is used interchangeably as Sampling rate.
- **Reading:** Complete Data from a certain timestamp. A line in the Readings CSV file. Depending on the sensor type, the 'reading' can be directly a single sample of the sensor or can be the result of averaging a set of measurements. With the exception of the alert messages which are not readings, there is a delay between the reading and the transmission. This delay is a random value within the slot time.
- **Periodic Reading (in normal/alert state):** Data which is gathered at synchronous intervals defined by configuration.
- **Reporting Period:** Time between two acquisitions of synchronous readings.
- **Radio message:** One single transmission from the edge device to the Gateway or from the Gateway to the edge device. To transmit a 'reading', one (e.g. wireless tiltmeter) or more than one radio message (e.g. digital logger connected to a dozen of in-place inclinometers) can be required.
- **Normal State:** Normal status of the device, when the values of tilt are in between the upper and lower thresholds.

- **Alert-to-normal Stoppage time:** time the values must be between the thresholds before the alert state is disabled.
- **Alert State:** Mode enabled when at least one axis is outside the threshold limits until a stoppage time has passed.
- **Alert message:** Triggered Real time message when a threshold is broken. Does not consider the slot times.
- **Continuous sampling for event detection:** Data gathered from a TILT90 sensor at a Sampling rate of 3.9 Hz.
- **Alert triggered reading:** Data which is generated because a threshold is broken or normal state has been reached back. Standard deviation will be 0 as only one sample is reported.
- **Latency:** In Loadsensing applications, latency refers to the time delay between a measurable physical change in the system being observed and output clearly discernible to the data management and visualization software. In the event detection solution, latency refers to the time delay between an event occurrence (tilt exceeding a preset threshold) and the delivery of the alert messages on the MQTT/Modbus TCP client.



1.Event Detection Solution Overview

The Event Detection Mode is an Operation Mode which runs on a preconfigured TILT90 wireless sensor device (compatible with both external (TIL90-X) or internal (TIL90-I) antenna models).

The Loadensing Wireless sensor Tilt90 is a long-range, low-power wireless data logger with an embedded 3 axis tiltmeter. It measures 3-axis inclination with respect to gravity's direction and reports the two axes of rotation from the horizontal plane in any orientation. When configured in the Event Detection Mode, the device operates in a data exception approach. It continuously acquires samples on a high sampling rate (3.9 Hz), but the data is only reported by radio when a certain condition becomes true, this is:

- 1) A configurable threshold is exceeded. Send a real time warning message declaring an "alert state".
- 2) When any threshold is broken or the system returns to the normal state, a readings message containing the exact data which changed the state is reported, with the specific time stamp (no periodic message). This message is sent after the alert message and is not real time.
- 3) A readings message is sent according to a configured period which is different in normal or alert states.

This operation mode is especially useful for applications where it may be necessary to receive alerts that allow the implementation of remediation actions such as evacuations, stopping traffic or allocating the necessary resources to act, besides preventive monitoring based on trends and on the evolution over time of the measured parameters. On the other hand, in some complex and challenging activities during the construction or repair of structures (such as load transfer, incremental launching of bridges, box-jacking underpass railways or lifting of structures to replace the bearings or to reinforce the ground, amongst many others) real-time monitoring of the movements is required.



The smart management of data permits acquisition in a non-discrete way, emitting an immediate message when the threshold is exceeded and yet keep the energy consumption low thanks to the limited transmission.

Thus, a non-exhaustive list of possible applications of this EDM is:

- Embankment integrity
- Control of slope stability
- Potential landslides
- Detection of rockfall activity
- Complex and challenging construction activities such as load transfer, lifting of heavy structures through jacks or incremental launch of the bridge deck.
- Earth works that could potentially affect infrastructures.
- Monitoring structures while performing ground improvement techniques, such jet grouting activities
- Any other application that requires monitoring a rotational deformation and triggering a notification when the set threshold is met or exceeded.

The system offers a latency lower than 5 seconds from the event occurrence to the publication of the message through any of the protocols used for data transmission to an external server (MQTT/Modbus TCP).

The event detection mode is a sensing component to be integrated in early warning systems that can also combine other technologies and that can act on other devices. In addition, the event detection mode is achieved with tiltmeters powered by internal batteries, achieving a battery life of more than two years and with a long-range radio.

A third-party software is needed to ingest and process notifications, then trigger a process or action accordingly. Based on the nature of the notification, the software could for

example send an email, SMS or automated phone call to an operator, trigger an alarm (siren, lights), or send instructions to devices (road closure, close gate, stop hydraulic pumps in a jacking system or decrease/increase pressure, take a picture/start video recording).

2. About this user guide and its content

The current document details the features , configuration procedure and data management for the Event Detection Mode (EDM).

The Loadsensing EDM is an operation mode which runs over the TILT90 family devices (TIL90-X and TIL90-I). To be operative, this mode must be factory configured. Nowadays it is not possible to reconfigure a standard TILT90 tiltmeter into the event detection mode.

As the hardware is based on the TILT90 series, you can refer to the TILT90 user guide for all information related to the hardware, installation, recalibration, etc. Please, consider reading the following sections from the TILT90 as a framework of the EDM:

1	Important instructions prior to use
3	Device Specifications
5	Equipment Provided
6	Wireless Tiltmeter installation
7	Powering up the Device
9	Safely Closing the Device
10	Understanding data
12	Errors Implemented
13	Maintenance and troubleshooting
15	Data storage

16	FAQ's (even though a specific EDM is presented in this guide)
Appendix B	Vibration Resistance Test (LS-G6-TIL90-I)

3. System requirements

The compatibility with the event detection mode needs the following prerequisites:

- Wireless tiltmeter hardware: LS-G6-TIL90-X, LS-G6-TIL90-I
- Product code: LS-G6-TIL90-X, LS-G6-TIL90-I
- Wireless tiltmeter Tilt90 Series firmware: From version 2.67 onwards.

CAUTION! The TILT90-X / TILT90-I has to be ordered to operate in the event detection mode of operation. Currently it is not possible to reconfigure the standard TILT90 tiltmeter to operate in this mode with the existing tools.

- Worldsensing Mobile App version: From version 2.0.1 onwards.
- CMT Edge version: From version 2.6 onwards. License activation required. Only available for the 4G rugged gateway edge.

From firmware version 2.7.0 onwards the event detection mode is also compatible with Modbus TCP protocol

- CMT Cloud version: From version 1.7.0 onwards. License activation required.

4.Event Detection Mode Specifications

4.1. Sensor’s, acquisition and edge-processing specifications

Here are shown specifications for the sensor operating in EDM. For mechanical specifications of the box, please, refer to the TILT90 User guide.

	Hardware:	LS-G6-TIL90-X	LS-G6-TIL90-I
	Product code:	LS-G6-TIL90-X	LS-G6-TIL90-I
	Type:	Tilt angle calculated from a 3-Axis MEMS Accelerometer.	
	Range:	± 90°	
	Axes:	Report the two axes of rotation from the horizontal plane in any orientation. Measure the angle with respect to the force of gravity in three axes (X, Y, Z).	
	Calibration:	Individually calibrated.	
In periodic readings.	Accuracy within ± 4°:	± 0.005°	± 0.006°
	Accuracy within ± 15°:	± 0.013°	± 0.013°
	Accuracy within ± 45°:	± 0.038°	± 0.075°
	Accuracy within ± 86°:	± 0.06°	± 0.15°
	Repeatability:	<0.0003°	<0.0015°
	Offset temperature dependency:	± 0.002°/°C	± 0.005°/°C
In continuous sampling.	Repeatability:	<0.001°	<0.005°
	Peak to peak noise:	<0.006°	<0.034°

- **Readings and reporting period**

- *Continuous sampling at 3.9 Hz.* When the trigger conditions are met, a message notification is transmitted to the network and some time after, a reading is transmitted containing the data which shot the trigger.
- *Periodic Readings in normal state:* frequency can be from 5 minutes (only selectable from the CMT) to 1 day, according to the size of the Network. Capture a baseline measurement during 9.6 seconds. Standard deviation of the set of samples collected during the reading is computed and transmitted with each tilt measurement. It can be used to filter noisy data .
- *Periodic Readings in alert state:* Frequency can be from 30 seconds to 1 day, according to the size of the Network. Default¹ frequency value is 30 minutes.

When an event of interest is detected, the node can increase the frequency of the reporting rate, moving from the reporting period in the normal state to the one configured for alert state.

- **Triggering algorithm: Absolute threshold**

- The "Absolute threshold algorithm" compares the last readings to a set of two threshold values that define the accepted range (threshold included) for any given axis.
- Any single sample outside this range for any axis will trigger a transmission of an event notification and the activation of the alert state. As an example of this, assuming a progressive movement in the direction of X and with a secondary movement in the direction of Y, one specific tiltmeter firstly will trigger a transmission when the threshold for X is exceeded, secondly will trigger a transmission when the threshold for Y is exceeded and finally for the Z axis.

¹ Default frequency value is set if after configuring the thresholds any frequency value is configured through the configuration set panel from the CMT

The tiltmeter will enter the alert state immediately after the first threshold is exceeded (X axis)

- Upper and lower limits for the threshold for each channel.
 - Thresholds in the range $[-90.00^\circ \dots 90.00^\circ]$
 - The threshold resolution will be centi-degrees.
- EDM must be enabled for each axis to define thresholds.
- To switch the reached threshold off, a stoppage time corresponding to 256 consecutive samples -just over a minute-, will have to be inside the accepted range.

Note: To avoid excessive detections. It is important to consider the peak to peak noise and the temperature dependency when configuring the absolute threshold.

- **Alert message:**

- A special message is transmitted when a threshold value is reached.
- The message details the exceeded threshold: Axis (X,Y,Z) and direction (Lower or Upper threshold).
- The angular amount exceeding the absolute threshold value. This value is always positive and must be related to the specific broken threshold (upper/lower) and its direction of exceedance (addition/subtraction, respectively). The value resolution presents one integer significant digit (ranging from 1 to 9) followed by two significant digits for the decimal positions, which can only take 33 multiples values (00; 33; 67). The exponents range from -2 (centi degrees) to 2 (hundreds of degrees). Differences are truncated to the closest lower value. This value is reported as a decimal number. The following table presents some examples of potential actual exceedances (only for illustrative purposes) and the related truncated and reported ones:



Exceedance		
Actual	Truncated	Reported
0.008	0.67E-2	0.00677
0.015	1.33E-2	0.01333
0.230	2.00E-1	0.2
3.456	3.33E0	3.3333
46.241	4.33E1	43.33333
104.315	1.00E2	100.0

- Typical information about radio signals including frequency, RSSI, SNR and SF.
- To optimize the capacities of the network, the timestamp is not transmitted in the radio message. The reception time is used as the timestamp.
- These messages are not displayed or processed in the dataserver but bypassed through MQTT or Modbus TCP.

4.2.Device Configuration in EDM

- **Set-up configuration (on-site)**
 - Configuration Application: Worldsensing App.
 - App features and functionalities:
 - Set the threshold values to trigger the transmission
 - Select the reporting period (only for the normal state).
 - Check the calibration parameters.
 - Take test samples on the field.

- Set-up the radio network.
- Conduct radio signal coverage tests.

For detailed information about the set-up configuration process refer to section 5 of this document.

- **Bidirectional radio communications**

Maintain or configure parameter values remotely on an operating device with EDM.

- *Automatic time synchronization by radio:* Time discipline better than ± 30 seconds.
- *Enable or disable the EDM:* EDM can be enabled or disabled for each channel. With EDM disabled no thresholds are configured for the channel and the channel will not trigger any message or reading.
- *Threshold values:* Remotely configure the thresholds used to trigger the alert transmission.
- *Periodic reporting of Readings:* Remotely configure the reporting period in both normal or alert state. For the alert state reporting period, the default value is 30 minutes. **Note: The reporting period in the alert state cannot be configured through the App.**

For detailed information about the on the air configuration process refer to section 6.1.

4.3 Radio Network and transmissions

- **Network limits**

- The maximum number of edge devices connected to the network is subject to the usual recommendations and limitations of the Loadsensing network size, considering the most demanding scenario (e.g. alert state reporting period).

- The solution can properly manage up to 25 wireless tiltmeters simultaneously transmitting alert messages (this is, a threshold has been surpassed).

Note: In most geotechnical and structural scenarios, depending on the distribution of the tiltmeters, it is improbable or even impossible that a group of more than 25 wireless tiltmeters will detect an event simultaneously. Consequently, depending on the monitoring program and the expected mechanism of failure or deformation pattern it is possible to increase the quantity of tiltmeters in the network,

- **Latency**

The latency can be divided into two components:

- **Radio time:** This includes the detection time from the node and the time needed for the first copy of the alert packet to reach the gateway. This time is the same both in CMT Edge and CMT Cloud, and independent of the protocol used to push the alert message.

Note that each node will have a different detection time. The sampling rate is 3.9Hz and the samplings are not synchronized across the nodes. This means that the time between the event and the detection could be up to $1 / 3.9 = \sim 257\text{ms}$.

- **Software time:** This includes several layers of software.

On CMT Edge the software time process is higher than on the Cloud architecture as it is influenced by the limited power of the gateway to process the arrival of alert messages. For the CMT Cloud solution the software time is scaled up to handle a higher number of messages.

We can say that the total latency between the event and publishing the message through MQTT/Modbus TCP for messages from 10 tiltmeters detecting an event at the same instant is less than 4 secs in the same scenario (3 rounds).

Adding compatibility with Modbus TCP has added more latency on the CMT Edge, regardless of whether or not integration through Modbus is being used.

The Probability of added latency sampling every 5 minutes is up to 6%

Typically (>99% of the cases), the total latency between the event and publishing the message through MQTT will be lower than 2 seconds for the first 5 wireless tiltmeters that have reached a threshold simultaneously.

Typically (>99% of the cases¹), the total latency between the event and publishing the message through MQTT will be lower than 5 seconds for the first 25 wireless tiltmeters that have reached a threshold simultaneously.

- **Techniques implemented to increase the successful transmission probability**
 - As usual in Loadsensing networks, each radio message is sent through a randomly selected channel from the eight channels² available in each frequency group.
 - The first radio message is transmitted at the moment in which the measurement that triggers an event of interest is detected.
 - Right after the transmission is activated, several copies of the message are sent within a window of 3 seconds. According to our tests (an installation

¹ Worst case considering 30 minutes of reporting period in normal state. For smaller reporting rates in a normal state, the percentage is higher.

² The number of channels available can be different depending on the regional radio channel plan. Contact us for further information.

with 25 wireless tiltmeters simultaneously transmitting because they have reached the thresholds), the first retry will be transmitted within 1 second for the first five tiltmeters.

- In typical operation, the probability of successful transmission reached with the implemented techniques is > 99.99%.

- **Radio**

To optimize the system capacities, the “Event detection mode” can operate in Spreading Factor (SF) 7.

For regional radio channel plans, coverage will depend on the spreading factors available in each region, considering that the maximum coverage will be always given for the maximum permitted SF. Thus, the limitation of operation in SF7 will have different impacts according to the radio used.

As an example, if we assume that for European radio it is possible to operate in SF7 to SF11, the radio coverage achieved operating in SF7 when operating in the Event detection mode will be 60% lower than for other Loadsensing data loggers (e.g. vibrating wire 5-channel or the wireless tiltmeter in standard mode).

And for regions where it is possible to operate in SF7 to SF9, like in Brazil or the USA (FCC), the radio coverage achieved while operating in SF7 for the Event Detection Mode will be 50% lower than for other Loadsensing data loggers.

The range estimates below are for Brazil, North America and Europe using a TIL90 operating the EDM.

RADIO RANGE	US 902-928MHz (FCC)	Brazil 915-928 MHz	EU 868 MHz
Open sight	7.5 km	7.5 km	6 km
City street	2 km	2 km	1.6 km
Manhole in a city street	1 km	1 km	0.8 km

Tunnel	2 km	2 km	1.6 km
Note: The distances have been tested by Worldsensing in real projects using standard antennas. However, the actual radio range depends on the environment, so these distances are only indicative values. Contact Worldsensing to discuss the details of your application.			
Bidirectional communications: Remote configuration changes/clock synchronization			
Sensitivity (SF7):	-127 dBm	-127 dBm	-127 dBm
Sensitivity:	-131 dBm (SF9)	-131 dBm (SF9)	-137 dBm (SF11)
Maximum link budget (SF7):	147 dB	147 dB	141 dB
Configuration: Star (no repeaters needed)			

As mentioned before, the EDM operates in SF7 to optimize system capacities, but in some cases, under certain conditions and only for some of the nodes connected to the Network, communication through SF8 would be possible. Please contact support@worldsensing.com to assess the number of devices that can be operating in SF8.

In those cases SF8 should be also fixed during the advanced radio configuration option through the Worldsensing App (see 5.1 Radio Configuration chapter).

4.3 Battery life estimation

For a Tilt90 device operating EDM, the battery consumption varies depending on the number of samples collected and transmitted and with the environmental conditions. In this mode of operation, not only the basic reporting period must be considered, but also if the node has entered the alert state, how much time has been in this state, and the reporting period configured for this state. This mode of operation is always restricted to SF7, so this parameter is not to be considered for battery estimation.

The following table provides the minimum expected battery lifespan in years for different configurations:

Battery life estimation**	2 LSH 14 cell
Reporting period 6 h	2.35 years
Reporting period 1 h	2.26 years
Reporting period 30 min	2.15 years

**Test settings in terms of radio: US 902-928MHz (FCC) radio configuration. Spreading factor 7. Radio transmit power 20 dBm. Considering standard laboratory conditions. Estimations for Saft batteries based on the lifetime mathematical model. Consumption varies depending on the events detected, periodic reporting rate and environmental and wireless network conditions. It has been considered the normal operation³.

4.4.Dataserver managing

- **Compatibility with CMT Edge and CMT Cloud**

From both user interfaces, it is possible to remotely manage the tiltmeters operating in event detection mode. These tiltmeters will be shown as LS-G6-TIL90-X or LS-G6-TIL90-I. These nodes can be remotely configured via long-range radio just as any edge device, but with the addition of the specific parameters:

- Event Detection Mode: On/Off
- Upper Threshold (degrees). Resolution: 0.01°.
- Lower Threshold (degrees). Resolution: 0.01°.

³ Battery life may vary considerably from specifications depending on the actual set-up and working conditions; such as events detected, reporting period, wireless network status and environmental conditions. The battery life rating is only achieved on the specific sensor models and configurations tested by Worldsensing under the specific test settings at the time of publication and is not an estimate of a system's battery life under any conditions other than the specific test settings.

- Add/Subtract Offset (degrees). So differential measurements can be applied automatically to the last collected reading.
- Reporting period for normal state.
- Reporting period for alert state.

A configuration change label will be shown next to the node id since the new configuration has been submitted and until the new configuration has been effectively loaded on the node, when a grey label will appear.

When the first periodic reading in Alert State is received by the CMT, a warning icon will be displayed next to the node. This icon is just meant to be a graphic tool to visualize what happened, but it cannot be used as a notification because, first, no real action is associated with it (the MQTT alert message should be the one used to trigger an action by a 3rd party SW), and second, the latency of that message is randomized inside the allotted slot time as any other periodic message.

One exception in comparison to a normal TIL90 display is that there are no engineering units available as of this version (2.6).

- **Sensor data retrieval over MQTT Pusher**

CMT Edge and CMT Cloud include a MQTT Client to push messages. Integrations with 3rd party software will require a MQTT broker to be subscribed to the pusher.

The implemented MQTT pusher also includes a persistent message queue. Beyond the event detection mode, all the messages from all the Edge devices and also related to the gateway monitoring can also be published over the MQTT Client.

In addition to the sensor data messages:

- CMT Cloud pushes gateway status data over MQTT every 30 seconds enabling the gateway monitoring from a 3rd party software. In addition, the gateway status data

is shown on the CMT cloud platform (ON/OFF) and any change in the status will be notified by email.

- CMT Edge publishes a gateway keep-alive message over MQTT every 30 seconds enabling the gateway monitoring from a 3rd party software. CMT Edge also publishes a gateway health message every 5 minutes including different metrics related to the gateway performance. The user can disable the publication of the described messages.

FTP Push and API calls are not compatible with the alert messages from the event detection mode in the Loadsensing system.

The message transmitted when a threshold is reached will be published ONLY using MQTT in JSON format. The data collected and transmitted in the periodic reporting on both normal and alert states, as well as the triggered data messages will be available in a similar way than for all the Loadsensing edge devices including CSV files.

- **Sensor data retrieval over Modbus TCP**

CMT Edge includes a Modbus TCP Client to push messages from CMT Edge firmware version 2.7.0. Please take a look at the [Modbus Memory maps document](#) for configuration.

Please note that polling alert registers at high frequency can increase the CPU usage from the Gateway. Some recommendations are published on the [CMT Edge user guide](#) from the Modbus TCP chapter.

4.5. Requirements for project success

- **Recommendations**

- Plan a test bench or develop a numerical model to define the proper absolute thresholds.
- Ensure compatibility with 3rd party software that will manage the events published by the Loadsensing system.
- Define and test the business rules for the 3rd party system with the selected thresholds and sampling rates of the tiltmeters.
- Install an uninterruptible power supply (UPS) to provide power to the gateways.
- In the CMT Cloud architecture, it is recommended to install redundant gateways.
- In the CMT Edge architecture, it is recommended to define an action in case of a disconnection of the gateway.
- It would be necessary to have a safety stock with some tiltmeters, batteries and a minimum of one gateway as close as possible to the project area.
- Guarantee the connectivity of the gateways.
- Review the location of the tiltmeters in the project area. The instrument locations have to cover all the zones that could register a zonal movement in the structure. Identify zones of particular concern and install more devices in these locations. Redundant sensors improve the robustness of the system.
- Plan maintenance of the wireless network including periodic tests of the event detection system.
- Devise remedial actions.

- **Related Services**

- Device Preconfiguration
- Technical Support: Project Management
- Extended Warranty
- Battery insertion and mounting plate attachment (coming soon)

5. Wireless sensor set-up configuration for the EDM

Most of the steps during the process for configuring the TILT90-X/I node are the same as for the other nodes. Please refer to the Worldsensing app [User Guide](#) for more details on Network and Radio configuration, as well as for the Coverage test. Also you can refer to that guide for recommendations about device compatibility with the App.

After connecting the App with a TILT90-X/I you will access the main menu of the App. You will see at the upper part, as usual for other models, node information (ID, model, serial number, network (if any) date-time and the uptime).

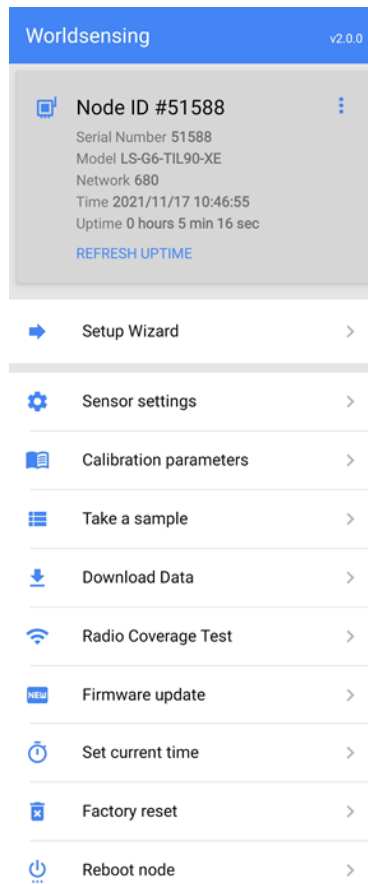


Figure 1: Main WorldSensing app screenshot for the TIL90-X/-I

From the options in the menu, start the setup Wizard to go through the entire configuration process, including the coverage test. To modify or perform only a specific step, use the options in the menu below. The details on the steps involved during the configuration are shown in the following subsections.

5.1.Sensor configuration

This datalogger integrates one embedded sensor (Wireless Sensor), and therefore it is not necessary to configure the sensor typology. Nevertheless, the three channels can be enabled or disabled, and the thresholds for each channel can be activated and configured through the WorldSensingApp.

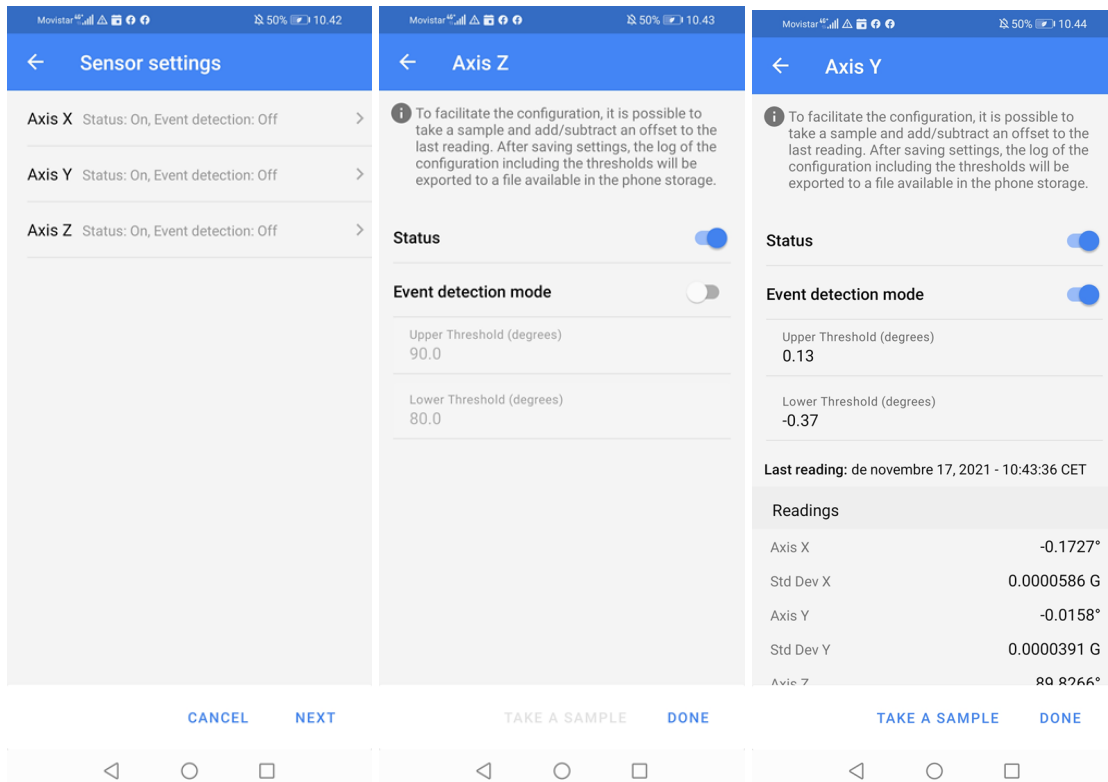


Figure 2: WorldSensing app screenshots for sensor configuration.

Press one of the channels to accede to its configuration. Once in a specific channel configuration, enable the channel with the status switch and activate the event detection mode with the Event detection mode switch.

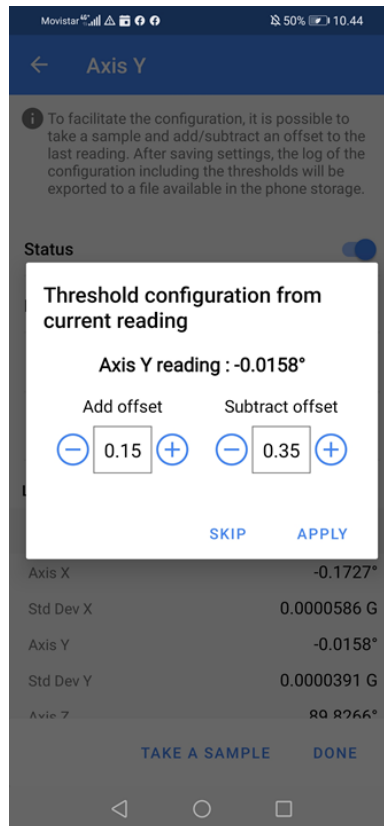


Figure 3: WorldSensing app screenshot for threshold configuration with offsets.

Below the switch for EDM activation, you can find the current (pre-set) upper and lower thresholds. Also, if available, the last reading will be shown below. If not available, you will see the “No reading available” message. Press the “take a sample” button at the lowest area of the page to collect one reading and access the threshold change menu. A reading will be collected and, based on the obtained value, you will be allowed to define a threshold by inputting and subtracting an offset. Values in this field are expected to be positive and with

2 resolution digits. The maximum permissible values for the defined threshold (value +/- offset) are +90.00 degrees for the upper threshold and -90.00 degrees for the lower one. When all the channel parameters are set, press the “Done” button to save the configuration. If you are in the setup wizard process, you will step ahead to the next section.

5.2.Take a sample

If you select the “take a sample” tab from the main menu, the last reading will be shown, and by clicking “take a sample” the App will force a new measurement. The angle for each axis and the related standard deviation will be shown. If the event detection has activated the alert state (alert state is active), the exceeded threshold and the related axis will also be reported.



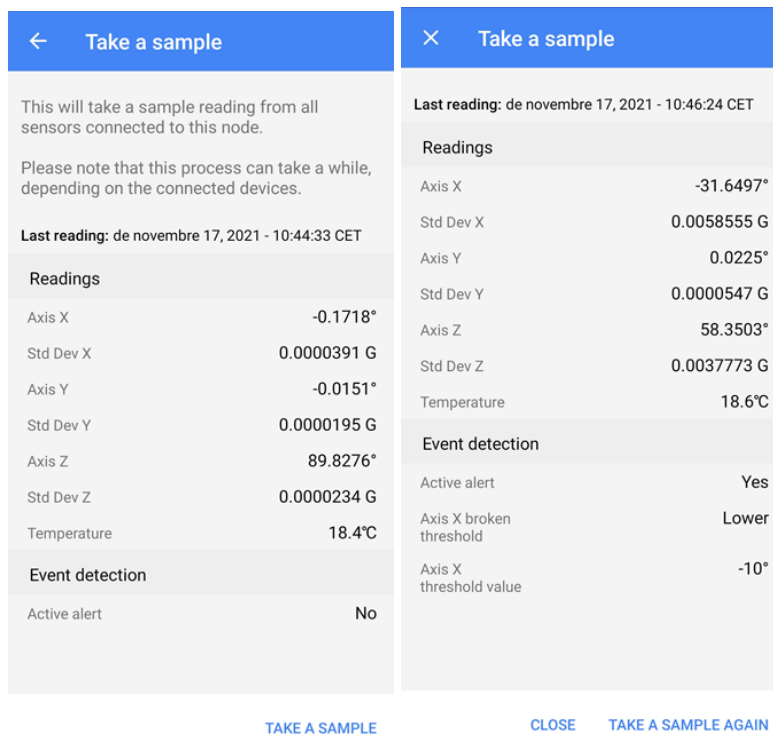


Figure 4: WorldSensing app screenshots for “take a sample” menú.

5.1. Radio Configuration

The radio configuration follows the standard steps (see WorldSensing app guide), where credentials for the network will be required. Notwithstanding, in this mode, the advanced parameters are restricted. The EDM system only operates in SF7. The default configuration for this node already switches off the ADR and allows setting the maximum SF to 7. As mentioned in the previous chapter, in some cases, under certain conditions and only for some of the nodes connected to the Network, communication through SF8 would be possible. Please contact support@worldsensing.com to assess the number of devices that can be operating in SF8.

In that case SF8 should be also fixed during the advanced radio options.

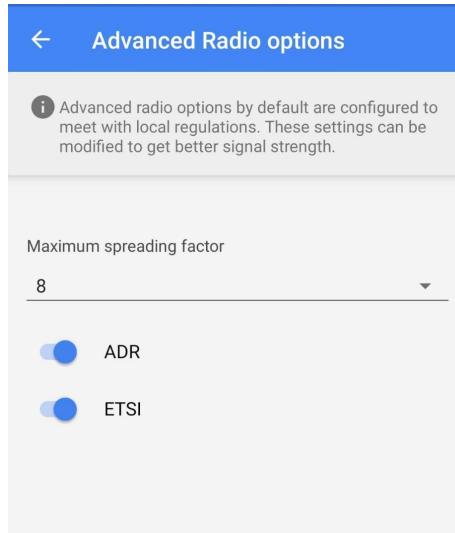


Figure 5: WorldSensing app screenshot for advanced radio options .

5.3. Calibration Parameters

This screen is only accessible by pressing the corresponding tab in the main menu and not through the wizard.

This screen shows the parameters of calibration (A and B for the three axis) for the specific node and the date time of calibration.

Note: the data offered by the wireless sensor is already corrected considering these calibration parameters A and B, so the readings are not to be corrected again.

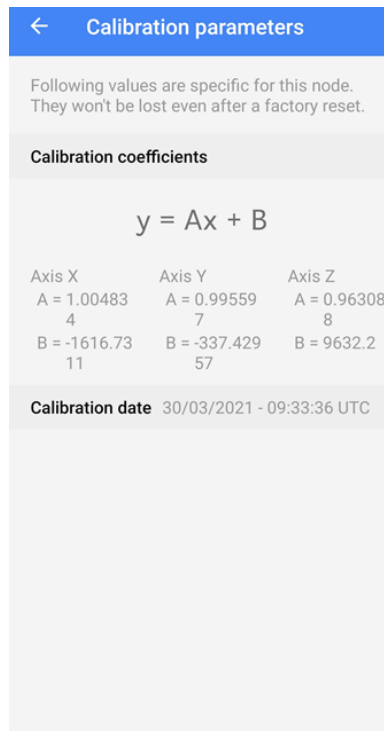


Figure 6: WorldSensing app screenshot for calibration parameters.

5.4. Sampling Rate

In this screen you can configure the reporting period in the normal state. The nomenclature Sampling Rate is for congruence with other Loadsensing devices: this is the readings transmission rate via radio in normal conditions (alert state not activated). The fastest sampling rate in this state is 5 minutes (available since firmware version 2.68) and it is only possible to be configured from the Gateway.

Note: The reporting period during the active alert cannot be configured through the App and must be remotely configured afterwards from the datasever (see section 6.1).

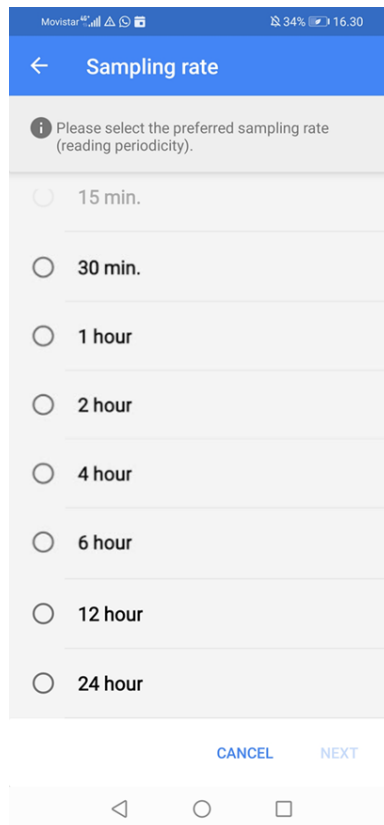


Figure 6: WorldSensing app screenshot for Sampling rate configuration..

6. Dataserver visualization

An example of the general view of a network of tilt90 devices operating in EDM is shown below:

[Signal coverage test map](#)

Nodes

Id, name, serial or model

All 0 nodes selected of 26








Id	Name	Status	Model	Serial
<input type="checkbox"/> 51381		Ok	LS-G6-TIL90-XE	51381
<input type="checkbox"/> 51393		Ok	LS-G6-TIL90-XE	51393
<input type="checkbox"/> 51497		Ok	LS-G6-TIL90-XE	51497
<input type="checkbox"/> 51498		Ok	LS-G6-TIL90-XE	51498
<input type="checkbox"/> 51502  New config set		Ok	LS-G6-TIL90-XE	51502
<input type="checkbox"/> 51509 		Ok	LS-G6-TIL90-XE	51509
<input type="checkbox"/> 51510  12h Setting config		Ok	LS-G6-TIL90-XE	51510

Figure 7: Worldensing CMT EDM network screenshot.

It is worth noting several specificities of this kind of nodes:

- A letter "E" is added at the end of the model label to state the EDM mode operational in this device. I.E. LS-G6-TIL90-X, for the external antenna tilt90 device.
- The symbol  by side of the ID means the alert state was active during the reception of the last reading for this node. Please note that this icon does not appear in real time on the CMT.

- The label  is active when a specific node configuration has been remotely changed (see section 6.1.). The label is active until the change of configuration has been effectively done in the node.
-  A configuration is set for the TILT90-E edge device from the CMT platform.
- For completeness we include also the labels  (Orange: Change in progress; Grey: change succeeded) even though it is common to all Loadsensing edge-devices. This label is activated when the periodic baseline sampling rate is remotely changed for a node, and until the change is effectively changed in the node. The label includes the new sampling value.

The menu for each node can be accessed as usual, by clicking the ID link. This node, in EDM operation mode, presents a configuration button at the upper part (right to the “edit” button). We can access the specific EDM configuration menu through this button (see section 6.1 for details).

Node 51393

[/ Networks / 680 / Node 51393](#)

Name	
Installation date	
Comments	
Model	LS-G6-TIL90-XE
Firmware version	2.67
Serial number	51393
Health CSV files	51393-health-current.csv + More
LS-G6-TIL90E CSV files	51393-readings-current.csv + More

Figure 8: Worldsensing CMT LS-G6-TIL90-XE node screenshot.

The “Last readings and Time series graphs” tab below presents the last readings in the format for this model. The typical fields are the same as in the TILT90 standard model (Temperature, and X,Y,Z, axis tilt). For the EDM, in addition to the temperature and the three angles reading, the data message includes a field telling if the thresholds have been configured.

Last readings and Time series graphs				
Temp (°C) ↗	X Axis (°) ↗	Y Axis (°) ↗	Z Axis (°) ↗	Alerts Configured
23.5	-0.4358	0.2196	89.5120	Yes

Figure 9: Readings from the LS-G6-TIL90-X during the normal state.

Note: For EDM, the engineering unit conversion formulas applicable for the TILT90 are not available.

When the alert state is activated, the data message will include additional fields, indicating which threshold (upper or lower) and for which component/s (X,Y,Z) have been surpassed and the effective value of the threshold.

Last readings and Time series graphs					
Temp (°C) ↗	X Axis (°) ↗	Y Axis (°) ↗	Z Axis (°) ↗	Alerts Configured	
24.6	-0.7797	0.0290	89.2197	Yes	
X Broken Threshold	X Threshold Value (°)	Y Broken Threshold	Y Threshold Value (°)	Z Broken Threshold	Z Threshold Value (°)
				Upper	10.00

Figure 10: Readings from the TIL90-X during an active alert event


The data and the health CSV files can be downloaded as usual from the node menu and in a compacted form from the network menu.

Custom compacted readings can be created by selecting both the node and the column to show in the custom file. See Appendix A for details about the columns available in files created for this mode of operation.

FTP can be configured to receive the reading messages from this kind of node in a specific folder, by checking the item and providing a valid path in the “FTP configuration” menu.

Note: The alert message (the real time message which informs about the threshold exceeding) is not available for downloading or FTP pushing: It will be only available through the MQTT pushing. See Appendix A.2 for more information.

6.1. Remote device configuration

To access the EDM node configuration page, click the  icon at the top of the screen.

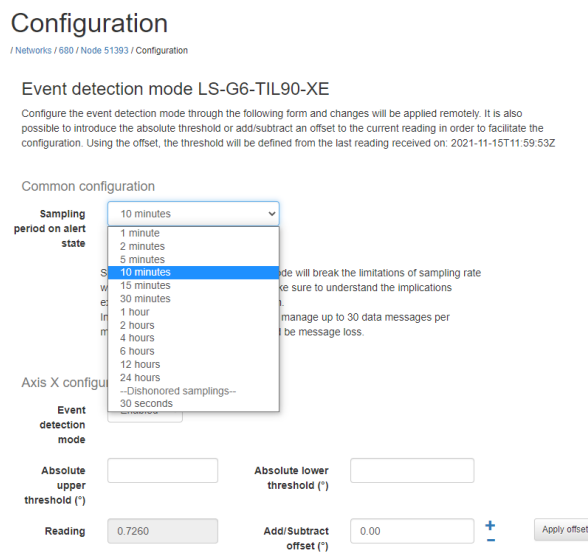


Figure 11: Configuration menu of a LS-G6-TIL90-X node in CMT platform.

The configuration menu allows you to remotely configure the specific EDM node parameters through the radio. The classic LS sampling rate (periodic reporting of readings) is to be defined in the main network page, as it is done for the other nodes.

In all cases, when changing the configuration to a node from the dataserver, a downlink message will be sent down from the Gateway to the node. To be effective, the message needs to be received by the node. To receive the message, the radio must be enabled and this will be true when a message is being transmitted from the node. Thus, the configuration change will be effective as soon as the node emits a message based on the already established reporting period and the message is captured by the CMT. As seen before, since the activation and until the change is effective, a label will be included on the node area, in the main network page.

The specific EDM configurable parameters are:

- *Sampling rate on alert state:* This parameter sets the reporting period of readings. This is: the denser reporting rate used when the alert state is activated. This parameter ONLY can be configured from the dataserver and the default value is 6 hours.

For monitoring coherence, we recommend setting the sampling rate in normal state lower than the sampling rate in alert state.

DISHONORED sampling rates can be configured for the alert status. Take into consideration for these sampling rates the number of messages will be high and, sometimes, and depending on the number of nodes in the alert state, GW could be unable to assign a proper slot time to all the incoming messages. This could lead to a missing package problem. The user must be aware that with these sampling rates some messages can be lost.

- *Axis thresholds configuration:* This menu allows you to define both the upper and the lower thresholds for each channel (X,Y,Z).
 - Each axis pair can be enabled or disabled.

- When the axis is not enabled in the node (not measuring), a threshold cannot be configured.
- For the enabled channel thresholds, there are two ways to establish the threshold:
 - **With absolute values:** Manually fill the Absolute upper and lower threshold values. The field format accepts positive and negative values, ranging between -90.00 and 90.00 degrees and up to 2 decimal places.
 - **Based on a deviation from the current value:** The current reading is shown in a grey box (label='Reading'). The threshold can be defined by introducing a range value (Δ°) on the "Add/Subtract offset" field. The value introduced must be positive and there are accepted up to two decimal positions. The resultant values are always in the range [-90.00 and 90.00]. Greater values will be truncated to these values. Based on this offset value and the current reading (r), the upper and lower absolute thresholds will be automatically filled (and the current values erased) as:
 - Absolute Upper Threshold = $r + \Delta^\circ$
 - Absolute Lower Threshold = $r - \Delta^\circ$

Note: The reporting period (sampling rate when alert state is off) is not configurable in the configuration menu of the specific node but from the main network page, following the common features of the other Loadsensing nodes. It is worth noting, the fastest period for the EDM in normal state is 5 minutes (available since firmware version 2.68) and that it is only configurable through the Gateway. The information regarding latency appearing at section 5.4 of the current guide applies also when configuration is done through the dataserver.



7. Data management

This section details what messages are sent through the EDM and how the datasever is managing them. Figure 12 shows a simplified system operation example. In the sake of clearness, only one axis and only one threshold have been considered in the figure.

Note: When the three axis are in EDM, thresholds may be sequentially broken and recovered during the alert state and, always that at least one axis is outside the thresholds, the alert state will remain and the system will collect readings in all the axis on the reporting period associated to the alert state. Only when all the axis are within the thresholds during at least the stoppage time, the system will return to the normal state mode.

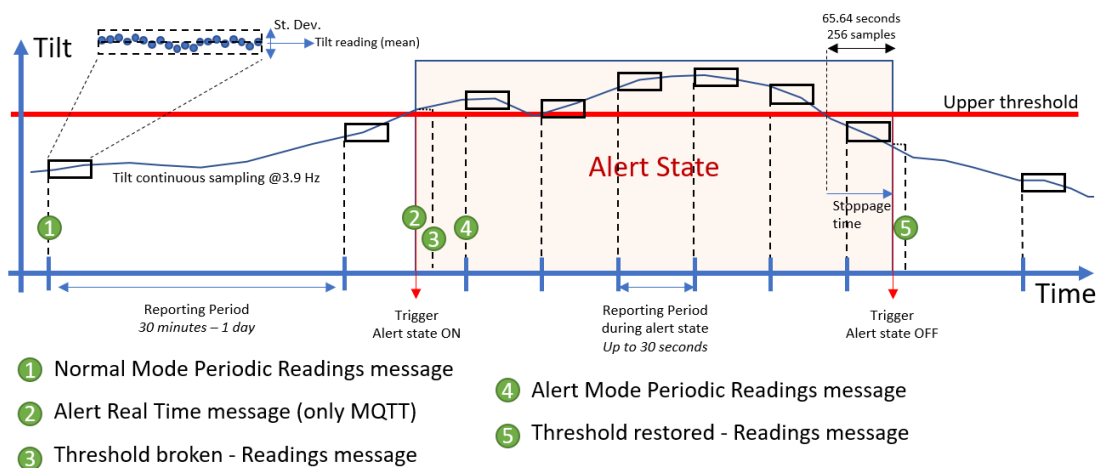


Figure 12: EDM simplified operation example. In green, are indicated the different messages transmitted.

In the prior figure we can identify up to five different messages, in three groups:

Periodic reading message:

1 4

Reading messages including data acquired according to a selected periodicity. This group of messages include:

- 1) Normal State Periodic Readings: Acquired according to the configured periodicity when the alert state is off.
- 4) Alert State Periodic Readings: Acquired according to the configured periodicity during the alert state.

The tilt reading is computed averaging several samples of tilt, as done in the regular TIL90 devices, and therefore includes a standard deviation (shown in the graphic as a black rectangle). This is a reading message and the fields include the TIL90 regular fields and adds several fields with information about the status of the alert state and classifying it as a periodic reading (see the table for reading message below).

Alert state trigger message: 2

This kind of message is marked as 2) in the plot. This is a near real-time message generated whenever the continuous sampling exceeds any threshold in any axis and contains information about the alert state activation. Typical information about radio signals including frequency, RSSI, SNR and SF is transferred as well. As it is transmitted in near real time, the transmission timestamp is considered the trigger timestamp.

In this message there is information about the specific threshold involved but does not include information about the specific data which triggered the system. Only the angular amount exceeding the absolute threshold value is reported. This value is always positive and must be related to the specific broken threshold (upper/lower) and its direction of exceedance (addition/subtraction, respectively). The value resolution presents one integer

significant digit (ranging from 1 to 9) followed by two significant digits for the decimal positions, which can only take 33 multiples values {00; 33; 67}. The exponents range from -2 (centi degrees) to 2 (hundreds of degrees). Differences are truncated to the closest lower value. This value is reported as a decimal number. The following table presents some examples of potential actual exceedances (only for illustrative purposes) and the related truncated and reported ones:

Exceedance		
Actual	Truncated	Reported
0.008	0.67E-2	0.00677
0.015	1.33E-2	0.01333
0.230	2.00E-1	0.2
3.456	3.33E0	3.3333
46.241	4.33E1	43.33333
104.315	1.00E2	100.0

This message will be sent only through MQTT and will not be accessible through the dataserver or the CSV file. For more details about this file format, please refer to the Appendix A.2.

Triggered Reading: 3 5

These are readings messages which are not periodically generated but triggered by one condition. Two kinds of messages are generated depending on the triggering condition:

- 3) Whenever a first or any subsequent threshold is crossed, the system will generate a reading message, timestamped exactly at the time when the threshold was broken, including the data which triggered the message and its timestamp.
- 5) When the continuous sampling returns in between the lower and upper threshold and remains there after a stoppage time (256 samples / 65.64 seconds) a message will be generated including the data of the last sample and its timestamp. This message indicates that the normal state has been reached again.

These messages are not generated instantly when the trigger is activated, but following the typical transmission cycle of the network, and for that they will not be considered real-time. The format of these messages is the same as the periodic readings, but includes several differences:

- The field `AlertTriggeredMsg-{ID}` will be 1 indicating this is a triggered message.
- The timestamp of this message will not be based on a periodic basis.
- The data transmitted will be the exact sample which generated the trigger, so no average is performed and standard deviation will be 0.
- Additional information about the thresholds will be provided for the messages 3).

7.1. Dataflow

All the readings messages will be transmitted and processed by the dataserver, as well as pushed through MQTT. On the other hand, alert messages will be only transmitted by MQTT.

For this reason, the CSV readings file downloadable from the CMT dataserer will only include the readings. From there, alert state activation and deactivation can be seen through the triggered readings, but take into account that these messages are not received in real-time and are not intended for integration in early warning tools.

Details on the CSV and JSON (pushed by MQTT) messages format can be found in the Appendix A.



8. FAQs

**How are the X Y Z axis related with the classical A and B axis in geotechnical tiltmeters?
Can I convert them directly from the CMT platform?**

The conversion between the angles X,Y,Z and A,B can be done through a trigonometric relationship which can be found in the TIL90 [user guide](#). When operating in EDM, the engineering conversion is not available from the CMT platform.

Is the accuracy from the wireless tiltmeter the same on all the ranges?

We have tested the accuracy within different positions (+/-4°, +/-15°, +/-45°, +/-86°). The results are shown on the [specs](#) (the biggest is the angle measured, the accuracy is reduced).

As the device can be installed on any position, we always recommend when possible to refer the measurements to the lowest angle measured to obtain higher accuracy.

We could say that as in most of the applications where the TIL90-X is used an angle below 4 ° is being measured, so the accuracy is +/-0.005° and +/-0.006° for the TIL90-i.

Is there a better way to install the device?

Even though the device can be installed in any direction, as seen above the accuracy in all the ranges is not the same (see section 4.1). So take into account, when defining the thresholds, which axis information will be more resolute. For example, in the horizontal position, the X and Y axis will be around 0 degrees while the Z axis will be around 90. In this conditions, the X and Y axis will be more accurate than the Z axis, and it can be a good idea to work with thresholds in these angles.

Do I need to apply temperature correction to the wireless tiltmeter?

The wireless sensor temperature dependency is up to $\pm 0.002^{\circ}\text{C}$ for the TIL90-X and $\pm 0.005^{\circ}\text{C}$ for the TIL90-I.

To reduce thermal effects, we recommend installing the device indoors where possible in order to avoid sun exposure. If not, we suggest installing it in the shade, as sun exposure causes a thermal gradient on the enclosure.

Changes in temperature will cause structure and tiltmeter thermal effects. The best way to measure tilt is to determine the temperature behavior of the structure before activities start. Ideally, this baseline should be extended for a year to cover seasonal changes. With this baseline, it will be possible to distinguish temperature-induced movements (including those of the tiltmeter) from others.

Why is there a difference in the accuracy between both devices (TIL90-X vs TIL90-i)?

The main difference is due to the vibration resistance of TIL90-I. This device has been designed to work in environments with accelerations below $\pm 80\text{g}$, this is mainly due to the fact that this device has been designed for railway application, where vibration is an important point to be considered. This makes the specs from TIL90-I lower than the TIL90-X.

Is it possible to install two CMT Edge gateways to provide redundant connectivity to a network of tiltmeters operating in Event Detection Mode?

No, it is not possible. Installing two CMT Edge gateways in the same network of Edge Devices will cause an inefficient performance of the network that could cause some packet loss and time discipline issues for nodes seeing both Gateways. If you are interested in a multigateway installation, we recommend switching to CMT Cloud.

Environmental best practices

Installation and operation

Please install Worldsensing products in an energy-efficient manner by minimising power usage for computers, mobile phones or other devices needed for setup and configuration. Minimise the use of small components needed for installation, like mounting brackets and other connection materials. Avoid using toxic materials and/or hazardous substances.

- Set the sampling rate only in the nodes you need.
- When configuring the nodes, use "Set last configuration" whenever possible.
- Remove the batteries if you are not using the node.
- For nodes with switch, use the usb mode when not in operation.

Return Material Authorization (RMA)

In the event of requesting a Return Material Authorization (RMA) please make sure to use the most environmentally friendly mode of transportation possible.

Product End of Life and disposal

Please take the necessary measures to extend the life of the product and reuse it when possible.

Once the product reaches its end of life (EoL) recycling is crucial to divert material from waste streams into new applications.

Electrical and electronic devices, and batteries must be recycled according to the European Union WEEE Directive 2012/19/EU.

Please separate batteries from equipment.

This product and the batteries it may contain should not be discarded as unsorted waste. Please send them to separate collection facilities for recovery and recycling.

Product packaging

Worldsensing's product packaging is recyclable. Separate the different materials for a correct waste management.

Safety and emergency procedures

Please read the safety sheet that comes with our products before installing them. For safety information on batteries and other materials, as well as instructions in case of emergency please read the safety information available at: <https://info.worldsensing.com/safety-information/>

In the case of an emergency and after it has been managed, please evaluate the waste generated in order to dispose of it in accordance with current legislation and local regulation.

It is your responsibility to dispose of your waste equipment, batteries and packaging properly to help prevent potential negative consequences for the environment and human health.

The cost of environmental waste management is included in the battery's selling price.

By following these best practices you can help protect the environment. Thank you for your cooperation.

Appendix A. CSV example and JSON format

In this appendix the format for CSV files and JSON files transmitted through MQTT integration are shown.

A.1. CSV data file

The EDM Readings message is similar to the other Loadsensing devices: It has a header with the typical information fields (Node ID, Gateway ID, Model ...) and it is closed monthly, being the ongoing data file named as "{ID}_readings_current.csv".

Regarding the Readings (time-series below the header), the CSV format for the EDM is more complex than for other nodes of the Loadsensing family. The first fields are common with the TIL90 fields, but after these, there are fields that present information about the

alert state, triggering and thresholds, which are only filled when required and remain blank when unused. The following table shows a description of the fields in a CSV Readings file for EDM.

Field	Description and format	Periodic Readings Normal State	Periodic Readings Alert state	Triggered Message Threshold Broken	Triggered Message Alert state off
Date-and-time	Timestamp "YYYY-MM-DD HH:mm:ss"	Time stamp according to baseline sampling rate	Time stamp according to alert state sampling rate	Exact timestamp when a specific threshold has been exceeded (based on the 3.9Hz samples).	Exact timestamp when the continuous samples (@3.9Hz) are within the thresholds after the stoppage time.
Temp-{ID}	Temperature in Celsius degrees XX.X	Internal sensor temperature during the acquisition.			
{XYZ}axisTilt-{ID}	Tilt measurement for each of the axis ±XX.XXXX	Tilt sample averaging (@3.9Hz)	Instant tilt value which exceeded the threshold	Instant tilt value within the thresholds after the cold down time without any exceeding	
{XYZ}axisStd-{ID}	Standard deviation of the tilt reading X.XXE±XX	Average associated standard deviation.		Is always 0,	
AlertConfigured-{ID}	EDM is enabled in any channel <i>Boolean</i>	0: EDM disabled in all channels 1: EDM enabled in one or more channels.		Always 1: EDM enabled in one or more channels	
AlertTriggeredMsg-{ID}	Message is triggered by threshold exceedance <i>Boolean</i>	0: Reading based on a sampling rate (baseline or alert state)		1: Triggered message (turn on/off alert state)	
AlertActive-{ID}	Alert state is enabled for this reading <i>Boolean</i>	0: Alert state is off.	1: Alert state is on.	1: Alert state is active or has just turned on..	0: Alert state has just turned down.

Below fields are EMPTY if “AlertActive-{ID}” parameter is 0. When the parameter is 1, the below applies.				
{XYZ}axisAlertActive-{ID}	{XYZ} Axis threshold is exceeded <i>Boolean</i>	Empty	0: No threshold is exceeded for this axis 1: A threshold is exceeded for this axis	Empty
Below fields for a specific axis are EMPTY if “{XYZ}axisAlertActive-{ID}” parameter is 0 in this axis. When the parameter is 1, the below applies.				
{XYZ}axisAlertLocation-{ID}	Upper or lower threshold exceeded <i>Boolean</i>	Empty	0: Lower threshold 1: Upper threshold	Empty
{XYZ}axisAlertValue-{ID}	Specific exceeded threshold value in degrees <i>±XX.XX</i>	Empty	Pre-set value for the exceeded threshold (X,Y,Z / upper or lower)	Empty

Table A-1: Reading CSV file fields, definitions and values for the EDM

In Figure, we include a CSV Readings file example to exemplify the process of declaring an alert state and deactivating it.

Date-and-time	Temp-80	XaxisTilt-80	YaxisTilt-80	ZaxisTilt-80	XaxisStd-80	YaxisStd-80	ZaxisStd-80	AlertCo nfigure d-80	AlertTtr igener d-80	AlertAc live-80	XaxisAI erActiv e-80	XaxisAI erLoca e-80	XaxisAI erValu e-80	XaxisAI erActiv e-80	XaxisAI erLoca e-80	XaxisAI erValu e-80	XaxisAI erActiv e-80	XaxisAI erLoca e-80	XaxisAI erValu e-80	
2021-11-12 14:30:00	21.4	0.720	-1.633	88.216	1.72E-04	1.29E-04	4.69E-05	1	0	0	0	0	0	0	0	0	0	0	0	78.45
2021-11-12 14:42:12	21.1	-23.595	-1.860	66.323	0	0	0	1	1	1	1	0	-11.19	0	0	0	0	0	0	78.45
2021-11-12 14:42:30	21.1	-87.675	-1.433	-1.831	8.20E-05	3.56E-04	4.68E-03	1	0	1	1	0	-11.19	0	0	0	0	0	0	78.45
2021-11-12 14:43:00	21.2	-86.171	-1.488	-3.527	2.34E-05	2.34E-05	3.40E-04	1	0	1	1	0	-11.19	0	0	0	0	0	0	78.45
2021-11-12 14:43:11	21.4	-76.339	-13.119	-3.741	0	0	0	1	1	1	1	0	-11.19	1	0	-11.00	1	0	0	78.45
2021-11-12 14:43:30	21.4	1.483	-88.067	1.241	2.27E-03	1.04E-03	3.46E-02	1	0	1	1	0	-11.19	1	0	-11.00	1	0	0	78.45
2021-11-12 14:44:00	21.4	1.431	-87.389	2.183	1.56E-05	1.17E-05	1.95E-05	1	0	1	1	0	-11.19	1	0	-11.00	1	0	0	78.45
2021-11-12 14:44:30	21.6	1.419	-87.400	2.178	2.34E-05	1.56E-05	3.52E-05	1	0	1	0	0	0	1	0	-11.00	1	0	0	78.45
2021-11-12 14:45:00	21.6	1.390	-87.432	2.159	4.26E-04	1.06E-04	3.01E-04	1	0	1	0	0	0	1	0	-11.00	1	0	0	78.45
2021-11-12 14:45:30	21.6	1.339	-87.491	2.122	1.56E-05	1.95E-05	2.34E-05	1	0	1	0	0	0	1	0	-11.00	1	0	0	78.45
2021-11-12 14:46:00	21.6	1.338	-87.491	2.122	1.95E-05	1.95E-05	2.73E-05	1	0	1	0	0	0	1	0	-11.00	1	0	0	78.45
2021-11-12 14:47:00	21.5	1.345	-87.481	2.129	1.95E-05	1.95E-05	2.34E-05	1	0	1	0	0	0	1	0	-11.00	1	0	0	78.45
2021-11-12 14:47:30	21.7	1.809	-0.577	88.102	3.20E-04	1.13E-04	1.17E-04	1	0	1	0	0	0	1	0	-11.00	1	0	0	78.45
2021-11-12 14:48:00	21.7	1.806	-0.598	88.098	2.34E-05	1.56E-05	2.73E-05	1	0	1	0	0	0	1	0	-11.00	1	0	0	78.45
2021-11-12 14:48:09	21.6	1.803	-0.597	88.101	0	0	0	1	1	1	0	0	0	1	0	-11.00	1	0	0	78.45
2021-11-12 15:00:00	21.4	1.784	-0.576	88.125	1.95E-05	2.73E-05	2.34E-05	1	0	0	0	0	0	0	0	0	0	0	0	78.45

Normal Sampling Period (30 minutes) – High quality data
 Alert Mode Sampling Period (30 seconds) – High quality data
 Data messages generated just after an alert. Exact data that triggered the alert. – Low quality data (single continuous sample)
 Alert Mode Sampling Period with all the axes already inside the thresholds – High quality data
 Data messages generated just after exiting Alert Mode. First data outside the mode. – Low quality data (single continuous sample)

Figure A-1: EDM CSV Readings file (without header) and different readings types.

In this example, we show data from 2021-11-12, and we can interpret the device status following the lines of data:

- This is an EDM device (Serial=80) in a normal state, periodically reporting every 30 minutes. A reading has been received at the periodic timestamp: 14:30:00 (first green highlighted message). We can infer this device has at least one channel configured in EDM with defined thresholds (*AlertConfigured-80=1*).
- At 14:42:12, the device has been rotated and a triggered reading (yellow highlighted message) has been sent (*AlertTriggeredMsg-80=1*). The alert state has been declared (*AlertActive-80=1*) and both axis X and axis Z have broken a threshold: (*X/ZaxisAlertActive-80=1*) and in both cases the lower threshold. (*X/ZaxisAlertLocation-80=0*). The obtained tilt values can be compared with the threshold values. As a single sample is used in these triggered messages, the standard deviation remains 0.
- At this point, the device has entered the alert state, and a real-time alert message has been sent through MQTT at the exact timestamp of the occurrence.
- After that, we found several periodic readings with the reporting period associated with the alert state (30 seconds) for all the axis, having or not broken threshold (Purple highlighted messages). We can see that the alert is active (*AlertActive-80=1*) and which axis remains outside the threshold limits.
- Later, the device is rotated again, and, as the Y axis crosses its lower threshold a new triggered message is sent. The system will send another real-time alert message through MQTT.
- Moreover, with the new rotation, the X values return to between the threshold ranges. Nevertheless, during the following minute, the alarm for this axis X remains active as it is necessary to be there for the entire stoppage time (65.64 seconds). The following 2 periodic messages present the X alert active, and later this alert is turned down.
- At some point between 14:47:00 and 14:47:30, the device is returned to its original position (all the values inside the thresholds). Nevertheless, the alert state keeps

activated until the stoppage time is reached with all the axis without a broken threshold and periodic readings at 30 seconds are collected until the normal state is declared (soft purple highlighted messages).

- No alert messages are sent through MQTT at this point.
- When the normal state is active again, a reading triggered message is sent with the exact timestamp when the stoppage time has finished 14:48:09 (orange highlighted message). In this case, the triggered message presents (*AlertActive-80=0*) as the alert state is off. Standard deviation is 0 here, as only one sample is used.
- At last, the system starts reporting in base to the normal state reporting period (30 minutes).



A.2. MQTT - JSON messages

When properly subscribed to a MQTT broker (see details in the [guide for configuration of the MQTT pushing](#)), all the data messages and the alert messages generated by the EDM operating device will be received in JSON format, along with the common MQTT messages sent by the Loadsensing system (Gateway keep alive and node health).

The fields in the Readings messages through MQTT are equivalent to the fields in the Readings CSV file (see the table A-1).

The alert message fields are presented in the table below.

Field		Description and format	Comments
Common part		See common JSON messages from Loadsensing	Information about the Radio Network, serial number, Firmware version, etc.
Alerts Tripllicated content for 3 channels 0: X axis 1: Y axis 2: Z axis	IsActive	The channel has an active alert. <i>Boolean</i>	1: Active alert 0: Non active alert
	IsRecent	This is the first notification with the axis alert. <i>Boolean</i>	1: It is the first notification. 0: It is an old alert.
	Below fields exists for the specific channel if "IsRecent" = 1		
	absoluteThresholdBrokenUpper	Lower or upper threshold broken <i>Boolean</i>	1: if the threshold that triggered the alert is the upper one. 0: if it is the lower threshold.
	excess	Excess from the threshold in degrees. <i>Double Byte</i>	The resolution is 1.33 digits.

Table A-2: Fields, definitions and values for the Alert message published through MQTT

Here, we attach an example for the two EDM specific JSON messages. In the following link, you can download an example of “log” for all the information published through MQTT.



TILT90-XE Readings message

```
{
  "commMetaData":
  {
    "networkId": "21781",
    "macAddress": "83937461",
    "receivedTimestamp": "2021-12-10T12:16:13Z",
    "frequencyHertz": 868.3,
    "messageFrames": 1,
    "snr": 10,
    "sequenceCounter":
    [
      105
    ],
    "gatewayId": 23605,
    "rssi": -70,
    "type": "longRangeRadioMetaDataV2",
    "sf": 7,
    "macType": "ETSIV1"
  },
  "temperature": 22.3,
  "nodeModel": "LS-G6-TIL90-XE",
```

```
"alerts":
{
  "triggeredDataMessage": false,
  "active": true,
  "configured": true,
  "thresholds":
  {
    "1":
    {
      "absoluteThresholdBrokenUpper": false,
      "absoluteThresholdAxis": -4.58
    }
  }
},
"nodeId": 51381,
"readings":
[
  {
    "std": 2.34E-5,
    "tilt": -2.6574,
    "channel": 0
  },

```

```
{
  "std": 5.86E-5,
  "tilt": -10.8819,
  "channel": 1
},
{
  "std": 2.34E-5,
  "tilt": 78.7906,
  "channel": 2
}
],
"readTimestamp": "2021-12-10T12:15:30Z",
"highPrecision": 1,
"type": "til90EReadingsV1"
}
```



LS-G6-TIL90-[X]E alert message

```
{
  "alerts":
  {
    "1":
    {
      "isRecent": false,
      "isActive": false
    },
    "0":
    {
      "isRecent": true,
      "excess": 3,
      "isActive": true,
      "absoluteThresholdBrokenUpper": false
    },
    "2":
    {
      "isRecent": false,
      "isActive": false
    }
  },
}
```



```
"nodeModel": "LS-G6-TIL90-XE",  
"commMetaData":  
{  
  "networkId": "21781",  
  "macAddress": "83937461",  
  "receivedTimestamp": "2021-12-10T12:13:44Z",  
  "frequencyHertz": 869.05,  
  "messageFrames": 1,  
  "snr": 9,  
  "sequenceCounter":  
  [  
    98  
  ],  
  "gatewayId": 23605,  
  "rssi": -67,  
  "type": "longRangeRadioMetaDataV2",  
  "sf": 7,  
  "macType": "ETSIV1"  
},  
"nodeId": 51381,  
"version": 0,  
"type": "til90EAlertV1"  
}
```



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