VirtualForests

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IO3 Internet of Trees

GUIDELINES

UVa Hochschule für nachhaltige Entwicklung Eberswalde cesefor iefc European Institute of Planted Forest HUS VNU University of Science AgroParisTech Talents for a sustainable planet

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0. Introduction

This educational product contains a guide that includes documentation to introduce the existing knowledge and experiences on sensorised forests. Cesefor has active projects on the implementation of sensors in forest plantations, namely the use of sensors in urban forests, chestnut and pine stands, and the use of sensors for advanced techniques in marginal land plantations. This guide aims to teach students why to sensor a plantation, the existing technology and a step-by-step guide to do this practice. An already finished Life+ project Quick Urban Forestation (www.quickurbanforest.eu), which deployed a sensors network to study the behaviour of a non-irrigated urban forest is used as the main and most clear example of the useful in sensoring a plantation. The next two cases studies presented in this guide are focused on their IoT systems, as an example of how they can be implemented.

1. State of the art of a forest plantation sensoring.

The sensing of environmental and physiographic variables of forest plantations dates back to the 1970s and 1980s with some early initiatives in the field of research. It is already in the XXI century, associated with the industrial mass production of sensors, the lowering of costs of electronics and the emergence of the Internet in non-urban environments, when this practice becomes more common, although it is also usually related to research environments of universities and research centres, until today.

The development of these solutions within the field "business as usual" comes in recent years only, in which commercial brands develop self-installation kits almost "plug and play", to obtain data from the sensors quickly and directly.

Bibliographic review of interest on this topic:

See Table as Annexed

2. Existing technology

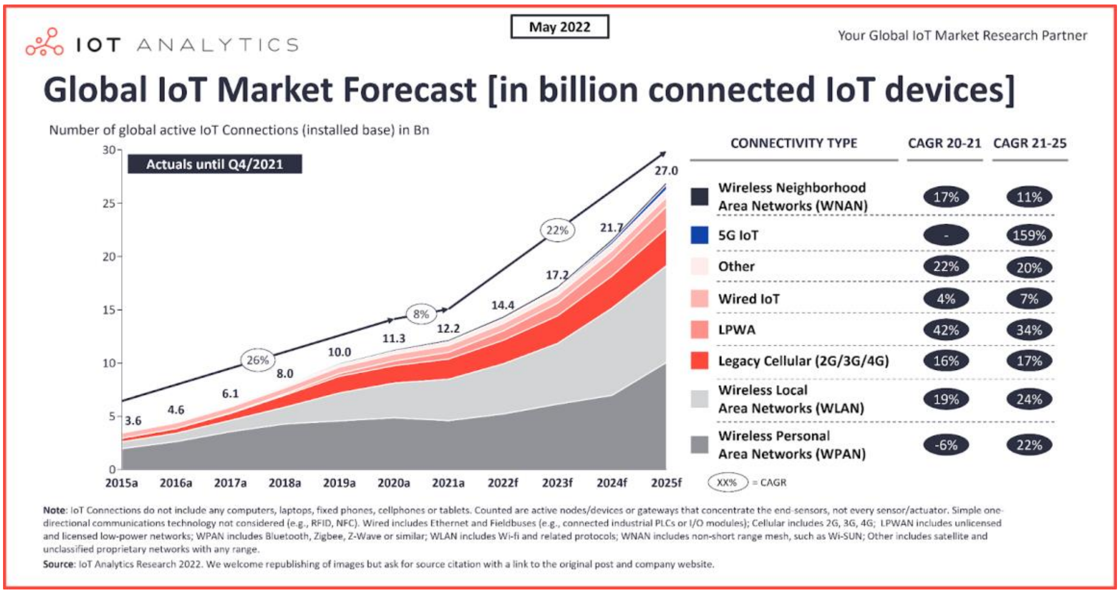
The fourth industrial revolution introduced us to the concept of the Internet of Things (IoT), which is indeed having a substantial impact on the world we live in today and the way modern businesses work. Everything seems to be connected to the internet these days, from your smartphone and laptop to baby monitors, wristwatches, refrigerators, medical equipment, cars, and even manufacturing tools.

What is IoT?

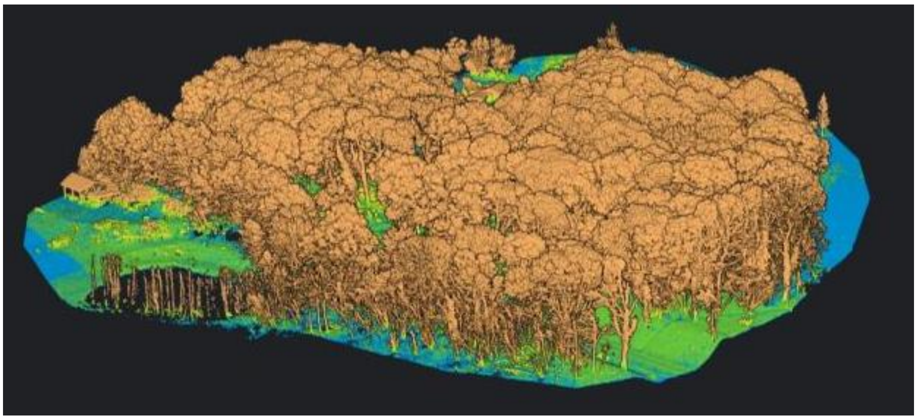
Internet of Things (IoT) is a massive network of physical devices embedded with sensors, software, electronics, and network which allows the devices to exchange or collect data and perform certain actions. Simply put, IoT is made up of two words: Internet & Things.

- Things – physical devices, appliances, gadgets, etc.
- Internet – through which these devices are connected

As a result, it cuts down the human effort and paves the way for accessing the connected devices easily. With autonomous control, the devices are operable without involving human interaction.



The Internet of Things has been one of the disruptive technologies for years. Its impact has been felt in all sectors, from industry to the home. The agricultural sector is no exception and is increasingly using IoT solutions to achieve greater efficiency and productivity. The application of IoT to agriculture represents a change in the way crops are worked, with the aim of automating processes, optimizing resources, reducing costs and increasing profitability. IoT technologies applied to agriculture are several years ahead of the Smart Forest concept or the integration of IoT into the natural environment. Both of these areas share one of the clearest examples of IoT technologies, which are the remote sensing techniques used by satellites and other similar supports that allow us to obtain data on a specific scale of terrestrial areas.



Source: UAV LiDAR mapping systems for Forestry

Digitalization of forests

To analyse the existing technology within the world of IoT applied to the natural environment, we will distinguish the implementation at various levels:

- Sensing technology (Sensor network)
- Big Data and Cloud Computing
- Advanced analytics (Artificial intelligence)

Sensing technology (Sensor network)

A sensor is an easy and small tool that measures or detects natural world conditions such as motion, heat, or light and converts this condition into an analogue or digital representation.

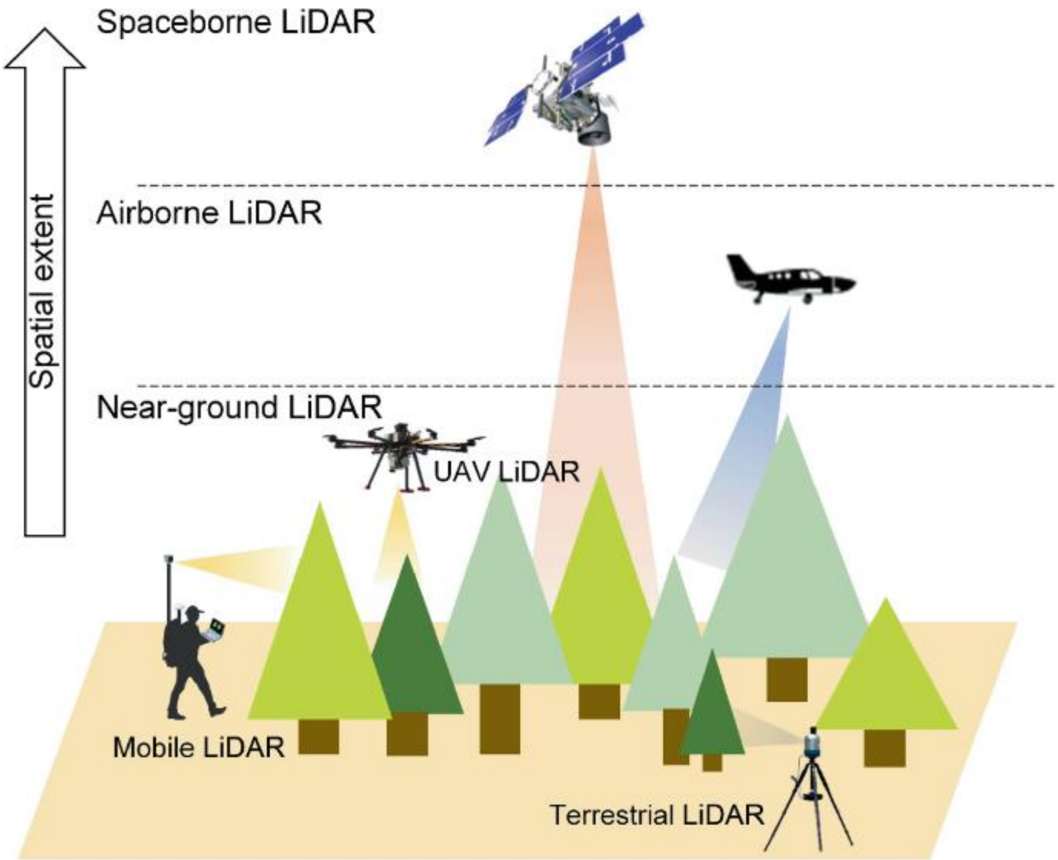
IoT technologies applied to agriculture are several years ahead, this allows us to have a wide catalogue of sensors already adapted to the use and parameterization of environmental and dendrometric parameters.

Type of sensors

1. Optical Sensors

These types of sensors base their operation on capturing the variations of electromagnetic frequencies within the frequencies of the visible and near range.

These sensors are placed in vehicles or drones, which makes it possible to collect and process data on soil reflectance, and structure and density of the forest mass. Optical sensors can determine clay, organic matter, and soil moisture content.



Source: https://link.springer.com/chapter/10.1007/978-981-19-3816-0_24

There is another type of optical sensors that are used to measure the morphology of the tree canopy using light transmission in 12 spectral bands. This allows analysis of leaf moisture, chlorophyll, crown density, average leaf size, etc.

2. <u>Electrochemical Sensors for Soil & Tree Nutrient Detection</u>

Electrochemical sensors provide information for soil and tree nutrient detection. Helps collect chemical data. Electrochemical sensors provide sensing information for the detection of nutrients in soils and trees. These sensors use a certain type of electrodes that allow determining parameters such as pH or conductivity in a fluid.

Source: https://www.nature4shop.com/

3. <u>Mechanical Sensors for dendrometric parameters</u>

Dendrometers are precision sensors that can measure the growth of plants. This equipment is used by researchers, growers and foresters to measure the growth of a stem, trunk, branch, roots or fruits over time.

In its simplest form, a dendrometer can be a tape measure, or ruler, that is wrapped around the trunk of a tree or a fruit.

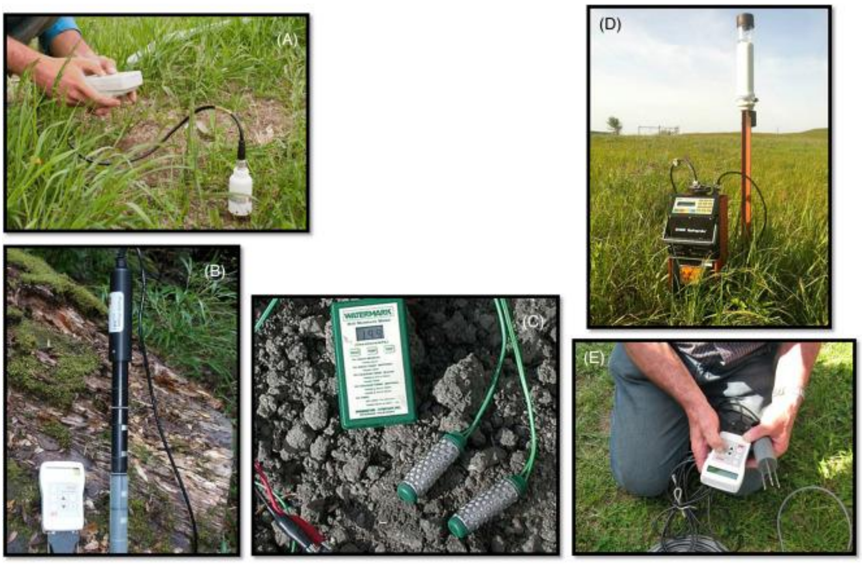
These sensors can measure very small growth variations on the order of nanometers, for example, to determine nocturnal variations in trunk dilation.

They can also be used to take very low frequency samples such as weekly or monthly samples to record plant growth.

There are other types of mechanical gauges that can be used to measure the 3D position of the trunk of trees to determine growth structure.

4. Dielectric Soil Moisture Sensors

It measures moisture levels in the soil. The moisture sensors are used in connection with weather station sensors placed near the location to measure. This allows for the observation of soil moisture conditions when vegetation level is low.



5. <u>Location Sensors for precise geolocation</u>

These sensors determine the range, distance and height of any position within the required area. They take the help of GPS satellites for this purpose.

7. <u>Weather stations</u>

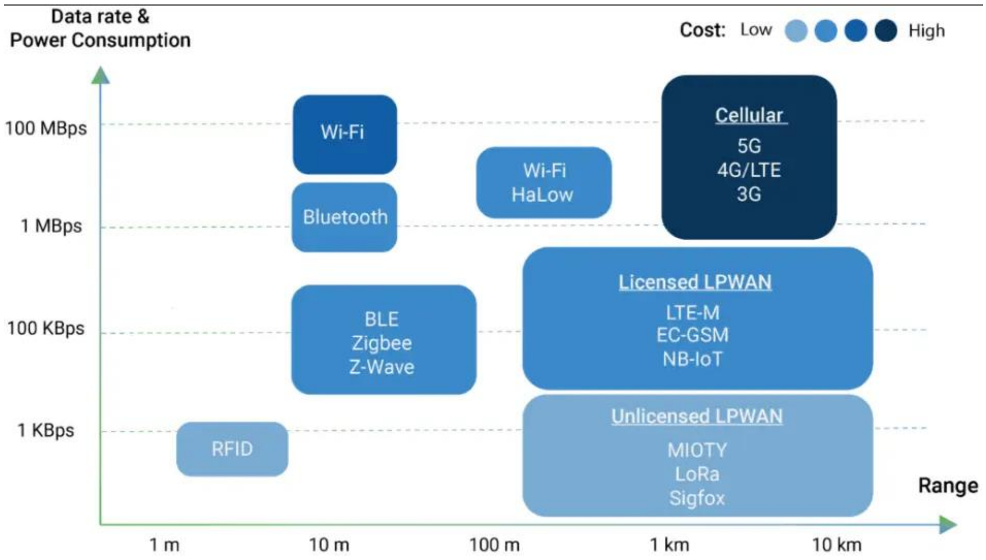
This sensor provides information such as air temperature, soil temperature at various depths, rainfall, wind speed, dew point temperature, wind direction, relative humidity, solar radiation, and atmospheric pressure is measured and recorded at scheduled intervals.

Sensor Networks

In turn, the concept of sensor network comprises a group of small, powered devices, and a wireless or wired networked infrastructure. The sensor network connects to the internet or computer networks to transfer data for analysis and use. Main characteristics of these networks are:

1. Easy deployment,
2. Self-configurable,
3. Efficient energy management, to achieve the necessary autonomy.

Pay special attention to Wireless Sensor Networks (WSNs), which are very important for forestry monitoring. These networks are designed to cover large areas without the need for physical infrastructure. The following graph shows different wireless technologies that identify the performance of the network against the range of distance, as well as its cost.

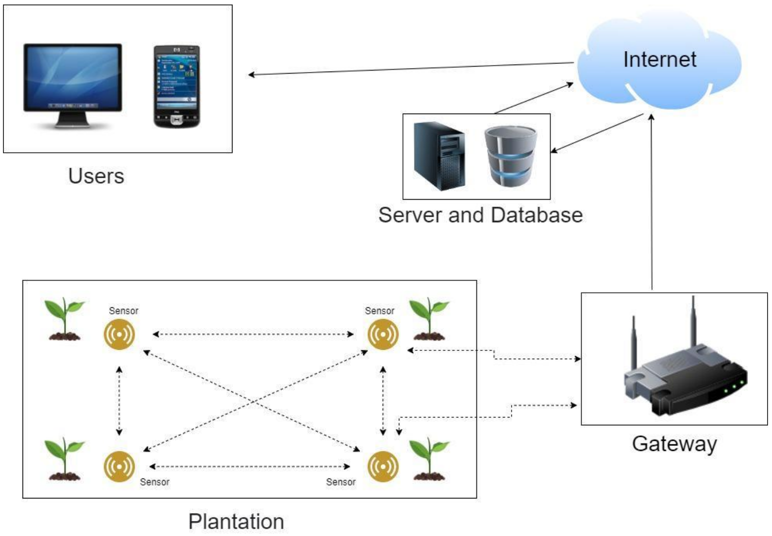


Source: https://www.mokolora.com/lora-and-wireless-technologies/

They form a network, in such a way that all the sensors are connected to each other. They send the collected data to the gateway.

Gateway: connection interface between devices, making it possible to share resources between two or more computers. It collects the data from the sensors and sends it to the server through the Internet.

Server and database: Devices that receive, store and serve information over the Internet. It collects the data provided by the sensors and stores them in a database. It also structures them and makes it possible to access them through other devices.



Sensor Network - Topology

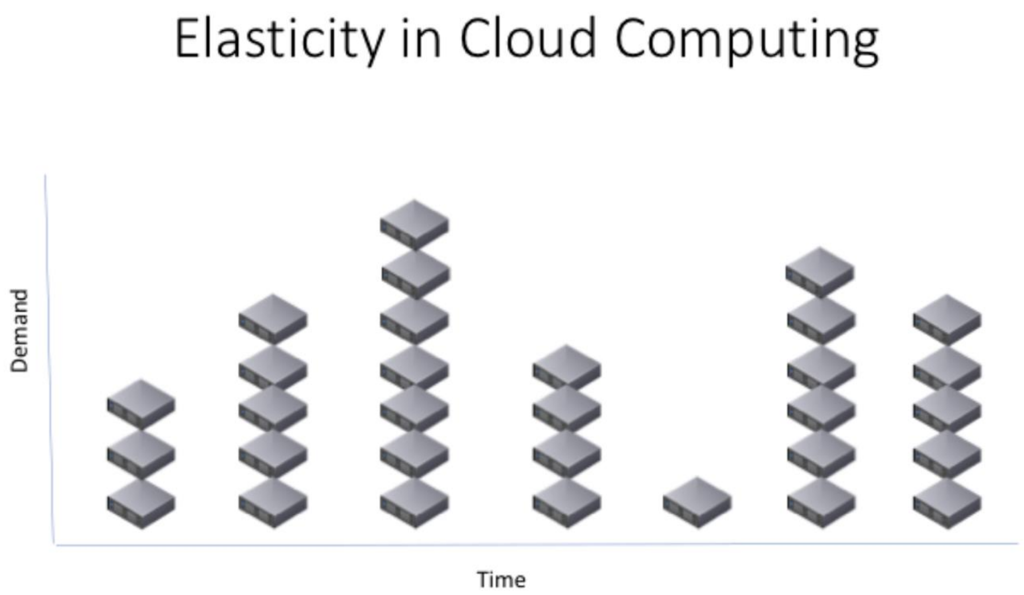
Big Data and Cloud Computing

All the information collected by the sensors must be properly labelled and structured in order to be sent to the data centres and to be kept in an orderly manner.

On many occasions it is necessary to pre-process the raw data received from the sensors because the electronics of the sensors are not always capable of carrying out a complex mathematical process of the physical signals collected.

Big Data systems must be able to support an incessant load of data produced asynchronously by the sensors and sent 24 hours a day by the gateways to the corresponding IoT platforms where the data is processed and stored.

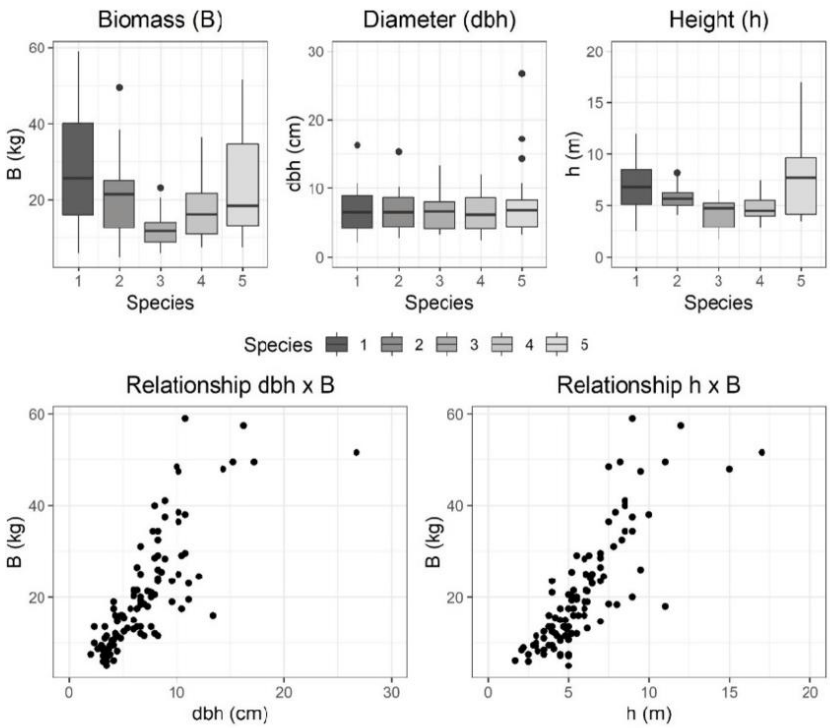
This type of infrastructure must be able to support growth in both the number of gateways and the number of sensors.

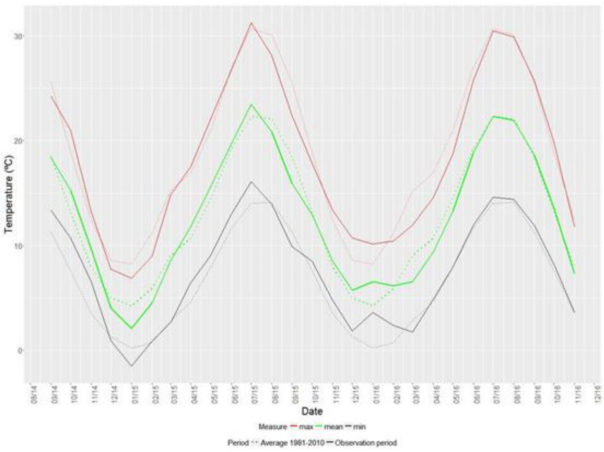


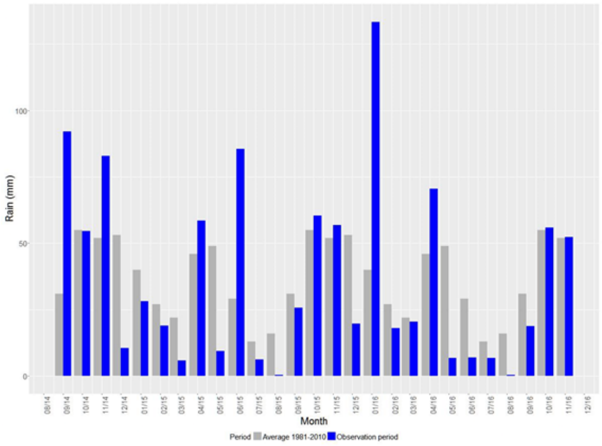
Cloud computing systems must be capable of collecting large amounts of information stored in databases on demand by the user who needs to consult certain data time ranges.

Advanced analytics (Artificial intelligence)

Increasing the number of sensor types, we will increase the data accuracy from the environment.







In this example, we can see rainfall and temperature data within a plantation. Crossing these data, we could analyse the evolution of forestry exploitation.

We could even develop predictive models using AI that allow us to improve the efficiency of our plantation!

IoT Platforms

An IoT platform serves as a mediator between the world of physical objects and the world of actionable insights. Combining numerous tools and functionalities, Internet of Things platforms enable you to build unique hardware and software products for collecting, storing, analysing and managing the plethora of data generated by your connected devices and assets.

IoT system architecture consists of four layers:

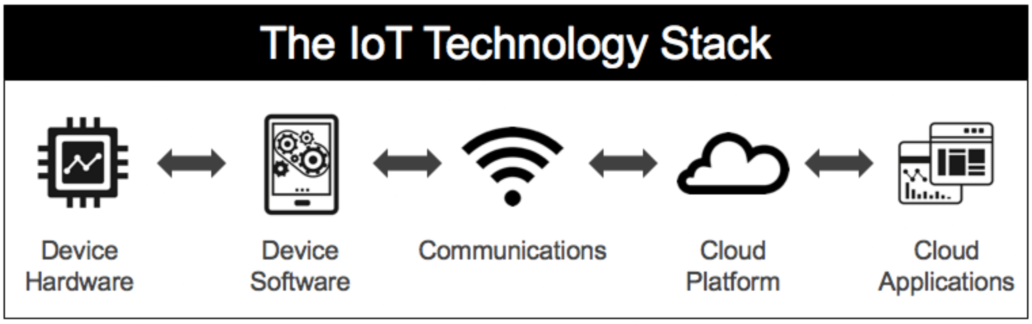
1. *Sensors and actuators* collect data directly from physical objects (devices, equipment, machines, vehicles, home appliances, people, animals, etc.).

2. *Gateways and data acquisition systems* convert gathered data from the analogue to the digital format.

3. *Edge computing* ensures there's immediate preliminary data analytics right on devices.

4. *Data centres or cloud services* provide deep data analysis, processing and storage.

IoT products consist of numerous components:



To cover each aspect while developing an IoT product, there are several **types of IoT platforms**.

- Hardware development platforms provide physical development boards for creating IoT devices, including microcontrollers, microprocessors, Systems on Chip (SoC), Systems on Module (SoM).

- App development platforms serve as an integrated development environment (IDE) with tools and features for coding applications.

- Connectivity platforms provide communication technologies to connect physical objects with the data centre (on premise or cloud) and transmit information between them. Among popular connectivity protocols and standards for the Internet of Things are MQTT, DDS, AMQP, Bluetooth, ZigBee, WiFi, Cellular, LoRaWAN and more.

- Analytics platforms use intelligent algorithms to analyse collected information and transform it into actionable insights for customers.

- End-to-end IoT platforms cover all aspects of IoT products, from development and connectivity to data management and visualization.

As a rule, IoT cloud platforms are end-to-end solutions that combine capabilities such as app development, device management, connectivity management, data acquisition and storage, and data analysis and visualization.

Some of the most popular IoT platforms are:

Google Cloud Platform

Core features of Google Cloud IoT:

- AI and machine learning capabilities
- Real-time data analysis
- Strong data visualization
- Location tracking

Core use cases:

- Predictive maintenance
- Real-time asset tracking
- Logistics and supply chain management
- Smart cities and buildings

Cisco IoT Cloud Connect

Core features of Cisco IoT Cloud Connect:

- Powerful industrial solutions
- High-level security
- Edge computing
- Centralized connectivity and data management

Core use cases:

- Connected cars
- Fleet management
- Home security and automation
- Payment and POS solutions

- Predictive maintenance
- Industrial networking
- Smart meters
- Healthcare

Particle

Core features of the Particle platform:

- Integration with third-party services via REST API
- Firewall-protected cloud
- Capability to work with data from Google Cloud or Microsoft Azure
- No need for technical expertise in order to use the platform

Core use cases:

- Real-time asset monitoring
- Live vehicle tracking
- Predictive maintenance
- Environmental monitoring
- Compliance monitoring
- Real-time order fulfilment

IBM Watson IoT

Core features of IBM Watson IoT:

- Data ingestion from any source with the help of MQTT
- Direct access to the latest data in the Cloudant NoSQL DB solution
- Built-in monitoring dashboards to control your assets
- Analytics Service to process raw metrics

- The Cloud Object Storage solution for long-term data archiving

Core use cases:

- Supply chain management
- Regulatory compliance
- Building management
- Energy consumption
- Shipping and logistics

AWS IoT

Core features of Amazon AWS IoT Core:

- A wide choice of connection protocols, including MQTT, MQTT over WSS, HTT and LoRaWAN
- Ability to use with other AWS services such as AWS Lambda, Amazon Kinesis, Amazon DynamoDB, Amazon CloudWatch, Alexa Voice Service and more to build IoT applications
- A high level of security provided by end-to-end encryption throughout all points of connection, automated configuration and authentication
- Machine learning capabilities
- A variety of services for edge computing

Core use cases:

- Connected vehicles
- Connected homes
- Asset tracking
- Smart building
- Industrial IoT

Microsoft Azure IoT Hub

Core features of Azure IoT Hub:

- Data protection all the way from the edge to the cloud
- The ability to operate even in offline mode with Azure IoT Edge
- Seamless integration with other Azure services
- Enhanced AI solutions
- Continuous cloud-scale analytics
- Fully managed databases
- Azure Industrial IoT solution

Core use cases:

- Automotive industry
- Discrete manufacturing
- Energy sector
- Healthcare
- Transportation
- Retail

3. Why to sensor a plantation

The study of the behaviour of forest plantations (plant survival in the first years, biomass growth, possible pests, etc.), find in the sensing of environmental and physiographic variables an ally to know the external factors that can influence these phenomena.

Some of the most measured variables are usually humidity and environmental and soil temperature, to be able to know situations of water stress for example, although in recent years there are sensors on the market that go into the study of variables such as plant sap flow, stem perimeter, daily expansion/contraction of the plant, and others.

This course will show several examples of the usefulness of sensorisation of plantations or natural forest stands, and the implementation of their corresponding sensor networks.

A sensorized experimental urban forest: How sensorization can help to manage a non-irrigated urban forest plantation

Based on the project *Quick Urban Forestation Life+*. More information and results at http://www.quickurbanforest.eu/

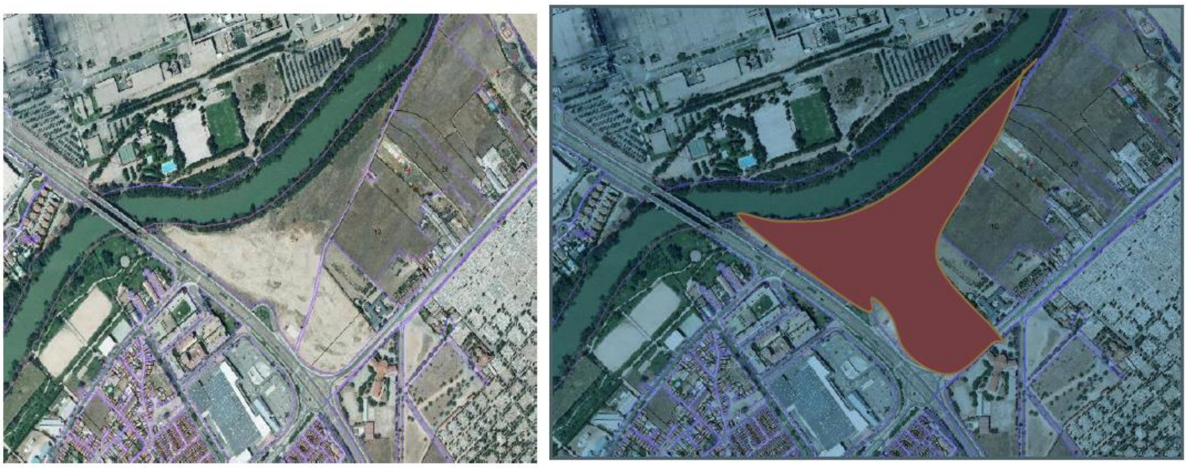
Background and context

An experimental forest plantation was set in the city of Valladolid, Spain, between 2013 and 2015 in the framework of a European Life+ project (QuickUrbanForestation). This plantation aimed to study the feasibility of an urban forest planted with innovative techniques that tried to avoid irrigation in summer.

The ultimate goal of the project was to promote arid and industrial urban areas forestation using methodologies to improve growing and survival without irrigation. In other words, to demonstrate the feasibility of creation of green areas and recover degraded soils without investing in irrigation infrastructure.

To do so, the sensorization of the plantation was key to study how water stress affected the plants, and thus to be able to analyse its effect on their survival rates and biomass growth.

The area selected for the urban forest plantation was a 13 ha. industrial plot, next to the Pisuerga river, with poor soil conditions. The plot belongs to the city council.



Area of study

Design of the plantation

The experiment was based in the plantation of 12.000 trees using 6 autochthonous species in mixed stands. The design of the plantation was planned to control the position of every single tree.

During the project, different treatments were tested (no treatment, mycorrhiza, retainers and mixed) and their effect in the plants were studied.

Species:

After a previous study the following species were selected: *Quercus ilex*, *Quercus faginea*, *Pinus pinea*, *Juniperus thurifera*, *Amigdalus comunis* and *Acer campestre*.

Coníferas

Nombre científico	Nombre vulgar	Tipo		
		a	b	c
Juniperus oxycedrus	Enebro de la Miera			•
Juniperus thurifera	Sabina albar			•
Pinus halepensis	Pino carrasco	•	•	
*Pinus pinaster**	Pino negral	•	•	
Pinus pinea	Pino piñonero	•	•	

**Pinus pinaster* no está recomendado en los términos municipales de Valladolid y Zamora.

Frondosas

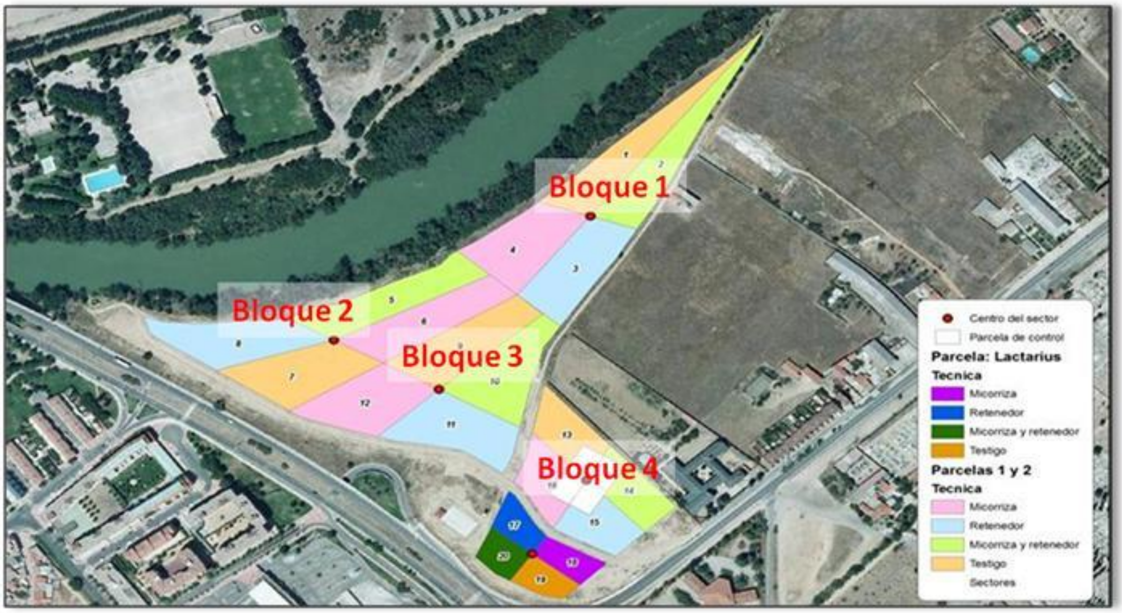
Nombre científico	Nombre vulgar	Tipo		
		a	b	c
Alnus glutinosa	Aliso			•
Amygdalus communis	Almendro			•
Crataegus monogyna	Espino majuelo			•
Fraxinus angustifolia	Fresno del país	•	•	
Juglans sp.	Nogal		•	
Populus alba	Álamo blanco	•		
Populus nigra	Chopo del país	•		
Populus x euramericana	Chopo (producción)		•	
Populus x interamericana	Chopo (producción)		•	
Prunus avium	Cerezo		•	•
Prunus spinosa	Endrino			•
Quercus faginea	Quejigo	•	•	
Quercus ilex	Encina	•	•	
Retama sphaerocarpa	Retama de bolas			•
Rosa canina	Escaramujo			•
Rosmarinus officinalis	Romero			•
Salix alba	Sauce blanco			•
Sorbus domestica	Serbal		•	•
Spartium junceum	Retama negra			•

Tipo: **a**: aconsejables **b**: posibles **c**: accesorias

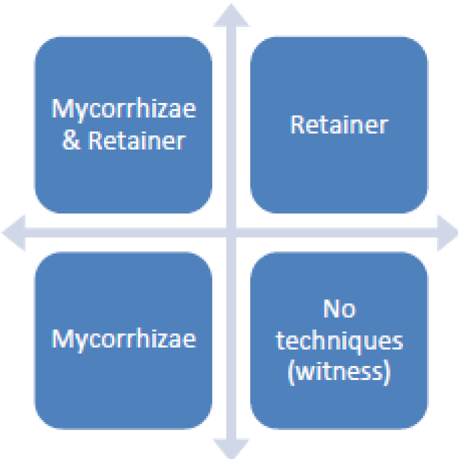
Plots

The area was divided into 5 blocks with 4 sectors in each block (each sector per treatment). Three of the blocks were approximately 2 ha. each, what implies 0.54 ha. per sector. A fourth block was a little smaller (0.33 ha. per sector) and finally the smallest one was planted with *P. pinea* and *Lactarius deliciosus* as mycorrhiza.

It was established 4 control plots in different areas of the plantation. In each plot 16 trees per control plot were monitored of 2 spices (*Pinus pinea* and *Quercus illex*), 2 per treatment (No, Ret, Mic and Mixed).



Design of the plantation. Blocks divided into section (one section per treatment and block)



Treatments:

The four treatments used were: no treatment, retainer, mycorrhiza and mixed (retainer and mycorrhiza).

<u>Retainer</u>:

Some plants were treated by “Stockosorb” which is a hydrogel formed by a polymer. By using this product in agriculture, a reduction of irrigation frequency of 50% is expected because 1 kilogram of product retains 250 litres of water.

Retainer Stockosorb

Mycorrhiza:

Some plants where treated with the following species of mycorrhiza:

- *Pisolithus tinctorius* (Pers.) Coker & Couch (ectomycorrhiza)
- *Scleroderma polyrrhizum* (JF Gmel.) Pers (ectomycorrhiza)
- *Glomus ssp*. (Endomycorrhiza)

These mycorrhiza fungi are present naturally in Valladolid, they are able to mycorrhizal host species and young plants and are efficient by spore inoculation. Each plant species of the project was mycorrhizal with the following fungi:

- *P. pinea with Pisolithus tinctorius,*
- *A. comunis, J. thurifera* and *A. campestre with Glomus;*
- *Q. faginea and Q. ilex with Pisolithus tinctorius + Scleroderma polyrrhizum*

Treatment with mychorrhiza

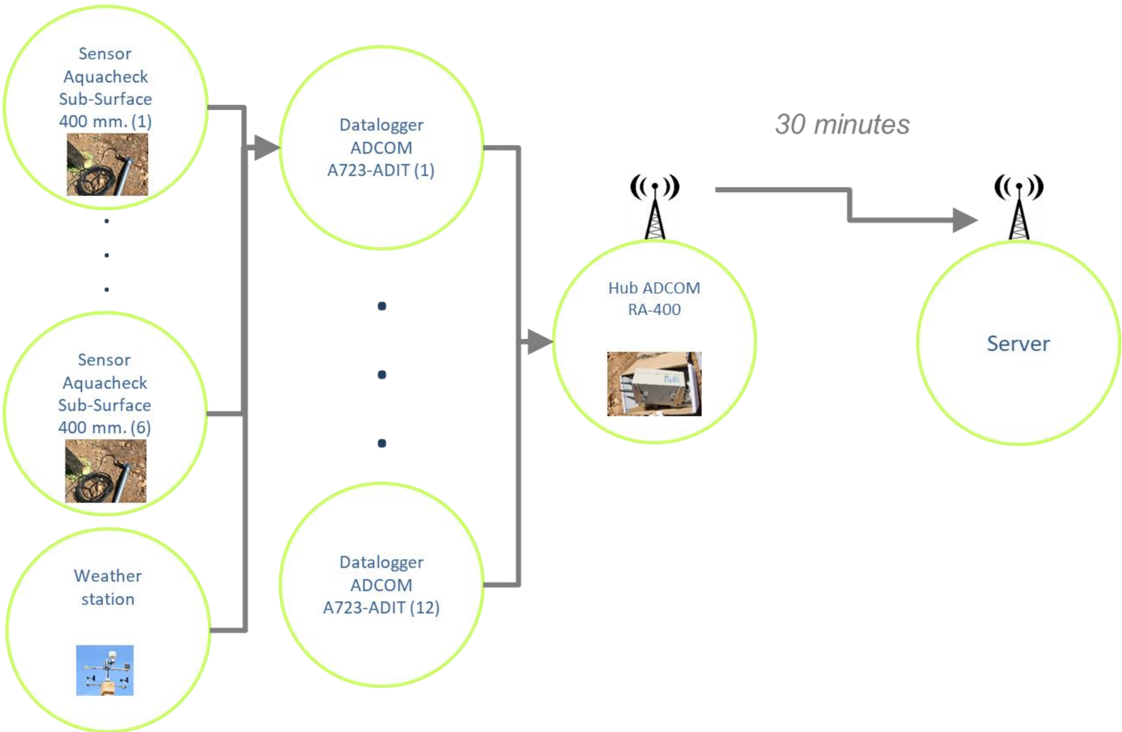
The sensor network

Characteristics:

- *Reliability.* A failure in one element does not affect the overall network.
- *Flexibility.* The network can be easily adapted to different needs. Trade-off between maturity, information provided, cost, and resistance against vandalism and theft.
- *Scalability.* The network can be easily scaled to add new sensors (both in number and types).

The sensors were of 2 types:

- Aquacheck: is a capacitance sensor that measures the frequency units (SFU) of the capacitance circuit generated by the electrodes of the probe. The sensor contains a pair of electrodes that act as a capacitor and the soil medium act as a dielectric of the capacitator and completes and oscillating circuit. The output of the capacitance probes is associated to the scaled frequency that is related to the soil moisture. The scale frequency is converted to volume percent of water in the soil through a calibration process.
- Soil temperature: measured in a range of -10ºC to +60ºC with accuracy of +/- 1ºC.



It included galvanized steel poles, about 5 m. high and at least 1 m. buried. The posts were coated wooden to go unnoticed.

It was installed one **data-logger** per pole. The data-loggers were connected to a hub of communications (addit) that collected and sent the information.

Datalogger in the plantation

The communication hub was hidden on the top of an electricity tower.

Communication hub of the monitor system

Data and analysis

The experimental design consisted of control plots and transepts, in which survival and growth dynamics at tree-level were measured periodically. In addition, the project relied on the data provided by the sensor network.

So, the following **data** were collected within the project:

1. Temperature and humidity at 20 and 40 cm. of 64 plants of two species (*P. pinea* and *Q. ilex*) along with climatic variables that register local climatic variables (air temperature in Cº, precipitation in mm., relative humidity in %RH, and wind speed

in km/h), every 30 minutes. More than 2 million of observations were provided by the sensors over the project life span.

2. Survival of 1.436 trees of the 6 species in the 4 control plots at key moments (7) of the project through field data collection.

3. Measurement of the variables of biomass at the end of the project in a sample of plants. Unlike the other data, biomass data were collected outside the control plots, through longitudinal transects, since they were destructive (plants were extracted from the ground). Different information was obtained from each tree: diameter, height, sector, soil, specie and treatment.

The **analysis** was performed comparing the results by treatment, specie and soil characteristics. Namely, 5 analyses were done:

1. *Analysis of the effect of the treatments on the water storage capacity of the soil after the rainfall*.

   Data from the weather station were used to identify rainfall events. Subsequently, the evolution of the soil moisture after the event (particularly during summer), was intended to provide insights about the soil capacity to retain water depending on the treatments.

2. *Analysis of the effect of the treatments on average soil humidity*.

   The objective was to determine the effect of the treatments on the soil water storage capacity selected for the forestation. Each treatment was compared with the no-treatment sector.

3. *Analysis of the effect of the treatments on the species survival*.

   The data provided by periodic measurements to control the survival rate along different stages of the project, and for different factors, specifically soil characteristics, species and treatment was related to the soil humidity data registered in the plants monitored.

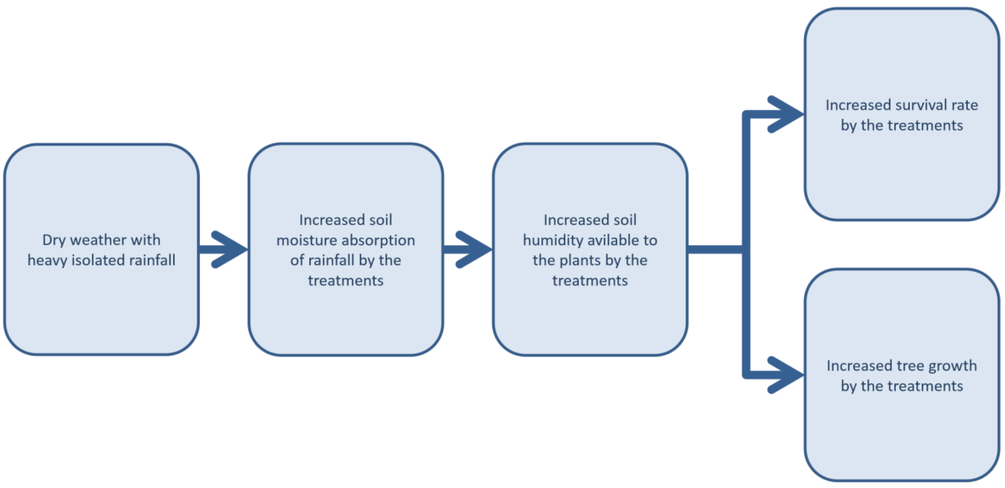
4. *Analysis of the effect of the treatments on plant biomass variables*.

   In order to determine the amount of carbon presented in the plants, the following procedure was carried out:

   - The plants were remove from the ground
   - The plants were divided into aerial and subterranean parts, and subsequently cleaned carefully.
   - Both parts were weighed. For the areal parts, the diameter at the bottom and the total height were measured.
   - All parts were dried in a laboratory oven, temperature must be 60º.

- The content of the trays was measured every 24h. When the weight loss in those 24 h. was lower than the 10% of the previous weigh, the plant was deemed to be dried.
- Once dried, every plant had to be weighed.
- The carbon content was obtained from the dry weight of every part and a coefficient that depends on the specie.

The model posed in the porject is shown in the following figure. Dry weather conditions with isolated heavy rainfall and extended periods of drought decreases the survival rates of tress under low watering conditions. The treatments were expected to improve the moisture absorption capacity of the soils and therefore to increase the water available for the plants. Higher levels of water available for the trees will yield higher survival rates while increasing the growth.

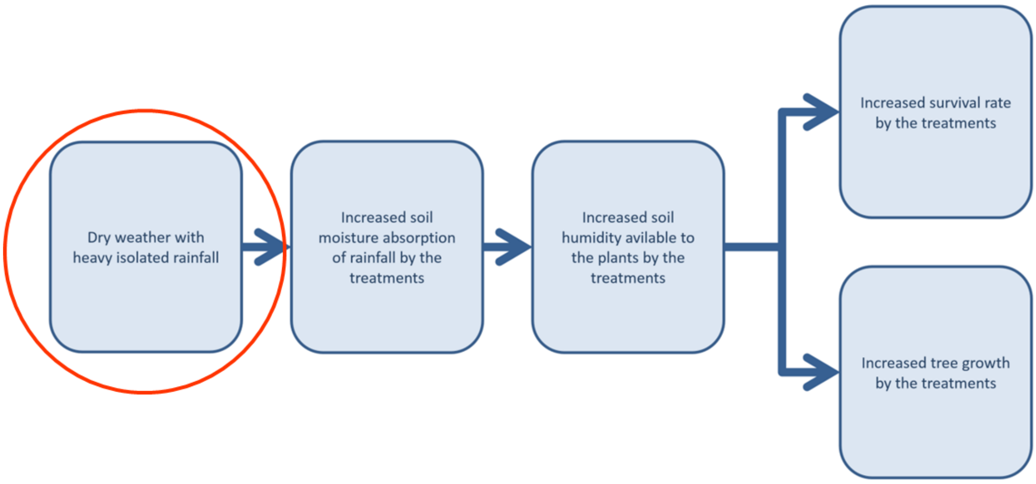


Analysis model established in the project

Results

<u>Weather information</u> during the project time:

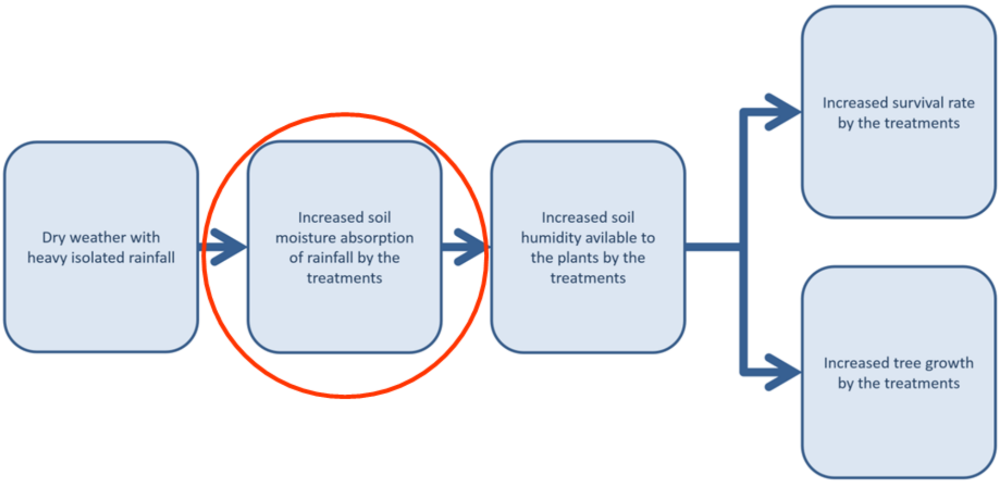
- There were not major differences between historical and experiment temperature.
- There were strong differences in rainy pattern.
- There were heavy isolated rainfalls, particularly in the vegetative period.



Conclusions of the analysis of the data:

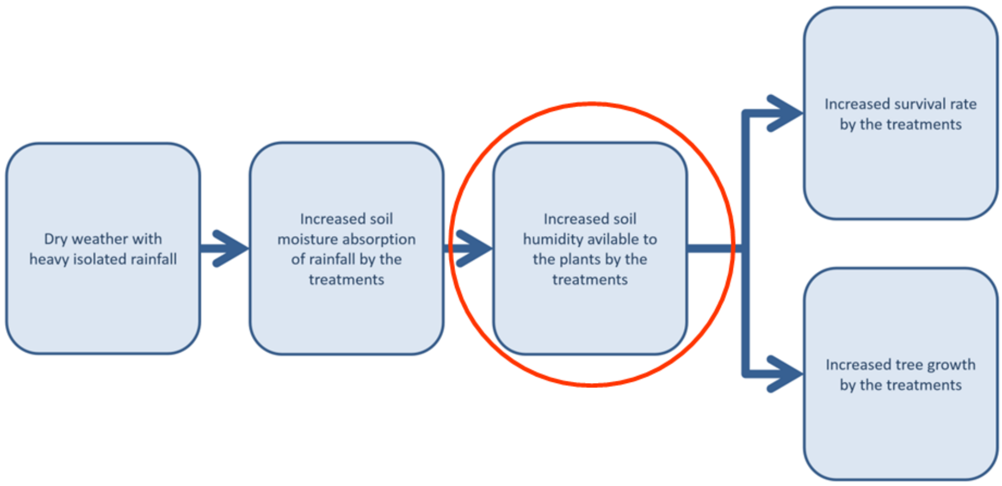
1. *Analysis of the effect of the treatments on the water storage capacity of the soil after the rainfall*: <u>The treatments are likely to increase water absorption of the soil after rainfall.</u>

    - For each litre of rainfall per hour the soil humidity after 24 h. increased between 0.15 and 0.2 points when using the treatments and the results were statistically significant.
    - The effect at 40 cm. depth was much lower, probably because it takes longer for the water to affect deeper layers in the soil.
    - It also was found strong differences between the blocks.



2. *Analysis of the effect of the treatments on average soil humidity*. <u>The treatments slightly increase the average soil moisture at 20 and 40 cm.</u>

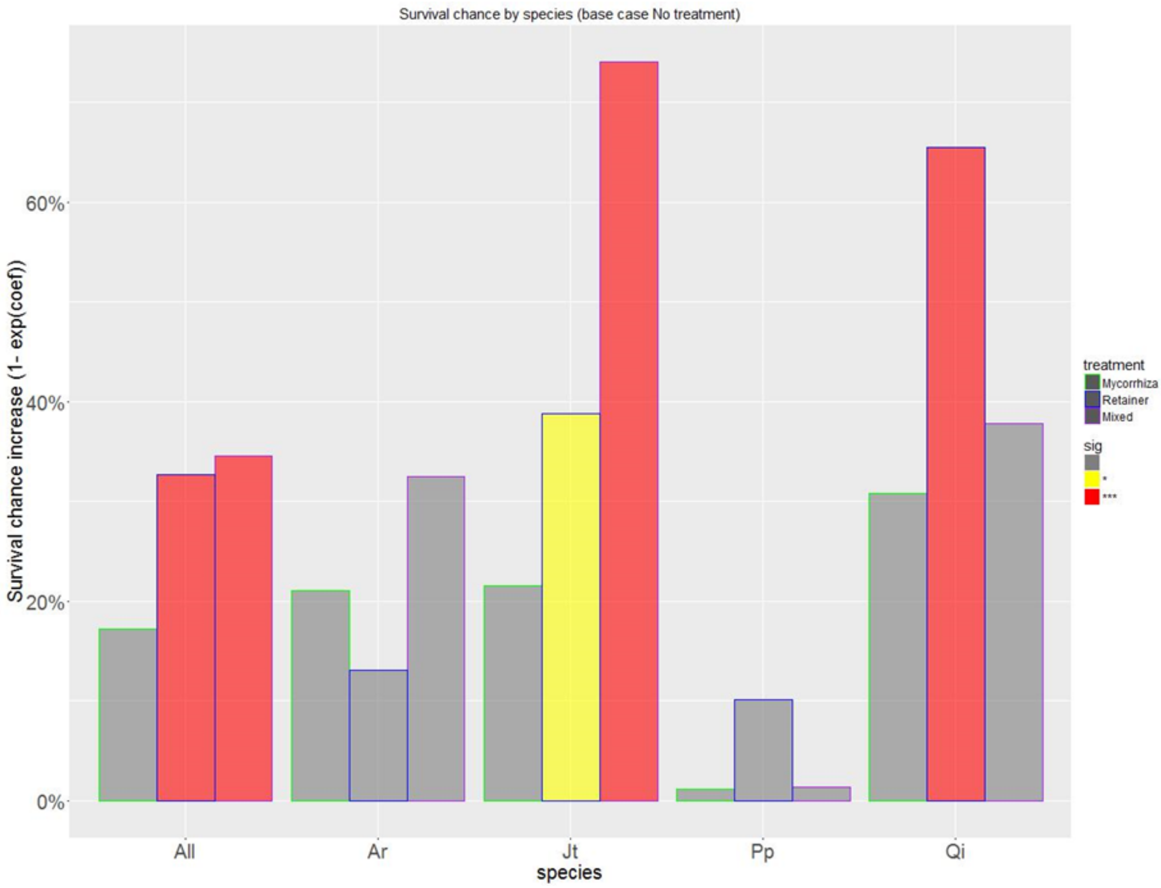
    - The magnitude of the increase was only significant for the mycorrhiza treatment.
    - The reasons for the absence of significant results may be due to measurement errors, the small size of the sample (64 trees), the big number of factors being consider (treatment, species and blocks), the high dispersion of the data and other unobserved factors.
    - The treatment decreased the absolute value of the difference of moisture between 20 and 40 cm.
    - The effect of the treatments on soil moisture depends on the soil characteristics.

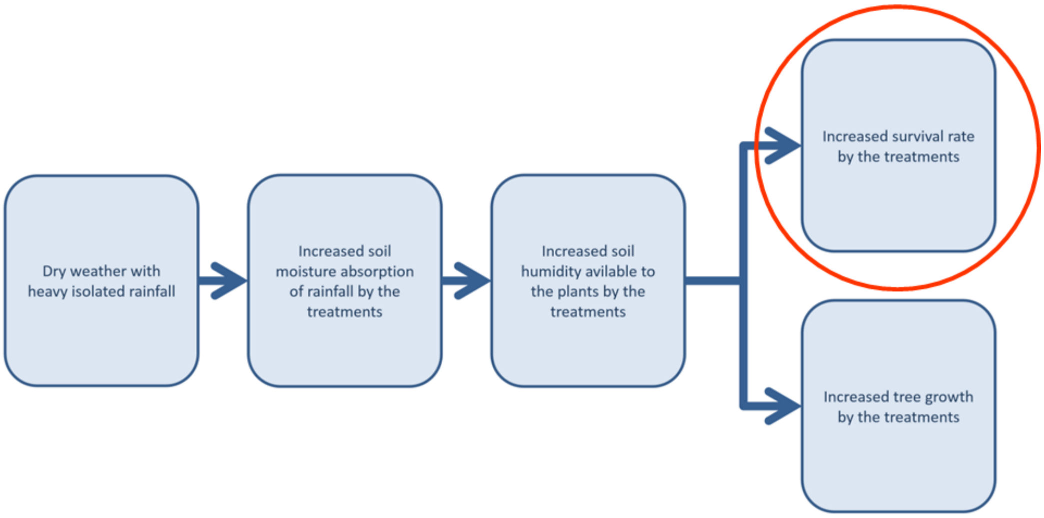


3. *Analysis of the effect of the treatments on the species survival*. <u>The treatments increase the survival rate of the trees.</u>

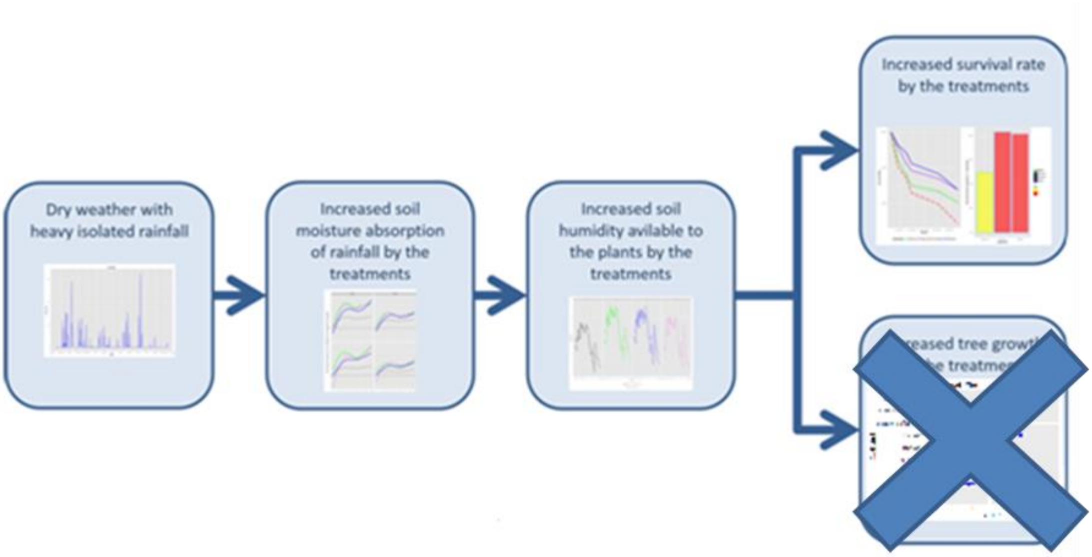
    - Considering all the species, the treatments showed to be effective, particularly when including retainers, increased the chance of survival rate more than 30%. The result was statistically significant. The effect was lower when using only mycorrhizas (17%) and the result was not significant.
    - The summary of findings when considering the whole plantation for each species:
        - Well adapted species such as *P. pinea* and *A. comunis* did not benefit from using treatments.

- The *A. campestre*, a more demanding specie, did not benefit from the treatment.
- *Q. ilex* are likely to benefit from using retainers, substantially increasing the survival rate (up to 66%).
- The *J. thurifera* also benefit for using retainers up to 74% on average when combined with mycorrhiza.





4. *Analysis of the effect of the treatments on plant biomass variables*. <u>The treatments do not seem to have a statistically effect on biomass at this stage of the plantation</u> (2.5 years after plantation).



Conclusions and tips

- The high complexity of measuring nature has to be taken into account. There are multiple variables that affect the development of species and cannot always be controlled when operating in the field. Therefore, big dispersion in the measurement should be expected challenging getting significant results.
- Select the data collection technologies more appropriate for your objectives. The data obtained in this project was very relevant for scientific and experimental purposes, mainly humidity and temperature of the soil, but this might not be the case of your project. In each case, a previous analysis of data requirement should be done.
- Most of the sensors in the market are developed to be applied in agriculture and the experience in forestry is still limited. Look for the most updated solution in the market and use technologies that have been previously tested in similar environments to yours.
- A possible risk is that the equipment may be stolen or vandalised. Consult the local authorities about the risks, analyse them carefully and design mitigation measures before installing your network.

A sensorized experimental chestnut stand

Background and context

The principal objective of the project was the analysis of the main eco-physiological parameters of chestnut trees and their correlation to study the two main conditioning factors that affect chestnut groves in El Bierzo.

Specifically, the project aimed to research phytosanitary conditions, climate change effect on water stress and the definition of optimal watering schedules.

There were some problems in plantations of chestnuts (*Castanea sativa*) that were addressed through the use of sensor network, namely:

- Phytosanitary conditions caused by pests (Chryponectria parasitica, known as Chestnut canker).
- Phenological and biological variables that directly affect both the maintenance and productivity of farms and disposal of the product.
- Constrains and limitations of chestnut harvesting.

There were also other needs to be analysed:

- Assessment of the chestnut tree clones resistance to the most common phytosanitary conditions.
- Foster the development of the sector through the implementation of support actions.
- Creation of general guidelines according to the environmental conditions of the region.

System design

Introduction

The research took place in Corullón (Castile and Leon, Spain) and the target species was *Castanea sativa*.

Experimental plot in the field

Nine trees were monitored using 'Treetalker' sensors (TT+) communicated by LoRa system, as follows:

- 3 healthy trees
- 3 trees affected by chestnut canker
- 3 trees affected but treated with hypo virulent strain

Detail view of the procedure for the treatment of trees affected by Chryponectria parasitica using Hypovirulent Strains (CH). Creation of holes of 1 cm diameter around the boundary of the disease (left), application of the inoculum with the Hypovirulent Strains in the holes (centre) and sealing, protection and identification of the treatment (right).

<u>Components of the system</u>:

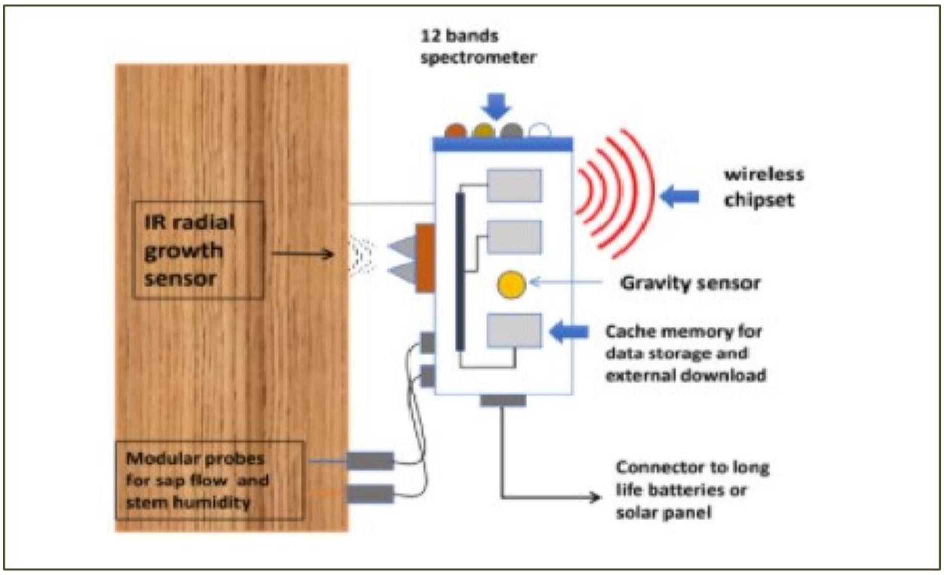
- 9 Treetalker sensors (TT+)
- 1 Soil wireless sensor (TT- Soil)
- Central computer GRPS or Gateway (TT – Cloud)
- Antenna
- Solar Panel Gateway (TT – Charger)
- TT+ power banks (+ solar panel)

INSTALLATION

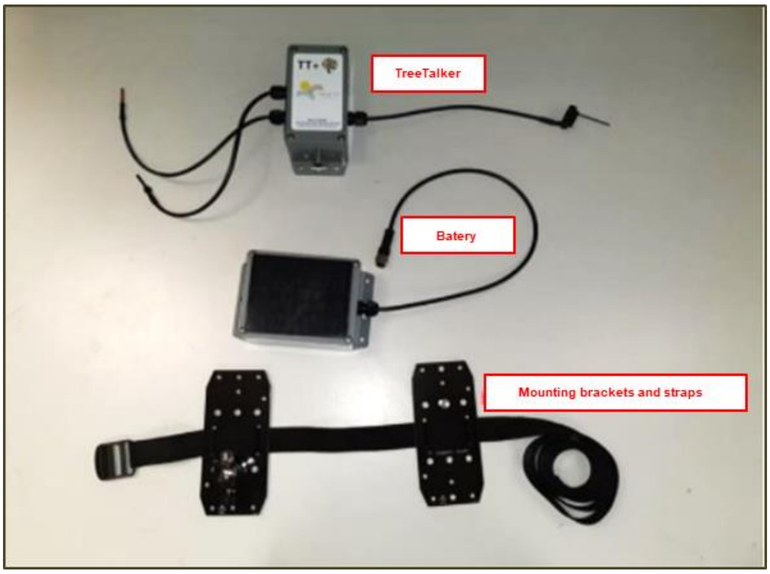
SENSOR	CODE	MONITOR TYPE
TT-Cloud	C19B0081	Gateway
TT+	C0796	Control without canker (SC)
TT+	C0799	Control without canker (SC)
TT+	C0791	Treated with hypo virulent strains (CHV)
TT+	C0794	Treated with hypo virulent strains (CHV)
TT+	C0795	Treated with hypo virulent strains (CHV)
TT+	C0788	With canker (CV)
TT+	C0792	With canker (CV)
TT+	C0801	With canker (CV)
TT - Soil	D190003	Soil Sensor

Sensor network in the field: gateway (left), TT+ installed in affected tree (centre) and TT+ installed in healthy tree (right).

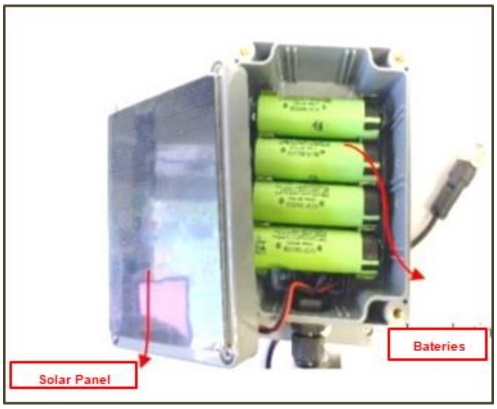
The different components and overview of the system is shown in a more detail view:



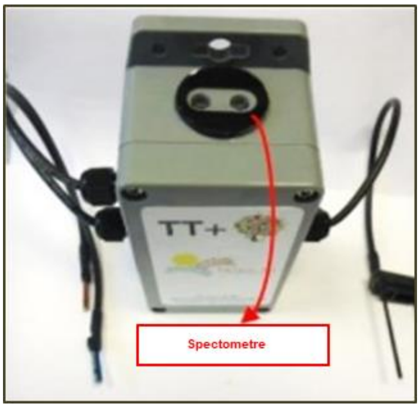
System overview



Tree Talker device, battery and the brackets and straps for attaching them to the tree.



Battery with solar panel for energy autonomy



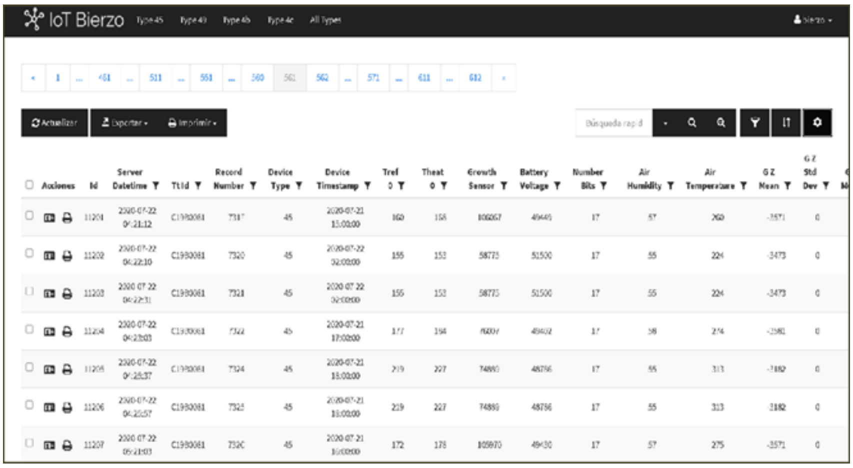
TT+ device in detail. 12- band spectrometer used to assess the canopy evolvement (left), and humidity, sap flow and growth sensor (right).

PARAMETERS

SENSOR TYPE	COMPONENT	DESCRIPTION
TT+ TreeTalker	Sap flow	Heating and reference temperature probe (+/- 0.1ºC)
	Inner moisture	Sensor MicroPCB (20x3x2) mm with copper plates
	Light penetration	12-band spectral radiometer (450, 500, 550, 570, 600, 650, 680, 730, 760, 810, 860 mm) (+/- 10 nm o +/- 20 nm)
	Radial growth	Infrared distance sensor (+/- 100 µm)
	Axial movement	Accelerometer (+/- 0.01º)
	Tª and air moisture	Thermohigrometer (+/- 0.1ºC; +/- 2%)
	Memory	16 Mb
	LoRa module	Transmission 600 m
	Battery	3.7 V

Data flow

1. LoRaWan protocol: wireless radio transmission of the information from TT+ to the TT-Cloud. To do so:
    a. Selection of the TT- cloud installation area.
    b. Communication, synchronization and pairing between each TT+ and the TT – Cloud.
2. Data transmission from GPRS to internet. It is needed:
    a. SIM card with internet service
    b. Programming the TT – Cloud and setting up the target server for the data collected by the network.
3. Data reception in server (Cesefor)
4. Development of the management platform for storage and data visualization.
    a. Data storage
    b. Data query
    c. Data export
5. Data analysis.



Management platform view

A sensorized *Pinus pinaster* forest to study resin production

Based on the operational group GO-Resinlab. More information and results at https://go-resinlab.com/

Background and context

The main objective of the project was to continuously monitor several physiological variables of the tree used for resin extraction, while measuring the resin pressure in real time in order to model its variation in response to climatic and physiological variables of the plant.

More specifically:

- Test a sensor for continuous resin pressure measurement.
- Study of the correlation between the resin production variable and climatic and physiological variables in real time.

The experimental plots were located in *Pinus pinaster* stands with traditional resin extraction management.

Test plot design

Five trees from Gata (Cáceres), three trees from Tardelcuende (Soria), four trees from Corbeta (Guadalajara) and three trees from Huerta del Marquesado (Cuenca) belonging to the Resinlab network of plots were monitored.

These plots were selected due to their good mobile network coverage for data transmission and the commitment of local resin makers to replace batteries when necessary.

Temporal resolution for data collection was establish in 1 hour. Every week the data collected was downloaded to:

- Early failure detection and proceed to re-install or replace the sensors affected.
- R script adjustment to automate data cleaning routines.
- Fitting models for resin pressure prediction as a function of physiological and environmental variables.

Sensor Network components

The equipment consisted of 3 modules: TT – cloud, TT – plus, TT – soil. It includes a microcontroller with a ATMega 328 processor chip enclosed in a box (11.5x6. 5x6 cm) that acquires signals form a number of sensors designed for the measurement of variables such as:

- sap flow
- wood temperature and humidity
- multispectral signature of light transmitted through the canopy
- radial growth of the tree trunk
- air temperature
- relative humidity

The TreeTalker has a wireless connection using a low-power LoRa chipset for data transmission to a node managed by another microcontroller (TT – cloud) serving up to 20 devices in a cluster. Data transmission is normally set to an hour frecuency.

TT- cloud

It acts as a communication link between TT+, TT- soil and the phone network for receiving, storing and sending data. The TT- cloud is in turn connected to the Internet via the GPRS network and sends the data to a computer server. It consists of the following elements:

- Electronic circuit for data management, enclosed in a waterproof box.
- Solar panel for power supply.
- Flash memory for data storage (16 Mbyte)
- Four lithium-ion batteries (3.7 V).
- Receive and send antenna (868 MHz).
- SIM phone card.

TT – plus

It measures and records the following variables of the stand on which it is installed:

- Sap flow rate (g cm^{-2} s^{-1})
- Temperature (ºC) and relative humidity of the trunk (%)
- Variation in trunk diameter (dendrometric growth, mm)
- Canopy light transmission

TT-plus with the sap flow and trunk growth probes (bottom), and the resin exudation pressure sensor (right).

Measurement of sap flow rate: were made using heat dissipation sensors (Granier 1987) (Murata Electronics; Japan; Model NCU18XH103F6SRB). This method is based on the continuous supply of heat through needles inserted inside the wood (sapwood), and the calculation of the sap flow rate as a function of the empirical relationship between heat dissipation and sap flow. The anatomical characteristics of pine wood are considered by applying a correction factor that distinguishes between ring-pored, diffuse-pored, and coniferous woods (Sun et al. 2011). The probe at the upper position is heated, while the lower one provides the reference temperature of the log wood and is additionally equipped with a capacitive sensor to measure wood moisture.

Measurement of trunk diameter variations: were made using infrared pulse distance sensors with an accuracy better than 100 µm (SHARP; Japan; Model GP2Y0A51SK0F) (Valentini et al. 2019). These sensors measure daily variations in shrinkage/stretch and diametric growth of the stem. They can detect unfavourable conditions for growth, i.e. they are able to detect situations of water or heat stress for the tree (Zweifel 2016).

Multispectral measurements of sunlight: were performed through 12 bands covering the visible and near-infrared spectrum and focusing on the wavelengths of 450, 500, 550, 570, 600, 610, 650, 680, 730, 760, 810 and 860 nm (maximum half-width of 40 nm) using a spectrometer with a field of view of 40˚ mounted on the top of the TT box.

TT – soil

It is the sensor in charge of recording the main meteorological data (atmospheric and edaphological) of the pine forest. It uses technology similar to that of the TT+. It is composed of:

- Electronic circuit for recording and sending data, protected in a waterproof box.
- Battery
- Capacitance sensor. It records frequency data (ECf) submerged in water and exposed to dry air.

It allows the measurement of the following variables:

- Air temperature (ºC).
- Relative humidity of the air (%).
- Water content present in the soil (%).

Sensor Network installation

TT- cloud

For the installation of this module, the following materials and tools are necessary: hammer, 7 cm nails, wire stripper, and screwdriver.

On a selected pine tree (located in the centre of the plot), the TT-cloud, its battery and a solar panel that will act as a source of energy supply were installed. They are fastened with two nails for each element. For the choice of its location, the incidence of solar radiation was taken into account, so that the TT-cloud and the battery were installed on the north side (minimum radiation), and the solar panel was installed on the south side (maximum radiation) to optimise its performance. Next, the antenna for receiving and sending data is placed.

Finally, to corroborate that the data is being sent correctly, check that the TT-cloud emits a green light every 15 seconds, visit the corresponding page where the data is stored (http://naturetalkers.altervista.org/CXXX/ttcloud.txt), XXX being the serial number of the TT-cloud.

Installation of a TT-cloud and battery (left panel), solar panel connected to the TT-cloud battery (middle panel) and the antennas (right panel). Detail of the two antennas: the grey one is the antenna for sending the signal, the black one (smaller) is the antenna for receiving information from the rest of the sensors.

TT – plus

The following tools are required to install the TT+: pliers, screwdriver, hammer, 7cm nails, drill, drill bits (15, 6, 4, 4, 3.5 and 3 mm), insulating adhesive (terostat), screwdriver, 1.5 mm screw, carpenter's glue, 6 mm pipe, syringe, needle, glycerine, and silicone. As with the TT-cloud and TT-soil, it is necessary to make sure that the sun does not shine directly on the sensor (install on the north side). On the other hand, the battery has a small solar panel for charging (install on the south side).

1. As a first step, with the help of the screwdriver, a portion of the pine bark is smoothed (as a notch) leaving approximately one centimetre of bark thickness. It is in this space where the TT+ and its different probes will be fixed. To determine the bark thickness, we use a specifically designed bark thickness gauge (Fig. 1).
2. The TT+ is fastened to a metal plate (by means of a thread) and in turn, this is nailed to the pine tree.
3. The sensor is oriented with respect to the vertical at an angle of 40° for proper recording of the light transmission of the crown.
4. With the fifteen millimetre drill, two holes are drilled (without reaching the cambium) vertically aligned at a distance of ten centimetres. In the centre of these, the pine is drilled with three and four millimetre drills to insert the probes into the sapwood of the xylem that will measure the speed of sap flow through heat pulses and the humidity and temperature of the trunk. Each probe is inserted with the help of a heat conductor in order to facilitate thermal contact between

the probe and the xylem. Finally, the installation is sealed with Terostat to limit the entry of air that could cause noise in the reading (Fig. 2 and 3).

Fig.1: Bark thickness measurement. It is necessary to press the flat tip of the gauge on the bark around the place of installation of the sensor, press the round tip into the bark with the hand. As soon as the tip no longer penetrates the trunk (it has reached the cambium layer), note the bark thickness by looking at the scale and remove the gauge from the trunk.

Fig. 2: Detail of sap flow measurement and insulation sensors with Terostat (left panel), detail of dendrometer installation (right panel).

5. For the installation of the dendrometer, with which we record the measurement of the diametral growth of the trunk, we locate the smoothest and most uniform area possible in the bark of the pine tree. Here, the location of the heads (needles) that fix the sensor to the pine tree will be marked with the punch. With the 3.5 mm drill bit, the respective holes are drilled. The dark box is placed in order to avoid direct radiation, as the reading is done by means of an infrared distance sensor (between the reader and the bark of the pine tree). The heads are smeared with carpenter's glue and inserted into the pine. To fix the installation to the pine, the box is fastened with two screws (Fig. 2 and 3).

Fig. 3: Installation of a TT-plus with its corresponding battery and probes.

TT – soil

The following tools are required for the installation of the TT - soil: hammer and 7cm nails.

It can be installed in the same pine in which the TT-cloud has been installed, or in its vicinity depending on the space available and the protection of the surroundings from potential damage caused by foot traffic (to be chosen by the technician together with the resin layer). As with the TT-cloud, the box and battery are installed on the north side to avoid direct sunlight. Once the box and battery have been placed in the pine tree, the probe is introduced into the ground to obtain the soil moisture content data.

Development and installation of the resin pressure sensor

Necessary adjustments in the electronic circuit for the development of the resin pressure measurement sensor to be implemented in the TreeTalkers: we start from elements such as manometers used to measure this variable (Perrakis and Agee 2011, Rissanen et al. 2016, 2019) and from the results obtained in previous studies conducted by the UPM in collaboration with the University of Ghent.

Specifically, the Jumo Midas C08 Type 401002 model, with pressure recording between 0 and 25 bar, will be modified and a 6 mm rubber tube will be adapted to be inserted into the xylem of the monitored foot. In this way, it is possible to In this way, it is possible to continuously record the resin pressure, without the need to record discrete data by reading the manometer beforehand.

Resin pressure sensor resulting from previous collaborative work between the UPM and the University of Ghent (Belgium).

For the installation of the resin pressure sensor, a hole with a 6 mm drill is drilled horizontally in the pine. The depth of the hole shall be 6 cm distributed as follows (Fig. 14):

a. Two centimetres of empty chamber where the resin is stored.

b. Three centimetres of xylem wood.

c. One centimetre of bark.

A seven-centimetre-long tube is then cut and pressed into the hole with the distances distributed as follows:

a. Three centimetres into the wood (xylem) of the pine.

b. One centimetre into the bark.

c. Three centimetres outside the tree.

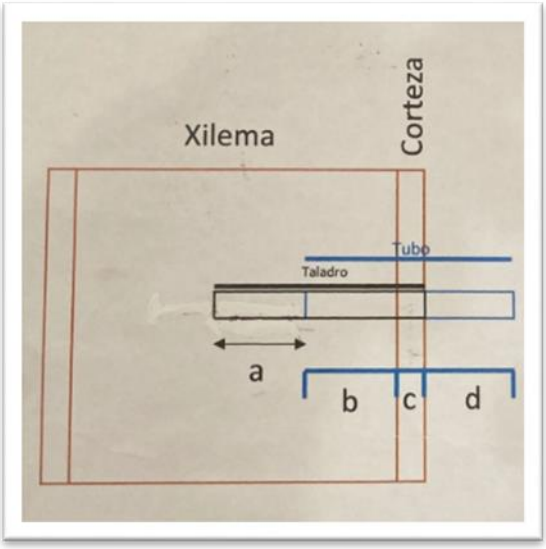


Diagram of the distance distribution for resin pressure measurement, where "a" is the resin accumulation chamber in the xylem, "b" the xylem section with tube, "c" the bark section with tube, and "d" the remaining part of the tube to be inserted in the pressure sensor.

Once the tube is in place, both the tube and the sensor head are filled with glycerine (using a syringe and a needle) and are coupled together without leaving any air inside to limit resin crystallisation in the tube. The glycerine acts as a resin pressure transmission vector in the tube. To seal the installation and make it as airtight as possible, it is isolated from the atmosphere with silicone applied to the crust surrounding the tube. This prevents the ingress of air which would cause the resin to solidify and affect the measurements.

Use of glycerine as transmission vector (left panel) and insulation of the pressure sensor with silicone to prevent air ingress (right panel).

4. How to sensor a plantation step by step

Here are its main features to implement effective smart digital forest sensorization techniques.

1. Using Satellite Data. All analytical information presented on the platform is based on satellite data. The received data is processed and interpreted in such a way as to give users a deep understanding of their fields' state.
2. Data Mapping for parameters and surface to be sensorized
3. Historical Data and Forecasting
4. Telecommunications infrastructure coverage to support wireless sensor networks
5. Choose the IoT platform to support the network deployed on the farm.

How to select the right IoT platform?

Choosing the right IoT platform(s) can be daunting. There are hundreds of options and vendors at each layer of the IoT Technology Stack. You'll need to do your research to determine the best option for you.

If you are not familiar with the IoT space, it's a good idea to get a third-party perspective from industry analysts like Gartner or IoT Analytics. Then you can zero in on specific vendors that fit your needs.

When selecting an IoT platform, you need to consider much more than just the technical capabilities of their solution. You are looking for a combination of technical, business, and operational capabilities that align with your company strategy and where you are in your product adoption lifecycle.

For example, if you are early in your journey, you should focus on IoT platforms that can help you build and test prototypes very quickly. Scalability, cost, and feature set should be less of a concern.

As you move towards market fit and scale, the focus should shift towards IoT platforms with more scalability, stability, and a global footprint.

Keep in mind that when you are transitioning to scale, you might need to completely re-platform your product, and that's okay. As Product Leaders, we need to set clear expectations with Executives and Investors. As your product adoption increases, it shouldn't be a surprise to them that your team will need to spend time refactoring the product for scale, which may mean transitioning to a new set of IoT platforms to support this new stage.

Here are 5 key areas to look for when selecting an IoT platform:

- Reputable company. IoT is risky enough as is. Trusting the core of your product to an unknown company might backfire. Make sure you evaluate their reputation, stability, financials, and track record.
- Large ecosystem. IoT is so big that there's no way a single company can dominate it all. Looking for a company with a strong app and partner ecosystem will be a good investment in optionality and expansion. Most of the top IoT platform providers don't do hardware themselves, but have a strong partner ecosystem to pull from. That is always a good sign.
- Open APIs. Extensibility will be key, so make sure you select a provider that gives you programmatic access to as much of their functionality as possible.
- Vertical focus. Aligning with a vendor that understands your industry is always a plus. Their solution will be designed to handle your type of data, analytics, and even help you comply with industry regulations.
- Strong on-boarding. Adopting a new platform is not trivial. Look for companies that have a strong solutions department (or professional services) that can train your team, help you with the architecture, and guide you through the proof of concept stage.

Ultimately, you are looking to build a partnership. It's a complex decision, and one you can't make alone. It'll require you to work closely with various groups in your company, including Engineering, UX, Data Science, Finance, and more.

Should you build or buy your IoT platform?

By now, it should be clear that there are many benefits to leveraging commercially available IoT platforms. But believe it or not, many companies, particularly those who are engineering-driven, believe that they need to build every single piece of their IoT solution.

These companies spend years and millions of dollars building non-value-added infrastructure, instead of focusing on building differentiated features to serve their customers.

So let me be clear. You simply don't need to build the complete IoT infrastructure yourself. There's no point reinventing the wheel.

By using commercially available IoT platforms, you reduce your development costs because you have more functionality sooner, with less engineering effort. This means you can focus your engineering team on what really matters: your core value proposition.

Think about it. IoT platform vendors have large teams of developers improving features, fixing bugs, and making sure their offering is rock solid. That is their business, so it makes sense for them to invest in it. By leveraging their work, the quality and stability of your product will ride the wave of their investment.

Use cases

Case A. Build your own kit

This scenario requires more experience in networks and electronics. You can take advantage of controlling your entire infrastructure and costs can be reduced.

Electronic shops

https://wiki.seeedstudio.com/

Case B. Set up infrastructure with end 2 end IoT Platform

The main advantage of this e2e platform is that you don't need to worry about technology. These solutions implement a complete IoT infrastructure stack.

Libelium (commercial example)

How to start: https://2318222212-files.gitbook.io/~/files/v0/b/gitbook-x-prod.appspot.com/o/spaces%2FhO0Cq0QDhVmiuGzYINXY%2Fuploads%2FTZ3jBV1pIbigaV1jaBR9%2FOne%20-%20Quick%20start%20guide.pdf?alt=media&token=d45c7740-d6ba-470c-b0d5-4ff3f5c1a95b