PROJECT IMPACT

19016

Miniaturized monitoring sensor systems for plants and agriculture.

PLANtAR

July 2024

PLANtAR developed cost-efficient, miniaturized, networked, biodegradable monitoring electronics to help tackle one of the world's biggest challenges: producing enough food over 9 billion people while also protecting the environment.

PLANtAR partners acknowledged that plant and environmental sensors or complete monitoring systems in the agriculture application field are in the range of 300 € up to thousands of euros, focused on professional users and complicated to use and therefore not suitable for a mass market or for a simple private usage. In addition, all the systems must be manually recovered at the end of the growing season which is time consuming and associated with high costs. Further costs arise due to expensive battery changes. Then, nanotechnology sensors are still limited by complexity, limited sampling frequency (single use tests) and/or the low sensitivity and selectivity. Finally, fully biodegradable and low-cost sensors which include all the necessary wireless sensor components (substrate, microcontroller, sensors, antenna, power supply and housing) are up to now not available in the market.

To address these issues, the PLANtAR project focused on development of affordable, highly integrated, miniaturized sensors and close-mesh sensor networks (including nano-sensors and paper-based microfluidic devices) and application intelligence in three areas: precision farming (field / urban), greenhouse / indoor farming and farm monitoring. In addition, it aimed to reduce the environmental impact and 'de-installation' costs of these technologies by ensuring that the sensors are biodegradable, so they can be left in place after their use and simply ploughed back into the soil.

With its ambition to provide for high-volume markets, PLANtAR aimed specifically to create low-cost sensors for the detection of pests and plant pathogens (putrefaction), soil moisture, leaf wetness, ammonia, CO_2, electrical conductivity (EC) and nitrate content (NO_3). It also wanted to work on creating highly integrated circuits and interfaces including signal pre-processing and battery management for connected sensor systems. By creating an ultra-low power microcontroller with an integrated transceiver and suitable interfaces that connect to different sensors, the PLANtAR consortium achieved the highest levels of integration and signal analysis at low power operation. This work also covered new combinations of interface materials and production technologies to meet the requirement for biodegradability.

As mentioned, biodegradability was a key challenge within the project and PLANtAR explored how printed electronics could be used to solve this challenge, creating devices that are almost fully biodegradable and have an adequate energy supply and data transmission capability.

Achievements and results of the project

As main achievements in the project PLANtAR we can emphasize the following:

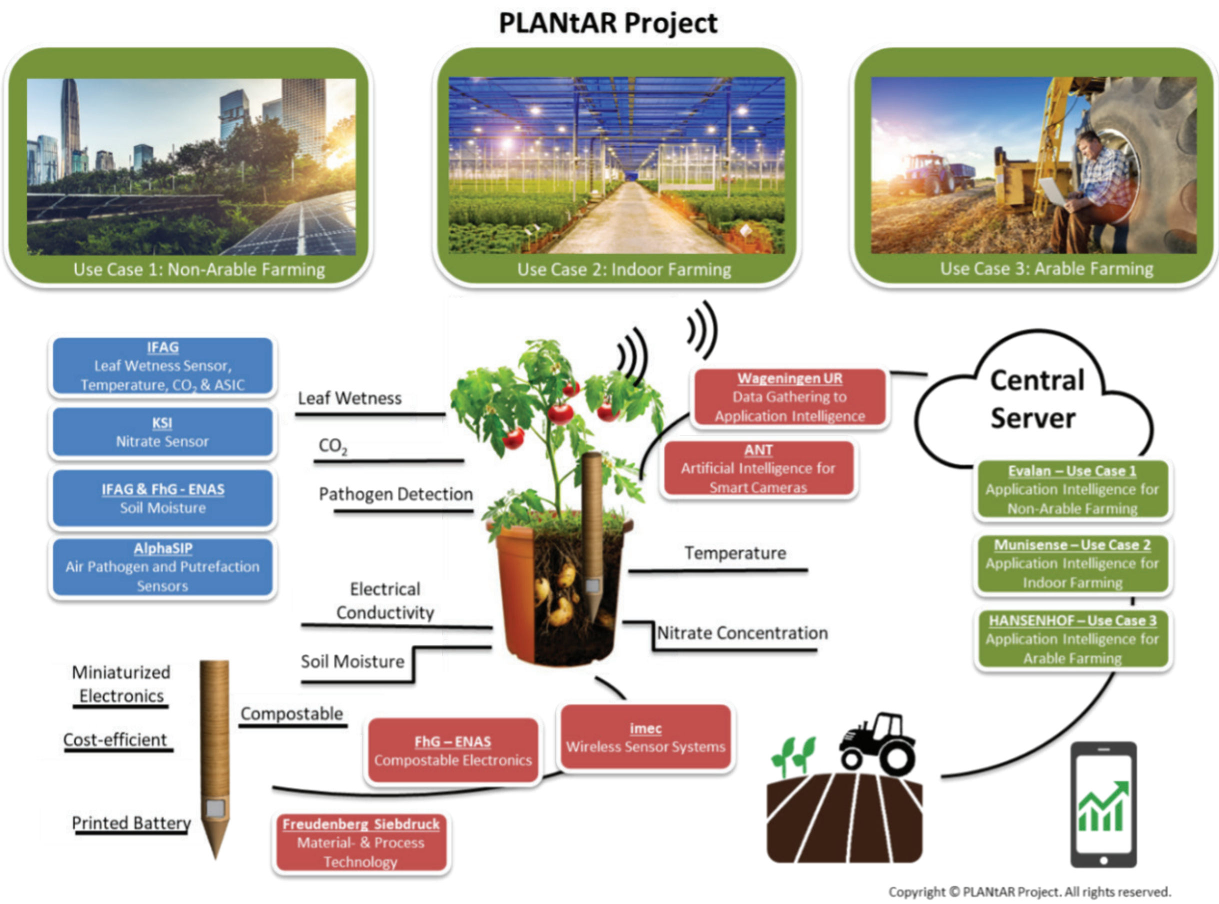
1. New and improved sensors and systems for use in the agricultural sector as well as in greenhouses or for ornamental trees – soil moisture sensor, EC sensor, nitrate sensor, CO_2 sensor, e-nose, camera surveillance system, putrefaction sensor and leaf wetness sensor – mostly low-cost.
2. Biodegradable smart systems that are consisting of sensors, a power source, a communication unit and other electronic components all integrated in a proper housing, low-cost, biodegradable and harmless to the environment – printed batteries, biodegradable housing materials, integration technology for biodegradable sensors and ICs as well as low-cost manufacturing processes based on printed electronics, antennas on biodegradable substrates and new ASIC technology.
3. Integration of different PLANtAR Sensors in Cloud & IoT Gateways.
4. 12 Different demonstrator set-ups for testing the biodegradable technologies as well es the developed sensors in the area of non-arable farming, indoor farming as well es arable farming.

Background, objectives of the project and challenges

The technological challenges addressed in the project were in the realization of affordable combination of close meshed sensor networks and application intelligence in order to allow for Precision Farming, Indoor Plant Monitoring and Farm Monitoring as well as limiting environmental impact at the end of use:

1. **Low-cost, highly integrated & miniaturized sensors:** The availability of low-cost and miniaturized sensors is essential for a high market penetration. Research efforts were spent on sensors for detection of plant pathogens (putrefaction), temperature, soil moisture, leaf wetness, CO2, EC and NO3.
2. **Highly integrated circuits, interfaces, signal pre-processing and battery management:** An ultra-low power micro controller with an integrated transceiver and suitable sensor interfaces to connect different sensors wanted to be adopted for highest integration level and signal analysis at low power operation. Furthermore, the design of the µC should allow for a minimum of peripheral components. Specialized firmware have been developed to manage the µC deep sleep mode.
3. **System Integration:** Based on the requirement of biodegradable, low-cost electronics suitable interconnection and system integration technologies have been delivered. New combinations of interface materials and production technologies have been evaluated.
4. **Printed electronics based on biodegradable materials:** The printed circuit board, the antenna, the battery, some sensors and the housing of the sensors should be made of biodegradable materials. It allows for leaving the sensors at the field after harvesting. The sensors need to be biodegradable and decompose after plowing and harrowing when they are mechanically destroyed and mixed with the ground. The development of the printing technology that is suitable for biodegradable substrate materials will be a challenge.

As main challenges in the sector of arable farming but as well for greenhouses, drought and costs of irrigation, the EU nitrate directives (limited nitrate use to 80% of crop potential and high fertilizer costs), chemical costs for pests and diseases as well es the salinity of the soil can be stated. There are several causes for crop stress in the environment like nutrients, the climate as well as the availability of water.



Technological achievements

In the framework of PLANtAR the partners worked on different new agriculture or environmental sensors, technology parts, the integration as well as on different applications in a partly biodegradable way. The following shows the key technology breakthroughs of the single partners: Sensors:

The first sensor PLANtAR (IMEC) worked on was a novel EC sensor for measuring inside hydroponic rockwool substrates. Next, we worked on the validation of miniaturized EC sensors in a greenhouse environment and verified the feasibility of using those sensors to provide fine-grained insight in the growing process. KSI developed a potentiometric nitrate sensor which has demonstrated effectiveness in two crucial environments: surface water analysis and direct soil measurement. The sensor is constructed in an all-solid-state configuration using screen-printed technology, providing high stability and reproducibility, resulting in accurate and consistent measurements over an extended period. The sensors can detect nitrate even in challenging environmental conditions, such as after a drying phase. The sensor components are made of 99% bioinert materials and are designed in a miniaturized format for cost-effective sensor production. The goal of the biocompatible, capacitive humidity, and leaf wetness sensor (IFAG) was to measure the local microclimate properties of leaves and the duration of wetness for pest management. Instead of mimicking leaf properties, this MEMS sensor is miniaturized to be attached to the real leaf and is intended to have very similar properties as the leaf. The sensor is coated with biocompatible Parylene C. The coating serves as a protection layer and as a sensitive layer. In the famework of PLANtAR, also a CO2 Sensor (IFAG) in a small form factor and with low production costs has been developed to measure the CO2 amount in greenhouses. The sensor worked quite well and has been tested at a mushroom grower during the project time.

Next, two kinds of electronic noses have been developed. First, we developed a sensor device for the sensitive detection of 3 relevant gases in the crop production, a portable, miniaturized and multiplex sensing instrument (AlphaSiP). Second, we developed an E-Nose (ANT): Development and validated on real conditions (from TRL2 to TRL 7) a novel, portable, economic and non-professional E-Nose based on an array of 12 commercial sensors (MOX, EC, NID technology…), detect industrial tomatoes' VOCs on crops: ripeness stages and putrefaction events by fungi (*Botrytis cinerea*). The E-nose is combined with an optical lateral flow rapid test reader to confirm by molecular methods the presence of *Botrytis cinerea* fungus.

Fraunhofer ENAS has developed various technologies and components for the realization of an almost biodegradable sensor stick for agriculture. This represents a complete sensor system and includes a battery and antenna printed on paper, inert electronics for sensor readout and data communication, a fully biodegradable and cost-effective soil moisture sensor, the inert nitrate sensor from project partner KSI and integration technologies for housing the components in an also fully biodegradable sensor housing.

Finally, the consortium also worked on a camera Surveillance System (ANT) - an Artificial Intelligence Surveillance and Prediction camera system (from TRL 2 to TRL 5) with economic-regular cameras to offer an affordable and nonprofessional use (without satellite or drones images) to help to monitor and detect optimal harvesting time. Validation of detection of tomatoes and cherries ripeness stages on crops.

Next to the sensors the project worked on printed electronics and sensor platforms systems which can be used for agriculture. In that content, the partner Freudenberg managed to print a very stable conductive trace which can be soldered to. The achieved resolution is 0.2mm which enables one to use smaller components compared to conductive glueing technologies. Munisense worked on a platform which is compact (60% of previous platform) for both measurement and telecommunication. Because telecom is geared towards sub 1 Ghz for range and we required a PCB-integrated antenna, the size of the platform was a major challenge due to the ground-plane being part of the PCB. As part of our continuous improvement the battery life improved by 10-20% which allows us to use a smaller battery for a number of applications; again, allowing reducing the size of the platform to ca 40% of today's production platform. Evalan developed a versatile IoT Middleware (Platform) Solution that can connect Sensors and Assets to Applications in the Cloud without the need for development or engineering. This solution was tested in various demonstrators in Agriculture and Horticulture, for ease of use, durability and operational reliability.

Finally, and next to the development of technologies and sensors, the consortium worked on the testing of the single components in a real atmosphere, in our case in the area of agriculture and greenhouses. The Wageningen University and Research has conducted an exploration into the application possibilities for the PLANtAR sensor prototypes for 3 application domains (indoor, outdoor and precision agriculture). It supported other partners sensor developments from the state-of-the-art perspective of the foreseen use cases. All sensors have been tested and evaluated under semi-practical conditions in the lab, a research greenhouse or at growers. The CO2 sensor from Infineon/Evalan has been demonstrated at a mushroom grower, and the moisture sensor from Munisense has been demonstrated at an ornamental pot plant and tree grower, together with the developed decision support system (DSS) for irrigation. Grodan gained more insight in the needs of greenhouse growers and sensors. Besides this they learned that miniaturising sensors, preferably biodegradable, is possible in the very near future. More attention is needed to transfer knowledge gained into MVP solutions.

Market Potential

According to the United Nations, the world's population has surpassed the milestone of eight billion people, and a further increase is projected. Thus, on the one hand, increasing food production is required. On the other hand, farmers have to reduce the environmental impact. The European Commission plans in the Farm to Fork strategy to reduce the use of chemical plant protection products by 50 % until 2030 as part of the European Green Deal. Smart farming is necessary in order to reach this reduction goal by knowing: the right time, right place, right amount, and right input of treatment on nutrients. Therefore, smart farming reduces the ecological footprint and also new business models with high quality and health benefit crops are possible. As farmers have to produce more food in a sustainable way, integrated pest management (IPM) is identified among others as a key element. Instead of traditional systems based on fixed dated or phenological stages, data-driven pest management is favorable. Sensors can help to increase crop growth, reduce crop damage, or save energy in maintaining the climate. These facts are exactly why PLANtAR was setted up why the single developments are having a big market potential in the future. They have a potential use case in optimizing this balance. The following will show an overview about the market potential of the single technologies the PLANtAR partners worked on:

- The market potential for the soil moisture sensor developed by FhG ENAS is difficult to estimate. However, they assume that this technology and potentially also some of the developed components can be transferred to industry or can be used as a basis for further research activities
- From KSI side, further investigations are being planned to assess the nitrate sensor's performance in agricultural applications. Collaborating with potential partners in Germany and Spain, who have experience in autonomous field monitoring, will facilitate the analysis of the nitrate sensor by integrating it into their existing systems
- E-Nose (ANT): Application link the whole value chain of tomato: from agri-food market to tomato production, processing and distribution chain. The sales strategy will be first a national expansion (Spain) and then an international expansion (Portugal, Mexico, USA, China, India...). Initial national and international sales forecast for 2026 and 2027 and sales for 8M€ for 2030
- AlphaSip: Development of additional sensor elements (including physical sensors), and integration in the multiplexed instrument. Development of control software (ML/AI) and IoT communication system. In field validation of sensor device. The concept of using synthetic images for (training) simulators has already existed for quite some time and more recently, synthetic images are being used for the training of AI algorithms (see Xecs TASTI Project).
- Camera Surveillance System (ANT): Precision or 4.0 Agri-food market. More difficult to penetrate the market due the great competition and lack experience of ANT. Most likely, it will be sold to a third-party company and ANT will be responsible for installing the cameras
- Evalan's IoT Middleware (Platform) Solution can be used across the entire spectrum of IoT Use Cases and enables companies to bring their IoT Applications and IoT Concepts to a mature Product or Service quickly. Evalan therefore anticipates that the potential for scale-up of this solution is significant
- IMEC : The developed technology has great potential in the high-tech greenhouse market, where the insights that it gives can help to increase crop yield, improve predictability of the production and achieve better quality
- Leaf wetness and microclimate sensing are essential because moisture and temperature are parameters that can be linked to how diseases spread, especially fungus and oomycetes. The agricultural sector shows an annual growth rate of 21% in global spending on enterprise internet of things (IoT) technology. That makes it one of the sectors with the highest spending increase in the IoT market. In the next 10 years the IoT Market Size is predicted to grow at 17.2% CAGR and the IoT Platform Market Size at 15.0% CAGR
- WR mainly foresees a market potential for its developed DSS for irrigation of container plants, apart from using the newly developed sensor prototypes from the other partners in further new to setup agro-sensor research projects. This DSS uses artificial intelligence technology to form a digital twin of the process, and has the unique feature that it can cope with uncertainties like individual calibration errors when using low-cost sensors.
- Autonomous agriculture with multiple sensors is developing rapidly and Grodan expect that in 10-15 years the majority of greenhouses in Europe will be autonomously controlled. They are eager to support this development in providing sensor technology to growers in order to achieve this
- There is as well a market demand evolving using additive manufacturing of conductive and materials on glass and meanwhile having contact to classical SMD components. First potential customers will come to sampling phase in 2024 (Freudenberg)

- Next, the market for compact outdoor, environment/agriculture sensing is very high. The hardware and software technology developed in this project (Munisense) gets us a step closer to new products in these challenging markets.
- The targeted, small-scale application based on eGrains saves application costs and secures yields, which ensures the profitability of cultivation, on the one hand, and on the other hand, application materials are saved or only used when necessary, which relieves the burden on the environment and thus defuses the conflict that has sometimes been observed between society and agriculture. A big market for the new technology is seen in Central Europe, particularly in high-quality crops.

Societal & Economic Impact

As already shown in the chapter before, the technologies developed in the PLANtAR project will have a big societal & environmental as well as an economic impact. This technologies have the possibility to help to reduce the cost and ecological footprint of food production and improve the economical position of countries like The Netherlands, Spain and Germany as an exporter of food and greenhouse technology.

The developed sensors for agriculture can support farmers in their decisions and enables nitrate fertilization and irrigation application in line with requirements and therefore preventing excessive leaching of nutrients to ground and surface waters (environmental impact). It also saves farmers time and burden during summer time when irrigation demand is highest, while trying to cope with a logistic puzzle of allocating water to multiple plots on their farm (societal impact). Next, they allowed early detection of diseases like fungus and oomycetes in cultivation and reduce the use of pesticides as well as the optimal harvesting time to minimize losses, which all over save costs. Also real-time monitoring of crops allows farmers to save time and work, making them more profitable and productive as well as more attractive to the young population.

All over this can increase the food production or reduce the use of resources, which in turn leads to economic benefits. Environmental pollution and the loss of biodiversity can also be reduced.

In addition, a major advantage of the developed almost biodegradable sensor is, that damage to the sensor itself does not lead to environmental pollution, which can be seen for conventional sensor systems available on the market.

Water scarcity, efficient use of nutrients and reducing greenhouse gas emissions are challenges for agriculture in the coming years. Smart miniaturised sensors at low-cost are key in not just monitoring progress, but also to achieve the sector's environmental goals through data supported decision making.

IoT is an enabler of applications and solutions that contribute to sustainability, better food at lower costs and improvements in healthcare. IoT Middleware (Platform) Solutions, like this from Evalan, accelerates the speed with which solutions that deliver real Societal and Environmental Impact can be applied, and it removes much of the development by delivering a out-of-the box building block for the solution.

The biological processes are complex and still a broad field of research. Losses in crop production from mildew are among the largest sources of yield reduction in susceptible crops. When the infection has begun, prolonged periods of high temperature and humidity cause increased rates of mildew production and spread. Especially the podosphaera xanthii grows in warmer temperatures around 22° C and saturated atmosphere. Also for cases like that, the developed sensors out of the project PLANtAR can help to unlock new opportunities for prevention.

Patents, Standardisation, Publications

During the 40 month of project running time of the project PLANtAR, the consortium created all over 35 scientific publications. Some of them were created for magazines as well as we had some publications just for LinkedIn, webpages and agricultural blogs.

Next, the consortium took part in around 20 dissemination events. On a few, PLANtAR was available with a project booth (for example the EFECS Event 2021 and 2022), posters and in-front-presentations, on others, just single partners were present and spreading the vision of PLANtAR.

There were no patents during the project running time of PLANtAR.

Future Developments

Regarding the big market potential of the developments out of the project PLANtAR, most of the partners also see a big potential for future developments. In the following, a small outlook of every single partner has been collected:

- **FhG:** The sensor stick is not yet 100% biodegradable. In the future, some critical materials are to be replaced or greatly reduced. Technologies must also be further developed or newly developed for this purpose
- **KSI:** Further investigations are being planned to assess the nitrate sensor's performance in agricultural applications. Collaborating with potential partners in Germany and Spain, who have experience in autonomous field monitoring, will facilitate the analysis of our nitrate sensor by integrating it into their existing systems

KEY APPLICATION AREAS

Digital Industry

ESSENTIAL CAPABILITIES

Systems and Components: Architecture, Design & Integration

Process Technology, Equipment, Materials and Manufacturing for ECS

PARTNERS

Infineon Technologies AG (IFAG)

Kurt-Schwabe-Institut für Mess - und Sensortechnik Meinsberg (KSI)

Fraunhofer Gesellschaft – ENAS (FhG)

Hansenhof Electronic GmbH

Freudenberg Industrie Siebdruck GmbH

Munisense BV

Evalan BV

Stichting IMEC Nederland

Wageningen University & Research (WR)

RockWool B.V. (Grodan)

AlphaSIP Santa Clara

Alianza Nanotecnología Diagnóstica ASJ, S.L. (ANT)

COUNTRIES INVOLVED

Germany

The Netherlands

Spain

PROJECT LEADER

Ms. Ulrike Glock
Infineon Technologies AG

www.plantar-project.eu

KEY PROJECT DATES

1 November 2020 - 29 February 2024

- **Freudenberg Industrie Siebdruck will promote the material stack** and tries to derive new products from it. This will save resources in production and via the overall product lifecycle
- **Hansenhof is thinking about developing additional sensors** to record plant parameters in order to be able to monitor their progression over time
- **IFAG:** Leaf wetness sensor – Further testing of possibilities for applications at arable and indoor farming; CO2: Improve battery lifetime (i.e. low power mode), extended sensor calibration, introduce advanced cross sensitivity compensation
- **Evalan will continue to build and strengthen its IoT Middleware (Platform) Solution** by adding new functions and features, by adding new communication protocols and by improving speed, data transfer rates, flexibility and versatility
- **IMEC:** The technology of the silicon-based EC sensor has been transferred to a partner company. IMEC investigates its usage in biomanufacturing / bioreactors and applying the experience in the greenhouse sector for their developments towards an autonomous greenhouse
- **Grodan:** Main challenge from this project will be to develop MVP's that are sales ready. Furthermore, reducing cost and improving accuracy of sensors will be the main topic in the next decade
- **Munisense:** The most important next steps are to make compelling applications which will involve both software, data intelligence and pilot projects to demonstrate the value
- **WR plans to collaborate with PLANtAR partners in projects to further develop applications for the PLANtAR sensors for the technology domains:** autonomous growing, circular horticulture and vision and robotics. Applications foreseen are a.o. a nitrate sensor for monitoring leaks from greenhouses (EU legislation), an eNose for detection of diseases in greenhouses, a biodegradable soil moisture sensor for lane trees, a cheap EC-sensor for precision fertigation in horticulture and a camera system for real-time phenotyping in greenhouses
- **AlphaSip:** Development of additional sensor elements (including physical sensors), and integration in the multiplexed instrument. Development of control software and IoT communication system. In field validation of sensor device
- **ANT: 2024-2025:** Optimization of Tomato E-nose (time, box capture sample, application of Artificial Intelligence, detection of other pests...) to be used on: crops, greenhouses and Q&C processes on industrial tomato juice. ANT has obtained funding from Extremadura regional government for this development during 2024-2026. 2026: start industrialization and sales. Furthermore, this device will be applied in 2025 on olive oil and wine production. Finally, the E-nose will be applied to drug of abuse market, where ANT is also working; Camera Surveillance System: 2024-2025: Improve image resolution from the crops tested to try to predict production by quantifying yolks. Introduce hyperspectral and multispectral cameras. Connect to other sensors as Tomato´s Nose