Fraunhofer ENAS

Chemnitz Seminar »Health Systems: Sensor Systems for One Health«

Environmentally friendly, partially compostable Sensors for Agricultural Applications

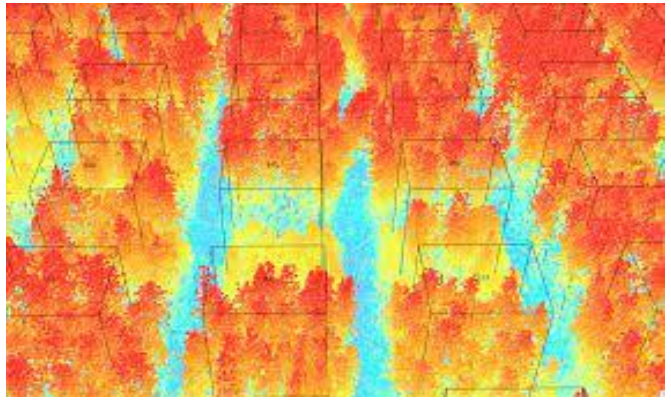
Sven Voigt

PLANtAR

Motivation

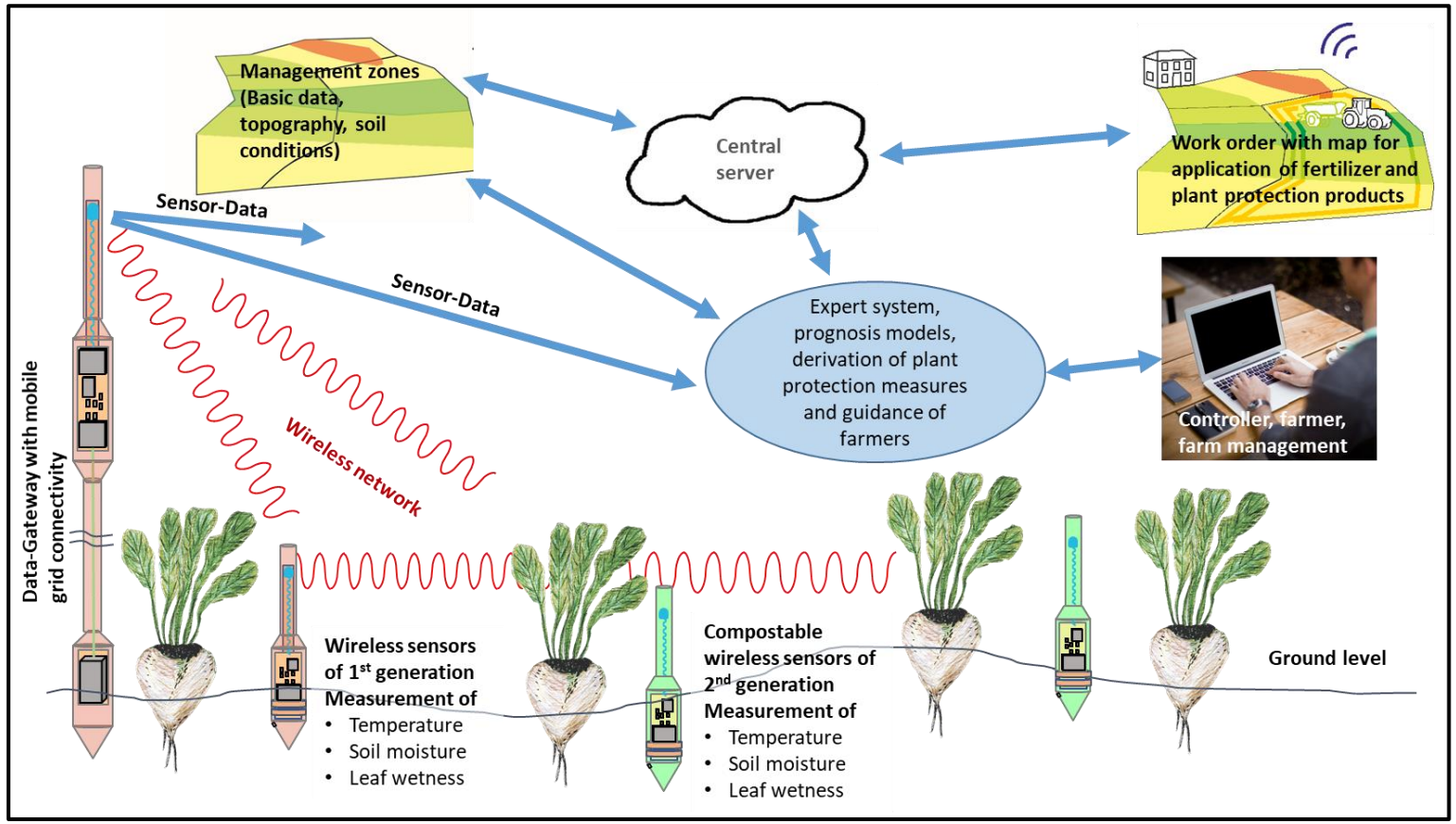
Challenges in arable farming

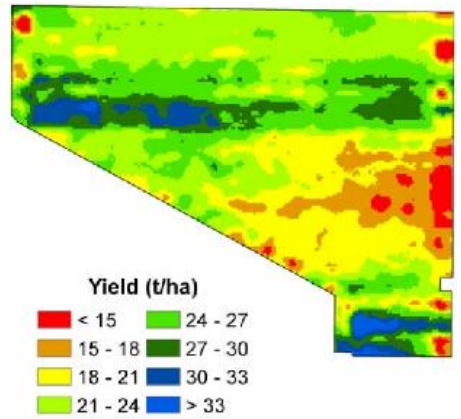
- **Drought**
  - Yield-limiting factor
  - Irrigation costs and difficulty of decision (costs vs. benefits)
- **Nitrate EU directives**
  - Limiting the use of nitrate to 80 % of the harvest potential
  - (a) Pollution concerns (b) Quality and selling price
- **Pests and Diseases**
  - Scouting cost, chemicals cost / lowered effectiveness
  - Regulations on maximum amounts, lesser products available
- **Salinity in some areas**
  - High EC levels due to salt intrusion
- **Crop stress**
  - Several causes (e.g. nutrients, climate, water ...)



Environmentally friendly, partially compostable Sensors for Agricultural Applications

Vision: Farmer receives help from various sensor systems





Environmentally friendly, partially compostable Sensors for Agricultural Applications

IFAG
Leaf Wetness Sensor, Temperature, CO_2 & ASIC

KSI
Nitrate Sensor

IFAG & FhG - ENAS
Soil Moisture Sensor

AlphaSIP
Air Pathogen Detection Sensors

Miniaturized Electronics

Cost-efficient

Printed Battery

Compostable

Freudenberg Siebdruck
Material- & Process Technology

FhG – ENAS
Compostable Electronics

Pathogen Detection

CO_2

Leaf Wetness

Electrical Conductivity

Soil Moisture

Temperature

Nitrate Concentration

imec
Wireless Sensor Systems

Wageningen UR
Data Gathering to Application Intelligence

ANT
Artificial Intelligence for Smart Cameras

PLANTAR

Central Server

Evalan – Use Case 1
Application Intelligence for Urban Farming

Munisense – Use Case 2
Application Intelligence for Agriculture

HANSENHOF – Use Case 3
Provision of Monitoring System for Data Processing

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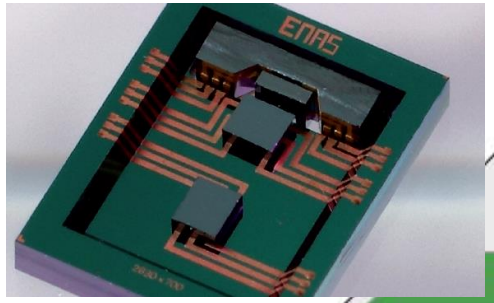
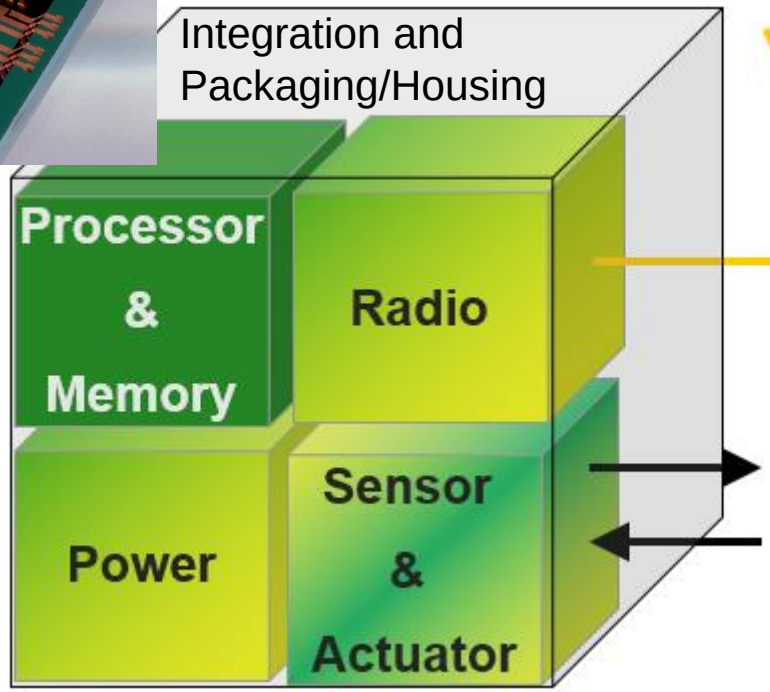
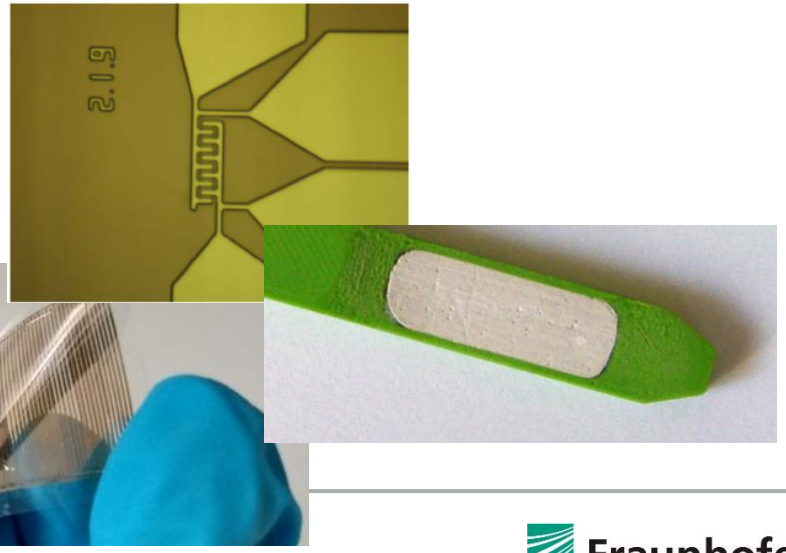
Environmentally friendly, partially compostable Sensors for Agricultural Applications

Basic building blocks of wireless sensor node:







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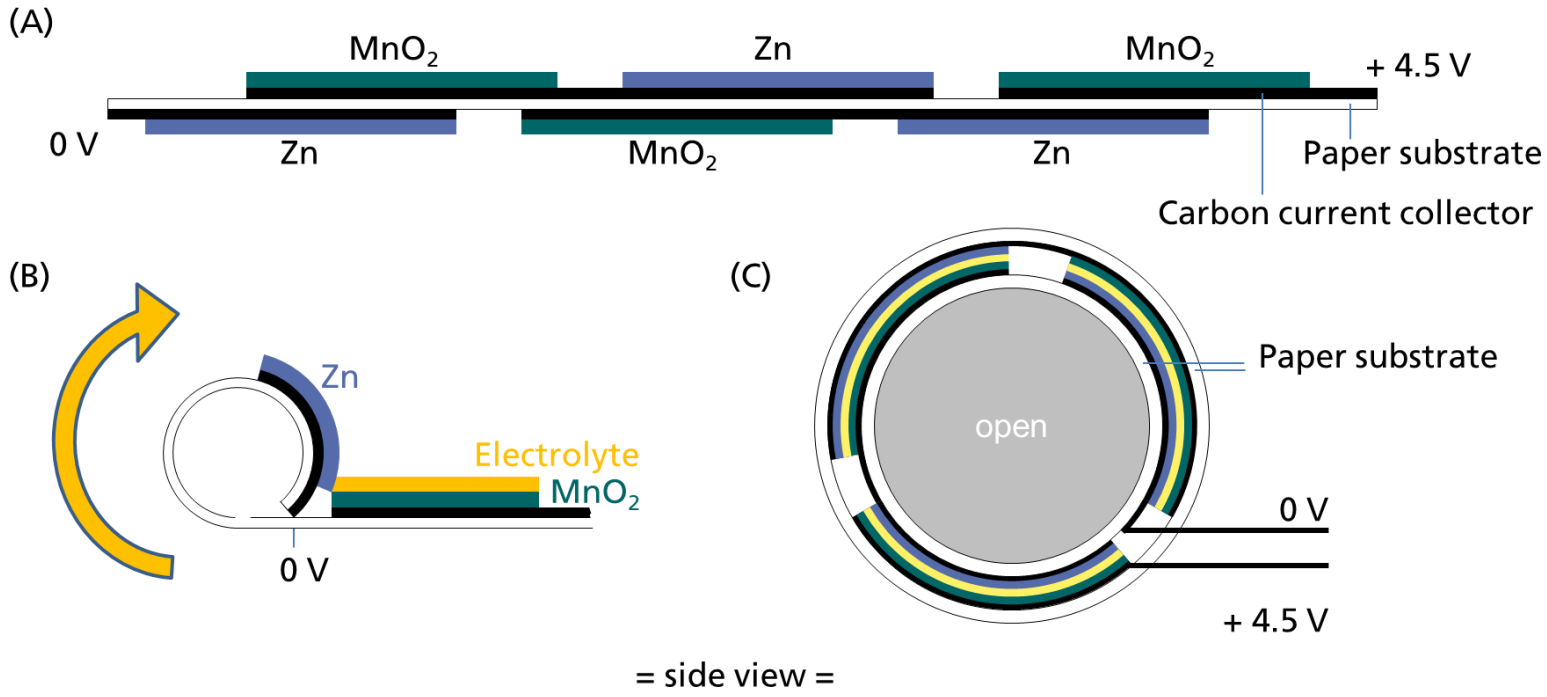
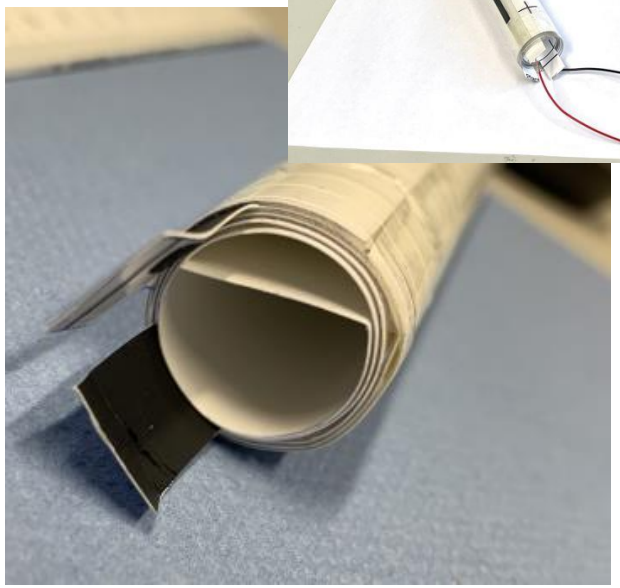
Printed battery

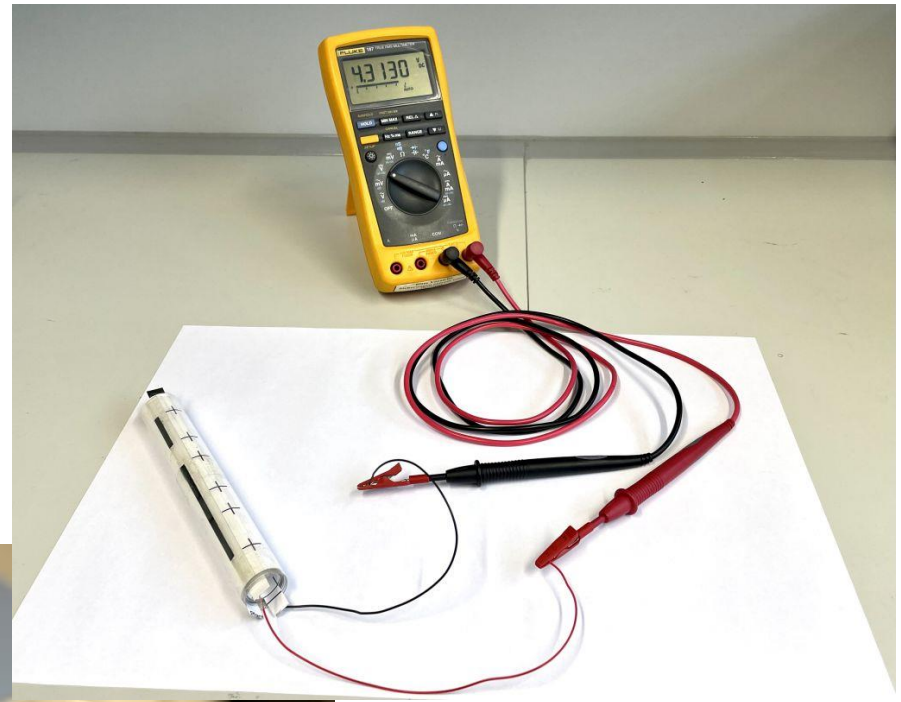
- Material: Zn, $ZnCl_2$, MnO_2, Carbon, Paper
- Manufacturing technique: roll up of screen printed layers on paper
- Voltage: 4.5V [3 cells]
- Nominal current: > 15 µA
- Pulse current: 10 mA (20 ms)
- Capacity: > 20 mAh

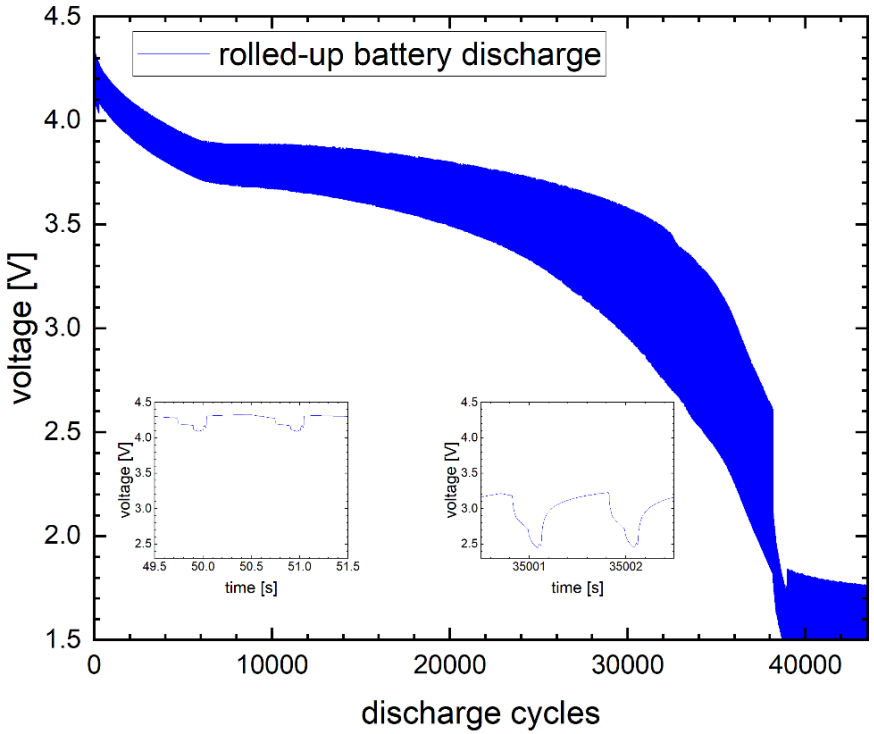


Environmentally friendly, partially compostable Sensors for Agricultural Applications

- Printed battery





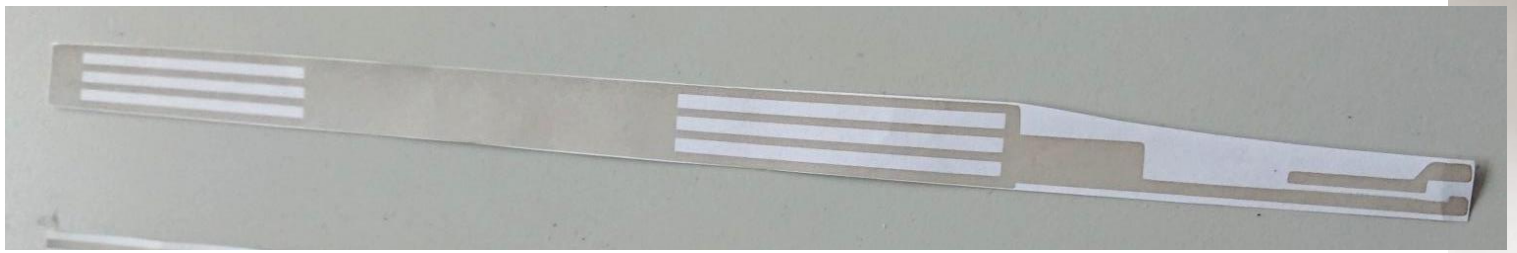


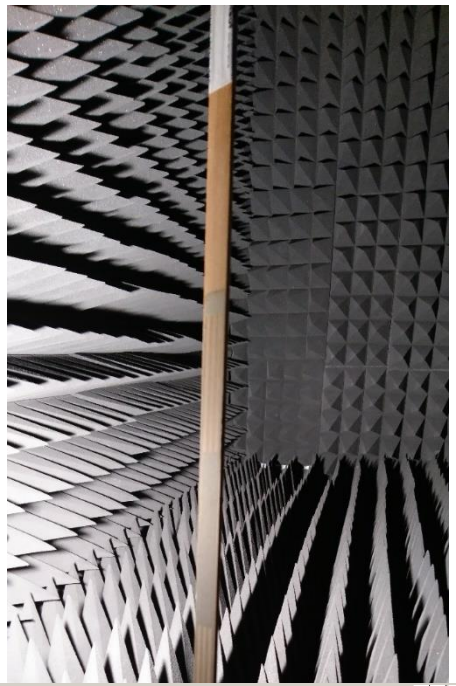
- About 35.000 discharge cycles with simulator circuitry in rapid discharge mode (1 discharge in 1.0064 s) ➔ This is clearly matching the demand of 20.000 discharge cycles per year

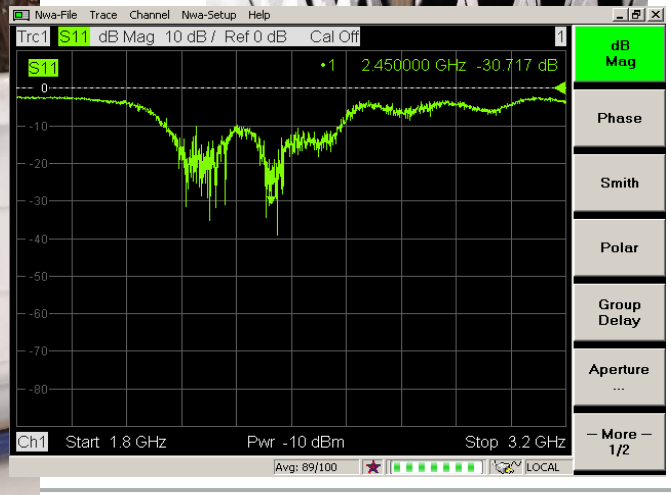
Environmentally friendly, partially compostable Sensors for Agricultural Applications

Printed antenna

- Resonance frequency: 2.45 GHz (90 MHz Bandwidth)
- Impedance: 50 Ω
- Effective gain: > 3 dBi
- Radiation pattern: omnidirectional
- Material: Ag, (Carbon), Paper
- Manufacturing technique: screen printing on wood or paper







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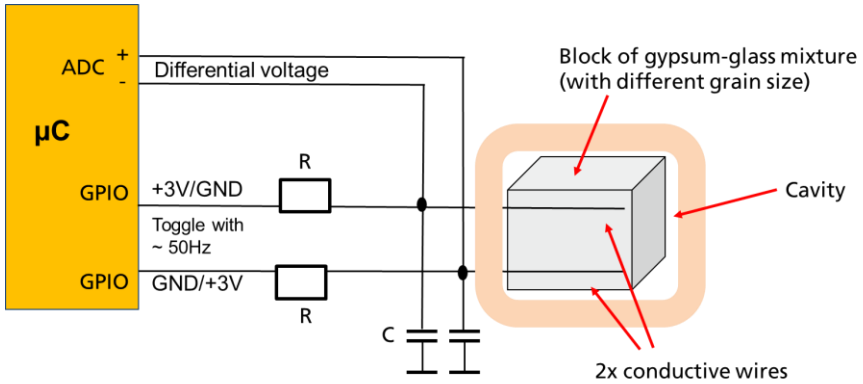
Soil tension sensor (matrix potential)

- Determines the suction tension in the soil (holding force of the water in the ground)
- Change its electrical conductivity due to solved calcium ions (increase with increasing water content)
- Simple readout electronics, almost no further components necessary
- Material: gypsum-glass mixture, carbon, paper

Soil tension sensor with conductive carbon wires on paper



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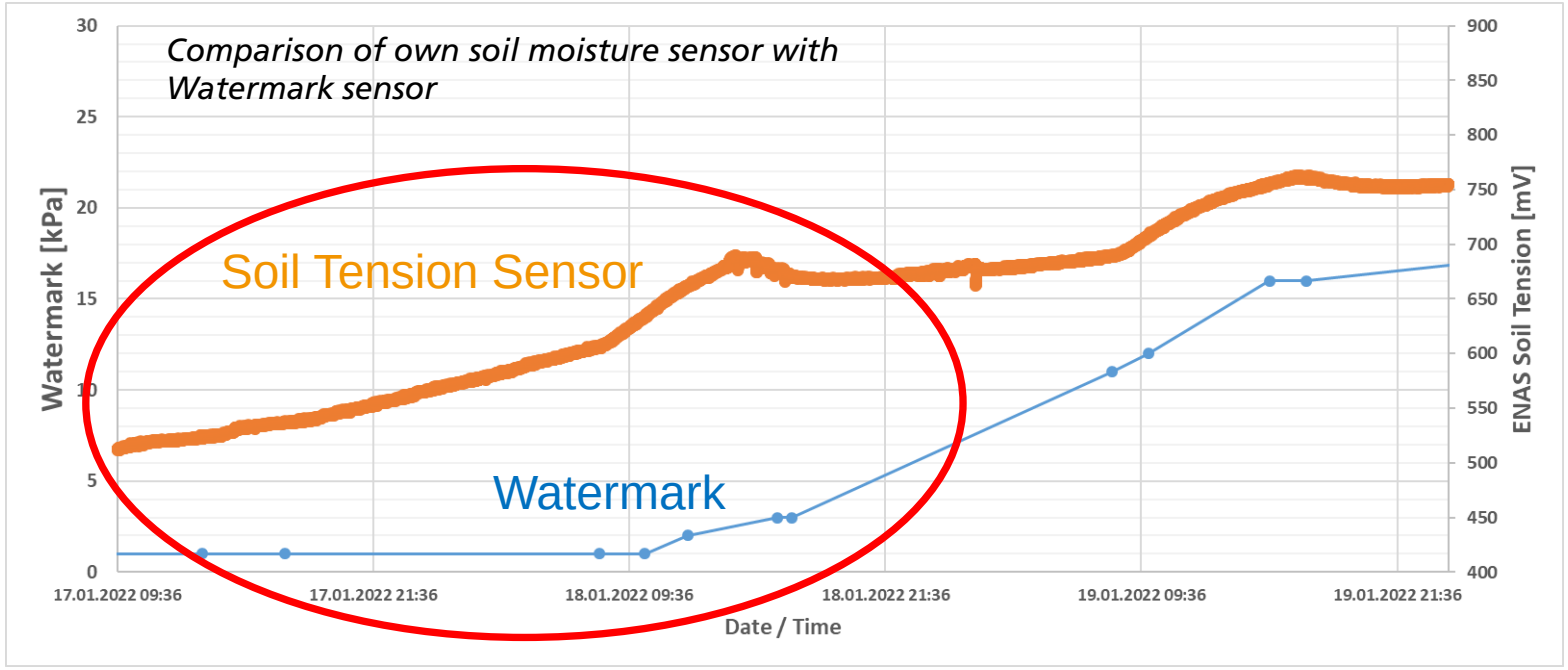
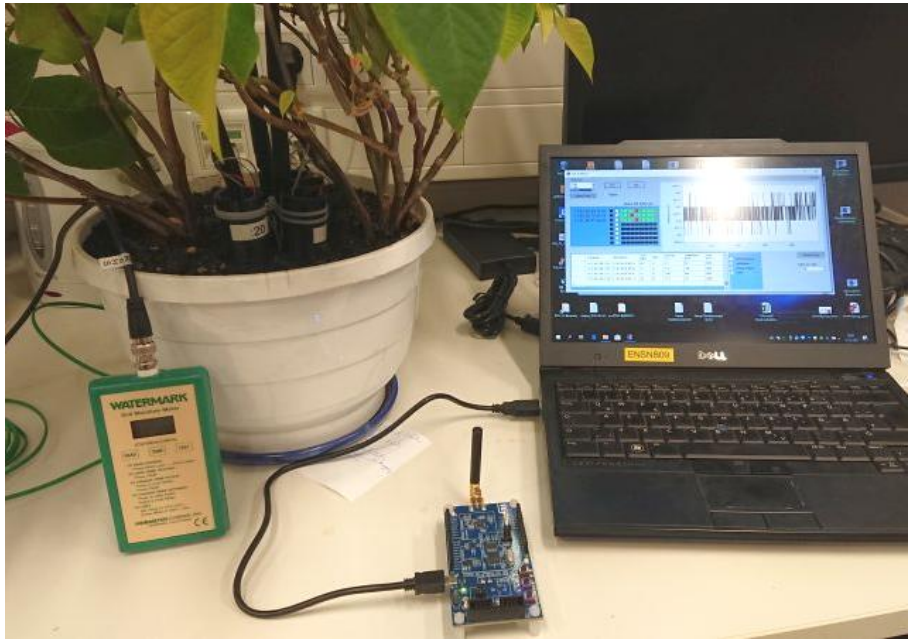
- Soil tension sensor (matrix potential)

  - Test with experimental plant (poinsettia) and Watermark reference sensor
  - Quite good performance

Watermark reference sensor





Test setup with sensors, readout electronics and gateway / PC with Graphical User Interface

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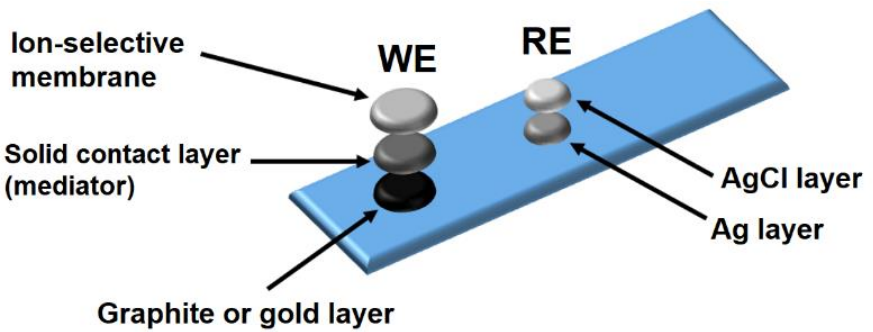
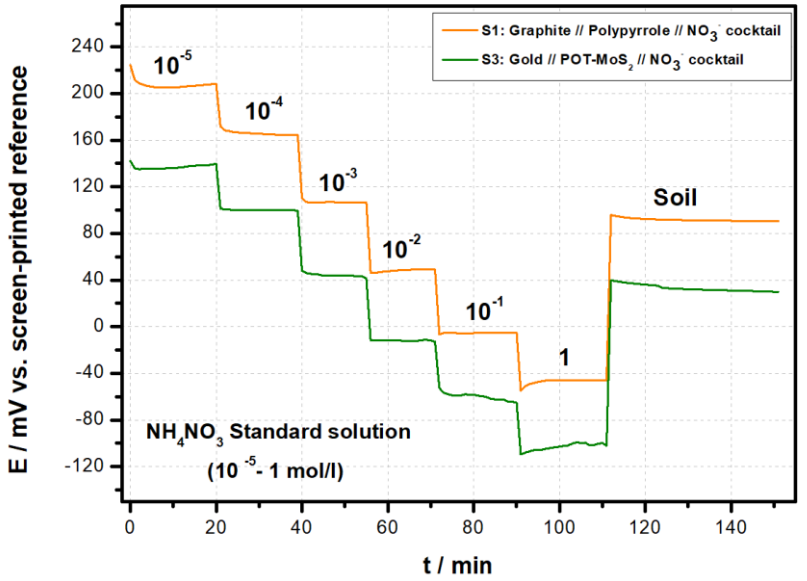
Nitrate sensor (KSI)

- Potentiometric determination of NO^{3-}
- All solid state configuration
- Consists of working electrode (graphite or gold layer) and reference electrode (Ag, AgCl)





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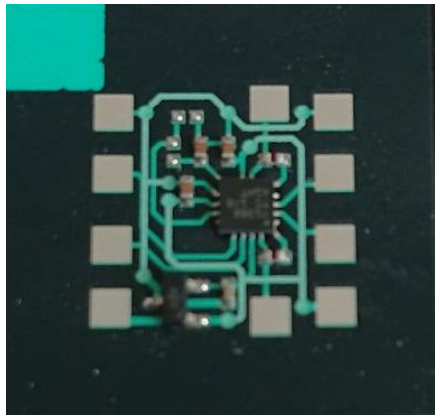
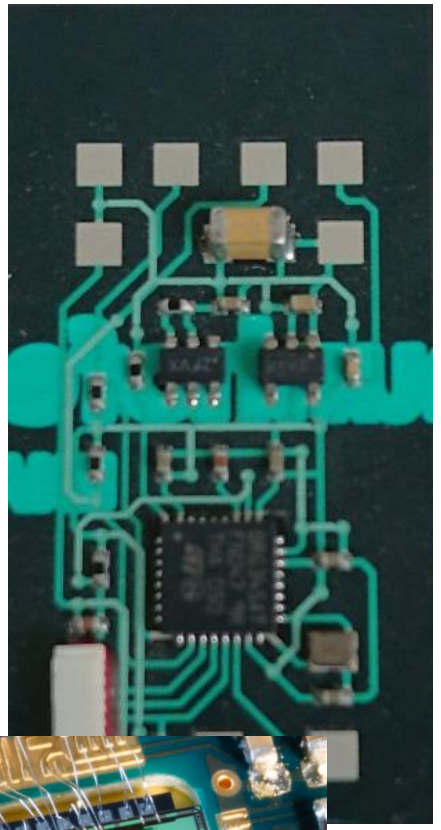
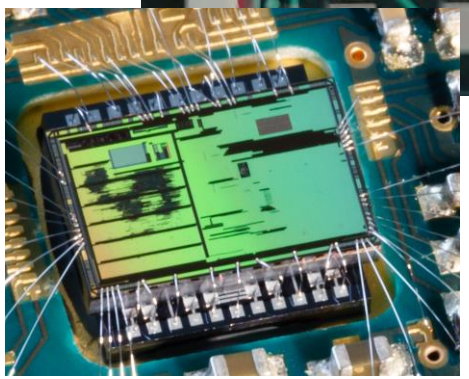
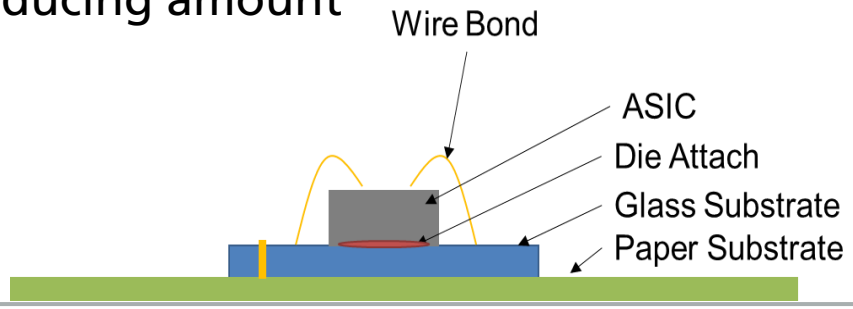
Electronics (Infineon/Freudenberg Siebdruck):

- µC and BLE transceiver for read out of sensors, evaluate sensor data, sending data over BLE (Bluetooth)
- Electronic layout on thin glass substrate by using industrial printing processes
- Soldering ICs and passive components with standard reflow processes
- Material: thin glass substrate, silicon, ceramic, Ag, Cu, Ni, Sn, Al, …
- Vision: using bare die ICs → for reducing amount of material









Environmentally friendly, partially compostable Sensors for Agricultural Applications

- Field test: Check radio transmission range of sensor node

  Setup:

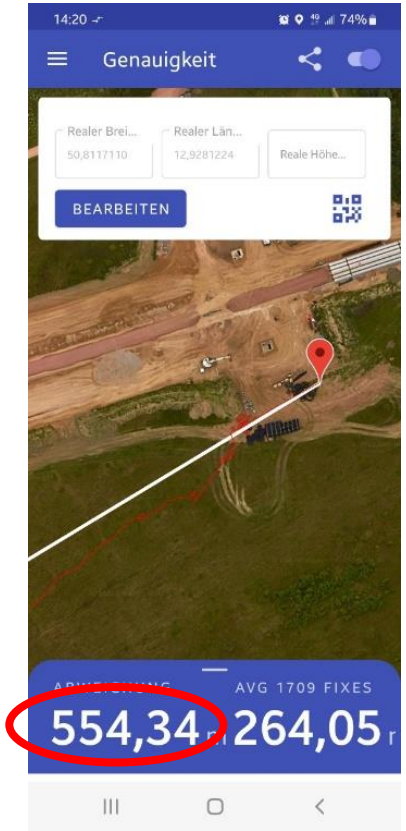
  - Base station: Flat panel antenna with 18dBi and receiver board
  - Sensor nodes: BLE transceiver generation with LongRange mode

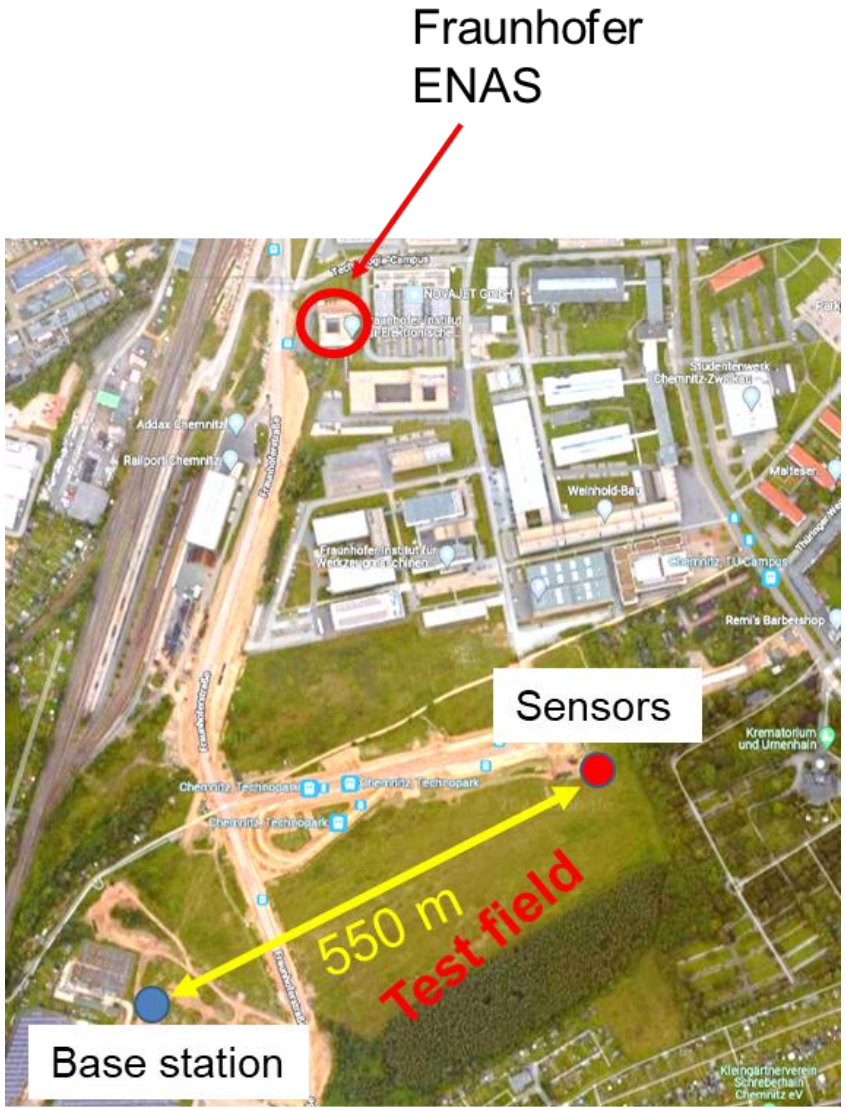
Sensor nodes on field

Flat panel antenna with receiver and PC

Environmentally friendly, partially compostable Sensors for Agricultural Applications

- Field test: Radio transmission range





→ Radio communication **up to 550m**

(Range limited due to fences)

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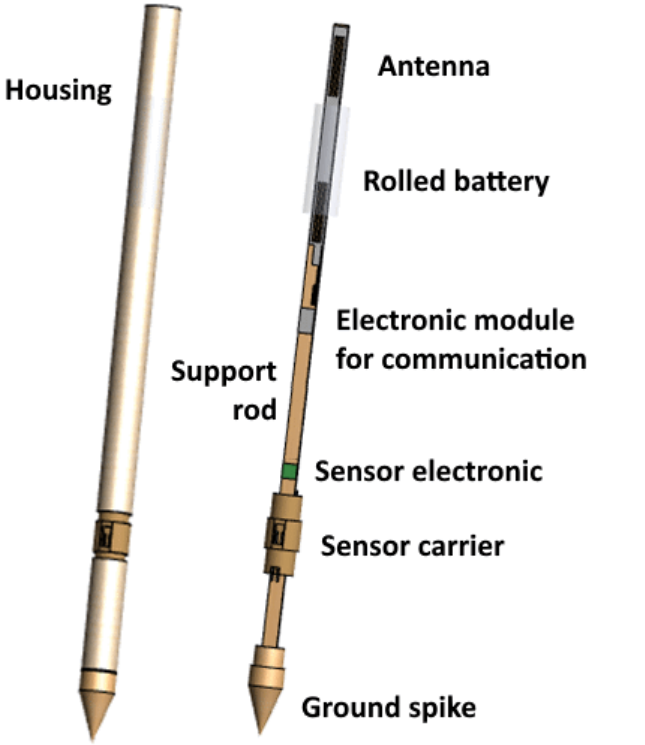
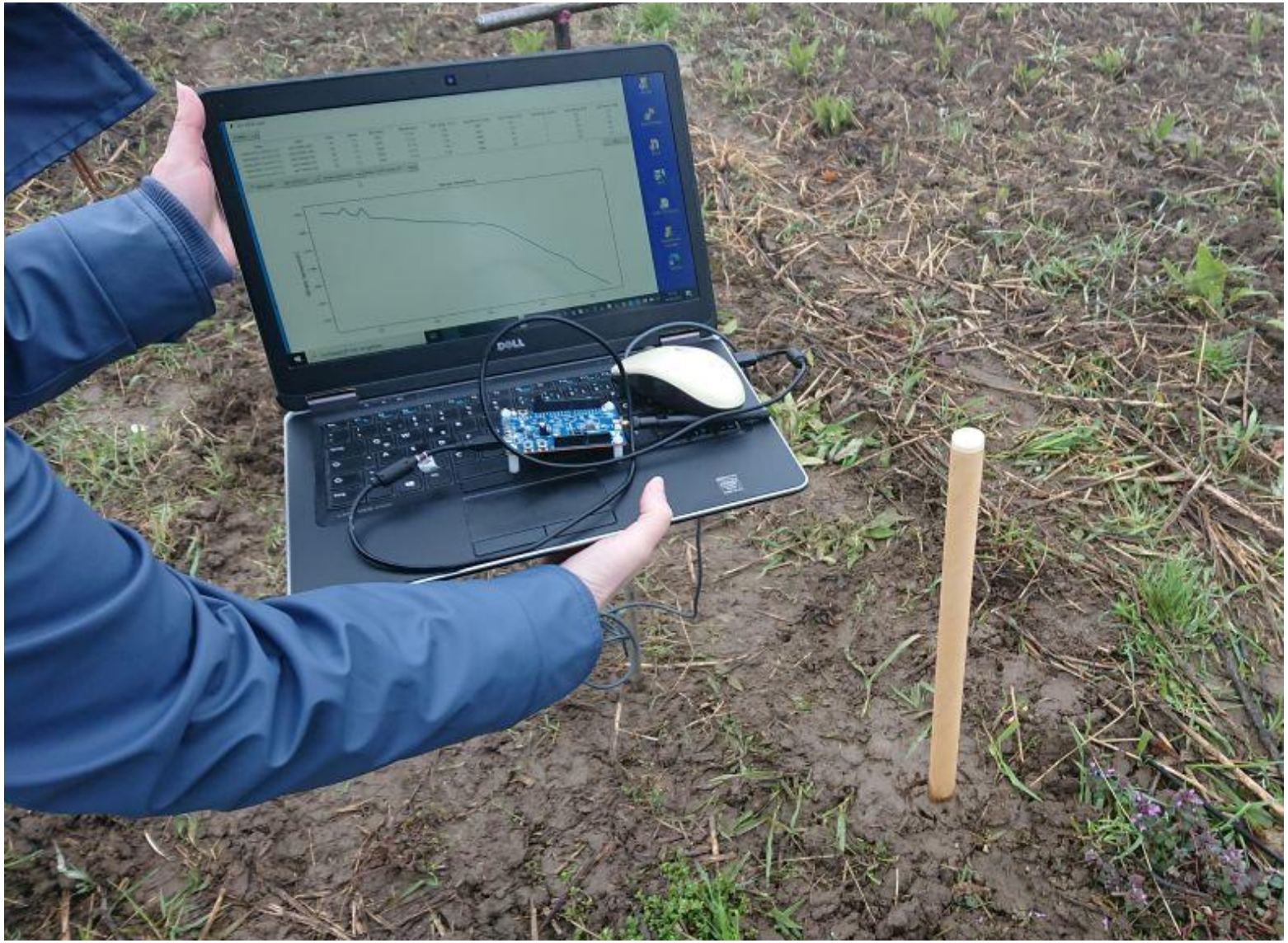
Housing

- Components: Ground spike (wood filament), Sensor carrier (wood filament), Housing hull (Ash), Cover, Carrier bar (Pine)
- Carrier bar:
  - Combining all components (µC, Sensor board, Sensor, Battery, Antenna)
  - Printed digital I²C bus for connecting the electronic along the carrier
- Sensor carrier:
  - Contains Soil moisture sensor (and nitrate)
- Material: Wood (Ash, Pine), paper, fully biodegradable 3D filament and Wax / Parylene (for sealing)

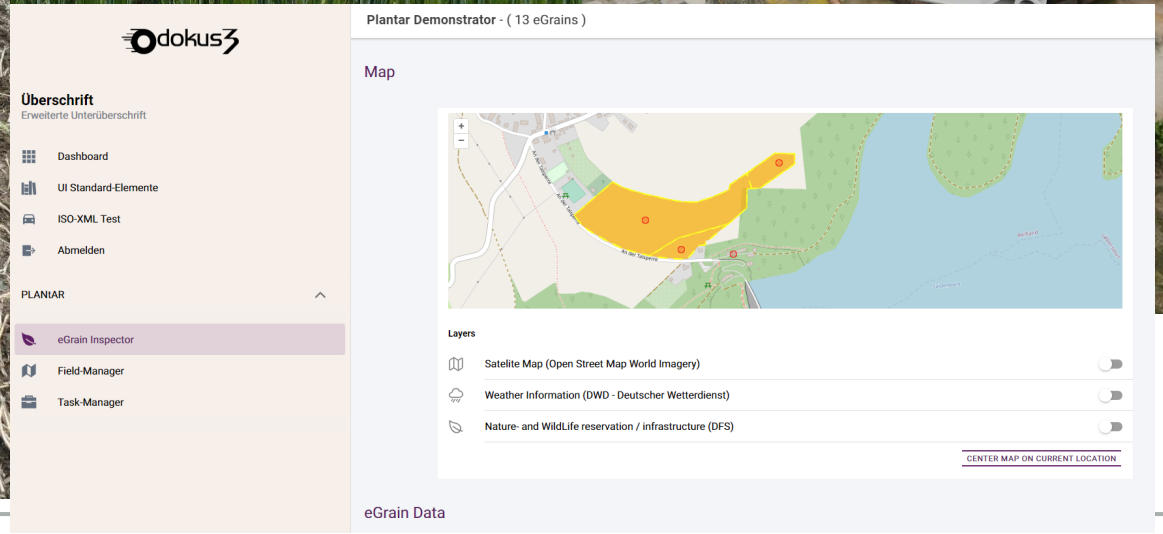


Environmentally friendly, partially compostable Sensors for Agricultural Applications



Environmentally friendly, partially compostable Sensors for Agricultural Applications

- Field tests



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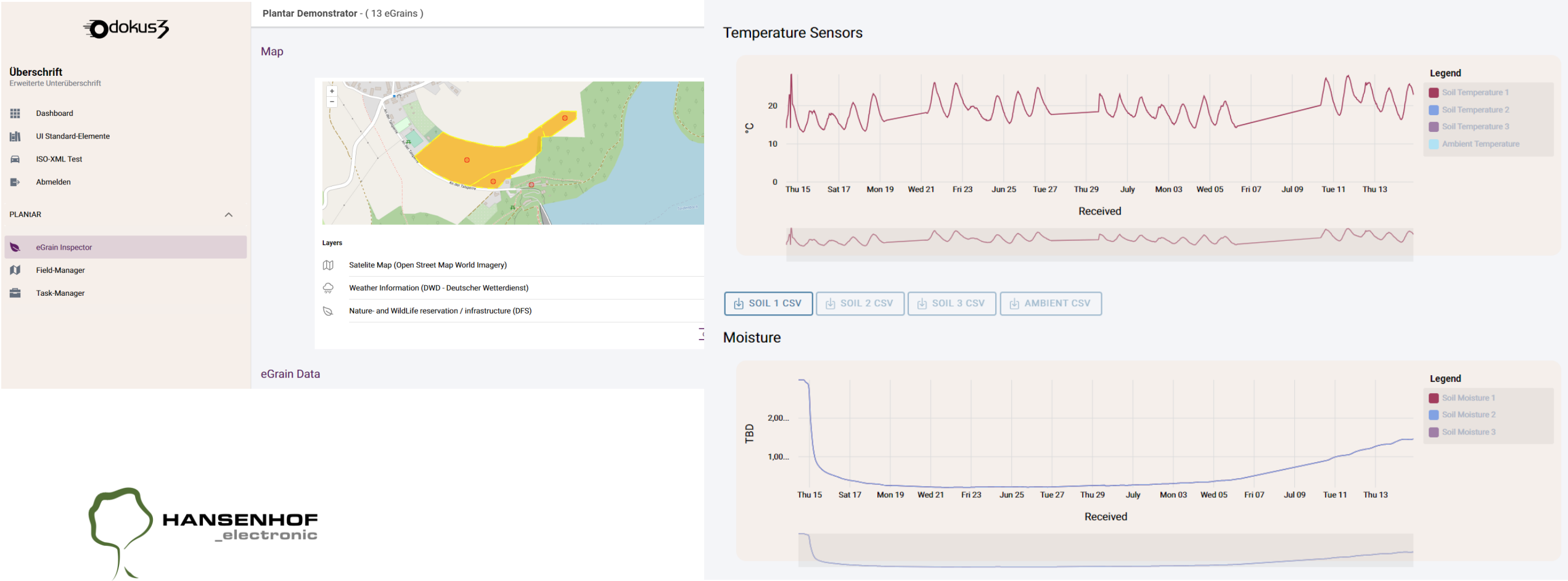
- Cloud platform (Hansenhof Electronic)



HANSENHOF _electronic

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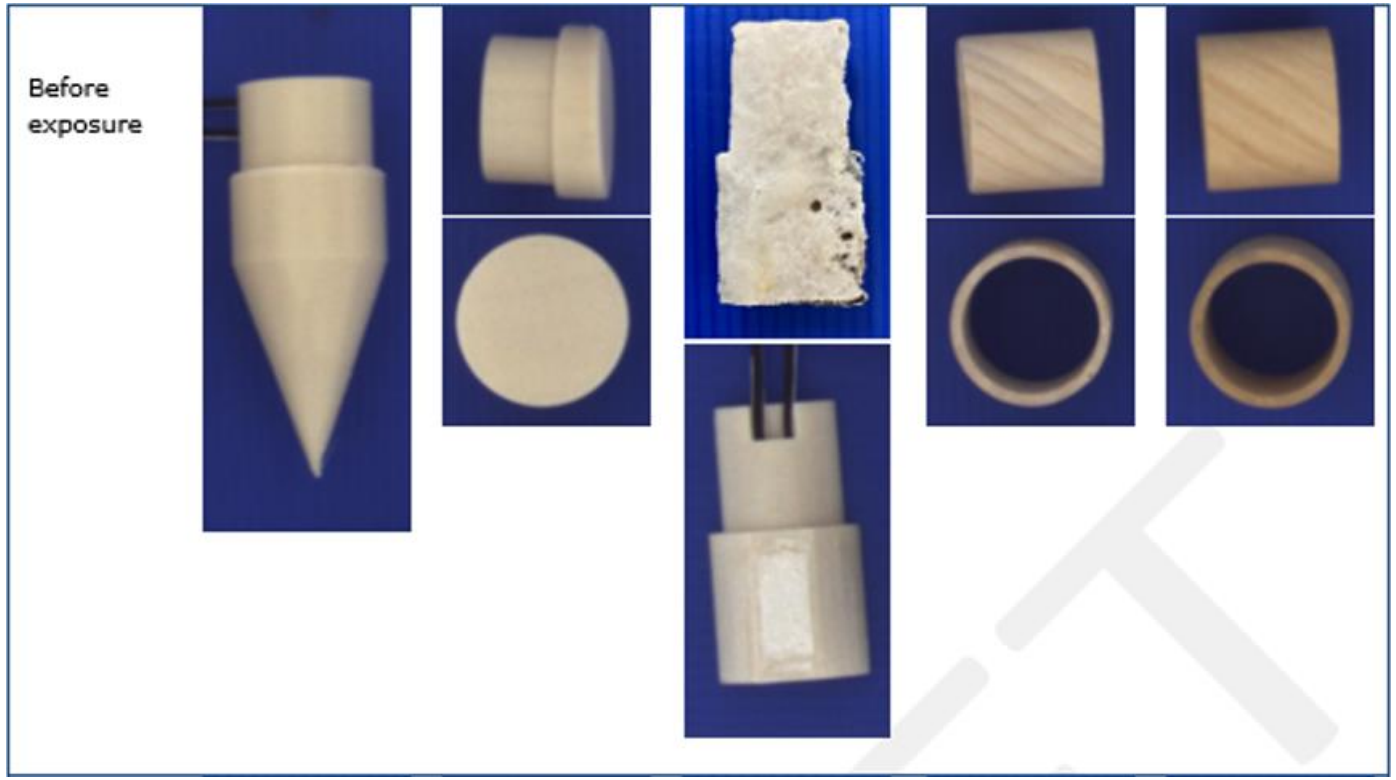
- Testing and validation of the biodegradability
  - Selected sensor components were incubated in containers filled with reference soil at constant temperature (25°C) and relative humidity (90%).
  - Moisture content of the soil was maintained constant at 80% of the water holding capacity.
  - The sensor components were periodically retrieved from the soil, with one sample buried per data point.

Environmentally friendly, partially compostable Sensors for Agricultural Applications

- Testing and validation of the biodegradability



Environmentally friendly, partially compostable Sensors for Agricultural Applications

- Testing and validation of the biodegradability

Environmentally friendly, partially compostable Sensors for Agricultural Applications

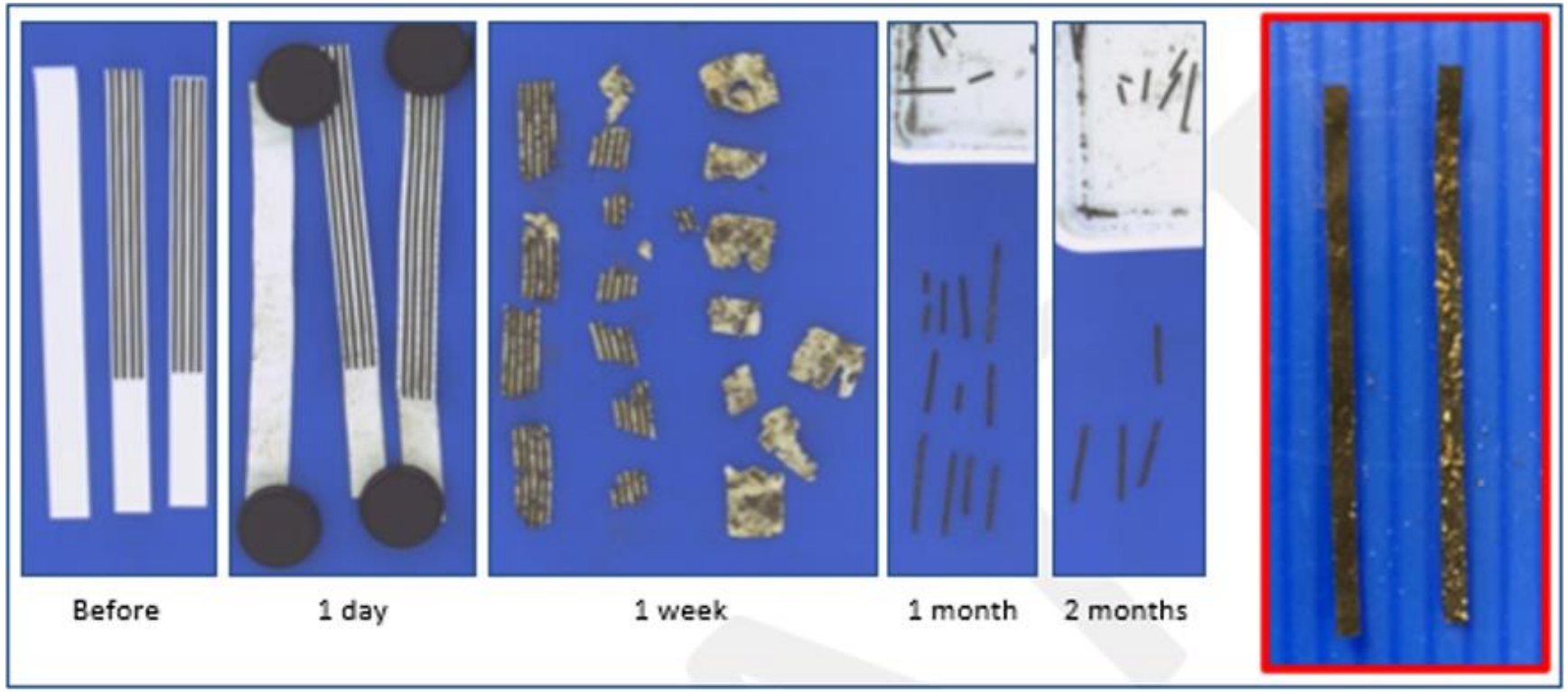
- Testing and validation of the biodegradability

→ The degradation of the 3D-printed items made of biodegradable (PHA) polymer progressed with longer exposure times. Samples recovered after 4 months had significant holes in the outer layers, and this was more prominently the case for samples recovered after 7 months.

→ The plywood tubing showed signs of delamination after exposure to the soil, Nevertheless, the integrity and strength did not differ substantially between samples recovered after 4 and 7 months in the soil

Environmentally friendly, partially compostable Sensors for Agricultural Applications

- Testing and validation of the biodegradability



→ Paper strips disintegrate very fast in the moist soil, after 1 month of exposure only the printed parts of the paper could be found in the soil, also after 2 months of exposure fragments were found, consistent only of the printed layer, the paper was almost gone

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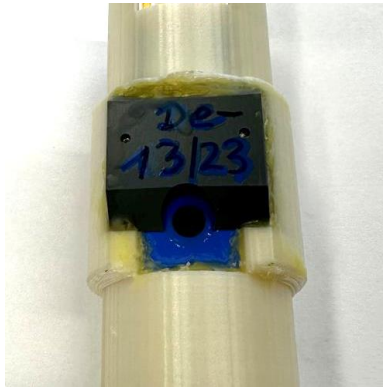
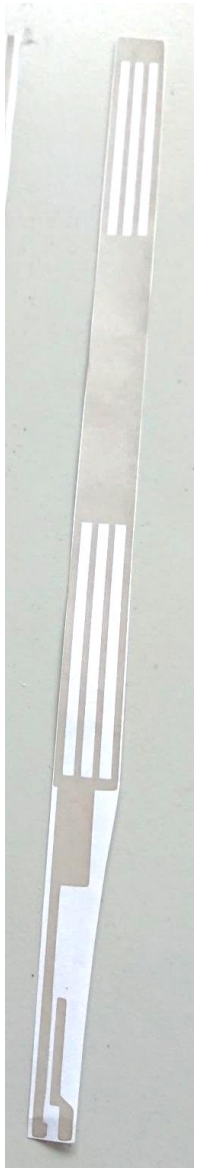
- Sensor system …
- for determining soil moisture (suction tension), soil temperature, nitrate content in the soil and leaf moisture
- with wireless data transmission to the base station and data server with expert system
- produced with cost-effective printing technologies (screen printing and roll-to-roll)
- consisting of compostable, inert and harmless materials (like wood, paper, Polyhydroxyalkanoates, MnO_2 and Zn)



Nitrate sensor

Soil moisture sensor

Printed battery on paper



Printed antenna on paper

Sensor in the agricultural field

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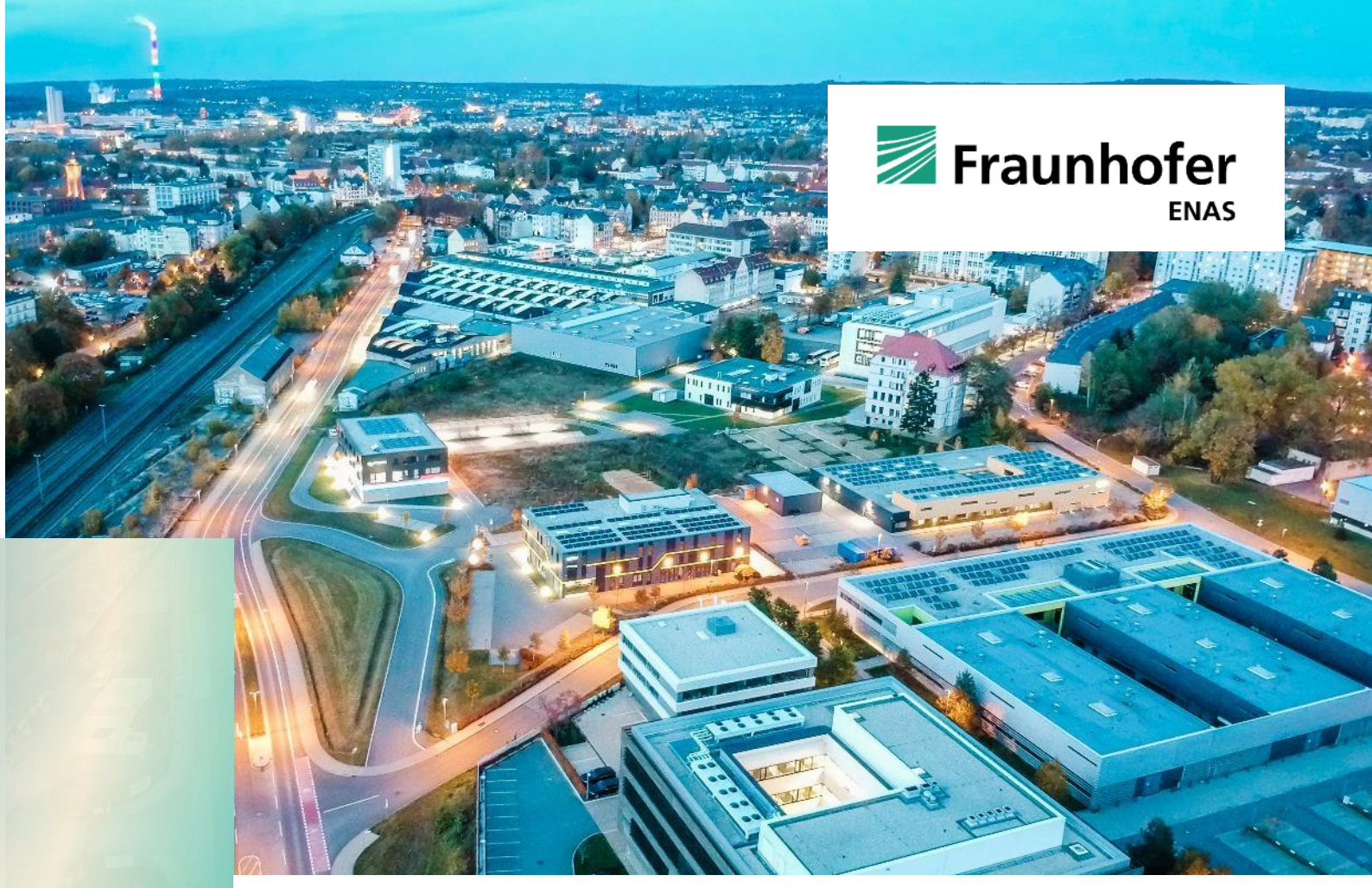
- Possible Applications:
  - Monitoring of ornamental trees and nursery stock (soil moisture, soil temperature)
  - Control of Phytophthora (leaf wetness and ambient temperature)
  - Optimization of crop production (soil moisture, nitrate content, soil temperature)
  - General environmental monitoring to protect nature and drinking water (nitrate content for needs-based fertilization and greenhouse gas reduction)

Control of Phytophthora in potato cultivation

Drinking water reservoir

Monitoring of Ornamental trees



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