BIO.PNT: Biosensors with PNT Integration

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Agenda

1. Project Overview
2. Introduction to Biosensors
3. Introduction to PNT Technologies
4. Market Overview
5. Use Case Identification
6. BIO.PNT Sensor
7. Business Case
8. Summary

Project Overview

Motivation and Background

PNT Solutions

- Positioning, navigation and timing (PNT) measurement solutions use the European global navigation satellite system (GNSS) Galileo integrated into miniaturized, energy-saving devices suitable for IoT applications
- Market increase of applications that rely on geo-localisation
- New concepts, such as PNT solutions with Low Earth Orbiting Satellites (LEO-PNT) are currently also being intensively investigated for their potential to be used in difficult terrain or even inside buildings.

Biosensors

- Biosensors consist of a biological detection element (biosensor) and a physical sensor (transducer) that converts the biological-chemical signal of the sensor element into an electrical or optical signal
- Widely used in different applications mostly known to be used for medical diagnosis, environmental monitoring, and monitoring and testing of medical events

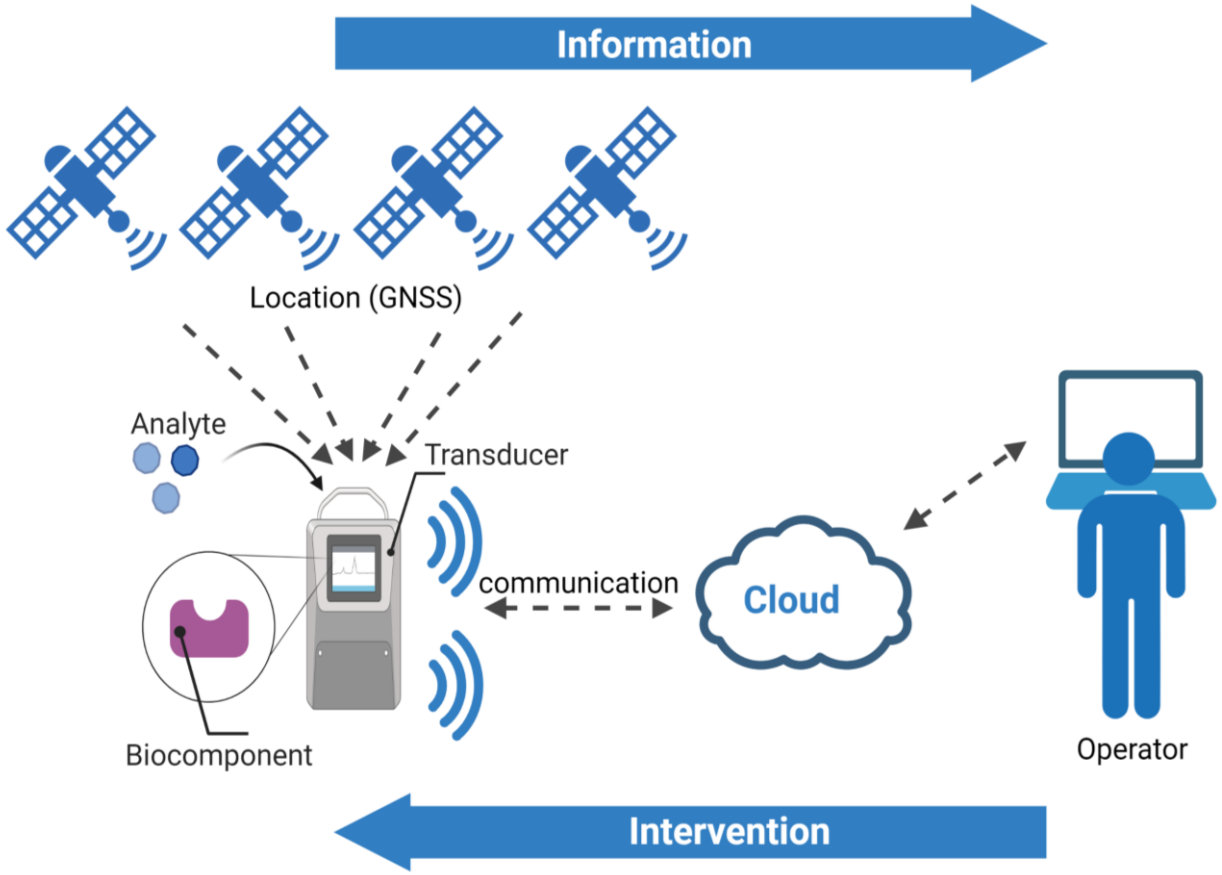
Biosensors with PNT integration could enable automation and high-throughput screening of both applications with high localization accuracy under field conditions worldwide

The Overall Goal

Goal of the BIO.PNT Project:

»analyse different categories of biosensors and investigate the integration potential for PNT«

- Unites knowledge from different scientific fields
- Range of different future use cases and applications
- Add value to available PNT alternatives



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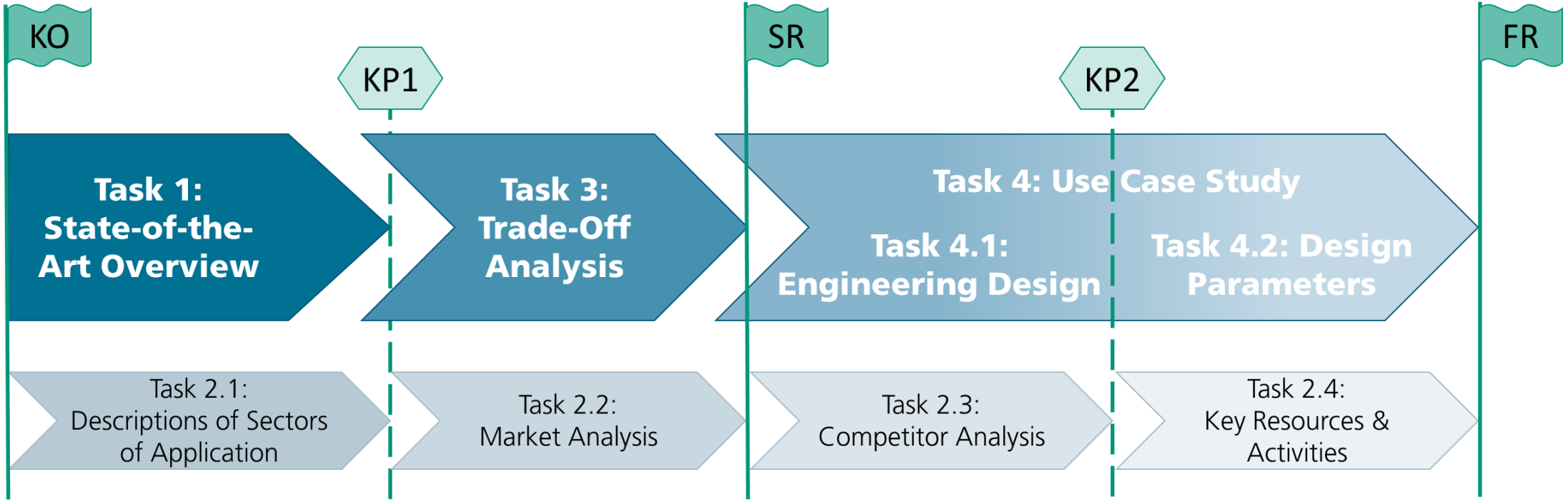
Work Package Management

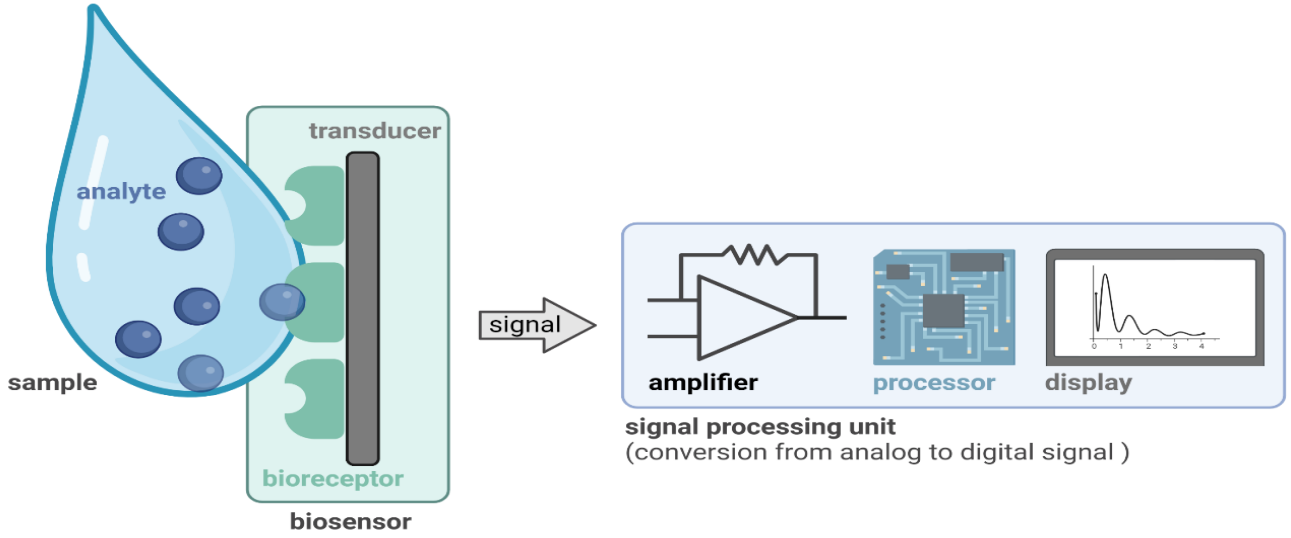
Relation and Co-Dependence of Milestones and Work Packages



Introduction to Biosensors

Definition of Biosensors

According to IUPAC



A device that uses specific **biochemical reactions**
mediated by isolated enzymes, immunosystems, tissues, organelles or whole cells (**bioreceptor**)
to detect chemical compounds
usually by electrical, thermal or optical signals (**transducer**).

(B Nagel, H Dellweg, LM Gierasch, PAC, 1992, 64, 143)

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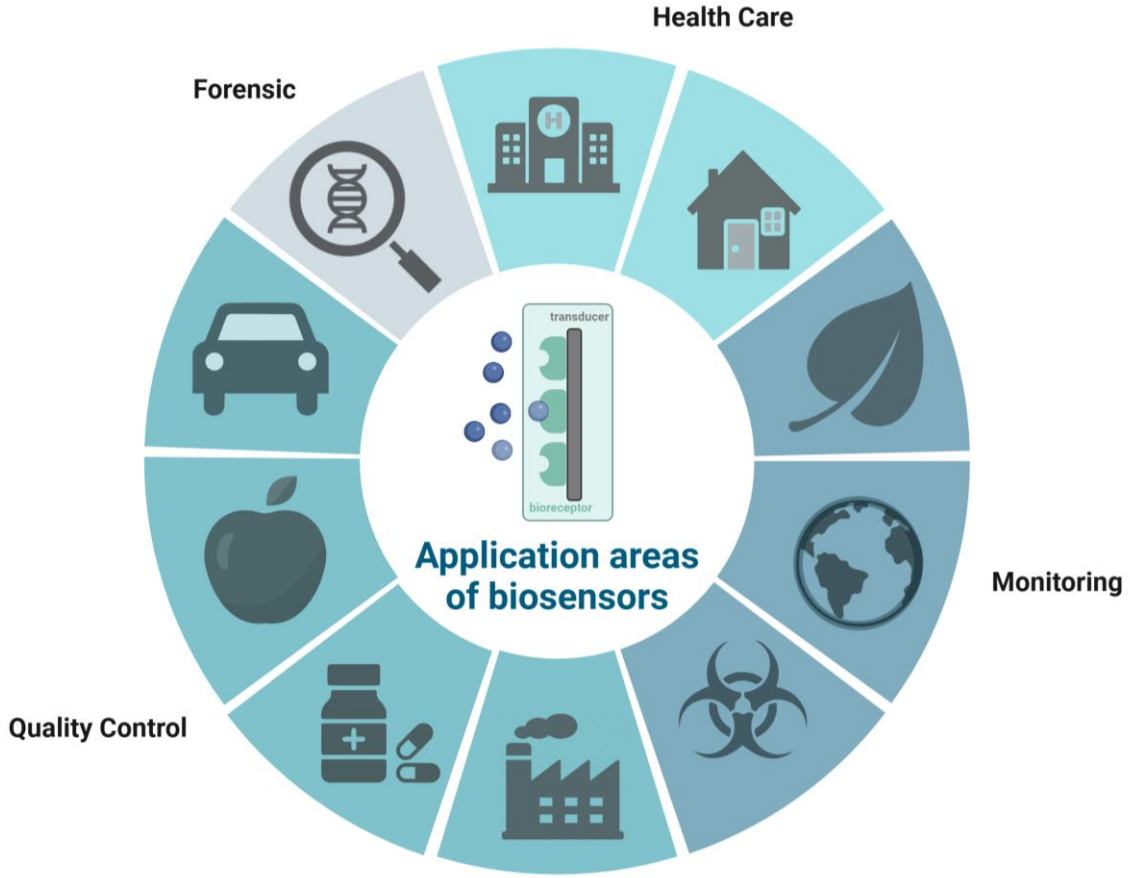
Sectors of Biosensor Application

Identification and classification of sectors of application

- **Health Care**
  - Point of Care Testing
  - Home Diagnostics for self-use
  - Wearable Biochemical Biosensors
- **Monitoring**
  - Environmental
  - Security & Biodefense
  - Agriculture and Plant Biology
- **Quality control**
  - Pharmaceutics
  - Process Industries,
  - Food monitoring
- **Forensic**



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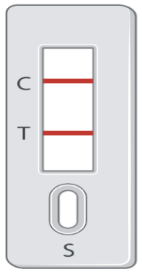
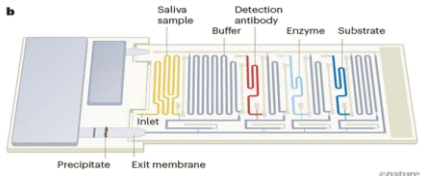
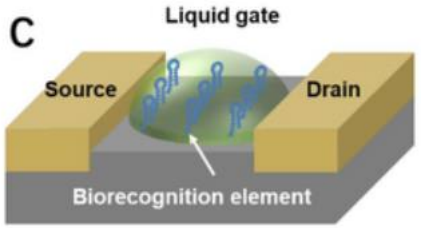
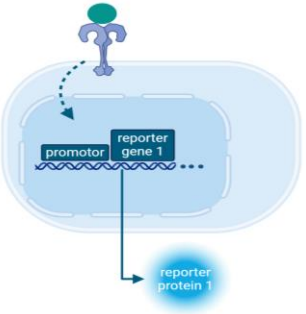
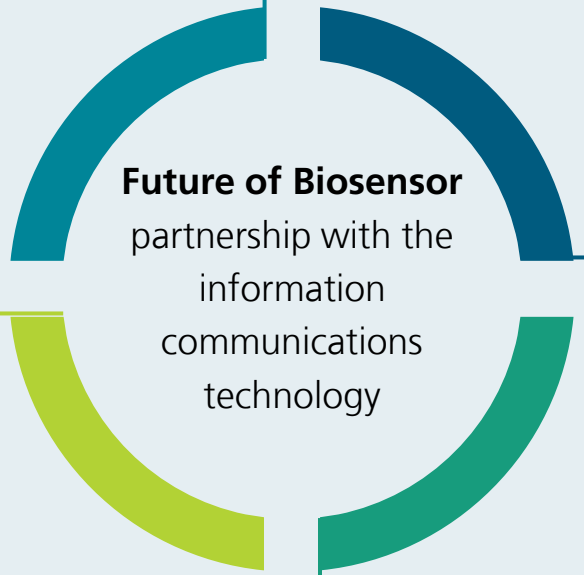
Examples of Biosensor Concepts

Biosensor Technology	Lateral Flow Assays	Lab-on-a-Chip	Field-effect transistor based Biosensors	Whole cell biosensors
				
Field of applications	Point of care diagnostics, environmental monitoring, Home diagnostics for self-use, forensic, biodefense	Point of care diagnostics, environmental monitoring, security and biodefense	Patient monitoring, environmental monitoring, security and biodefense, forensic	Environmental monitoring, security and biodefense, forensic
Prominent examples	Sars-Cov2 test, pregnancy test	Devices for pathogen identify-cation or the measurement of metabolite concentrations	Wearable blood glucose monitors	Environmental Biosensors for drinking water quality
Technical potential to combine with PNT	**no**	**good**	**very good**	**less**
Image Reference	The figure was created with Biorender.com	https://doi.org/10.1038/d41586-022-01299-6	DOI:10.1002/EXP.20210027	The figure was created with Biorender.com

Future Trends of Biosensors

Innovative Materials
graphene, hydrogels, and nanocomposites as support material

Combination with Smartphones
Image acquisition, measure, process and store data, power supply



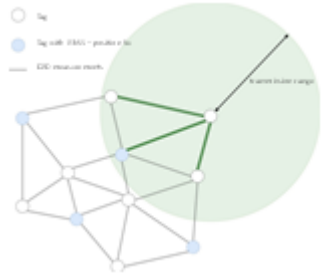
Commercial of the Shelf Products
Transducers, electronic components, energy supplies

Smart Environments
Combination of biosensors, smartphones, and wearable biosensors with IoT / IoMT

Introduction to PNT Technologies

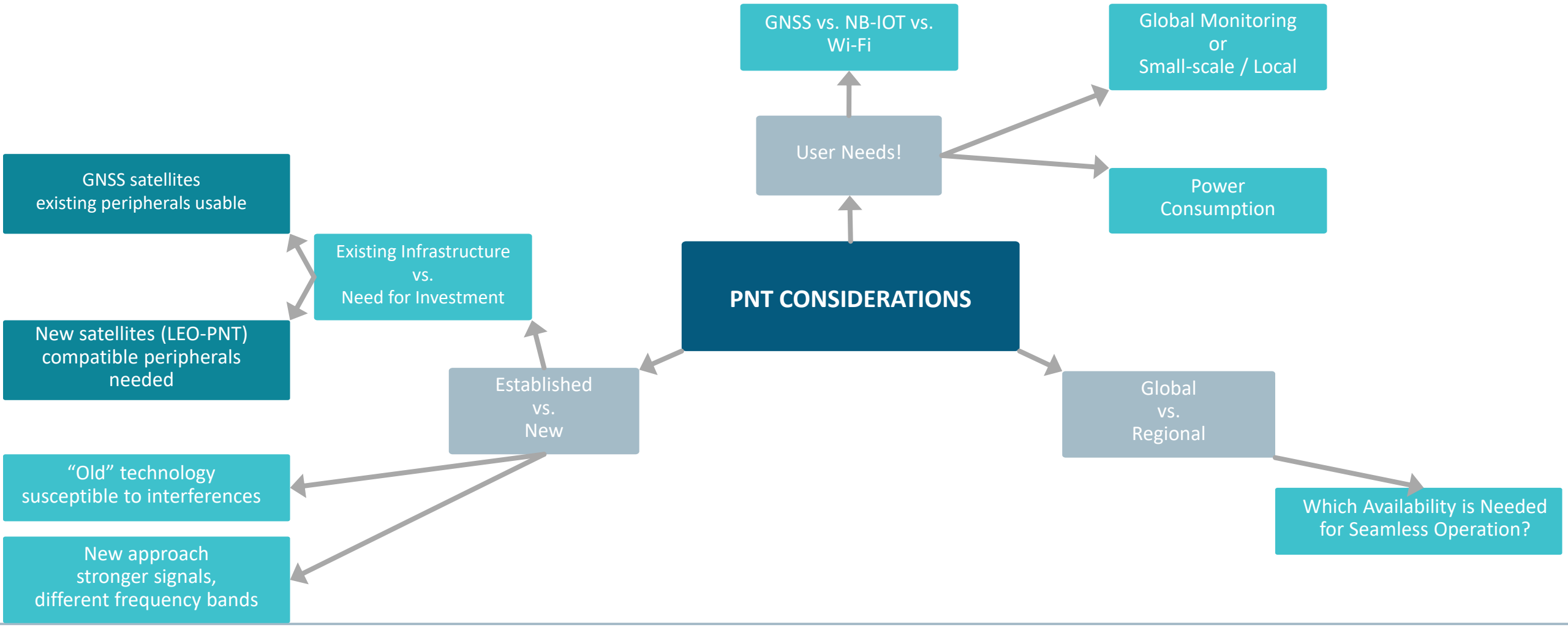
PNT Technology

Exemplary SotA Research Results

Category/ Product	"Standard" Smartphone	COTS Products	Swarm Localisation	STRATOS Solution HASARDS – HAPS-Augmented Search-And-Rescue Demonstration System (ESA NAVISP EL1)	LEO-PNT
					 © Jackson Labs Technologies (JLT)
CotS	Yes	Yes	Partially	No	Partially
New/innovative PNT Technology	No	No	Rare but not new	Yes (HAPS)	Yes
Combined PNT Sensors	GNSS + BLE + LTE + Gyro + Barometer + Humidity…	GPS + LTE	GNSS + BLE (rel. pos. between tags) (+ LTE)	GNSS, GSM, COSPAS / SARSAT	LEO-PNT (Iridium STL, 6G NTN) + GNSS
Biosensor Integration Potential	Possible. Ideal scenario: connecting a biosensor via BLE for time / GNSS stamping, etc.	Integrated: heart rate & blood pressure test, fall down alert, body temperature detection	Not foreseen as focus was low-energy positioning; possible if requirements are adapted; technology can be integrated	Not direct focus of project but possible if embedded in system requirements and implemented in user devices	Not direct focus of project but possible if embedded in system requirements and implemented in user devices

PNT Technology

Considerations for applications



Market Overview

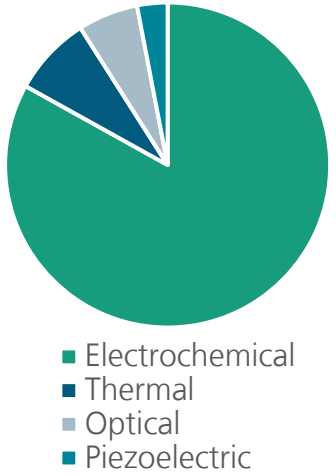
Market Sector Description

Market Overview

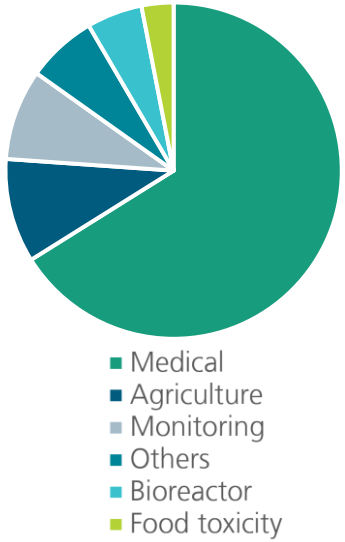
BIOSENSORS

- TAM: 25.19 billion € (2022)
- Predicted TAM: 46.72 billion € (2030)
- CAGR: 8.03%

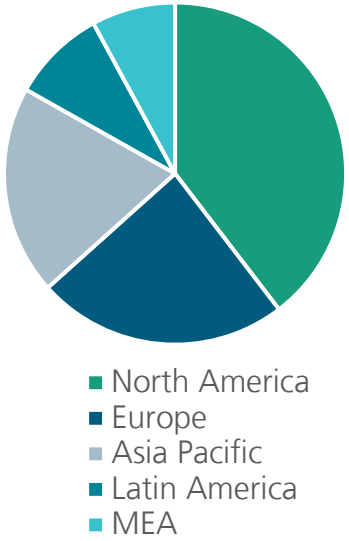
Markets by Technology:



Markets by Application



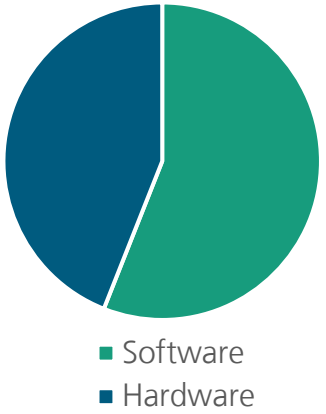
Regional Share



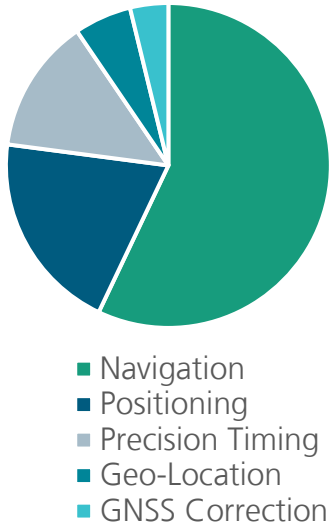
PNT

- TAM: 2.83 billion € (2022)
- Predicted TAM: 13.8 billion € (2030)
- CAGR: 22.3%

Markets by Technology:



Markets by Application:



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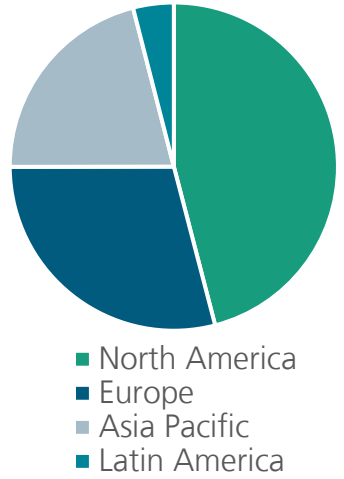


Market Sector Description

Drivers & Challenges

BIOSENSORS

DRIVERS

- Increasing demand for point of care
- High sensitivity / non-invasive methods of diagnosis
- Large range of applications
- Personalized medicine
- Technological advancement (miniaturization, ease-of-handling, lightweight)

CHALLENGES

- Sensor fabrication challenging
- Commercialization for non-medical applications limited
- Data handling and security
- High prices / unfavorable reimbursement policies
- Single dominant demand from healthcare industry

PNT

DRIVERS

- Increasing demand for accurate & reliable navigation
- Advancements and upgrade of satellite technology
- Increasing adoption of PNT in past 5 years
- Increasing demand for location-based services
- PNT contribution to green technologies

CHALLENGES

- Cyber security concerns (jamming, spoofing, hacking of PNT signals, data theft or encryption)
- Signal interference through natural (atmosphere, solar radiation) and man-made (electromagnetic radiation through cell phones, wireless routers, power lines) sources

Use Case Identification

Use Cases

Collection, identification and discussion of potential use cases (total of 17)

Environmental Monitoring	
- Landfill monitoring	- Disaster response
- Mine blasting	- Soil pollution management
- Volcanic gas sampling	- Underwater detection
- Precision agriculture	- Marine environment monitoring
- Ship emission monitoring	- Wastewater / sewage quality monitoring
Healthcare & Medical	
- Healthcare monitoring	- Indoor air quality
- Exoskeleton	
Others	
- Food quality monitoring	- Research
- Wearables: Life vests	- Animal tagging

Trade-Off Analysis

Use case 1: BIO.PNT sensor for Precision Agriculture

STRENGTHS

- Rapid, cost-effective, small-scale (sampling)
- Multiparameter analysis (several biomarkers)
- Scalability
- On-the-spot testing
- Real-time information access
- Increasing need for stable food production

Weaknesses

- Little / no sample preparation / pre-treatment
- Technology not proven yet
- Location transmission upon burial of sensor box unknown
- Biosensor lifetime

SWOT

OPPORTUNITIES

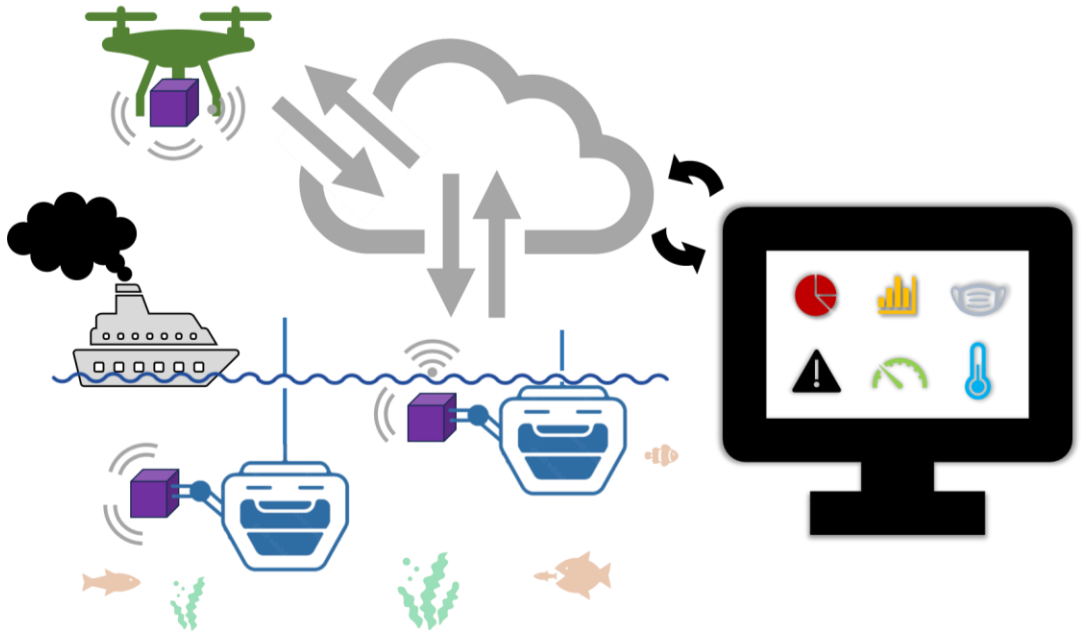
- Environmental monitoring
- New onsite applications
- Food quality control post harvest
- Remediation control
- New biosensor materials

THREATS

- Conventional sensor systems
- Slow rate of commercialization
- Reluctance of market to novel products
- Strong competitors

Trade-Off Analysis

Use case 2: BIO.PNT sensor for Ship Emission Monitoring



STRENGTHS

- Rapid, cost-effective, small-scale (sampling)
- Multiparameter analysis (several biomarkers)
- Scalability
- On-the-spot testing
- Real-time information access
- Increasing global pressure to reduce and assess ship emissions

Weaknesses

- Little / no sample preparation / pre-treatment
- Technology not proven yet
- Policies and regulations on the operation of autonomous vehicles
- Biosensor lifetime

SWOT

OPPORTUNITIES

- Environmental monitoring
- Nanotechnology
- Landfill monitoring
- Water and soil quality monitoring
- Disaster response
- New onsite applications
- New biosensor materials

THREATS

- Conventional sensor systems
- Slow rate of commercialization
- Reluctance of market to novel products
- Missing enforcement / penalties
- Strong competitors
- Emission-free fuels (all electric)

- But: Physical Air Quality sensor more efficient and available
- Biosensor in Salt Water for continuous monitoring challenging

➡ Use case „Detection of Pesticides within Freshwater“ selected

BIO.PNT Sensor

Use Case: Bio.PNT Sensor for Monitoring of Water Quality

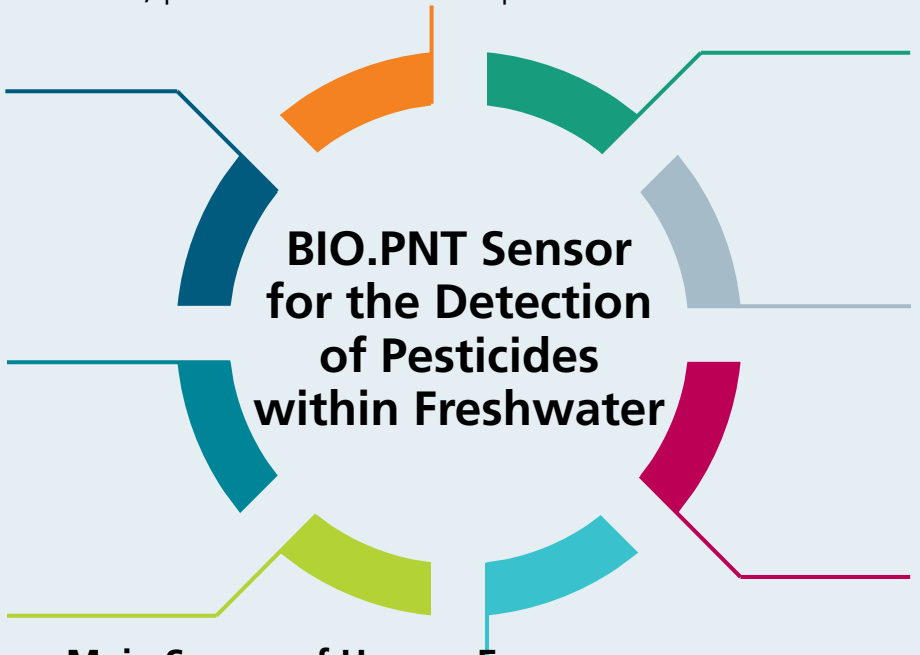
Motivation for Use Case Selection

Natural Freshwater Lakes and Human-made Reservoirs
water management for various purposes

Strict Regulations for Water Quality
Water Framework Directive (EU) 2000/60/EC (2000); Drinking Water Directive (EU) 2020/2184/EC (2020) ,

Huge Pollution by Pesticides
2 Mio. tons of fungicides, bactericides, herbicides, haulm destructors and moss killers, insecticides and acaricides

EU Priority List of Crucial Water Pollutants:
PFAS, pharmaceuticals and pesticides



Standard Pesticide Detection
costly, time-consuming and require a laboratory facility with trained personnel

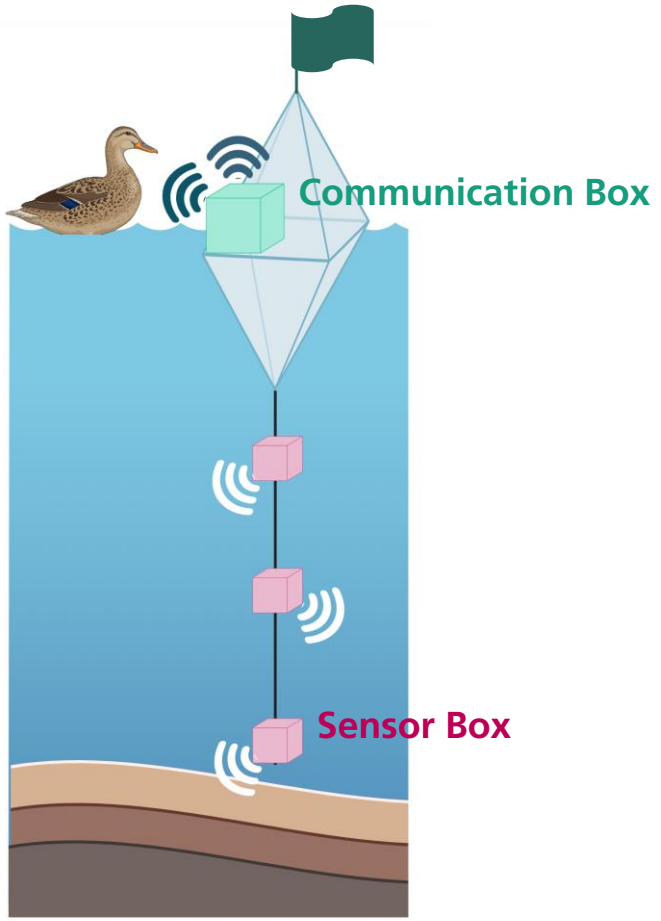
Need for PNT information of contaminations
spread, identification of sources, initiation of countermeasures

Serious negative Effects of Pesticides
toxic, persistent, bioakkumulative, long half-lives of several decades

Main Source of Human Exposure
indirect exposure through contaminated food and drinking water

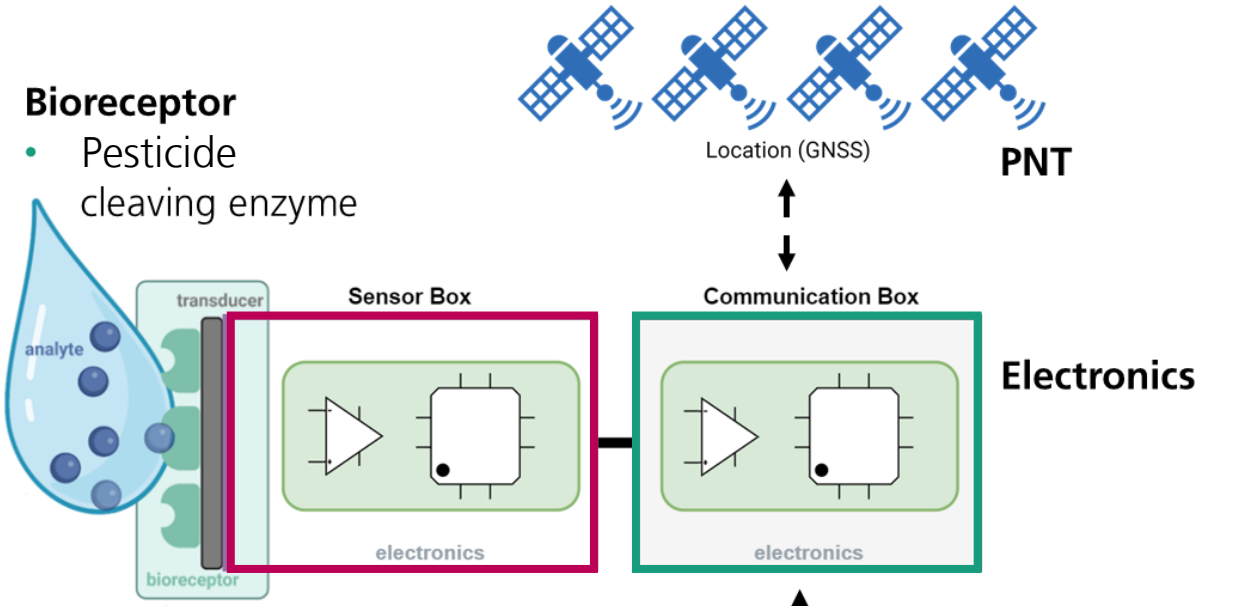
Use Case: Bio.PNT Sensor for Monitoring of Water Quality

Engineering Design



Bioreceptor

- Pesticide cleaving enzyme



Transducer

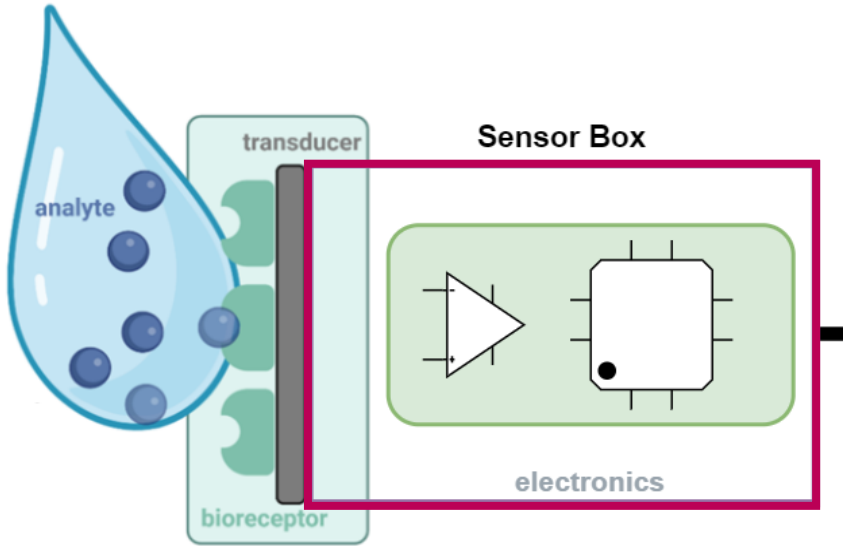
- ICs for electrochemical analyses such as amperometry or EIS
- ISFET

The figures were created with Biorender.com.

Use Case: Bio.PNT Sensor for Monitoring of Water Quality

Biosensor

- Analyte:
  - Pesticides in freshwater
- Bioreceptor:
  - Pesticide cleaving enzyme
- Transducer:
  - Modified field-effect transistor (FET) with amperometry, voltammetry or electrochemical impedance spectrometry (EIS)
- Physical sensors:
  - Temperature and pH sensor for calibration and reference measurement
- Lifetime:
  - Depends on long-term stability/activity of the enzyme and biofouling (at least 30 days)
  - Biosensor and the physical sensors must be replaced



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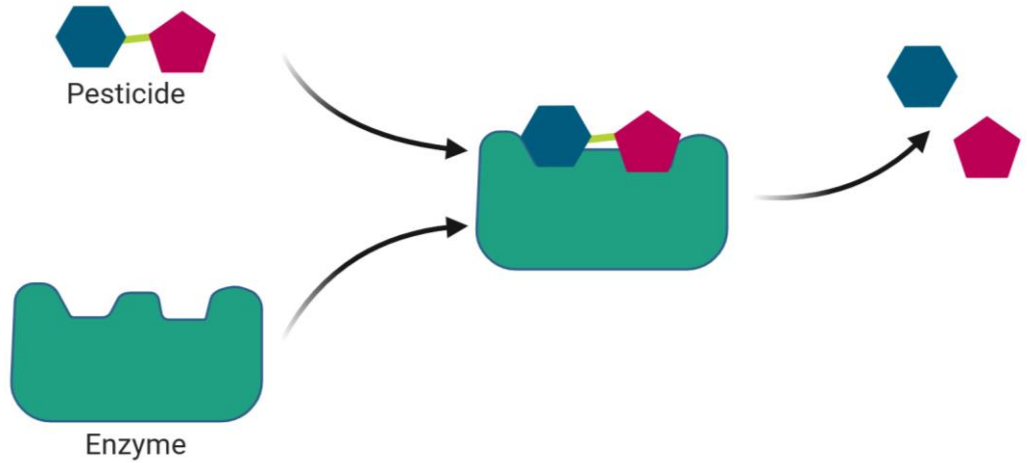
Use Case: Bio.PNT Sensor for Monitoring of Water Quality

Choice of Bioreceptor

- Environmental Parameters of Freshwater influencing Enzyme Activity:
  - pH
    - Freshwater: pH 6 - 8
    - Enzyme: pH 5 – 12 with optimum in alkaline
  - Temperature
    - Freshwater: 2 to 25 °C
    - Enzyme: 10 to 100 °C
  - Ionic strength
    - Freshwater: salinity of fresh water with less than 0.5 ppm
- Choice of Enzyme:
  - Pesticide cleaving enzyme
    allows continuous measurement of the cleavage product
  - Already shown limit of detection: 9 x 10^{-14} µM
  - Remarkably stable



- Sample Preparation not necessary:
  - Expected pesticide concentration is within the measurement range (also according to regulatory threshold levels)
  - No need to adjust reaction parameters

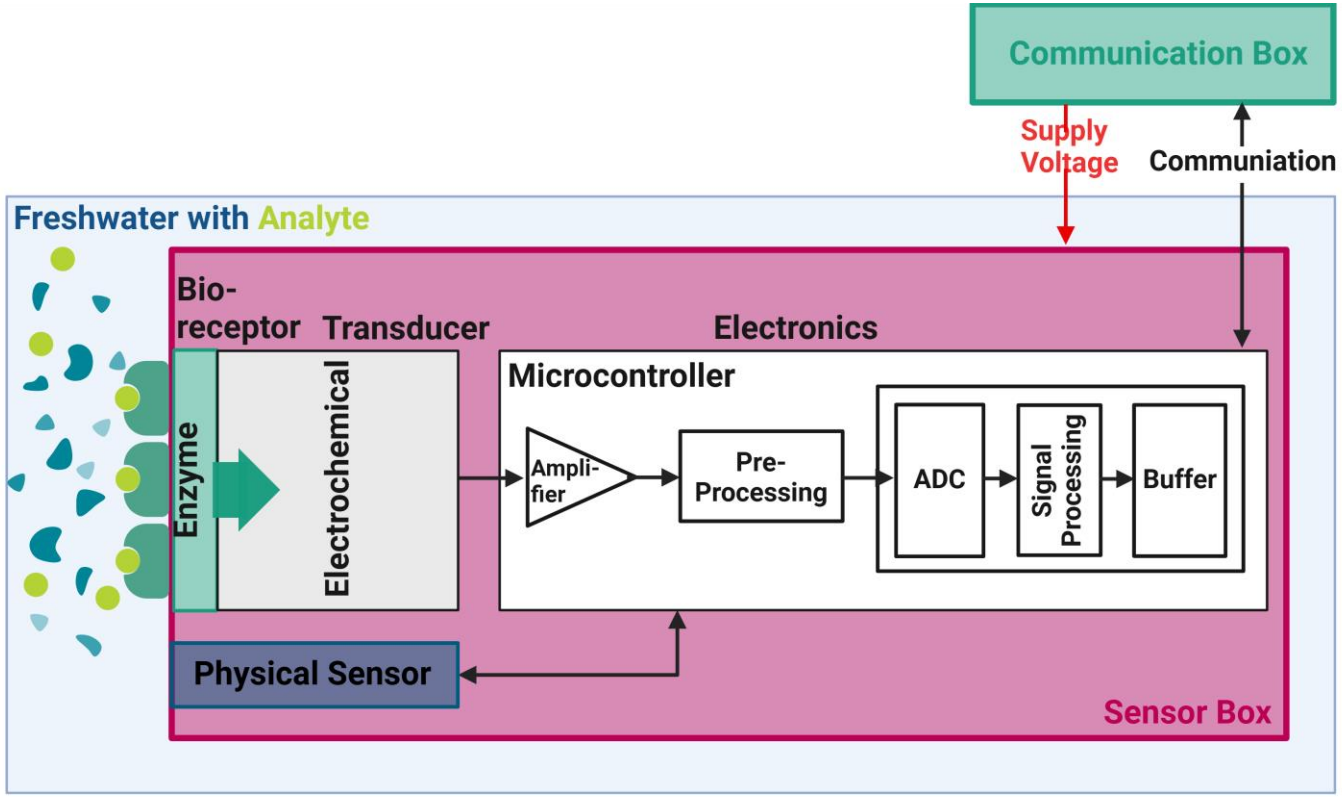
The figure was created with Biorender.com.

Use Case: Bio.PNT Sensor for Monitoring of Water Quality

System Architecture

Sensor Box

- Physical Sensors for calibration and reference measurements
  - Adjusting the biosensor to correct deviations
  - Determine the operating conditions
  - To exclude false-positive values due to pH changes caused by external factors (e.g. acids)
  - Automatically integrated into the measurement routine
- Pre-Processing and signal processing via second microcontroller or analog front end that has been specifically developed for this purpose



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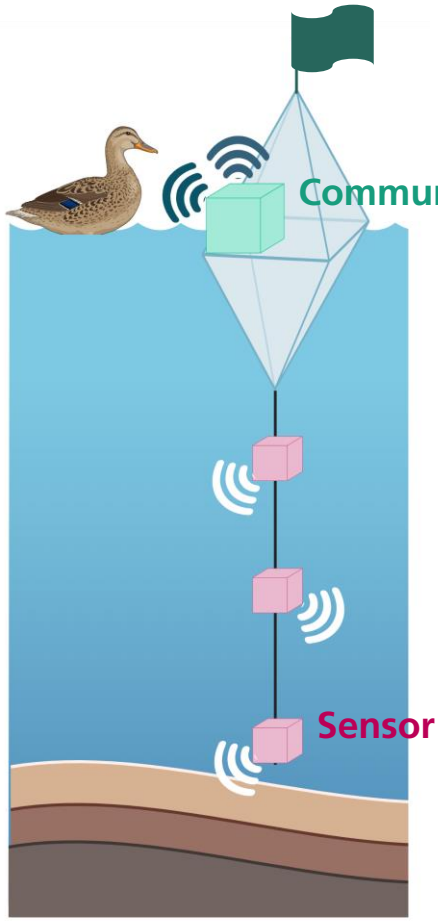
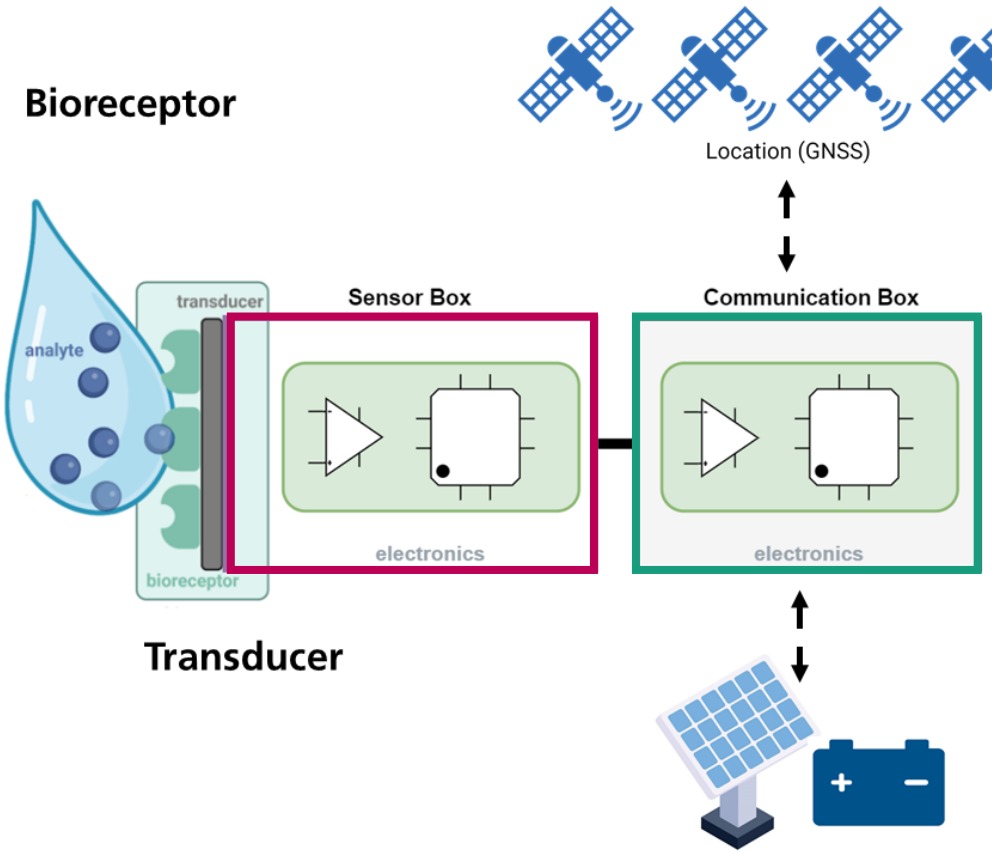
Use Case: Bio.PNT Sensor for Monitoring of Water Quality

Engineering Design





PNT
- Single-band or dual-band GNSS receiver

Electronics
- Low-power microcontroller
- Micro SD card
- ECM (communication module)

Power supply
- Solar panel
- Battery

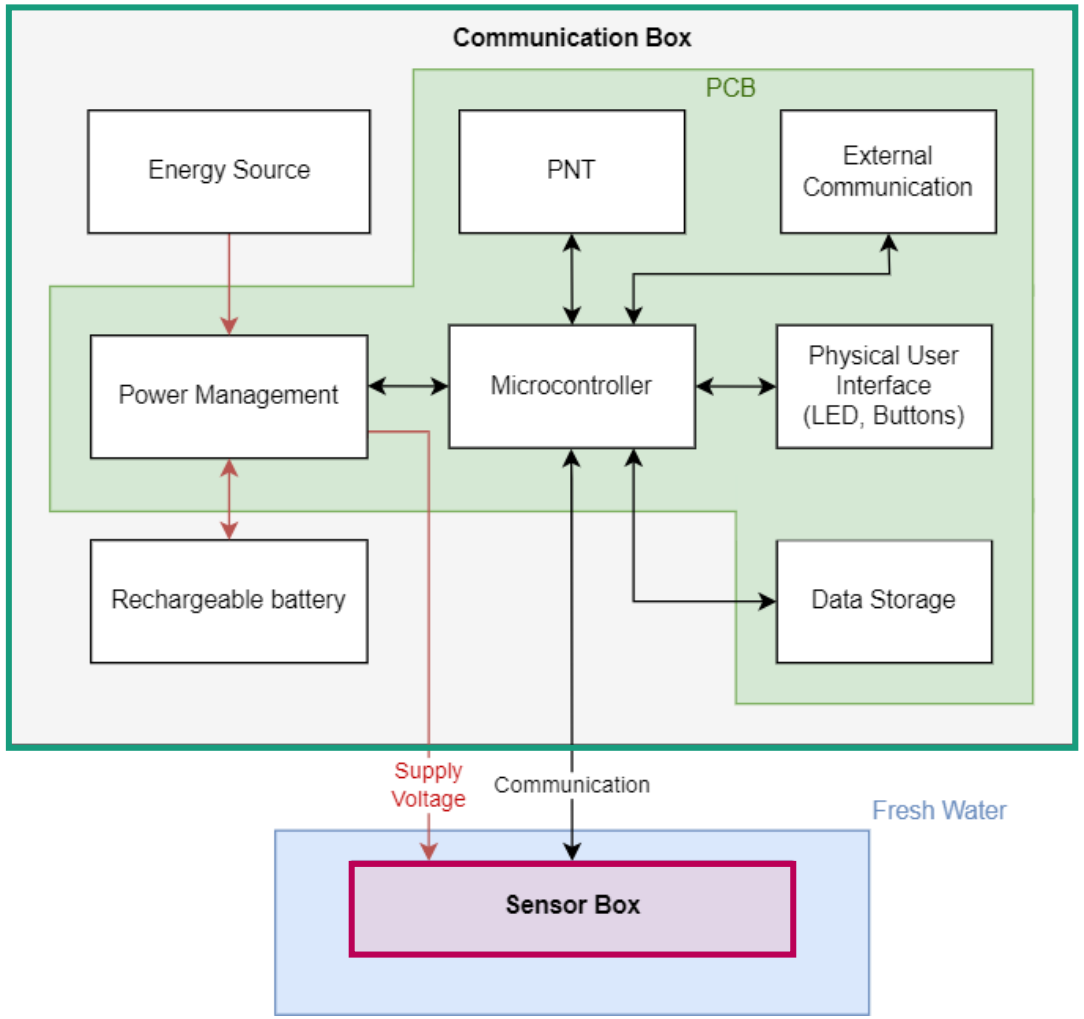
The figures were created with Biorender.com.

Use Case: Bio.PNT Sensor for Monitoring of Water Quality

System Architecture

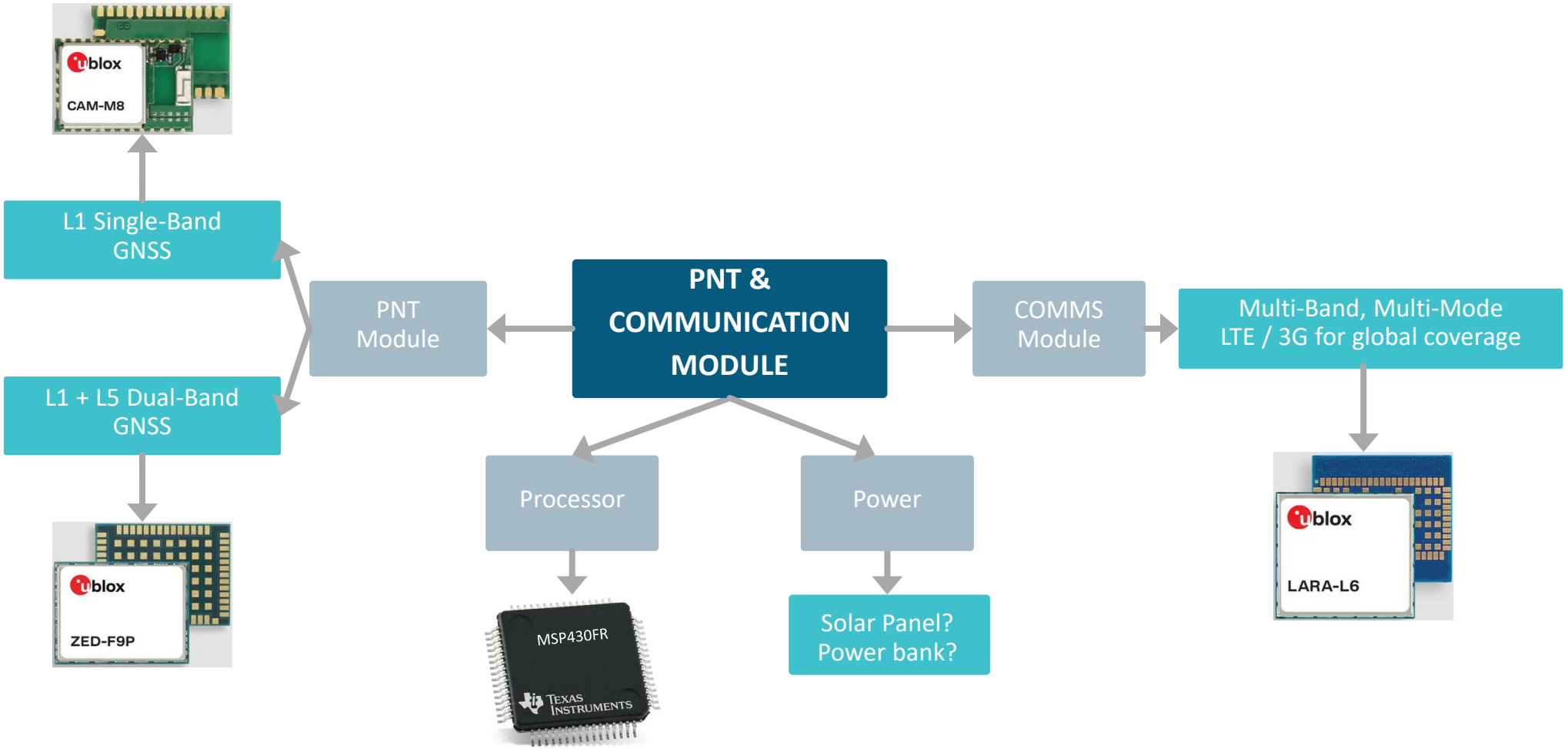
Communication Box

- Low-power Microcontroller, serving as the primary control unit
- Power supply via solar panel
- Power Management:
  - Controlled battery charging
  - Monitoring battery status
  - Generates voltages for all components
- Data storage handled via microSD card
- External communication module sends data to user



Design Parameters

PNT and Communication Module



Business Case

Identification of Key Resources and Key Activities

Business Canvas Model

Key activities

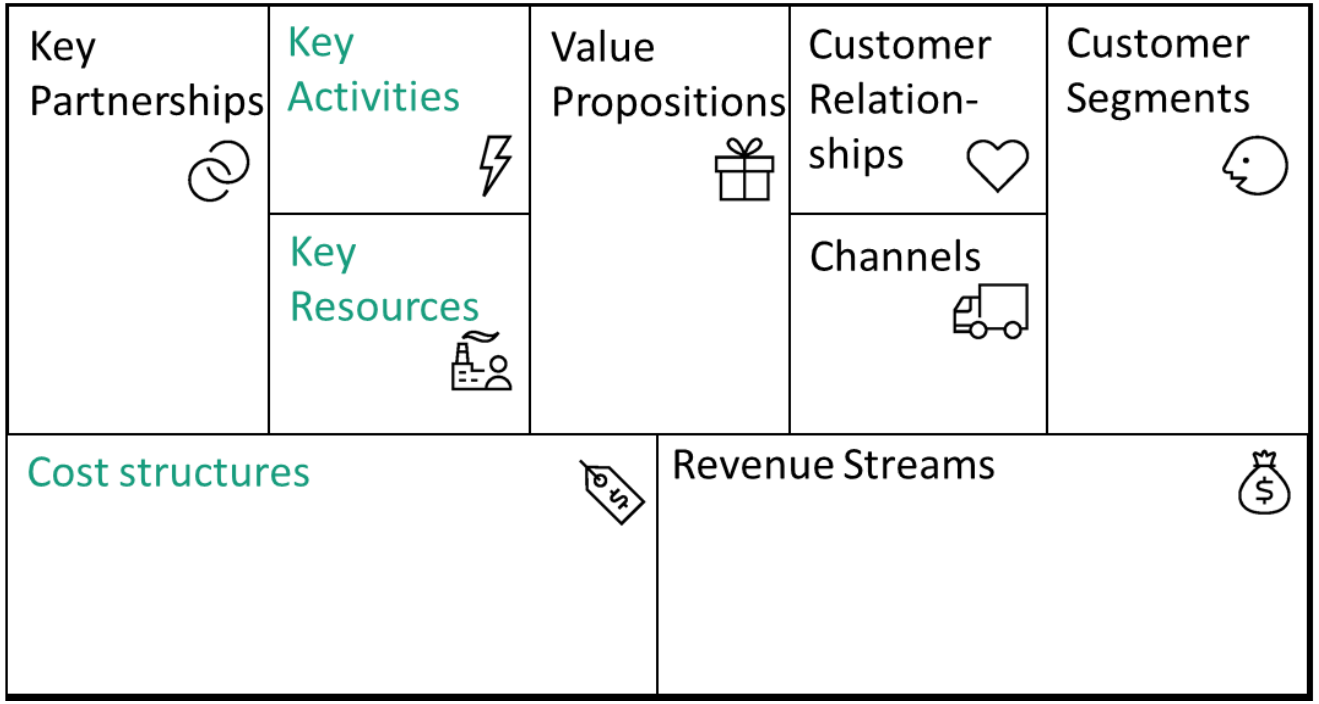
- Research and Development
- Production
- Marketing

Key resources

- **Human Resources**
- **Material Resources**
- **Intellectual resources**

Cost structures

- **Variable costs**

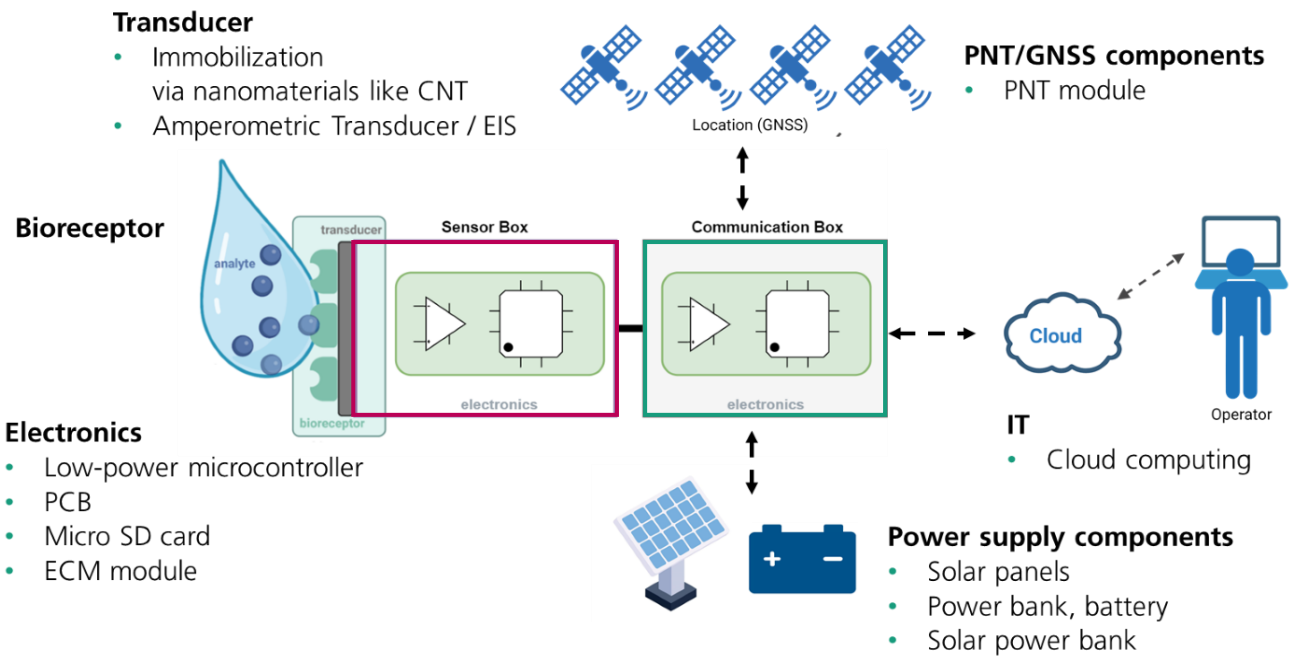


Developed by Alexander Ostwalder

Identification of Key Resources and Activities

Key Resources

- **Human Resources:**
  Biological and electrical engineering, material science, surface chemistry, PNT / GNSS engineering, IT competence, electrical and electric engineering competence ➔ **Highly Interdisciplinary**
- **Material Resources**:
  All electronic components designed as COTS products and enzyme has to be produced on customized request
- **Intellectual resources:**
  Innovative step: how to use the specific enzyme for direct detection of pesticides within freshwater samples without any sample preparation and setting of reaction parameters ➔ **Patentable in General**



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Identification of Key Resources and Activities

Cost Structures – Variable Costs

Communication Box	Estimated costs in €
Printed circuit board	50 - 150
Low power microcontroller	4 - 13
SD card	3 –8
EMC module	< 120
PNT module: a) single band GNSS receiver or b) dual band GNSS receiver and antenna	< 30 150
Power supply: a) solar panel and power bank or battery b) solar power bank	7 – 40 2 – 27 17 - 70
Cloud computing	2.3 – 1,620
Total sum (without cloud computing)	**216 - 511**

Sensor Box	Estimated costs in €
Enzyme	0.005
Enzyme immobilization	0.007
Transducer: a) Integrated Circuit (IC) for electrochemical analyses such as amperometry or EIS or b) FET	2.4 - 11 < 5
Printed circuit board	50 - 150
Total sum	**57 –166 €**

Estimated End price

assumed with a margin of 3 to 15 %

Sensor Box: € 59 to 191

Communication Box: € 229 to 605

BIO.PNT Sensor (€ 288 to 796) is marketable and competitive to less complex commercial physical sensors (€ 1,500 to 3,500).

Summary

Summary

- **Motivation:** Increasing market of PNT and Biosensors technologies. Potential for combination?
- **Methodology:** Analysis of different types of biosensors and PNT technologies, State-of-the-art analysis, Market scoping and Trade-off analysis, BIO.PNT sensor design concept
- **Achievements:** Exemplary application design concept for environmental water quality monitoring
  - Allows to continuously detect possible organophosphate contamination in fresh water without sample preparation
  - In combination with PNT parameters can be assigned to each measured value
- **Future:** This data would allow for environmental monitoring assessing water quality in natural ecosystems, lakes, and rivers to understand and mitigate the impact of human activities

Thank you!

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