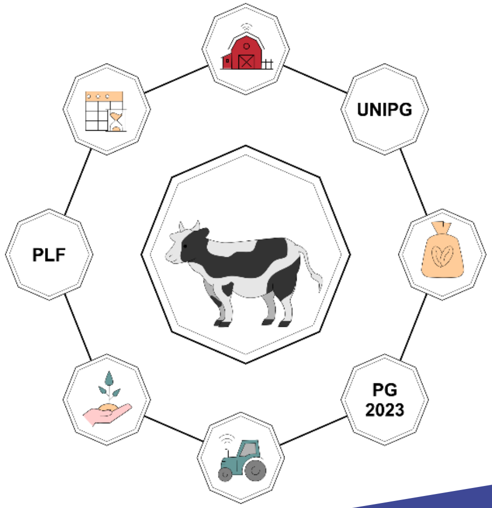
Livestock Welfare Technologies

Analysis of the information provided by sensors and technologies installed on farm, labelling, validation and development of PLF systems



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Dipartimento di Ingegneria

Digital Video Processing Lab

Outline

- Introduction
- Technologies for Smart Livestock Welfare
- Projects and activities of UNIPG team
  - PSR Livestock Smart Farming
  - On-going & Future Activities
- Contacts for further insights, internships, degree thesis

Introduction

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- The concept of animal welfare includes three elements:
  - The animal’s normal biological functioning (which, among other things, means ensuring that the animal is healthy and well-feed),
  - Its emotional state (including the absence of negative emotions, such as pain and chronic fear),
  - its ability to express certain normal behaviors (Fraser et al., 1997).
- Nevertheless, not all behaviors are equally important in terms of animal welfare. From a practical standpoint, the clearest indication that a given behavior is important is whether **the animal shows a stress response** or exhibits abnormal behavior when prevented from performing it.
- In accordance with the 'Five Freedoms' principle, an animal's welfare is ensured when the following five conditions are met (FAWC, 1992; 1993):
  - The animal is free from hunger, thirst and malnutrition, because it has ready access to drinking water and a suitable diet.
  - The animal is free from physical and thermal discomfort, because it has access to shelter from the elements and a comfortable resting area.
  - The animal is free from pain, injury and disease, thanks to suitable prevention and/or rapid diagnosis and treatment.
  - The animal is able to express most of its normal behavioral patterns, because it has sufficient space, proper facilities and the company of other animals of its kind.
  - The animal does not experience fear or distress, because the conditions needed to prevent mental suffering have been ensured.

Some Involved Authorities & Organizations

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efsa EUROPEAN FOOD SAFETY AUTHORITY

NSF Food and Water Safety & Quality in Europe

USDA U.S. DEPARTMENT OF AGRICULTURE

THE WORLD SMALL ANIMAL VETERINARY ASSOCIATION WSAVA Global Veterinary Community

Innovative technologies to ensure welfare

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- Farmers need reliable and affordable technologies to assist them in daily management tasks and to guarantee accurate and continuous individual animal monitoring and increase the farmer's ability to keep contact with individual animals to prevent health, welfare and management issues.
- The increasing world population has led to a rapid intensification in Livestock related production systems. This has affected animal health and welfare, although in recent years consumers have become more concerned about the welfare, health and living conditions of farm animals.
- We are living in the 4th technological and industrial revolution era (i.e., technology 4.0) which is about using cyber-physical systems, wireless communication and technology.
- Technological advancements are used to control the integration of communication systems, increase production efficiency, lower operational costs and provide reliable and accurate tools for monitoring Livestock health and welfare.

Livestock Welfare Technologies

There is growing interest in detecting animal behavior and body postures through the application of technology that enables remote communication, welfare assessment and behavioral pattern recognition.

Appropriate choice of technology with the correct application to measure animal welfare is critical in the successful automation of animal health and welfare monitoring.

Emerging technologies with potential in the dairy industry includeInternet of Things, near-infrared spectroscopy, machine vision, 5G technology, cloud computing, biosensors, augmented reality, and the Artificial Intelligence,

Internet of Things (IoT)

Near-infrared spectroscopy

Machine vision

5G technology

Cloud computing

Biosensors

Augmented reality

Artificial intelligence

Internet of Things (IoT)

The **Internet of Things** is a new paradigm that connects devices through high-speed internet to sense, gather and share data so that it can be processed and utilized to fulfil common goals.

For example, IoT-embedded smart collar belts can be used in dairy cattle management systems to give real-time location of the cattle and send signals to the owners every 15 minutes.

In addition, the IoT can be applied to auto-milking, heat-cycle tracking, health tracking, decreasing mortality with security alerts and controlling disease outbreak

https://www.ruminantia.it/precision-livestock-farming-luci-e-ombre/

Near-infrared spectroscopy is a multi-analytical technology that applies the infrared region of the electromagnetic spectrum (from 800 nm to 2,500 nm) to explore the physio-chemical characteristics of samples.

Near-infrared spectroscopy is a rapid, non-destructive, precise and cost-effective technology for feed analysis.

This technology can be applied on-farm for precision feeding systems to provide the right amount of daily nutrients with fewer metabolic alterations.

Near-infrared spectroscopy portable tools can be used directly in the barn in “on-line” and “on-live” mode to obtain information in real time and to avoid the long waiting times for laboratory analysis responses, allowing timely prevention and correction

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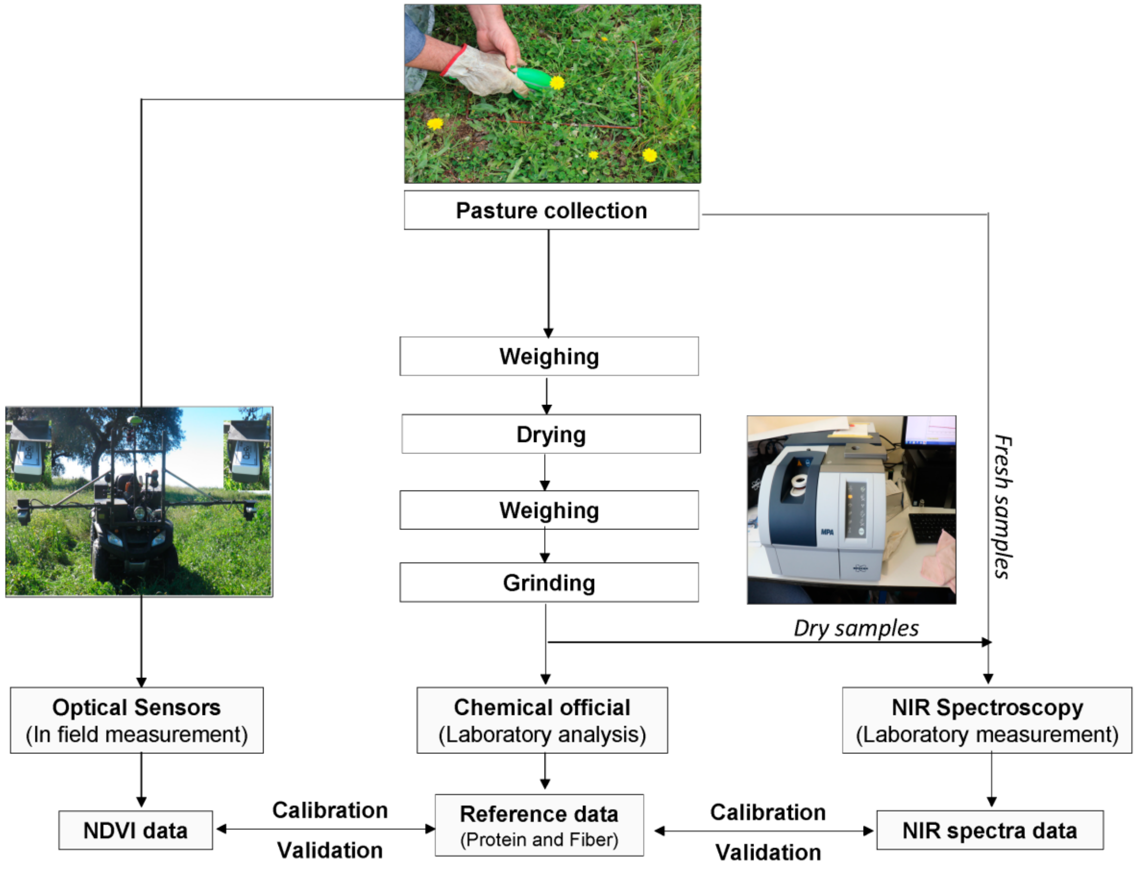


Near-infrared spectroscopy

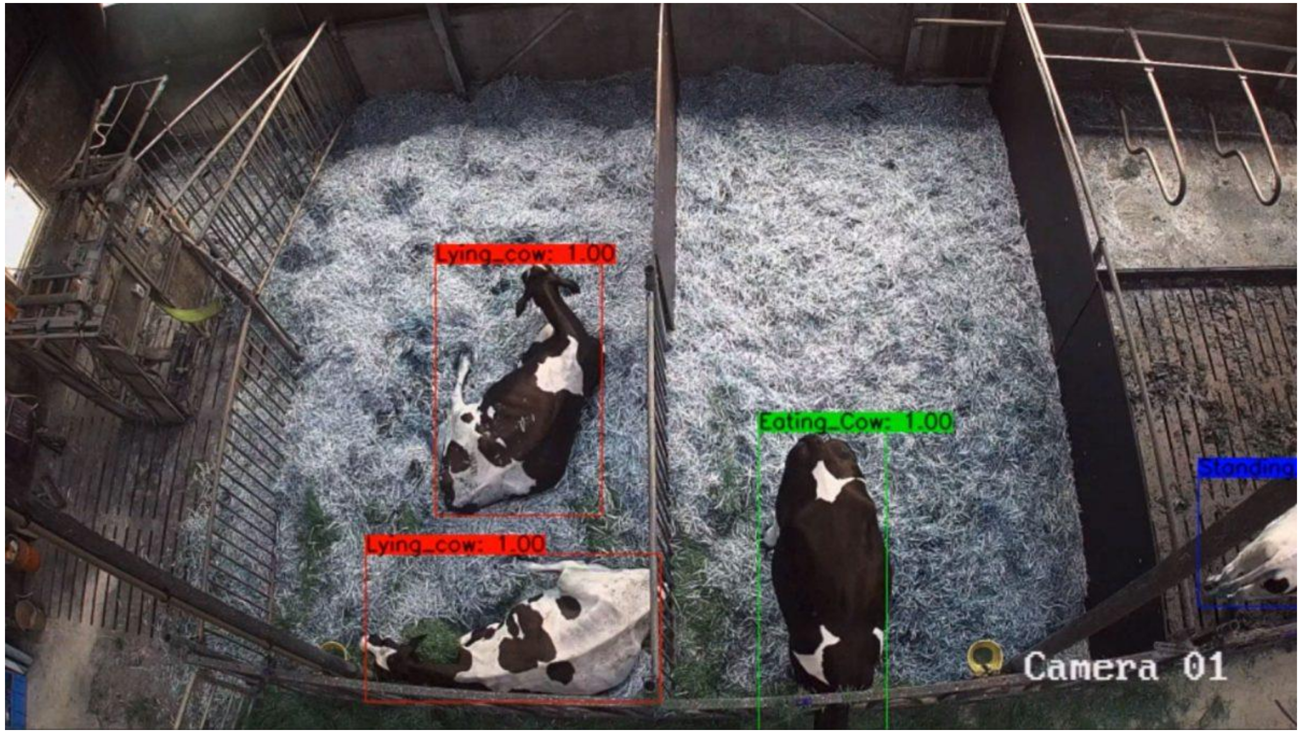
AgriEngineering 2021, 3(1), 73-91; https://doi.org/10.3390/agriengineering3010005

Machine vision uses machines, sensors and data-processing algorithms to “see”, analyse and make decisions about the surroundings.

Machine vision will have a massive impact on many fields, including agriculture and animal science.

It is especially useful for problems that currently need a person to view the situation, such as dairy cow feed intake monitoring and observing the gradual change in body condition score.

Systems based on machine vision are suitable for the dairy environment, as they do not inhibit workflow, are capable of continuous operation and can be fully automated.



Machine Vision

https://mediaan.com/mediaan-blog/computer-vision-calving

5G technology is one of the major futuristic visions in communication and data transformation due to its capability of supporting 1,000-fold gains in capacity, connections for at least 100 billion devices and a 10–20 GB/s individual user experience of extremely low latency and response times.

Deployment of 5G networks is expected to emerge between 2020 and 2030.

In intensive dairy production systems, dairy cows can wear a 5G-connected collar that controls the robotic milking system.

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5G technology

https://gadgetsandwearables.com/2019/04/16/5g-biometric-wearables/

Cloud computing links cyber-physical systems intelligently and in real-time, allowing data sharing across connected devices to the same cloud within milliseconds or faster.

In addition, cloud computing enables the delivery of computing services such as servers, storage, databases, networking, software and analytics through visualised and scalable resources over the internet.

Cloud computing offers a great opportunity to monitor dairy cattle health and behavior and to enhance dairy farm efficiency, productivity and profitability.

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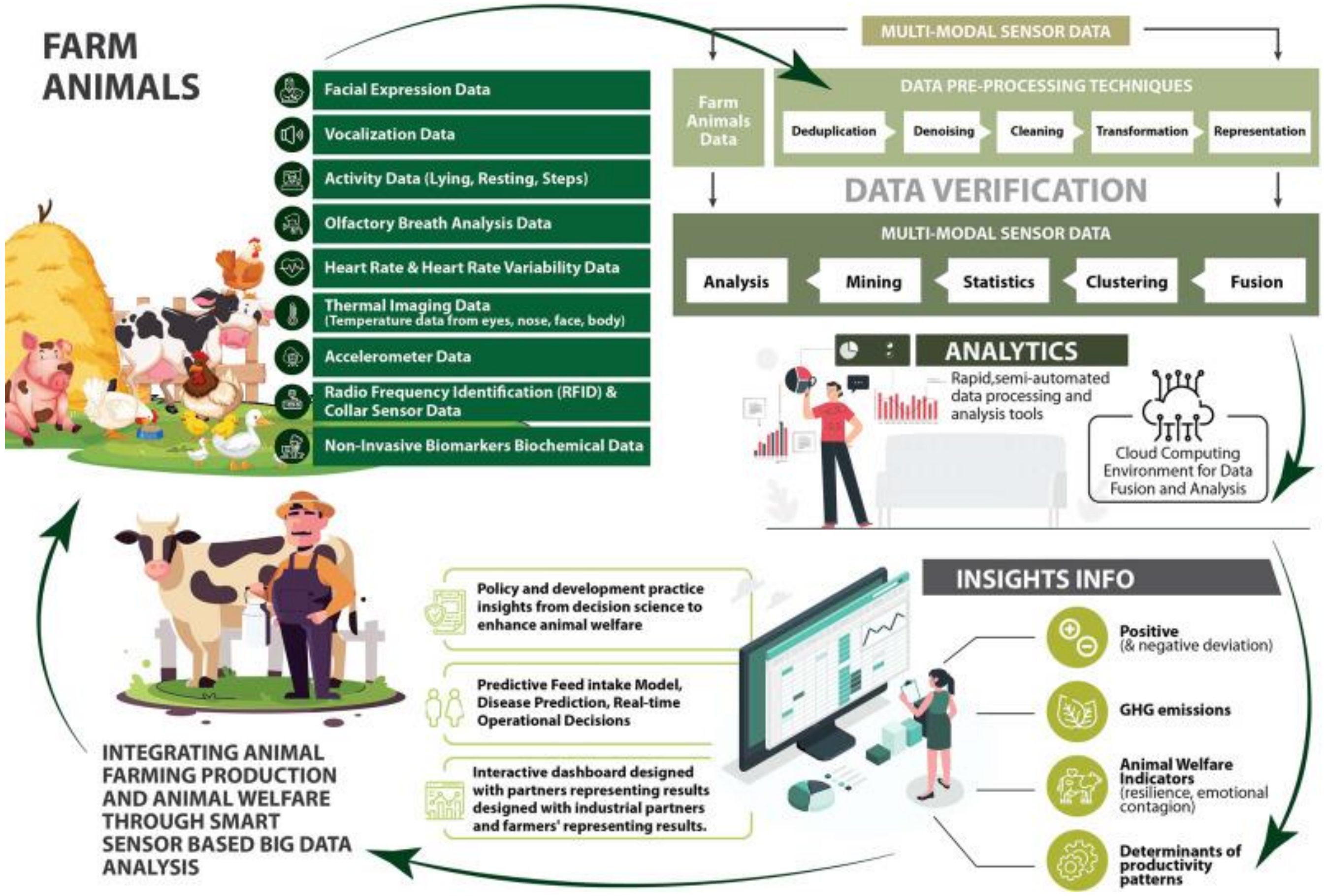


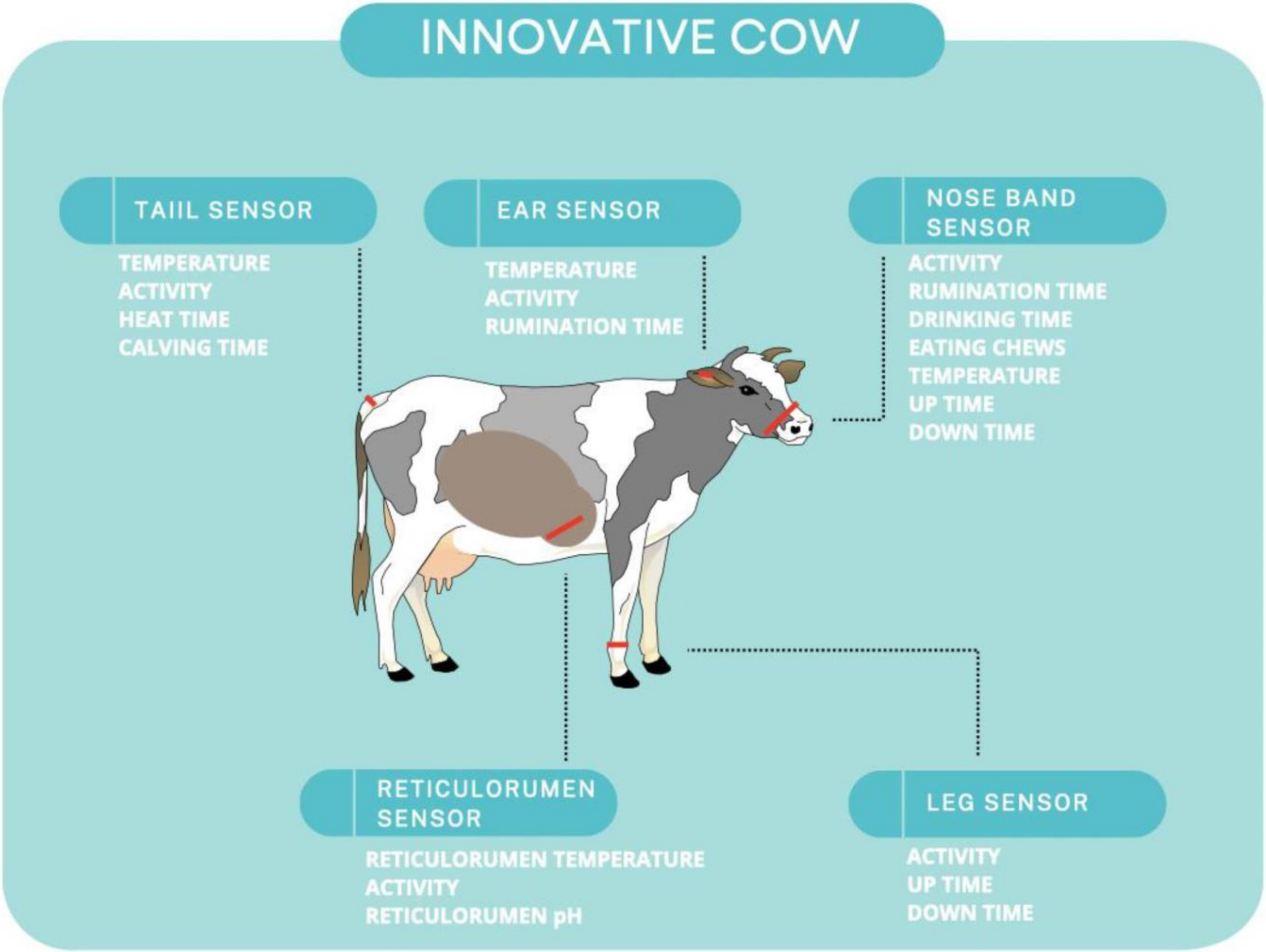
Cloud computing

https://www.computer.org/csdl/magazine/co/2019/10/08848671/1dC4IYhDPfW

Wearable wireless biosensors comprise battery, data transmitter and one or more sensors mounted on the cow's body to measure, collect and transmit biometric data at specified time intervals.

The collected data are computed into physiological and behavioral parameters by algorithms, software or cloud computing to predict, detect and diagnose the physiological and health status of dairy cattle.

These sensors include ear tags, halters, neck collars, reticulo-rumen bolus sensors, leg tags, tail tags, tail head tags and vaginal tags.



Biosensors

https://encyclopedia.pub/entry/42228

Augmented Reality is associated with technologies that combine physical and virtual objects over the real environment, interact in real time and align physical and virtual objects with each other.

The overlaying of different virtual elements generated by a computer over the real world can give information about the physical elements that human senses could not provide.

Augmented Reality provides useful information about individual cow identification, health status, productivity, feed ration, heat signals and behavior.

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Augmented Reality

https://xfarm.ag/2022/06/23/xfarm-and-parmalat-together-to-make-the-milk-supply-chain-sustainable-through-digitalization/?lang=en

Artificial intelligence is described as the simulation of human intelligence in machines that are programmed to have traits associated with the human mind, such as learning and problem-solving.

It aims to understand and design systems displaying intelligence properties such as the ability to learn, derive knowledge from data, rationalize and take actions to achieve specific goals.

Big data combined with artificial intelligence algorithms can be transformed into useful information to improve decision-making on Livestock farms.

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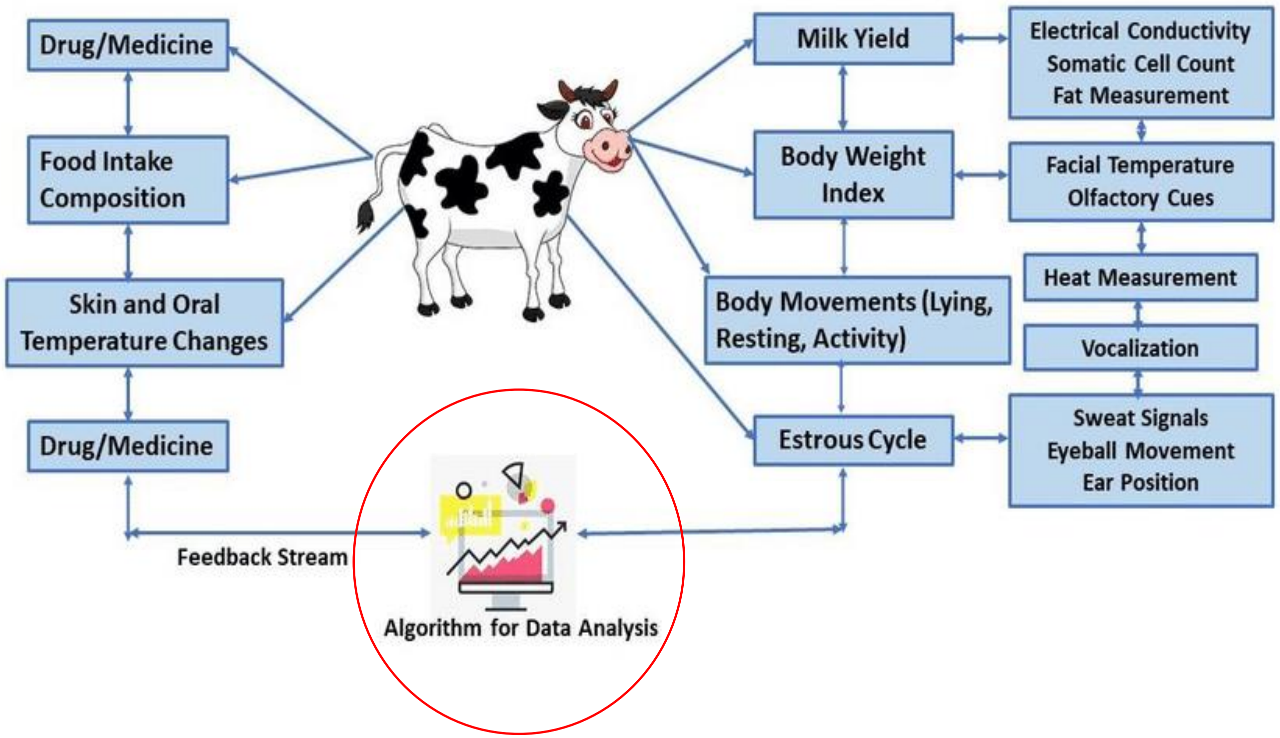

Artificial intelligence

https://www.researchgate.net/figure/A-representation-of-how-machine-learning-algorithms-might-interpret-data-to-create_fig3_342766662

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Projects and activities of UNIPG-DI Team

SMART FARM (in a nutshell)

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IoT applied to zootechnics

Resilient and Efficient animal production systems

Improved animal welfare/health (biomarkers)

Animals POV
Production increase

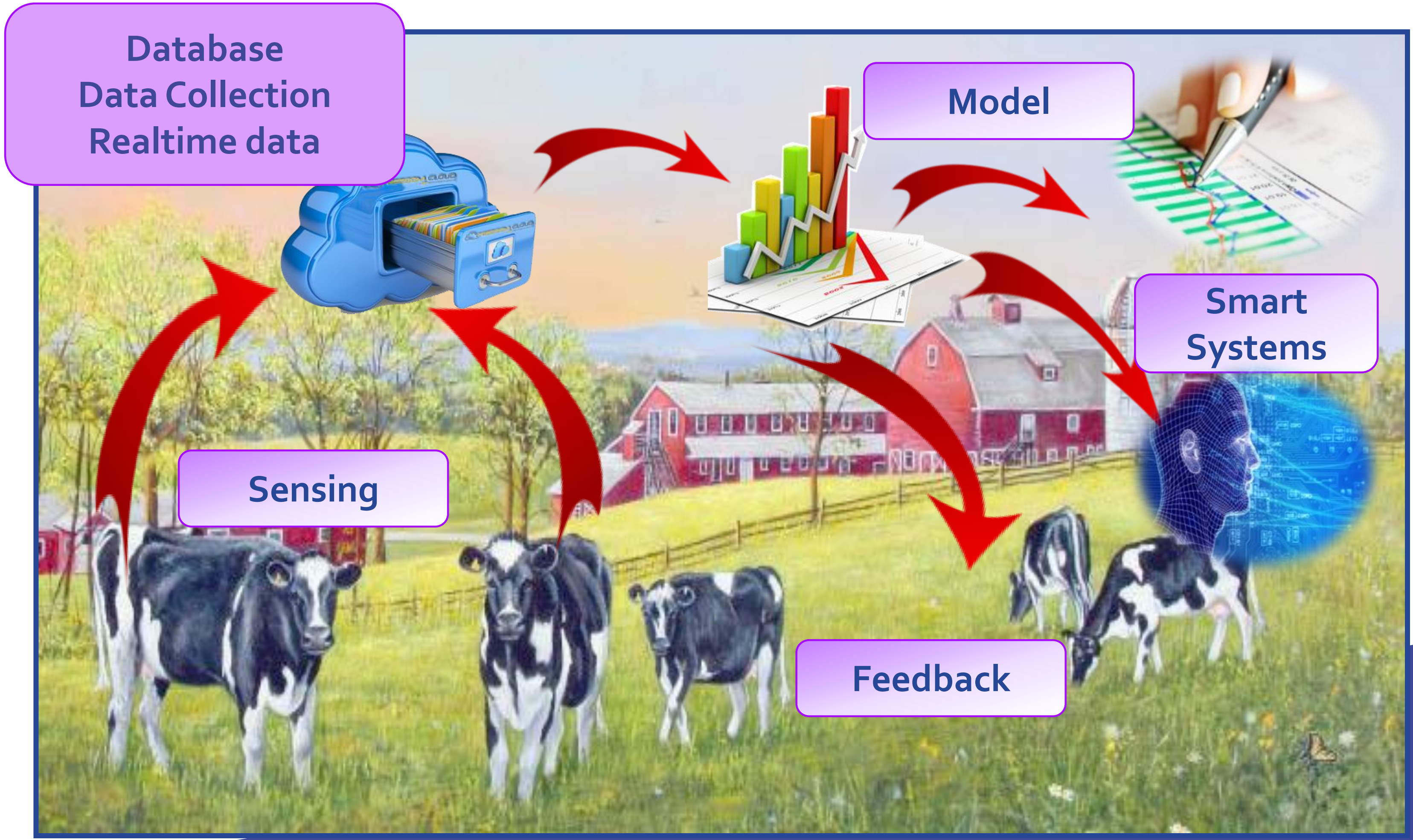
Improved security/safety of producer (traceability)

Consumers POV

Higher quality/quantity of producer at lower costs

Farmers POV
Economic

Multidisciplinary Approach



Vision

- Understand the power of applying data gathering (edge intelligence), data processing, data analysis and **automation technologies** on the overall value chain.

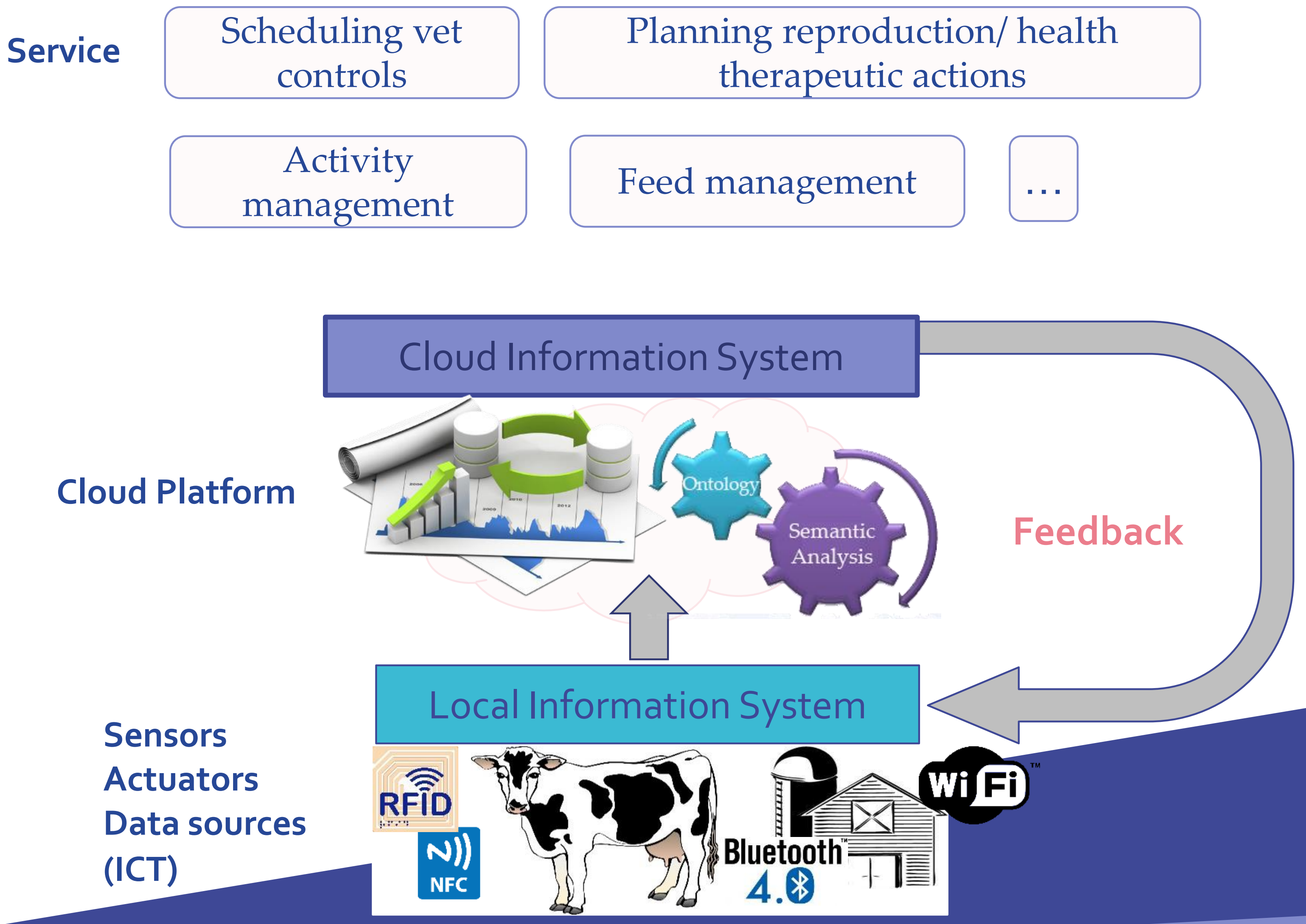
- Jointly orchestration to allow operation and management improvement (analytics) of a farm with respect to standard operations (near real time) and re-use of data (animal-plant-soil) in improved **chain transparency** (food safety) and **chain optimization** (smart data)

- Exploit the capabilities enabled by **Internet of Things** (IoT) technologies.

- The **real-time detection of pathologies** (e.g. laminitis) **or of physiological events** (e.g. estrus) will allow prompt action in the interventions to follow (e.g. planning therapeutic protocols, mating), with significant savings in both terms of time and cost.

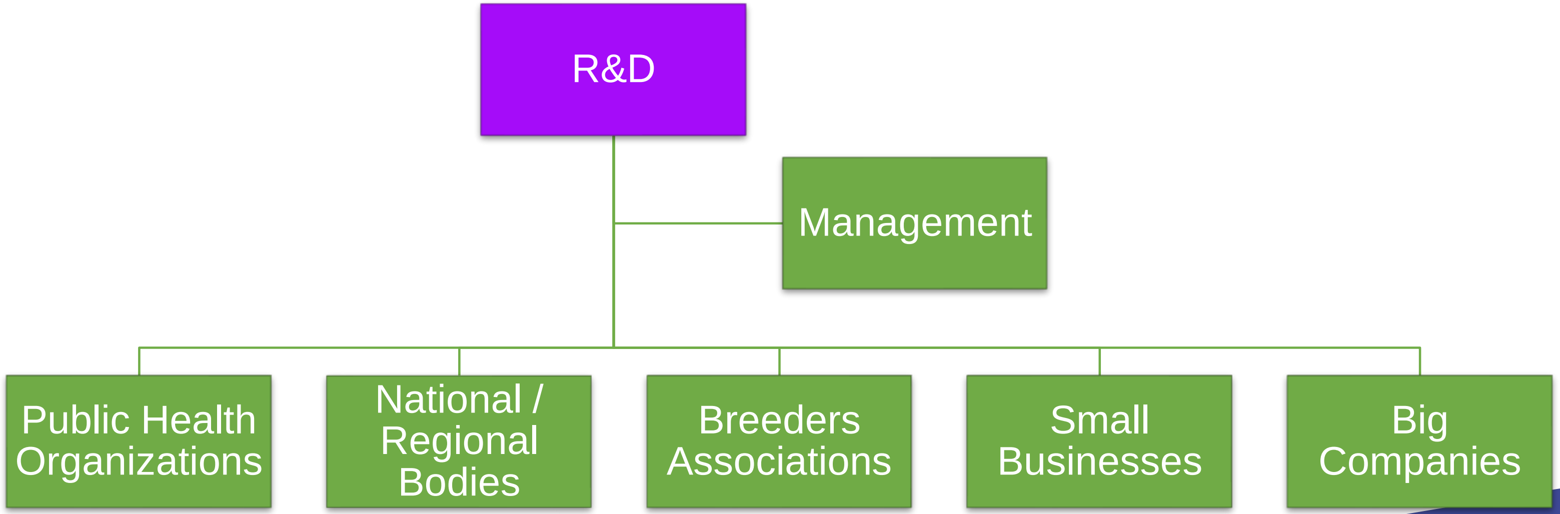
- Put together a set of skills, with a multidisciplinary approach, that can be a starting point for **future**

Overall Architecture



Business Model

- As researchers and project promoters, we intend to address all the main national and international players in the field of animal husbandry and intensive and extensive breeding, including the entire value chain
- Sets of diversified and specialized technologies will be provided for each of the partners of interest
- Through dedicated **Service and Monitoring Centers** it will be possible to supply these advanced technologies and services also to small and medium sized companies



PROGRAMMA DI SVILUPPO RURALE PER L'UMBRIA 2014 2020

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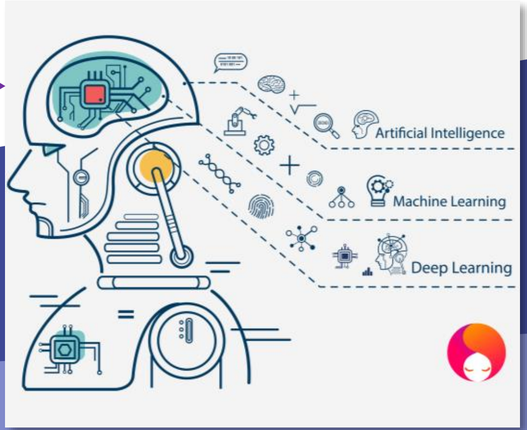
Misura 16.1

Project
Livestock Smart Farming

Project Scope

- Data acquisition from wireless sensors
  - Environmental (temperature, humidity, etc.)
  - Biomarkers (body temperature, movement, etc.)
  - Internet of Things (IoT) approach
- Data transfer to the Cloud
  - Security and reliability
  - Development with non-proprietary technologies
- Analysis and processing of the collected data
  - Machine learning, Big Data, etc.



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Project Activities

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Sensors Development

- Scenario: animals in stables
- Scenario: grazing animals

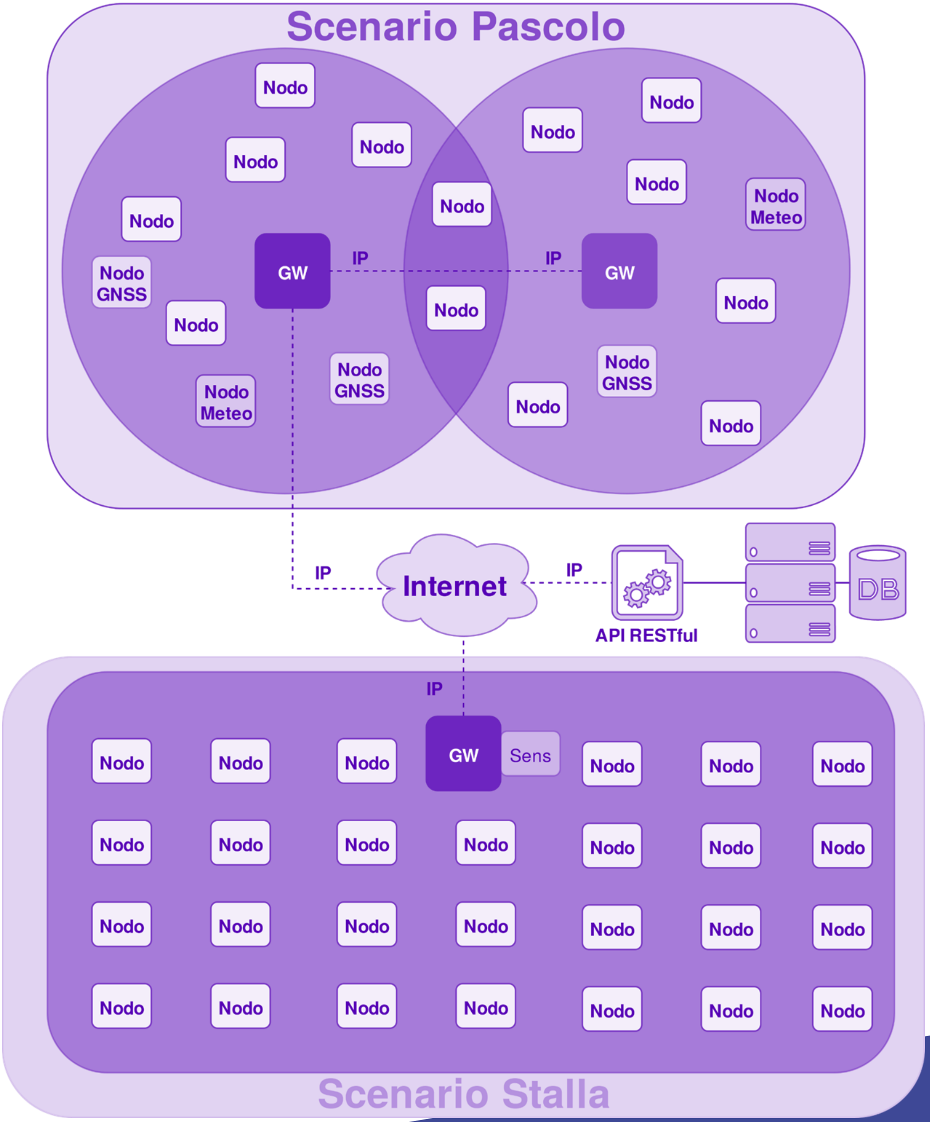
Data Gathering Infrastructure Development

- Telecommunications Protocols
- Data Base and Data Processing

Machine Learning Algorithms Development

- Alarms on single animal
- Herd parameter monitoring

Infrastructure Architecture



'Nodo' = Node = single animal

GW = Gateway – Provides Connection to Cloud

'Pascolo' = Grazing Animals

Base Node Configuration: biomarkers
'Nodo GNSS' = GNSS Node: Biom. + GPS
'Nodo meteo' = Meteo Node: temp. + umid. + press. +light.

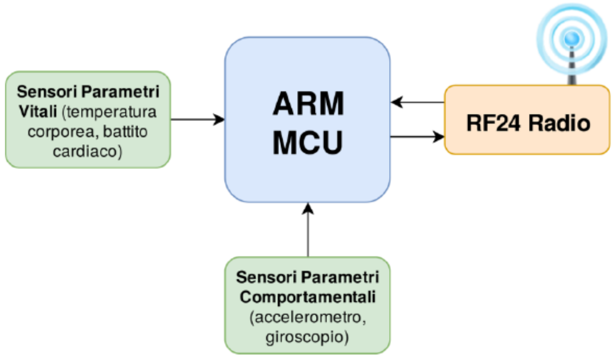
'Scenario Stalla' = Shed

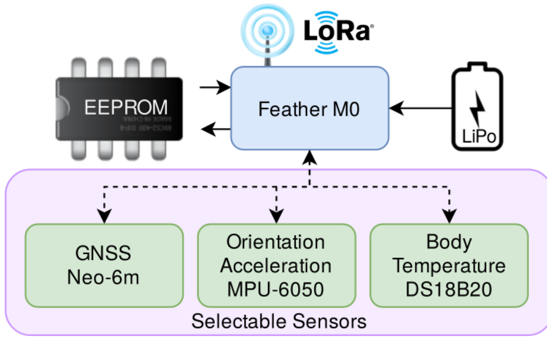
Base Node Configuration: biomarkers
Sens: Environment parameters + ammonia

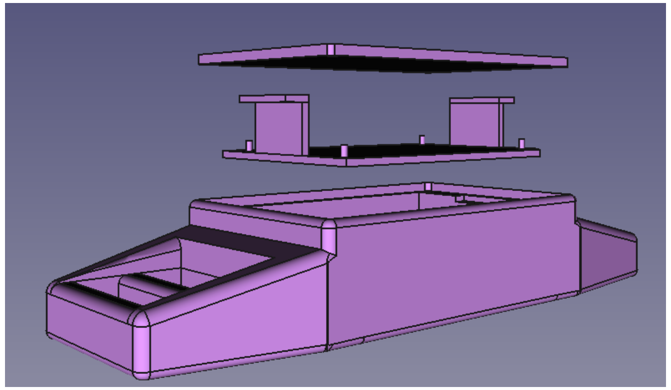
To Cloud

WiFi, Ethernet, 3G/4G/5G

Developed systems – Indoor Cattle Biosensor

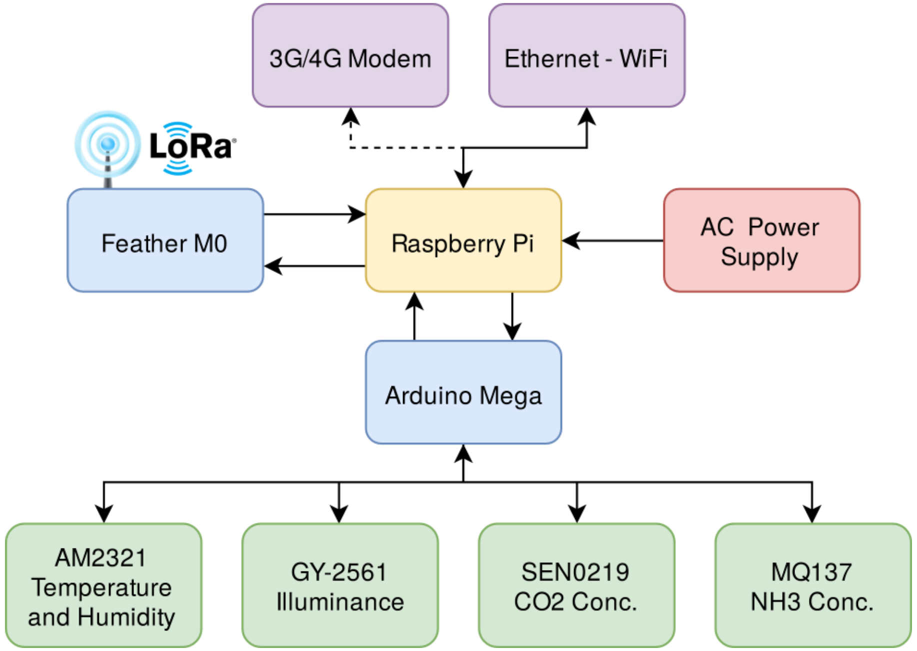






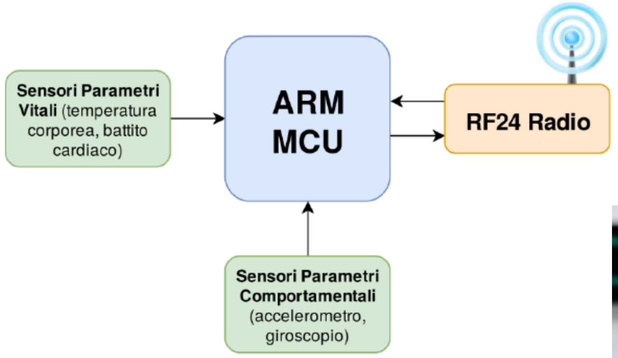
- Name
  - **Indoor Cattle Biosensor**
- Function
  - Monitoring vital parameters of the animal.
- Dimensions and installation methods / integration with the animal
  - Sensor enclosed in IP66 packaging (Ingress Protection - Totally protected against dust, sand and in general any small solid body Protected from rain and liquids) of size 12 cm * 8 cm * 3 cm and installed on a collar.
- Power and Autonomy
  - It uses a battery pack made up of Energizer L91 lithium cells with an expected life of approximately 2 years.
- Operating range
  - 200 – 400m
- Measured data
  - I. Vital signs : Body temperature, Heart rate
  - II. Behavioral parameters: Accelerometer, gyroscope

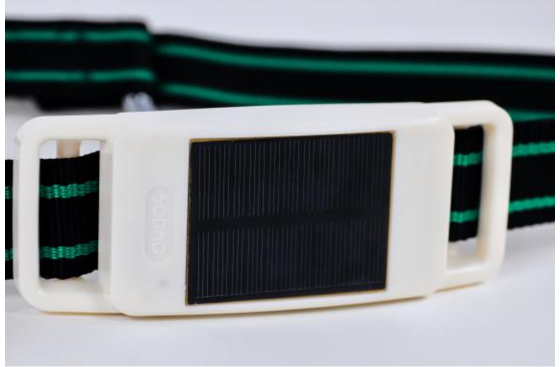
Developed systems – Indoor Environmental Sensor

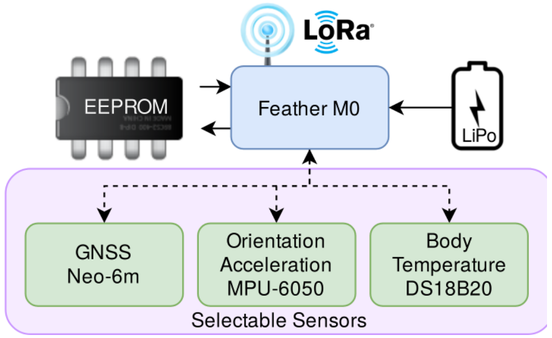


- Name
  - Gateway + Indoor Environmental Sensor
- Function
  - Monitoring of stable environmental parameters
  - Communication and acquisition of measurements from the nodes, and interface for data transmission with the outside world via the Internet towards the information collection point
- Dimensions and installation methods
  - Gateway + Indoor Environmental Sensor 30 cm x 20 cm x 10 cm.
- Power and Autonomy
  - 5 V/2.5 A DC via micro-USB connector
  - Power over Ethernet (PoE)–enabled (requires separate PoE HAT)
- Operating Range
  - 200 – 400 m
- Measured Data
  - Environmental Parameters: Temperature, humidity, ammonia, luminosity and atmospheric pressure

Developed systems – Outdoor Cattle Biosensor







- Name
    - GNSS Grazing Cattle Node
- Function
    - Monitoring vital parameters of a single grazing animal.
- Expected dimensions and methods of installation/integration with the animal
    - Sensor enclosed in an IP66 packaging (Ingress Protection - Totally protected against dust, sand and in general any solid body of small dimensions - Protected from rain and liquids), with a dimension of 12 cm * 8 cm * 3 cm and installed on a collar for cattle.
- Power and Autonomy
    - It uses a battery pack made up of Energizer L91 lithium cells with an expected life of approximately 2 years.
- Operating range
    - 1-3km
- Measured data
    - Vital signs: Body temperature, Heart rate
    - Behavioral parameters: Accelerometer, gyroscope
    - Geolocation

Developed systems – Outdoor Gateway + Environmental Sensor

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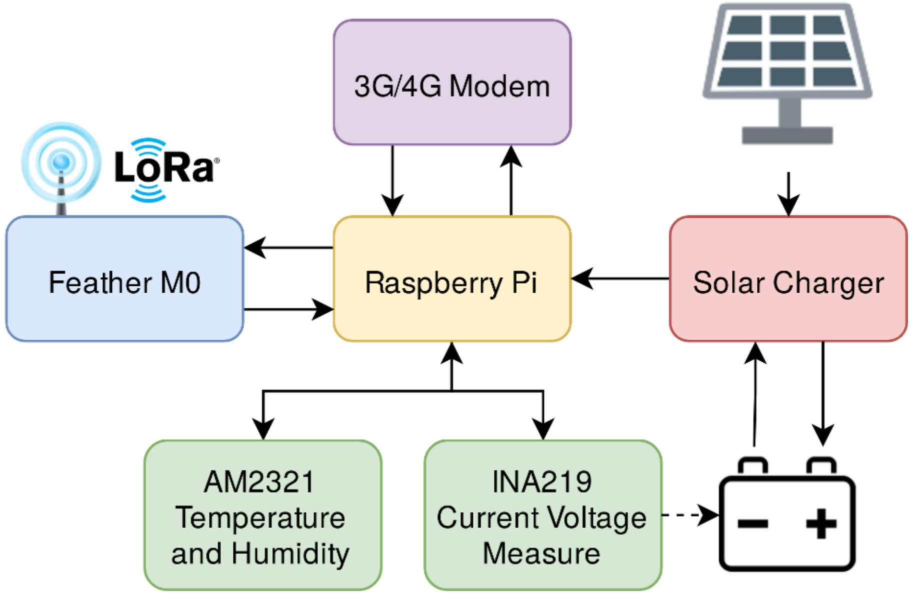
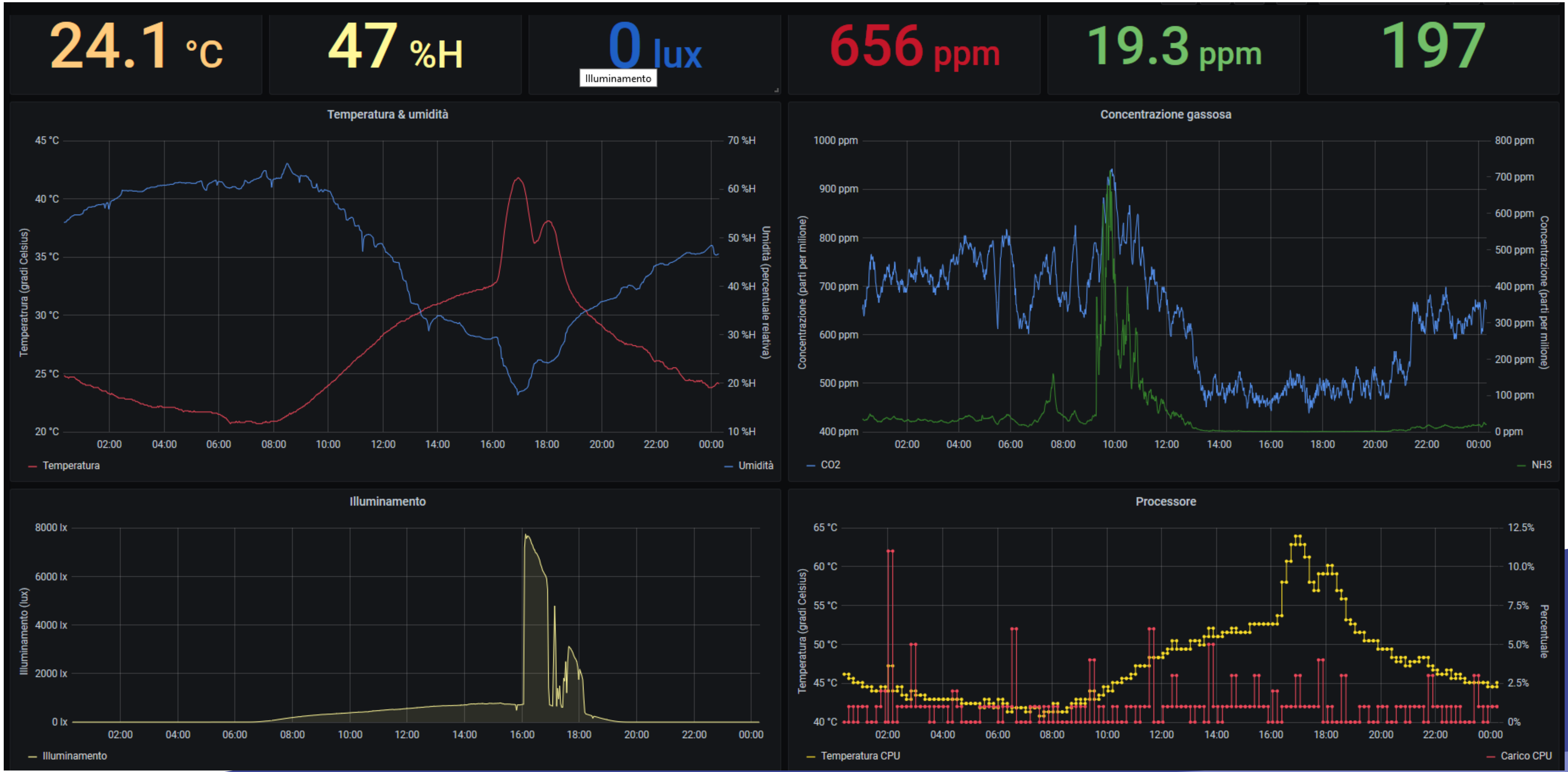


- Name
  - Outdoor Gateway + Environmental Sensor
- Function
  - Communication and acquisition of measurements from the nodes, and interface for data transmission with the outside world via the Internet towards the information collection point.
- Expected dimensions and installation methods
  - Unit in IP66 packaging (Ingress Protection - Totally protected against dust, sand and in general any solid body of small dimensions - Protected from rain and liquids), designed for outdoor use and can be installed on poles or walls with dimensions of approximately 30 cm x 20 cm x 10cm. + Solar panel
- Power and Autonomy
  - 12V DC mains power supply - Battery powered + solar panels
- Operating range
  - 1-3km

Sensors Control & Monitoring (1/2)

Indoor Gateway



Sensors Control & Monitoring (1/2)

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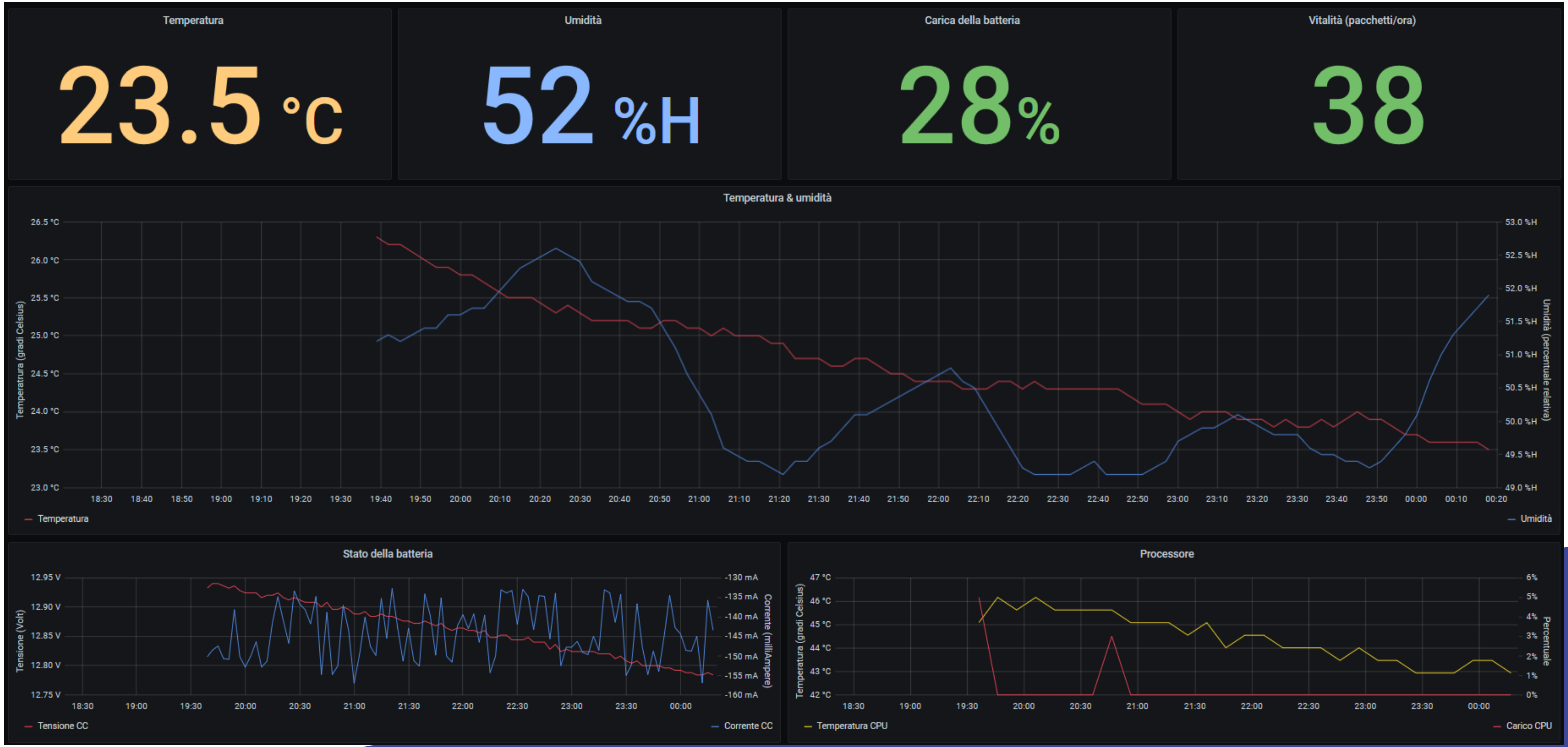
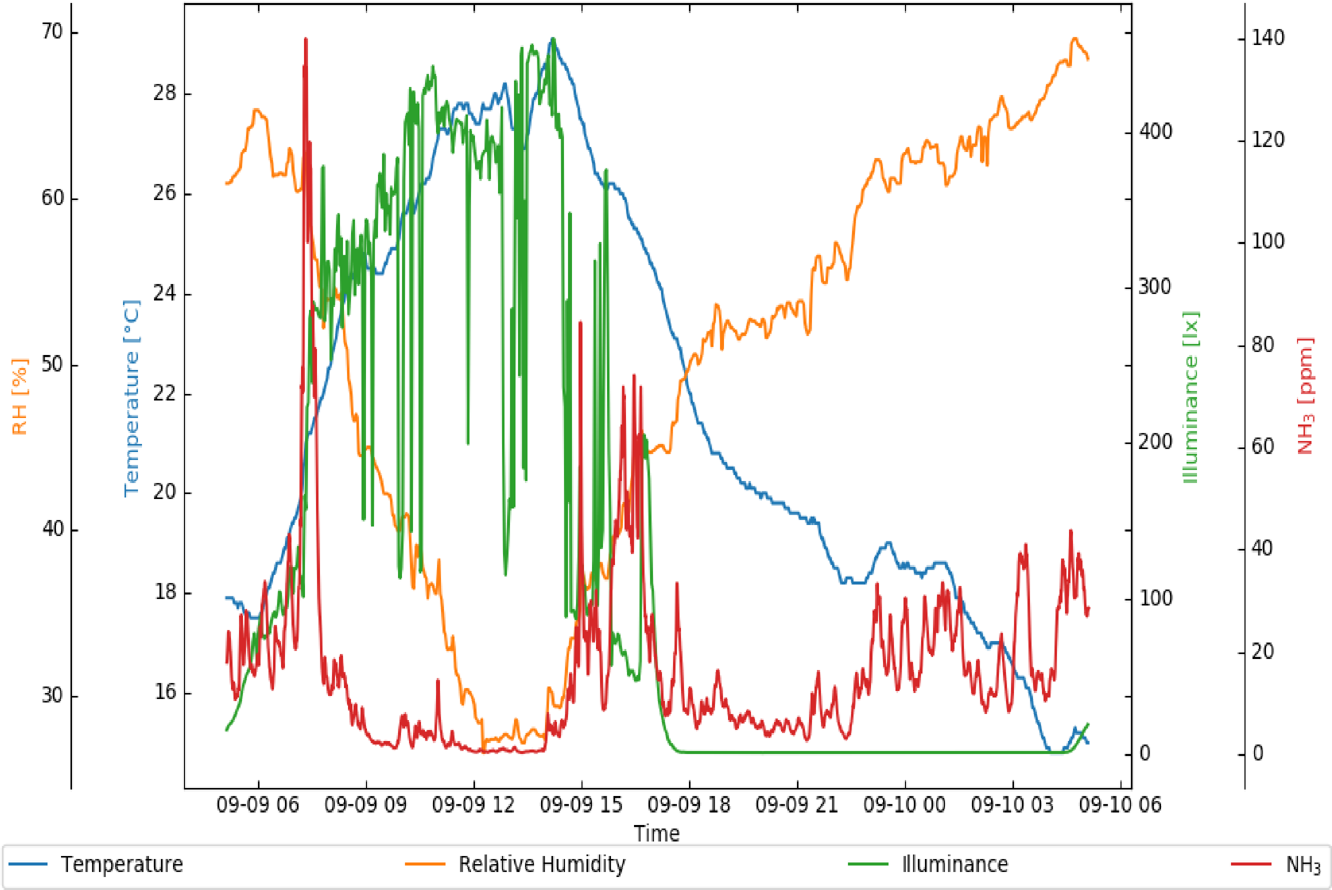
Outdoor Gateway

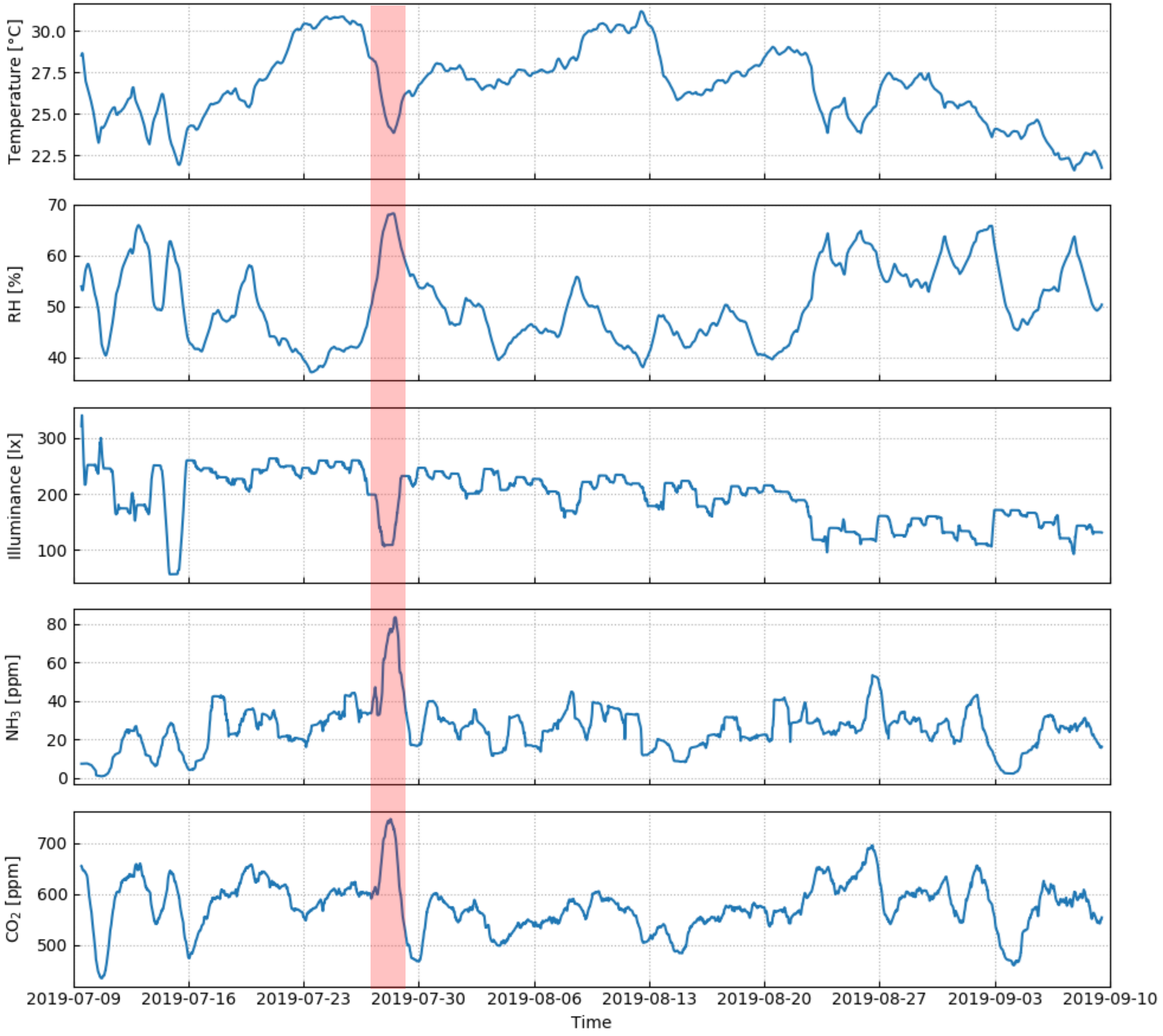


Data Gathering & Analysis (1/3)



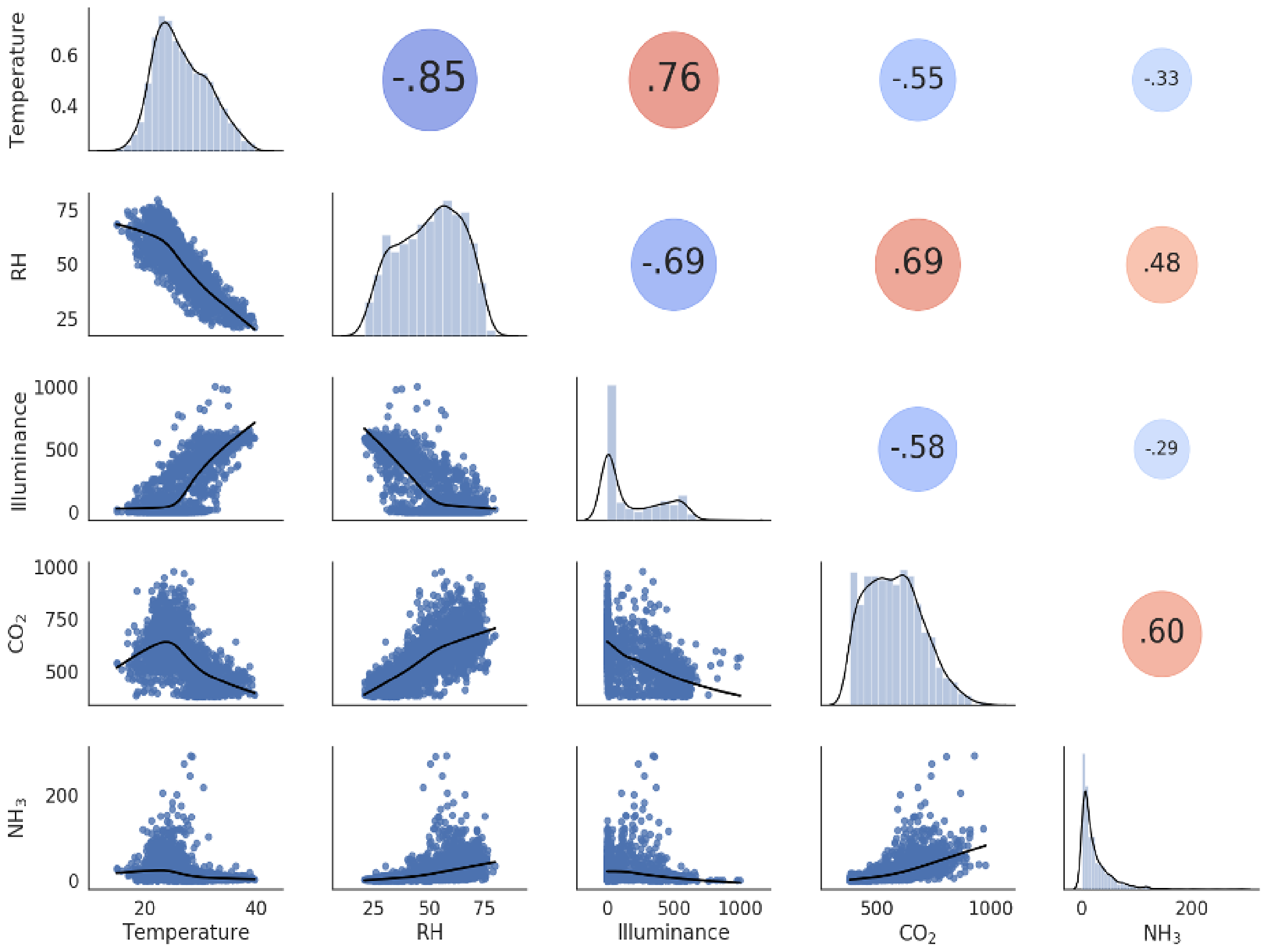
- Some sample data collected by our platform with an exploratory data analysis (EDA) approach.
- As a first example, the data plotted in the Figure are the values of temperature, relative humidity, illuminance and NH_3 concentration captured by an indoor Gateway on 6 September 2019.
- This type of results visualization is typically experienced by web GUI users, who want to check the variation of the parameters in the previous hours.

Data Gathering & Analysis (2/3)



- The Figure shows all the seasonal trends: in this way it is possible to visualize the correlations between the parameters.
- For example, during the day of July 29, 2019, a decrease in temperature and illuminance was observed, as well as an increase in relative humidity.
- At the same time, CO2 and NH3 concentrations increase.
- This correlation should prompt further investigation into the event.

Data Gathering & Analysis (3/3)



Statistical analysis example with scatterplots, cross-correlation values, and kernel density estimation (KDE).

- The five graphs in the main diagonal are the calculated histograms of the five corresponding quantities, together with the pdf of the estimated Gaussian mixture.
- The ten graphs in the lower triangular part represent the scatterplots of each pair of quantities, together with the locally weighted regression curve.
- The ten values in the upper triangular part, on the other hand, represent the correlation coefficients between each pair of quantities, where red (blue) colors represent a positive (negative)
  - correlation and the size of the circle is proportional to the magnitude of the correlation.

How data are gathered and processed

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Data from environmental sensors:
- **temperature, humidity, pressure, lighting**
- **CO_2 and NH_3 concentration,**
- **Noise pollution**

Machine Learning & AI

Indicators and/or Alarms:
- Environmental AlarmsEx: CO2 in stable too high

Alarms on individual items
- Animal XXX has not moved for 3 hours

Alarms on groups of animals
- XXX-YYY animals are getting a higher temperature

Data from the sensors on the collars:
- GPS location
- Movement (accelerations, orientation)
- Temperature
- Heartbeat

DI Dipartimento di Ingegneria Department of Engineering

Validation phase - issues

- The activity involved the design of a system to automate the collection of data from environmental sensors and sensors worn by grazing or stabled animals, as well as the construction of a limited number of prototypes. In particular, the following prototypes were assembled:
  - no. 2 stable control units in Wi-Fi and LoRa technology for detecting temperature, humidity, brightness, CO_2 presence and NH_3 presence. Installation of control units at Taglioni and Ipericon companies.
  - no. 2 stable control units in Wi-Fi technology for detecting temperature, humidity, air quality and H_2S presence. Installation of the control units at the Mezzasoma company.
  - no. 2 Wi-Fi and LoRa technology grazing control units for detecting temperature and humidity, equipped with solar panel and battery.
  - no. 7 stable control units in Wi-Fi technology for detecting temperature, humidity, CO_2 presence and NH_3 presence.
  - no. 3 sensor prototypes for detecting animal mobility. Installation of a sensor prototype on a dairy cow at the Taglioni and Ipericon companies, for a total of 1 day each.
- The prototyping activity also included the setup of the servers necessary for the collection of data produced by the prototypes and the creation of the software environment necessary for the collection and visualization of the data produced by the prototypes.
- Criticalities Emerged:
  - Battery life
  - Reliability of Mechanics
  - Reliability of Connectivity at Farmers

Project Related Pubblications

1. G. Baruffa, L. Rugini, L. Germani, and F. Frescura, "Error Probability Performance of Chirp Modulation in Uncoded and Coded LoRa Systems," Digital Signal Processing, vol. 106, no. 102828, pp. 1–11, Nov. 2020.
2. G. Baruffa, L. Rugini, V. Mecarelli, L. Germani, and F. Frescura, "Coded LoRa Performance in Wireless Channels," in Proc. of 2019 IEEE 30th Annual International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC), pp. 1668–1673, Istanbul, Turkey, Sep. 2019.
3. L. Germani, V. Mecarelli, G. Baruffa, L. Rugini, and F. Frescura, "An IoT Architecture for Continuous Livestock Monitoring using LoRa LPWAN," Electronics, vol. 8, no. 12, pp. 1–28, article no. 1435, Dec. 2019.
4. M. Maranesi, G. Baruffa, and F. Frescura, "Livestock Smart Farming e Benessere Animale," Ruminantia Mese, Mar. 2018.

On-going & Future Activities

Other scenarios:
grazing dairy sheep (extensive breeding)

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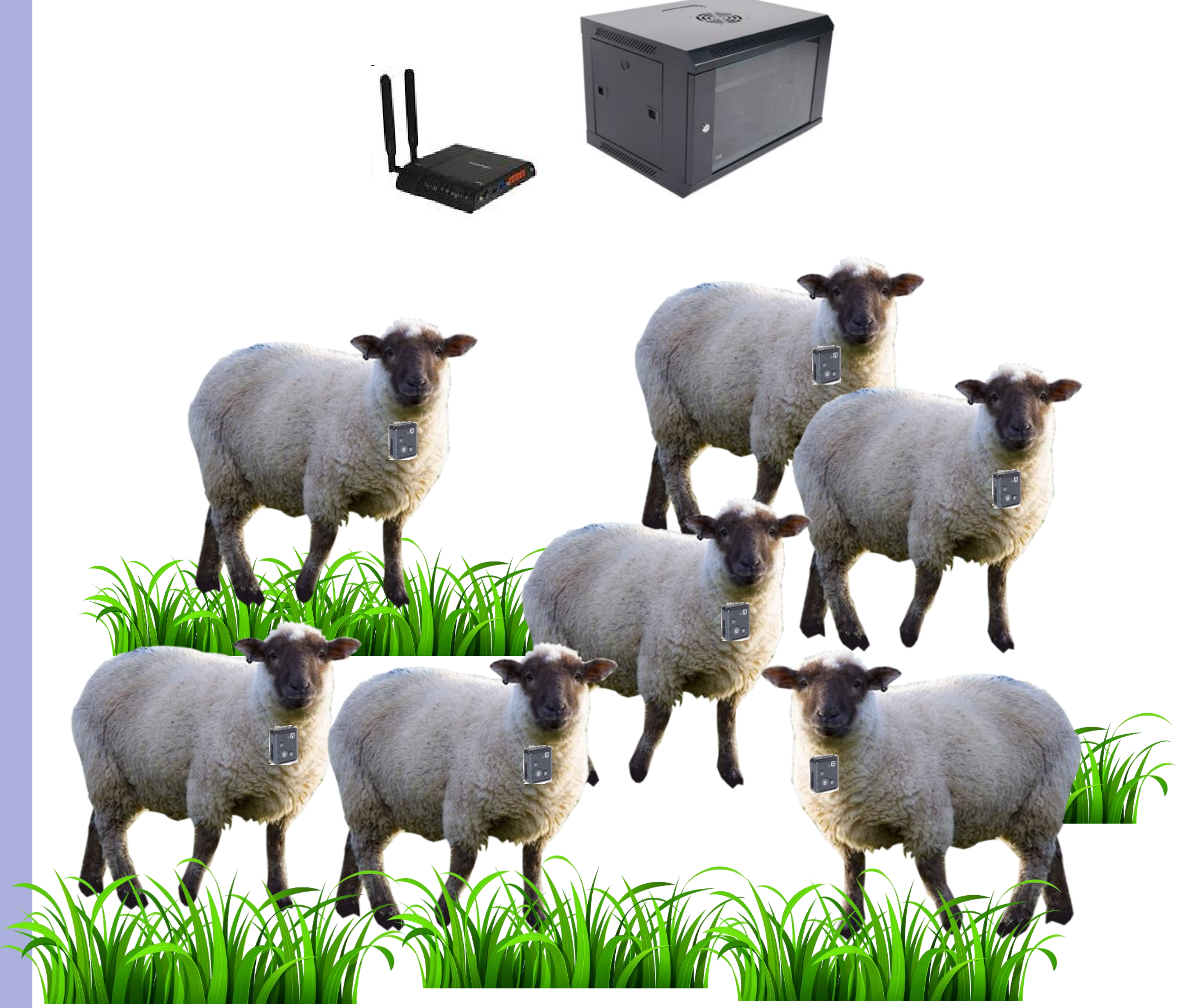
Objective:

Detection of physiological states (e.g. estrus) and pathologies (e.g. lameness, mastitis)

- Positioning (tracking) and podometry
- Single animal identification
- Udder temperature (or of the whole subject)

What is needed:

- GPS tracker with temperature sensor for each animal
- Communication modules for each animal
- grazing agent with LTE module and farm server



Other scenarios:
stabled pigs (intensive farming)

Objective:

- Detection of physiological states (e.g. estrus), pathologies (e.g. lameness, respiratory forms), aggression states and environmental state (e.g. ammonia and heat stress) of the subject
- Cough frequency
- Single animal temperature reading and recording

What is needed:

- microphone array
- adjustable IR video camera
- ammonia sensor
- RFID for each animal
- RFID reader
- stable agent and farm server

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Other scenarios:
Low-cost thermal image devices to detect cow lameness

Objective:

- Detection of pathologies lameness, respiratory forms
- Single animal temperature reading and recording

What is needed:

- adjustable IR video camera
- RFID for each animal
- RFID reader
- Computer Vision and Data Analysis

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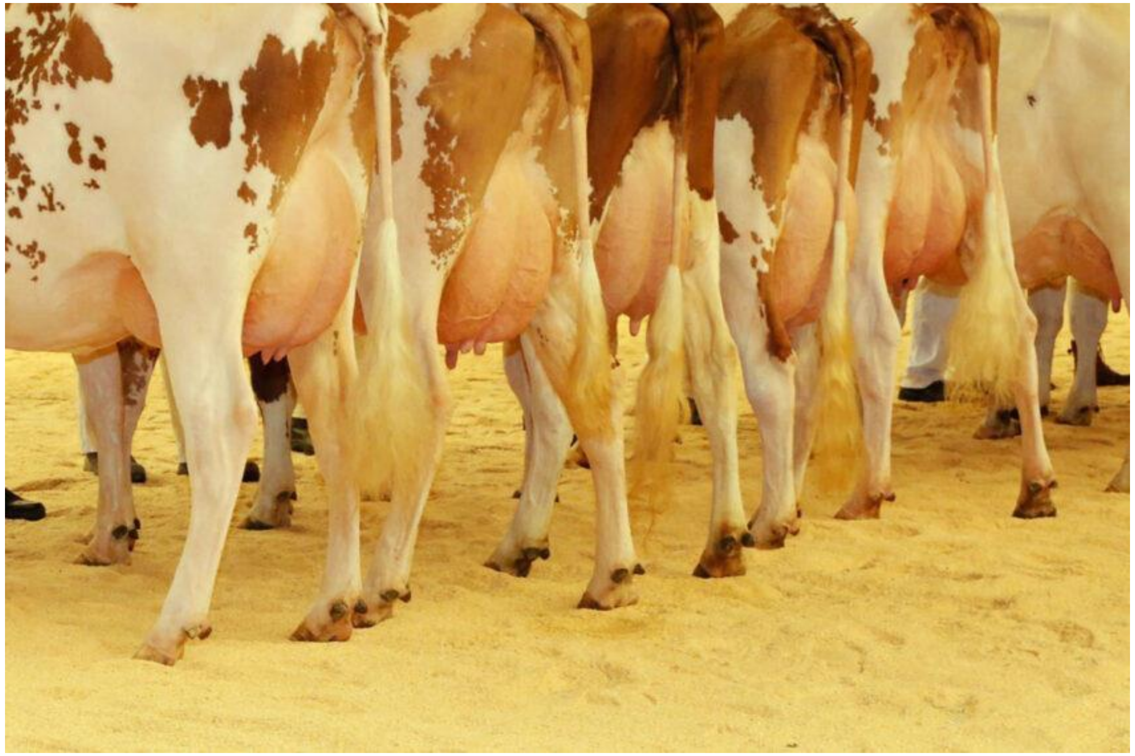

Lameness is a huge issue for the dairy industry, with between a fifth and a quarter of cattle affected
https://www.dairyglobal.net/industry-and-markets/smart-farming/low-cost-thermal-image-devices-to-detect-cow-lameness/

Other scenarios:
Lifestock welfare during transportation

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Objective:

- To monitor, track and certificate, the quality of livestock transportation

What is needed:

- Environmental Monitoring
- Acceleration monitoring
- Thermal imaging monitoring
- GPS logging
- Water drinking quantity/quality monitoring

Welfare of cattle during transport

https://www.efsa.europa.eu/en/efsajournal/pub/7442

Other scenarios:
Sensors for real-time monitoring of a cattle's rumen

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Objective:

- real-time and in situ monitoring of various chemical and physical parameters in the rumen
  - implantable microsensor technologies.
  - non invasive techniques, ultrasonic, thermal imaging

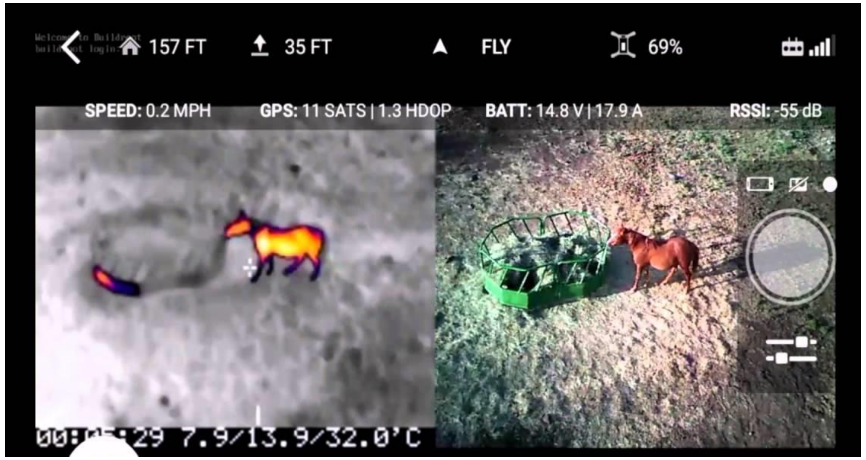
What is needed:

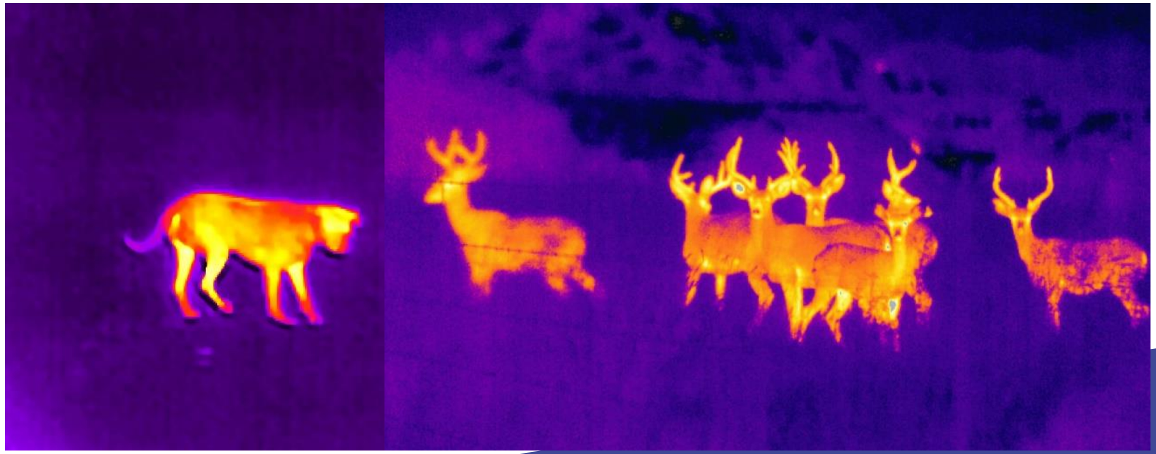
- ISFET-based pH sensors
- EGFET-based pH
- Ecography
- Termal Imaging Systems
- Computer Vision and Data Analysis

Sensor technologies for real-time monitoring of the rumen environment.

Journal of Dairy Science. 105:6379–6404.

Other scenarios: monitoring of grazing herds using UAVs (Drones)



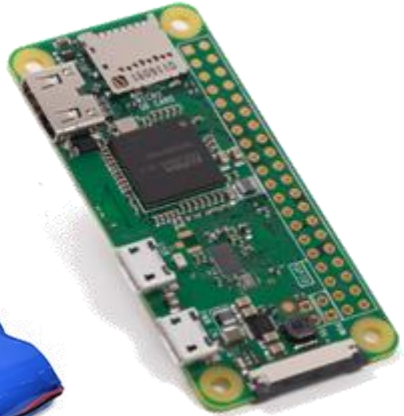


- Objective:
  - Detection of anomalous states of grazing animals autonomously:
  - Illness
  - Imminent birth
  - Presence of predators
- What is needed:
  - Drone with thermal and visible camera
  - Base station for Data/Video connection
  - GPS maps of the areas to be monitored
- Cost
  - 3 Drone system + Base station: 25,000 euros

Tecnologies Showcase

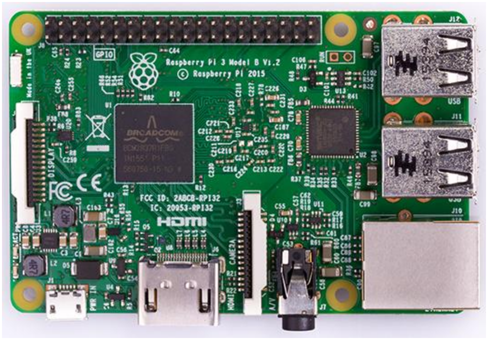
Waspmote + LoRa

1-5y, DSSS, 868MHz, 0.3-50kbps, 2-22km



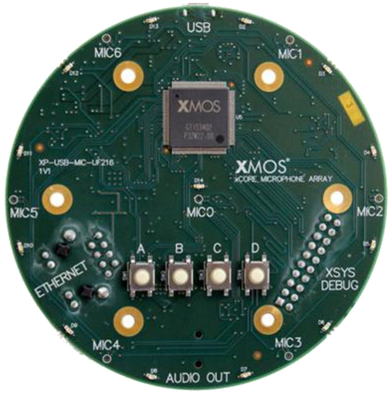
Raspberry

1-4c, 0.5-1.2GHz



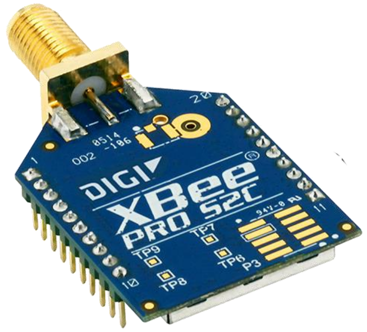
Xcore

7x microphone array



XBee

-100 dBm, 60-1220m



ThingMagic

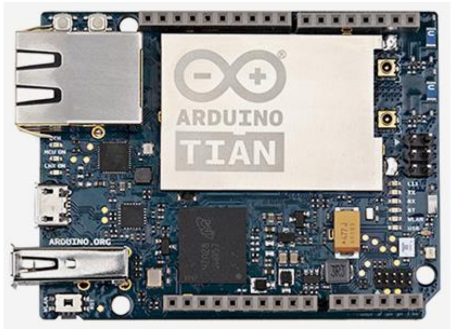
10m, 750tag/s

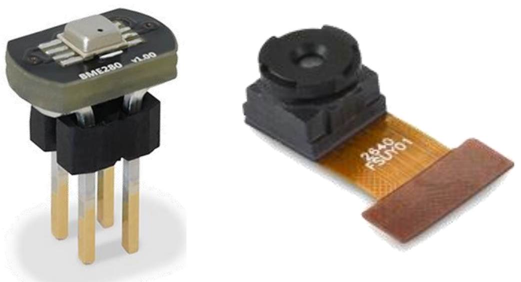
Flir

640x512, 9fps, -25°/+135°±5%

Arduino

3.3V





Temp+Hum+Press+Video

Not only **Sensors**, **Big Data Analysis** and **Machine Learning** are mandatory

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- The data collected in the previous scenarios (and others) are aggregated through one or more Service Centers where they are analyzed in real time
- Through statistical analysis of historical data and comparison with current data, anomalies are automatically identified that require the intervention of the breeder or veterinary garrison.
- The reporting of the anomalies is done with synoptic panels on dedicated portals and / or through e-mail / sms etc
- Advantages:
- Near autonomous system
- Reduced costs for the farmer
- Fast intervention times
- Early diagnosis that decreases the risk of epidemics

Contacts for further insights, internships, degree thesis

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