UNIVERSITÀ DEGLI STUDI DI NAPOLI FEDERICO II

itee PhD information technology electrical engineering

DIETI UNINA

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PON RICERCA E INNOVAZIONE

PhD student Maria Teresa Verde

"Innovative Sensors and Advanced Engineering Solutions to Enhance Animal Welfare, Production, and Sustainability in Dairy Buffalo Livestock Farming"

Tutor: Leopoldo Angrisani

co-Tutor: Francesco Bonavolontà

Cycle: XXXVII

Year:2022

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Candidate's information

- MSc degree in **Veterinary Medicine**
- DIETI Research group **Electrical and Electronic Measurement Group (IMIS-01/B)(Previously SSD ING-INF/07)**
- PhD start date **1/1/2022**– end date **31/12/2024**
- Scholarship type **PON Dottorati di ricerca su tematiche dell'innovazione e green - Azione IV.5 (Green)**
- Periods in company (6 months) Azienda **Azienda Agricola Castelluccia snc dei f.lli Cacciapuoti**
- Postgraduate Specialization in **Infectious Diseases, Prophylaxis, and Veterinary Control**

Summary of study activities

- Given the focus of the Ph.D. activities, centered on the development of innovative sensors and advanced engineering solutions to improve animal welfare, production, and sustainability in dairy buffalo farming, the academic path was primarily oriented towards:
- Courses in **Electrical and Electronic Measurements**: Aimed at acquiring skills in measuring physical quantities, with a particular focus on biological organisms.
- Courses in **Big Data Architecture** and **Analytics and Artificial Intelligence**: Designed to develop expertise in processing and analyzing large datasets and applying artificial intelligence techniques.
- During the third year of the **Specialization School in "Infectious Diseases, Prophylaxis, and Veterinary Control“,** several courses were completed in epidemiology, infectious and parasitic diseases, and pharmacology. These proved extremely valuable for conducting and gaining an in-depth understanding of research activities in the field of Livestock Farming.

Summary of study activities

Attended Courses

Year	Course Title	Type	Credits	Lecturer	Organization
1st	Piattaforme di misura e monitoraggio basate su Internet of Things.	External PhD course	6	Rosario Schiano Lo Moriello, DII, University of Naples Federico II	PhD in Industrial Engineering, University of Naples Federico II
1st	Big Data Architecture and Analytics	Ad hoc course	5	Proff. Giancarlo Sperlì, Giovanni Improta, Jari Haukka, Peter van Ooijen	ITEE
1st	Sensori e Trasduttori di Misura	MsD Electronic engineering	9	Prof.Domenico Antonio Grillo	DIETI, University of Naples Federico II
1st	Sensori e Smart Metering	MsD Electronic engineering	9	Prof. Francesco Bonavolontà	DIETI, University of Naples Federico II
1st	Intelligenza Artificiale	MsC Type A2 course	6	Prof. Flora Amato	ITEE, DIETI, University of Naples Federico II
2nd	Misure su Sistemi Wireless	MsC Type A2 course	9	Prof. Leopoldo Angrisani	ITEE, DIETI, University of Naples Federico II
2nd	Data Uncertainty	MsC Type A2 course	6	Prof. Leopoldo Angrisani	ITEE, DIETI, University of Naples Federico II

She attended ***23*** seminars held at Italian Universities, Research Centers, and Training Institutions.

Research area

During the three years of the Ph.D., the research activity focused on the **multidisciplinary field of Precision Livestock Farming (PLF).**

The aim of PLF is to improve animal health and welfare, productivity, and environmental sustainability through the use of sensors and advanced data analysis techniques, enabling more precise (individual animal-based) management of livestock farming.

Research Problems

Specifically, the research addressed:

- *The lack of reliable and scalable measurement tools for the detection of subclinical mastitis in Italian Mediterranean buffalo;*
- *The absence of systems for the early detection of stress signals in animals (e.g., cortisol concentration in milk);*
- *The lack of tools for precise quantification of feed intake in buffalo;*
- *The absence of accurate measurement instruments for methane and ammonia emissions in buffalo farms.*

Research results

- *Development of an effective methodology, based on artificial intelligence, that enables the use of infrared thermography as a diagnostic method for subclinical mastitis in Italian Mediterranean buffalo.*

- *Study on the evaluation of animal stress through the analysis of cortisol levels in biological samples, using advanced laboratory techniques and statistical analysis to identify factors influencing stress.*

- *Development of an innovative 3D camera system for accurate measurement of the volume and weight of dairy buffalo feed.*

- *Development of a measurement system for CH4 emissions monitoring from ruminants in livestock farming.*

- *Development of a wireless sensor network for ammonia measurement in Italian Mediterranean buffalo farms.*

Research products

[P1]	*Alessio Cotticelli, **Maria Teresa Verde**, Roberta Matera, Isabella Pividori, Alberto Prandi, Gianluca Neglia & Tanja Peric (2022) **Validation of a radioimmunoassay method for cortisol in buffalo milk whey. A preparatory step for future sensor technology**, Italian Journal of Animal Science, 21:1, 1622-1631, DOI: 10.1080/1828051X.2022.2147868*
[P2]	*Nadia Piscopo, Oscar Tamburis, Francesco Bonavolontà, **Maria Teresa Verde**, Maria Manno, Marianna Mancusi, Luigi Esposito, **"Assessing wild boar presence and activity in a monitoring specific area of Campania region using camera traps"**, ACTA IMEKO, ISSN: 2221-870X, December 2023, Volume 12, Number 4, 1 – 5, DOI: https://doi.org/10.21014/actaimeko.v12i4.1617*
[P3]	*__Maria Teresa Verde__, Pierluigi Guerriero, Francesco Bonavolonta, Leopoldo Angrisani, Francesco Lamonaca, Ioan Tudosa, Oscar Tamburis, Gianluca Neglia, **"A measurement system for enteric CH4 emissions monitoring from ruminants in livestock farming"**, ACTA IMEKO, ISSN: 2221-870X, December 2023, Volume 12, Number 4, 1 – 6, DOI: https://doi.org/10.21014/actaimeko.v12i4.1618*
[P4]	*Alessio Cotticelli, __Maria Teresa Verde__, Annalisa Liccardo, Giorgio de Alteriis, Francesco Lamonaca, Roberta Matera, Gianluca Neglia, Tanja Peric, Alberto Prandi, Francesco Bonavolontà **"On the use of 3D camera to accurately measure volume and weight of dairy cow feed"**, ACTA IMEKO, ISSN: 2221-870X, December 2023, Volume 12, Number 4, 1 – 6, DOI: https://doi.org/10.21014/actaimeko.v12i4.1633*
[P5]	*__Maria Teresa Verde__, Francesco Bonavolontà, Annalisa Liccardo, Francesco Lamonaca, Emilio Di Stasio, Giampaolo Raimondi, "**A smart combination of IoT and blockchain enabling technologies to measure and improve workplace safety in dairy farm"**, ACTA IMEKO, ISSN: 2221-870X, December 2023, Volume 12, Number 4, 1 – 7, DOI: https://doi.org/10.21014/actaimeko.v12i4.1634*

Research products

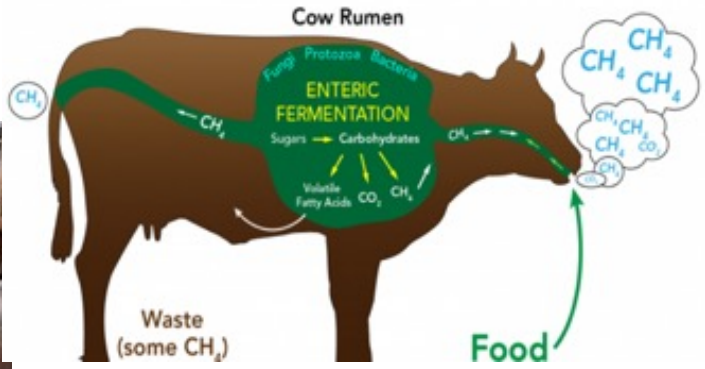
[P6]	***Maria Teresa Verde***, *Roberta Matera, Francesco Bonavolonta, Francesco Lamonaca, Leopoldo Angrisani, Concettina Fezza, Luca Borzacchiello, Alessio Cotticelli, Gianluca Neglia,* ***"Comparative performance analysis between two different generations of an automatic milking system",*** *ACTA IMEKO, ISSN: 2221-870X, December 2023, Volume 12, Number 4, 1 – 6, DOI: https://doi.org/10.21014/actaimeko.v12i4.1646*
[P7]	*Leopoldo Angrisani, Angela Salzano, Roberta Matera, Francesco Bonavolontà,* ***Maria Teresa Verde****, Nadia Piscopo, Domenico Vistocco, Oscar Tamburis,* ***"Reliable Use of Smart Cameras for Monitoring Biometric Parameters in Buffalo Precision Livestock Farming" ,*** *ACTA IMEKO, ISSN: 2221-870X, December 2023, Volume 12, Number 4, 1 - 7, DOI: https://doi.org/10.21014/actaimeko.v12i4.1638*
[P8]	*A. Cotticelli, G. Bifulco, I. Pividori, R. Matera,* ***M.T. Verde****, M. Santinello, T. Peric,(2024).* ***"Assessing cortisol concentration in different matrices: predictive potential and relationship with production levels, lactation stage and parity in dairy buffaloes"****, Italian Journal of Animal Science, 23(1), 802–812. https://doi.org/10.1080/1828051X.2024.2354502*
[P9]	***M.T. Verde****, L. Angrisani, F. Amato, M. Fonisto, R. Matera, G. Neglia, F. Bonavolontà,* ***"AI-Driven Large-Scale Early Detection System of Subclinical Mastitis in Italian Mediterranean Buffalo Based on Infrared Imaging",*** *IEEE Transactions on Instrumentation & Measurement, Manuscript Number TIM-24-10525.*

Best Poster Award ***"Artificial Intelligence-enhanced infrared imaging for early detection of subclinical mastits",*** *Università degli Studi di Napoli "Federico II" – Dipartimento di Ingegneria Elettrica e delle Tecnologie dell'Informazione,* ***WORKSHOP Precision Livestock Farming per l'adattamento e la mitigazione del cambiamento climatico: applicazioni e nuove frontiere della ricerca.***

Patent Application ***No. 102023000019425 dated September 21, 2023****, titled* ***"System and Method for Capturing Wild Boars."***

PhD thesis overview

- **Problem statement**
- The global population is increasing, and a growing number of people can afford to purchase meat and dairy products.
- To meet this rising demand, intensive farming systems are increasing, aiming to produce more while keeping costs low.
- However, the uncontrolled growth of intensive farming can lead to:
  - ***A decline in animal health and welfare***
  - ***A potential reduction in product quality***
  - ***An increase in atmospheric gas emissions (Methane, Ammonia)***



PhD thesis overview

- **Objective**

The objective of this work is to apply Precision Livestock Farming (PLF) techniques to improve animal health and welfare, productivity, and environmental sustainability in livestock farming.

The focus is on the **Campania Region**, where the growing interest in buffalo and its derivatives, such as **Mozzarella di Bufala DOP**, represents a strategic sector for both the local and national economy.

PhD thesis overview

- **Methodology**

The methodology for developing the various solutions was structured according to the following common principles:

- ***Use of innovative technologies:*** *Thermal cameras, biochemical analyses, environmental sensors, and sniffers.*
- ***Collection of real-world data:*** *Data were gathered directly on farms to ensure the validity of results in real-world contexts.*
- ***Integrated analysis:*** *Quantitative methods, such as statistical models and artificial intelligence, were employed.*
- ***Validation of methodologies:*** *Each proposed system or technique was tested and validated in operational scenarios.*

PhD thesis

AI-Driven Large-Scale Early Detection System of Subclinical Mastitis in Italian Mediterranean Buffalo Based on Infrared Imaging

Problem Statement: **Mastitis is a significant challenge in the buffalo farming, affecting both milk production and animal health, and resulting in economic losses. Traditional diagnostic methods for subclinical mastitis, including somatic cell count (SCC) and California Mastitis Test (CMT), have limitations in speed and accuracy, especially in large herds.**

Objective: **Developing an effective method for the early detection of subclinical mastitis.**

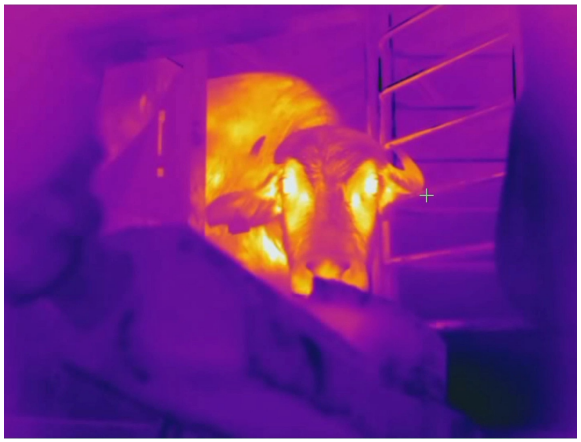
My research proposes an AI-Driven thermal imaging system to detect early subclinical mastitis in Italian Mediterranean buffalo.

Methodology: **The proposed system integrates strategically placed thermal cameras within a robotic milking system. This setup ensures consistent and non-intrusive monitoring of udder health.**

Mastitic Milk

California Mastits Test (CMT)

Thermal Imaging in Motion: Infrared View of Udder During Milking



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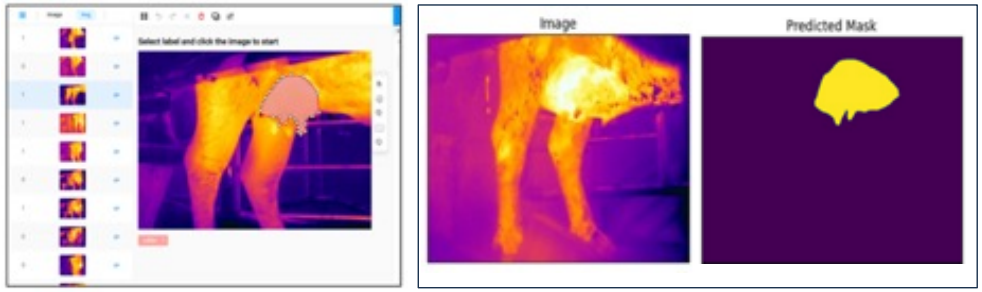
Methodology:

Udder Segmentation: A U-Net neural network performs segmentation to isolate udder regions from the background. The model was trained using a dataset of annotated udder images to achieve precise segmentation.



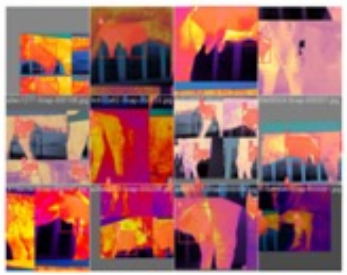
Ground truth obtained by means of experts labeling images in LabelStudio.

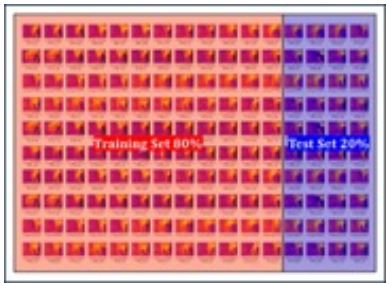
Experimental Setup: An automated system has been developed for capturing thermal images of the udder synchronized with the milking phase, enabling easy association of each image with the parameters detected by the robot (SCC, EC, etc). These data are used to assess the health status of buffalo while managing a substantial amount of information.

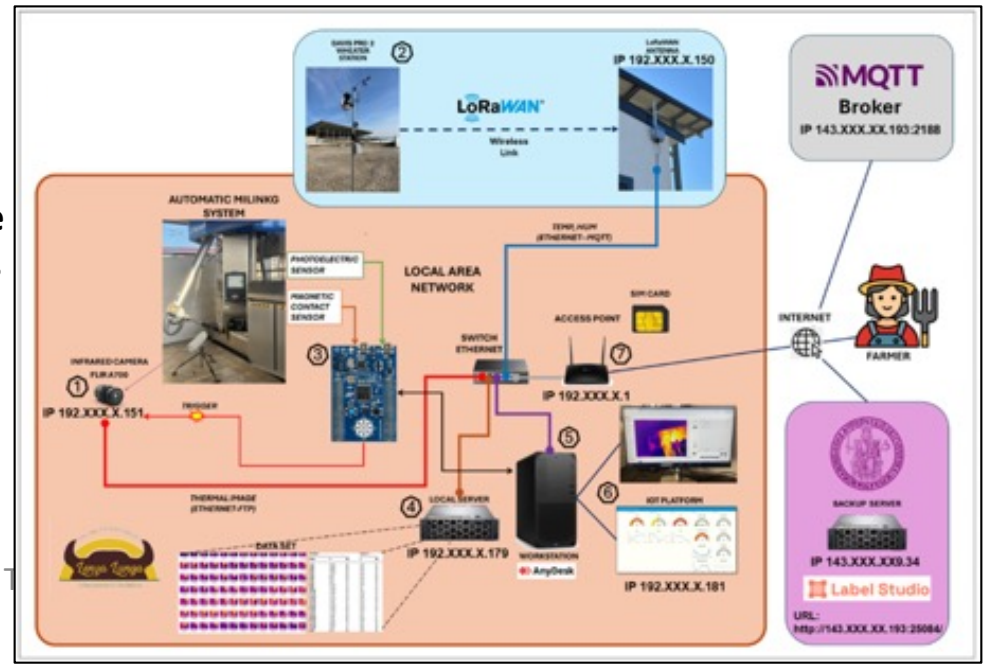
Data Collection: Thermal images and SCC samples were collected, covering 728 milking sessions.

Model Training and Validation

- **Dataset:** The dataset included 2,148 thermal images. Data augmentation techniques, such as rotation and scaling, were applied to enhance model robustness.
- **Training:** The U-Net model was trained using 80% of the dataset, with the remaining 20% reserved for validation.







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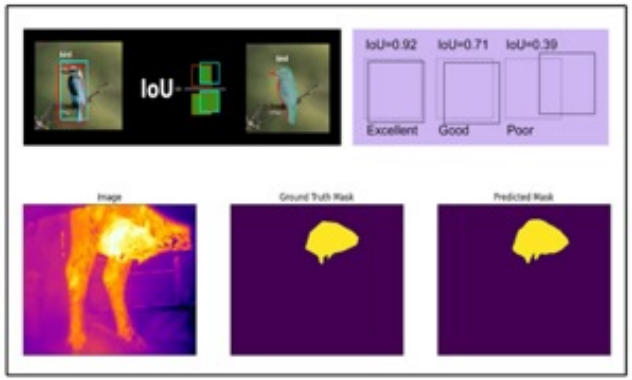
PhD thesis

AI-Driven Large-Scale Early Detection System of Subclinical Mastitis in Italian Mediterranean Buffalo Based on Infrared Imaging

Model Performance: The first checkpoint for evaluating the accuracy of the developed model was the Mean Intersection Over Union (mIoU), a number that quantifies the degree of overlap between two boxes

The mIoU of two areas can have any values between 0 (no overlapping) and 1 (perfectmatch). The greater the region of overlap, the greater the IoU. The mIoU measures the overlap of the predicted and actual segmentation regions against their union,

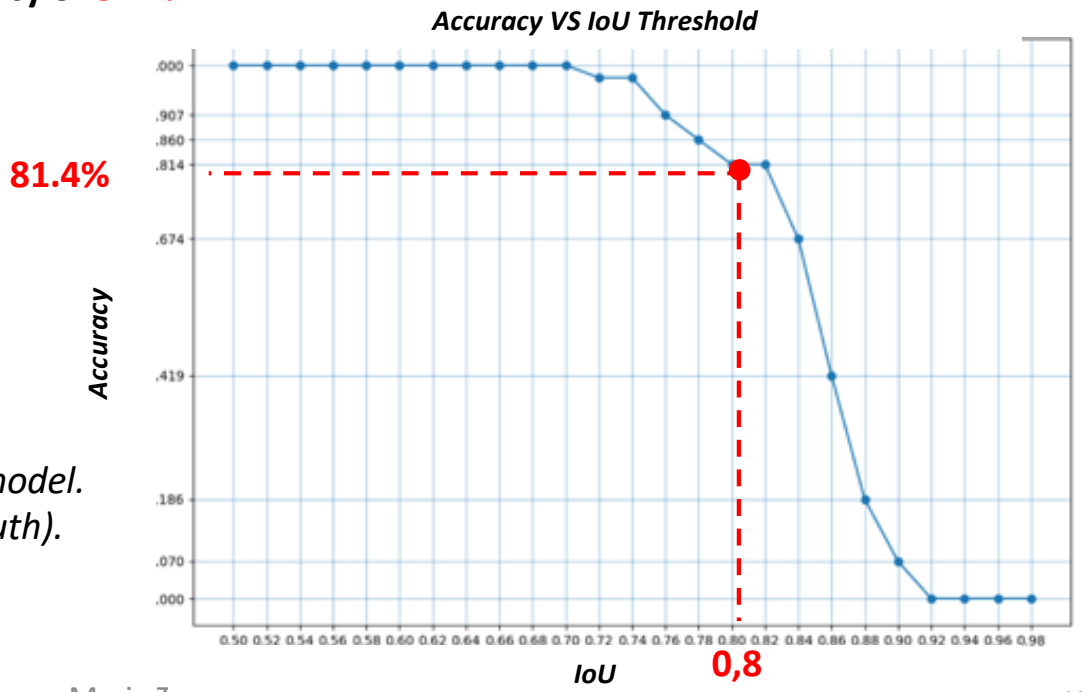


To evaluate the model's ability to automatically detect the udder region, a detection is considered correct if, in our case, the IoU (Intersection over Union) between the predicted and actual udder segmentation is higher than a threshold of 0.80. Using this criterion, the model achieves an accuracy of 81.4%.

$$IoU = \frac{|A \cap B|}{|A \cup B|}$$

Where:

- *A is the region of the segment predicted by the model.*
- *B is the region of the actual segment (Ground Truth).*



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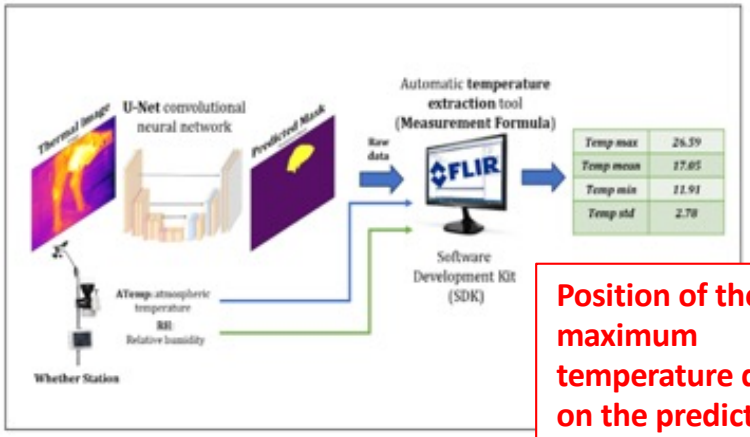
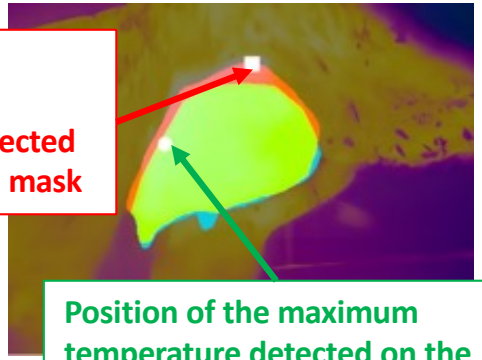
AI-Driven Large-Scale Early Detection System of Subclinical Mastitis in Italian Mediterranean Buffalo Based on Infrared Imaging

Temperature distributions were extracted using the FLIR SDK and corrected for emissivity, distance, ambient temperature, and humidity, with the last two parameters obtained continuously via a LoRaWAN weather station.



Position of the maximum temperature detected on the predicted mask

Comparing the predicted maximum udder temperatures with the actual measurements from the validation images showed that there were discrepancies in just the 6.5% of the images. An example of such a case is depicted in the figure below:



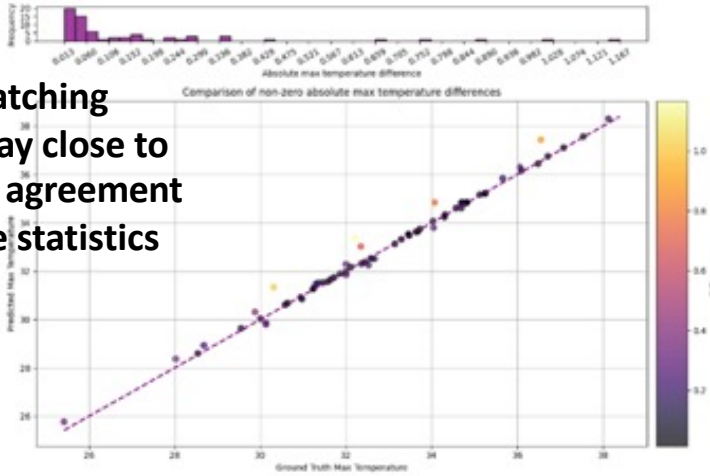
Position of the maximum temperature detected on the Ground Truth

In green the correctly segmented area. In blue the incorrectly unsegmented area, pixels in the Ground Truth that the model failed to predict. In red, the incorrectly segmented area represents pixels predicted by the model but not present in the Ground Truth

The descriptive statistics of these absolute temperature differences, reported in Table below, validates the accuracy of the automatic measurement system in detecting the maximum udder temperatures, as the mean difference between those is 0.159.

Mean	Std. Dev.	Min	25th Pctl.	Median	75th Pctl.	Max
0.159	0.242	0.013	0.028	0.055	0.172	1.167

These discrepancies were also investigated visually by plot-ting the predicted and actual maximum udder temperatures against each other, as shown in the chart beside.



Most of the non-matching temperature pairs lay close to the bisector line, in agreement with the descriptive statistics

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PhD thesis

AI-Driven Large-Scale Early Detection System of Subclinical Mastitis in Italian Mediterranean Buffalo Based on Infrared Imaging

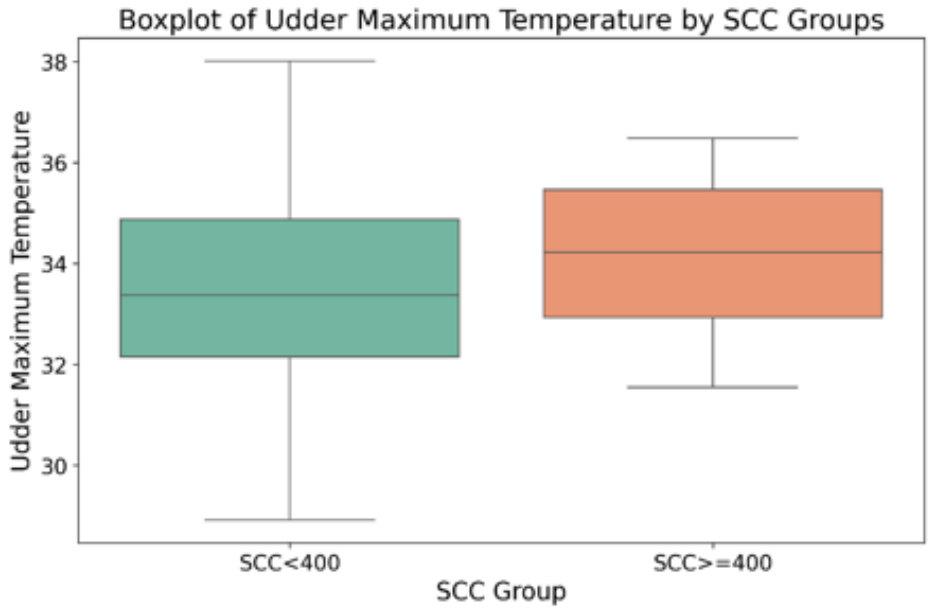
Statistical Analysis: The 728 milking instances were divided into two groups according to the udder health

- **685 instances were from healthy buffaloes**
- **43 instances were from mastitis-affected buffaloes**

An instance was considered from a buffalo affected by mastitis if its SCC is greater than 400.000 cells/ml in raw milk.

The maximum udder temperatures were examined in relation to their respective health conditions, distinguishing between healthy and mastitic udders, to determine the presence of statistically significant temperature variations between the two groups.

To confirm the significance of the temperature difference, we conducted a t-test, which yielded a t-statistic of -3.1737 and a p-value of 0.0025 as shown in the figure below:



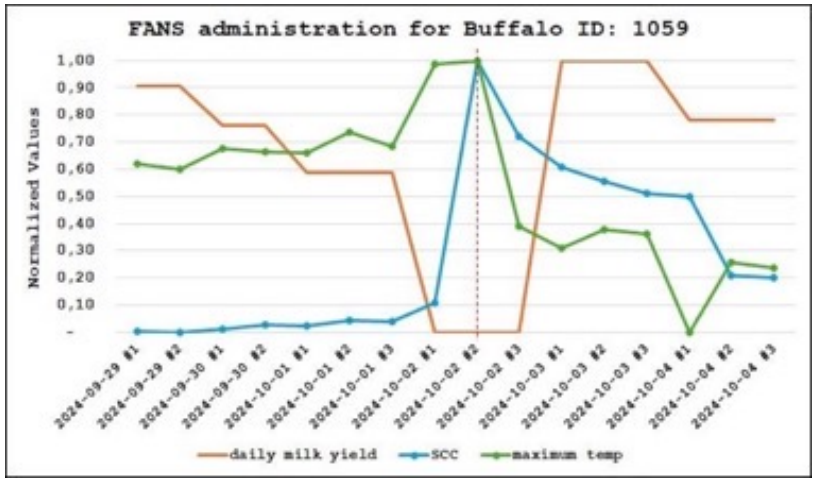
Since the p-value is less than the conventional threshold of 0.05, the observed temperature difference is statistically significant.

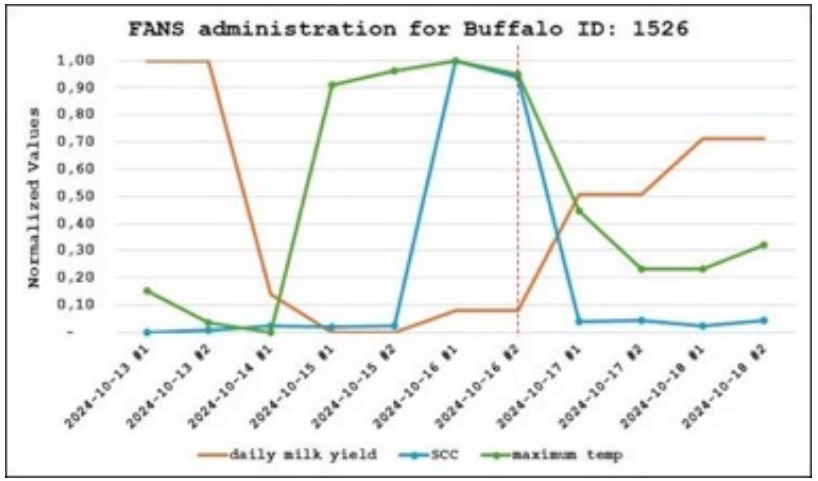
This supports the hypothesis that higher SCC values are associated with elevated maximum udder temperatures, potentially indicating infections such as mastitis. Therefore, the automated temperature measurement system effectively captures this relationship, demonstrating its potential as a reliable solution for continuous udder health monitoring through thermal imaging, even in large-scale applications.

PhD thesis

AI-Driven Large-Scale Early Detection System of Subclinical Mastitis in Italian Mediterranean Buffalo Based on Infrared Imaging

Results: In addition to what has already been discussed, some animals have exhibited behaviors typically associated with subclinical mastitis. In particular, in these animals, the maximum udder temperature increased well before there was a significant rise in SSC, which usually marks the onset of true mastitis. These trends are evident when comparing the variations of these variables over time in the same graph.





When expert veterinarians identified significant increases in udder temperature using the automated system, they treated early-stage mastitis with NSAIDs instead of antibiotics, typically used for this condition. This approach led to a rapid reduction in temperature, lower somatic cell counts, and restored milk production. Therefore, early diagnosis through thermographic analysis improved milk quality and quantity while reducing antibiotic use, helping to combat antibiotic resistance.

PhD thesis

AI-Driven Large-Scale Early Detection System of Subclinical Mastitis in Italian Mediterranean Buffalo Based on Infrared Imaging

In Conclusions:

Advantages over Traditional Methods (Strengths)

- ***Speed**: Automated detection significantly reduces the time required for mastitis diagnosis.*
- ***Non-Invasive**: The system eliminates the need for physical sampling, reducing stress on animals.*
- ***Scalability**: The integration with robotic milking systems makes it feasible for large-scale operations.*

Challenges and Limitations (Weaknesses)

- ***Initial Costs**: The high upfront investment in thermal cameras and AI infrastructure may deter small-scale farmers.*
- ***Model Generalization**: Further testing is needed to ensure the model's reliability across different breeds and farm environments.*
- ***Environmental Variability**: Extreme environmental conditions may still affect system accuracy despite compensation mechanisms.*

PhD thesis

AI-Driven Large-Scale Early Detection System of Subclinical Mastitis in Italian Mediterranean Buffalo Based on Infrared Imaging

"Why is it original and scientifically sound?"

Most studies on mastitis focus on dairy cattle (cows), leaving little attention to buffalo, despite their economic importance in various regions, such as Italy. The specific focus on Italian Mediterranean buffalo fills a gap in the state of the art

Early Detection: Most existing research focuses on advanced (clinical) mastitis.

Infrared Imaging: While thermal imaging is used in other veterinary contexts, its specific application for diagnosing subclinical mastitis in Mediterranean buffalo is rare. This represents a methodological innovation compared to traditional methods such as milk analysis (somatic cell count, SCC) or physical palpation.

The use of Artificial Intelligence represents a technological innovation compared to the state of the art: AI enables greater accuracy, automation, and the ability to analyze large volumes of data, overcoming the limitations of conventional approaches. AI enables large-scale application, offering a more effective and sustainable method compared to traditional approaches.

Tool: ThermoMED (Thermography Mastits Early Detection) *is the proposed commercial name for the system developed in collaboration with the hosting company, Castelluccia s.n.c. The name highlights the use of thermography for early mastitis detection, emphasizing its innovative application in livestock management.*

Research results

- *Development of an effective methodology, based on artificial intelligence, that enables the use of infrared thermography as a diagnostic method for subclinical mastitis in Italian Mediterranean buffalo.*

- *Study on the evaluation of animal stress through the analysis of cortisol levels in biological samples, using advanced laboratory techniques and statistical analysis to identify factors influencing stress.*

- *Development of an innovative 3D camera system for accurate measurement of the volume and weight of dairy buffalo feed.*

- *Development of a measurement system for CH4 emissions monitoring from ruminants in livestock farming.*

- *Development of a wireless sensor network for ammonia measurement in Italian Mediterranean buffalo farms.*

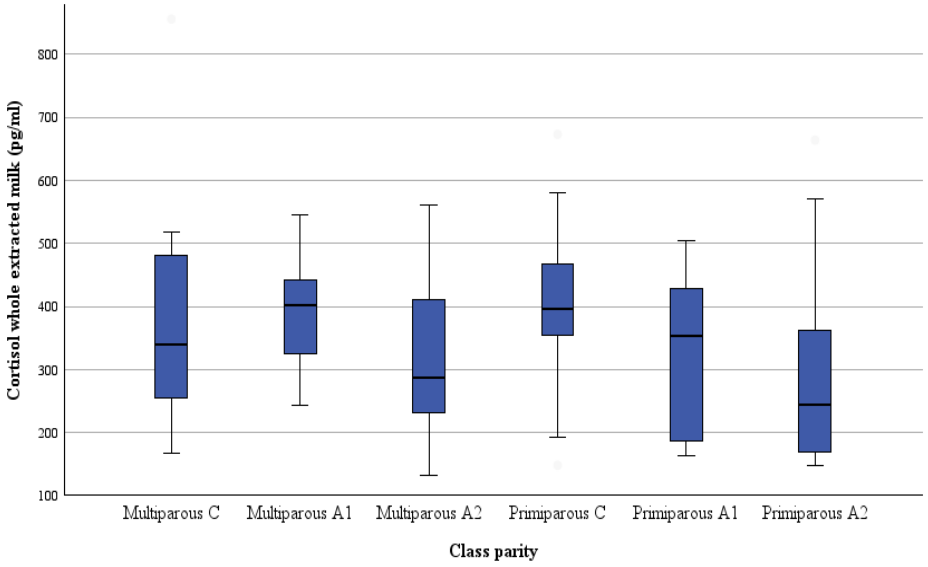
PhD thesis

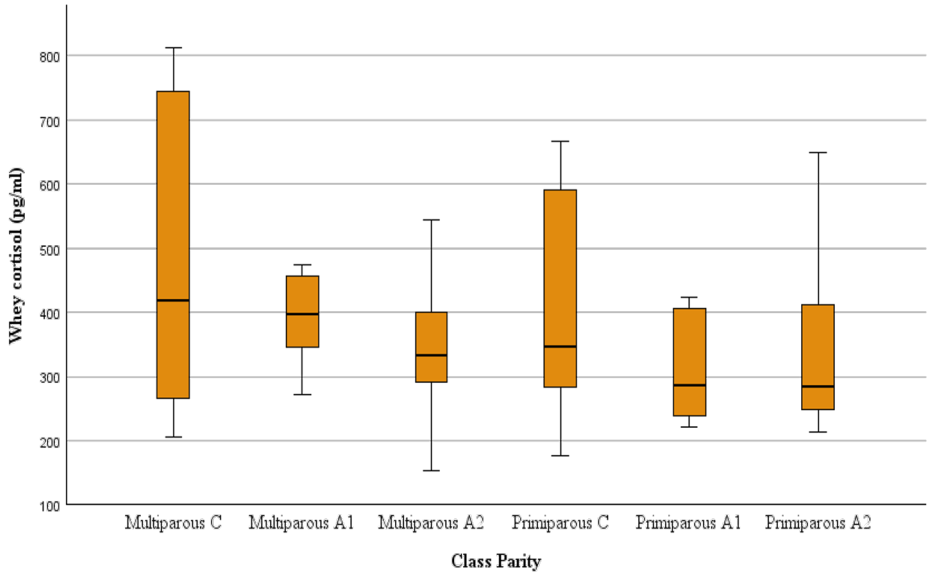
Assessing cortisol concentration in different matrices: predictive potential and relationship with production levels, lactation stage and parity in dairy buffaloes

The scientific proposal **Evaluating cortisol as a stress biomarker in Italian Mediterranean buffaloes, aiming to measure its levels across various matrices (milk, whey, plasma, hair), explore its links to lactation and productivity, and develop non-invasive, real-time measurement techniques.**

Result: **The analysis of the stage of lactation on cortisol concentrations (pg/mL) in whole extracted milk revealed that significantly ($p < 0.05$) higher concentrations were recorded during the catabolic compared to second anabolic phase in whole extracted milk.**

Concentrations (pg/mL) of 68 milk samples according to parity and stage of lactation



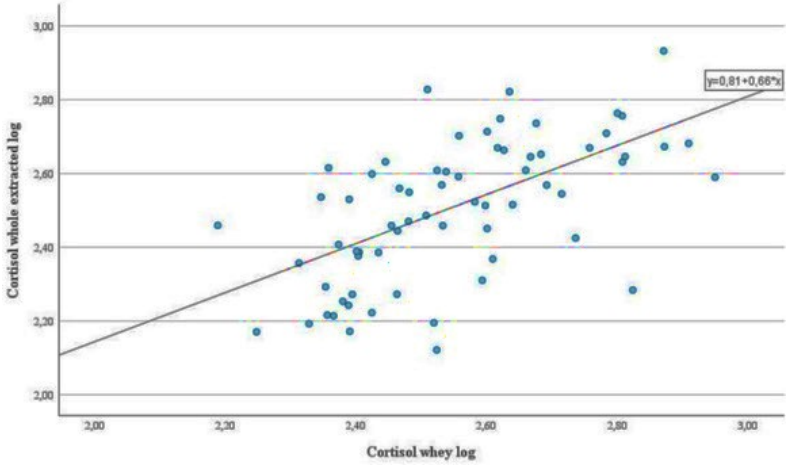


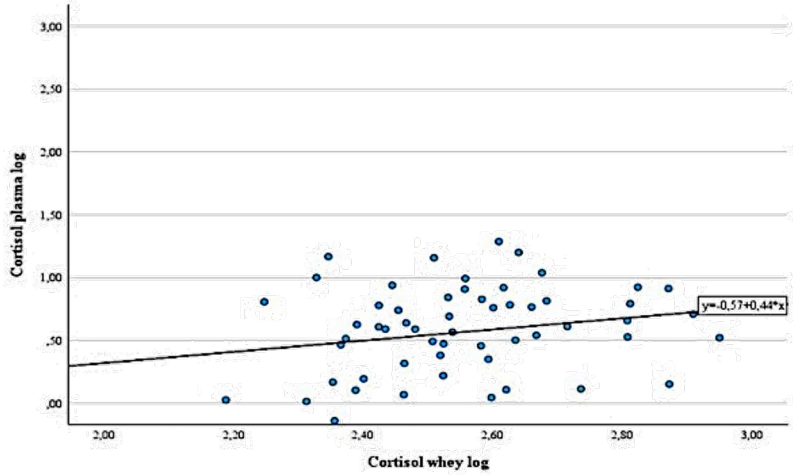
PhD thesis

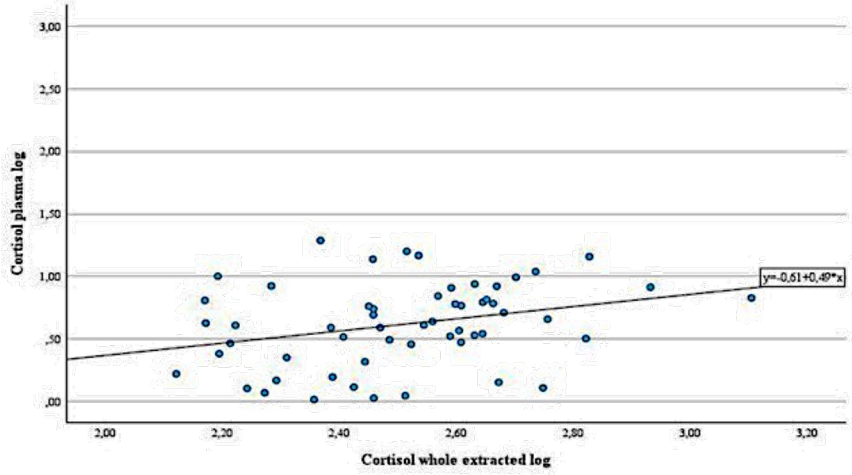
Assessing cortisol concentration in different matrices: predictive potential and relationship with production levels, lactation stage and parity in dairy buffaloes

Results: Significant positive correlations were recorded between whey cortisol concentrations and both plasma cortisol (q ¼ 0.229, p < 0.10) and whole extracted milk (q ¼ 0.631, p < 0.001), and between these last two (q¼0.298, p < 0.05), suggesting the potential of the two milk formulations to predict plasmatic concentrations of cortisol in buffalo. Therefore, milk concentrations were tested in a linear regression model.

Cortisol concentrations of whole extracted milk (pg/mL) (left panel) and plasma (ng/mL) (right panel) regressed on whey (pg/mL) and of plasma (ng/mL) regressed on whole extracted milk (below panel) (pg/mL) in a linear model. The whole extracted milk, whey and plasma cortisol concentrations were log-transformed and included as independent and dependent variables, respectively.







PhD thesis

Assessing cortisol concentration in different matrices: predictive potential and relationship with production levels, lactation stage and parity in dairy buffaloes

"Why is it original and scientifically sound?"

- *First comprehensive study on cortisol across four matrices in buffaloes.*
- *Development of a non-invasive approach to assess animal welfare.*
- *Potential to replace invasive blood sampling with milk-based cortisol measurement.*
- *Foundation for integrating biosensors in smart farming systems*.

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Research results

- *Development of an effective methodology, based on artificial intelligence, that enables the use of infrared thermography as a diagnostic method for subclinical mastitis in Italian Mediterranean buffalo.*

- *Study on the evaluation of animal stress through the analysis of cortisol levels in biological samples, using advanced laboratory techniques and statistical analysis to identify factors influencing stress.*

- ***Development of an innovative 3D camera system for accurate measurement of the volume and weight of dairy buffalo feed.***

- *Development of a measurement system for CH4 emissions monitoring from ruminants in livestock farming.*

- *Development of a wireless sensor network for ammonia measurement in Italian Mediterranean buffalo farms.*

PhD thesis

On the use of 3D camera to accurately measure volume and weight of dairy cow feed

Problem Statement: **During the weaning phase of calves, monitoring the intake of solid feed by each individual animal is critically important. Adequate consumption is essential to ensure a smooth transition from a liquid to a solid diet. This monitoring allows for the timely detection of any feeding difficulties, reduces the stress associated with weaning, and promotes balanced growth while improving the overall welfare of the animals.**
However, the growth of farms and the shortage of skilled labor make this monitoring increasingly difficult, with potential negative impacts on the health and development of calves.

Objective: **To address this challenge, the goal is to implement Precision Livestock Farming (PLF) techniques to automate the monitoring of calf weaning. This involves introducing a system capable of quantifying the feed intake of each animal and providing an early warning to the farmer in the event of feeding difficulties.**

*[P4] Alessio Cotticelli, **Maria Teresa Verde**, Annalisa Liccardo, Giorgio de Alteriis, Francesco Lamonaca, Roberta Matera, Gianluca Neglia, Tanja Peric, Alberto Prandi, Francesco Bonavolontà **"On the use of 3D camera to accurately measure volume and weight of dairy cow feed"**, ACTA IMEKO, ISSN: 2221-870X, December 2023, Volume 12, Number 4, 1 – 6, DOI: https://doi.org/10.21014/actaimeko.v12i4.1633*

PhD thesis

On the use of 3D camera to accurately measure volume and weight of dairy cow feed

Methodology: Therefore, a methodology is proposed that uses a 3D camera to measure the volume of feed, collecting three-dimensional data and calculating the weight based on the material's density. This automated system provides greater accuracy compared to the rough estimates made by human operators, enabling reliable monitoring of calves' feed intake during weaning and improving individual management, welfare, and growth.

Proposed Solution: As the 3D camera for the development of the system, the Intel RealSense D455 was used. This stereo depth camera operates similarly to how human eyes perceive depth. It uses two cameras to capture slightly different perspectives of a scene. By comparing the differences, or disparities, between the two images, it calculates the depth of objects in the scene.

Additionally, the D455 features an optional infrared projector to enhance depth accuracy in environments with low texture, where distinguishing details might otherwise be challenging. This approach ensures precise and reliable depth measurement across a variety of scenarios.

disparity

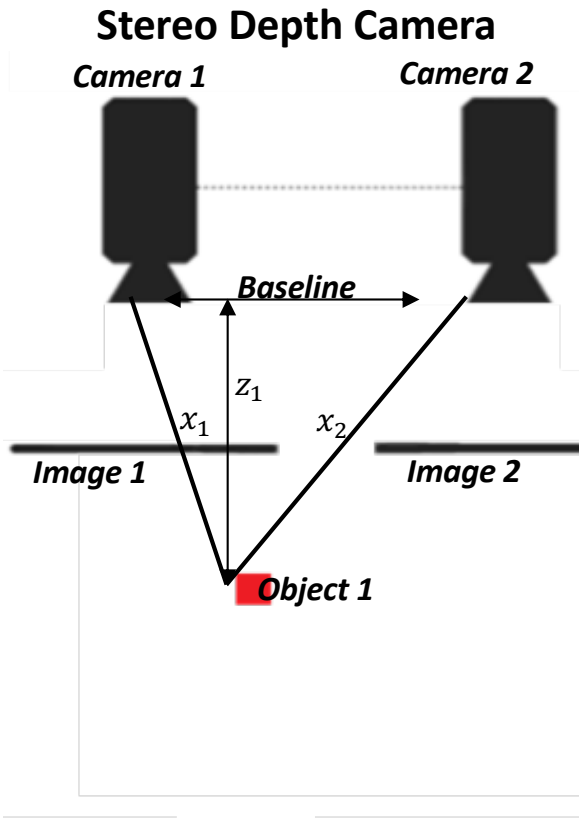
$$d_1 = |x_1 - x_2|$$

Formula for depth:

$$Z = \frac{f \cdot B}{d}$$

where *f* is the focal length

D455



The larger the disparity (*d*), the smaller the depth (z), indicating a closer object.

PhD thesis

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disparity

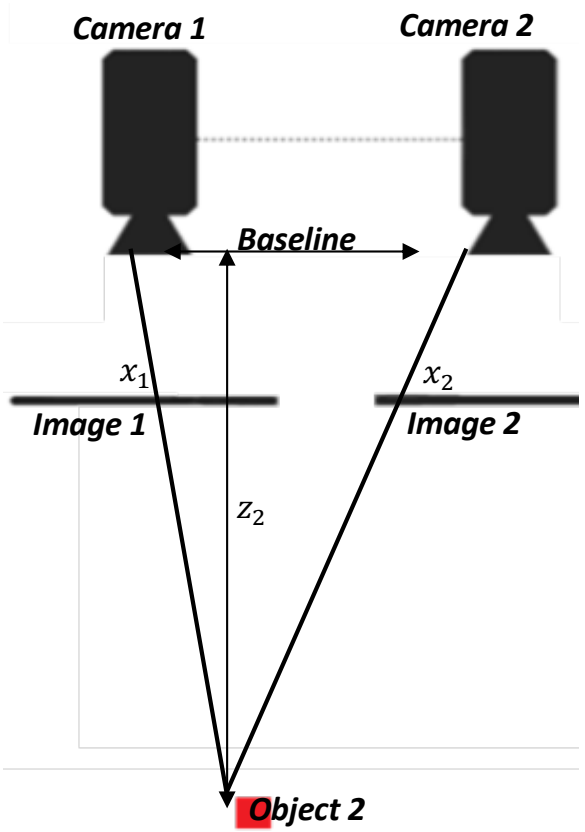
$$d_1 = |x_1 - x_2|$$

$$d_2 = |x_1 - x_2|$$

$$d_2 < d_1$$

$$z_2 > z_1$$

D455



Conversely, a smaller disparity indicates a farther object.

PhD thesis

On the use of 3D camera to accurately measure volume and weight of dairy cow feed

Measurement Setup: To preliminarily assess the feasibility of the proposed method, a suitable measurement setup was implemented in laboratory conditions. The 3D camera was installed on a camera holder whose distance from a reference plane could be modified and controlled thanks to a hand crank mechanism. The reference plane acted as the trough, and feed was exploited to assess the method's feasibility. The 3D camera was positioned at a distance of 65 cm from the reference plane.

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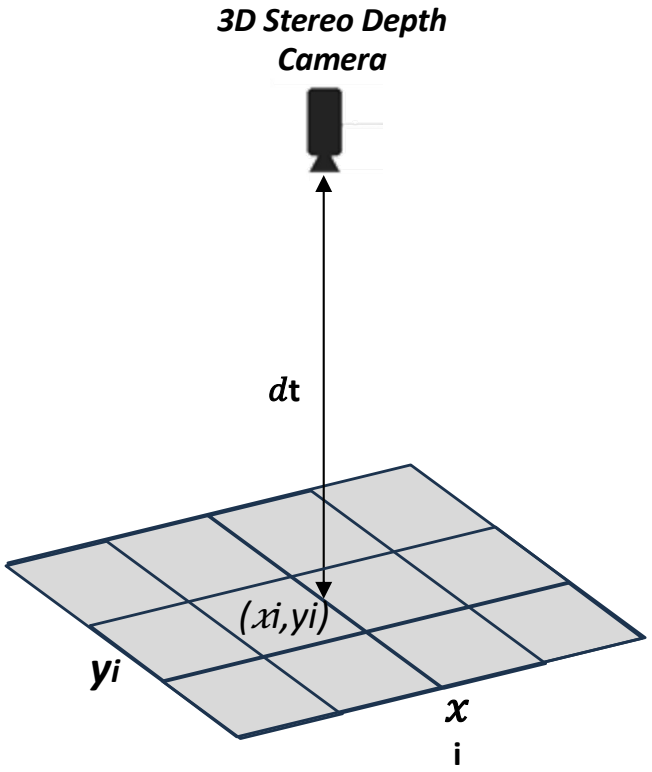
PhD thesis

On the use of 3D camera to accurately measure volume and weight of dairy cow feed

The volume associated with the generic pixel (x , y) can be evaluated as the parallelepipedon whose height is given by the difference between the estimated distance of the trough at the same pixel dt (x,y) and the distance of the pixel from the camera d (x,y).



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PhD thesis

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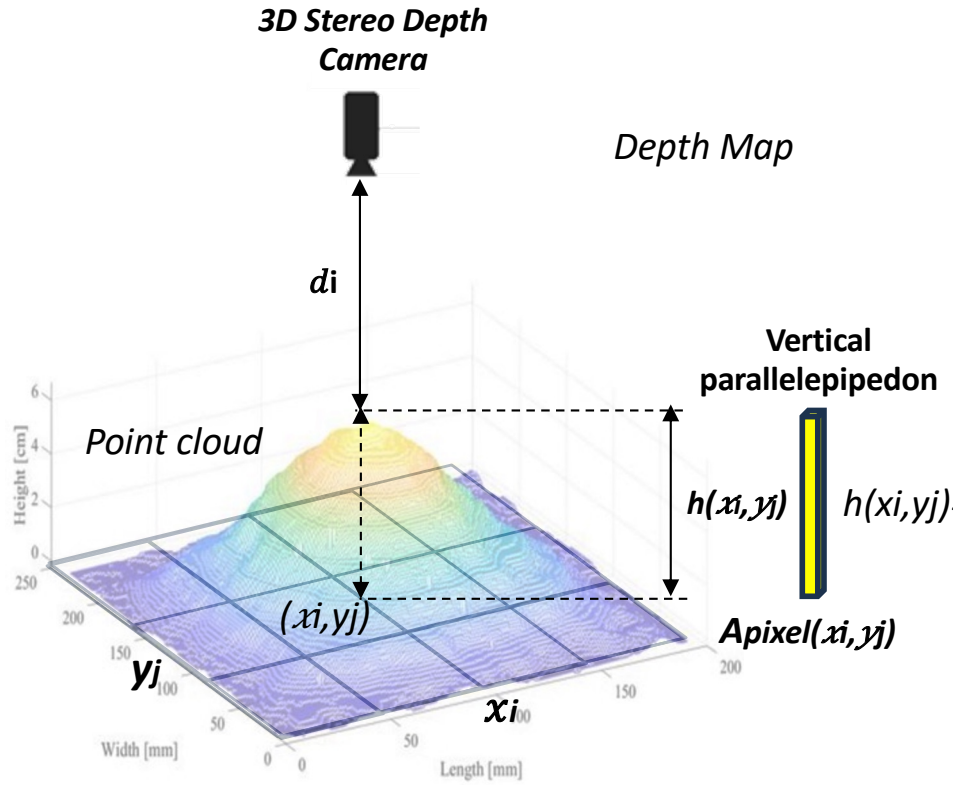

The area under a curve can be approximated using the **sum of the volumes of vertical parallelepipeds**

For a pixel ***(xi, yi)*** *the area of the pixel is given by:*

$$A_{pixel} = dx \cdot dy$$

where ***dx*** *and* ***dy*** *are the physical dimensions of a pixel on the plane. The volume of the parallelepiped is:*

$$V_{ij} = A_{pixel} \cdot h_{ij}$$

where ***hij*** *is the depth measured at the pixel (**xi**,**yj**)*

$h(xi,yj)=dt(xi,yj)-d(xi,yj)$

The total volume is the sum of all the volumes:

$$V_{TOTAL} = \sum_{ij} V_{ij}$$

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PhD thesis

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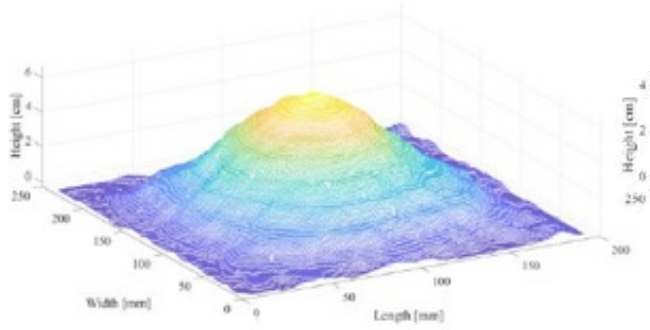
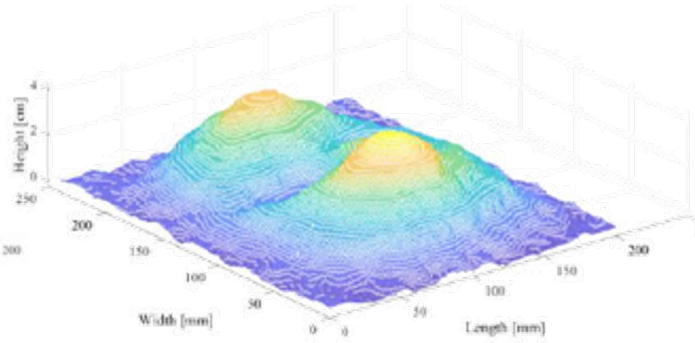
Some preliminary results obtained in the laboratory are shown, based on tests performed on feed for calves.

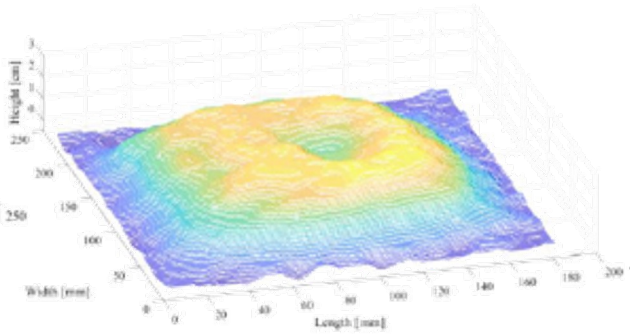
A starting volume of 1500 cm3 of feed was initially placed on the reference plane and the proposed method was applied to the acquired image. Figures show the MATLAB reconstruction obtained by means of the proposed method; as for the measured volume, the value of 1490 cm3 was obtained.



1500 cm3



1200 cm3



1000 cm3

The volume of feed was then reduced in two successive steps, whose value was 300 cm3 and 200 cm3, respectively. The corresponding volume measures were equal to 1220 cm3 and 1007 cm3. As it can be appreciated, differences with respect to the nominal values always lower than 2 % were observed.

The estimation of feed density can be affected by irregularities in composition, variations in humidity, temperature, water content, and compaction, etc.

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PhD thesis

On the use of 3D camera to accurately measure volume and weight of dairy cow feed

"Why is it original and scientifically sound?"

Originality

•***Focus on weaning***: *Weaning is a crucial phase in calf development, where the transition from milk to solid feed significantly impacts growth and long-term health. Studying feed intake during this phase allows for an understanding of feeding dynamics that are rarely explored with precision.*

•***Direct approach***: *Measuring actual feed intake provides concrete and real data on feeding behavior, as opposed to indirect methods that estimate consumption based on theoretical models or aggregate measures.*

•***Adaptability***: *This approach can be applied to various types of feed and environmental conditions, making it versatile and innovative compared to standardized methods*.

Scientifically sound

This method is scientifically sound because it provides objective, validatable, and repeatable data on feed intake, closely linked to calf growth and metabolism, allowing hypothesis testing and optimization of feeding strategies.

The next step involves testing and validating the proposed method in the field. An automatic measurement system has been developed through a collaboration between the University of Naples Federico II and the University of Udine. The system captures images directly in a barn located in Udine and transmits them via GSM using the FTP protocol to Naples, where the images are analyzed, and measurement algorithms are studied and developed.

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Research results

- *Development of an effective methodology, based on artificial intelligence, that enables the use of infrared thermography as a diagnostic method for subclinical mastitis in Italian Mediterranean buffalo.*

- *Study on the evaluation of animal stress through the analysis of cortisol levels in biological samples, using advanced laboratory techniques and statistical analysis to identify factors influencing stress.*

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- *Development of a measurement system for CH4 emissions monitoring from ruminants in livestock farming.*

- *Development of a wireless sensor network for ammonia measurement in Italian Mediterranean buffalo farms.*

PhD thesis

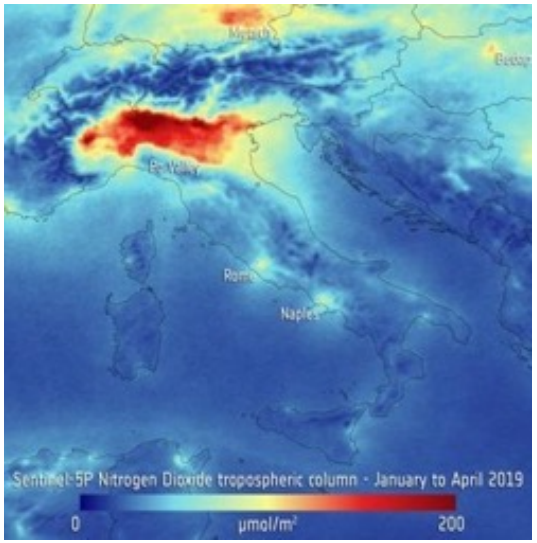
A measurement system for CH4 emissions monitoring from ruminants in livestock farming

Problem Statement: Cattle farming primarily produces ***methane*** and ***ammonia***, two substances with a significant environmental impact. Methane is mainly emitted during the digestion process of cattle, while ammonia originates from the decomposition of nitrogenous residues in manure and urine.

Environmental Impact

Greenhouse Effect: *Methane (**CH_4**) is a highly potent greenhouse gas, with a global warming potential approximately 25 times greater than that of carbon dioxide (CO_2) over a 100-year period. Cattle and buffalo farming represent a significant source of methane emissions.*

Air Pollutio: *Ammonia (NH_3), primarily released from urine and manure, contributes to the formation of fine particulate matter (PM2.5) through reactions with other atmospheric compounds. This degrades air quality and negatively affects both human health and the environment.*



Soil and Water Acidification: *Ammonia can deposit in soil and water bodies, leading to acidification that harms biodiversity and decreases soil fertility.*

PhD thesis

Objective: Measure methane and ammonia emissions in livestock farms to identify inefficiencies in cattle feeding and manure management, with the goal of developing more sustainable techniques and strategies, thereby contributing to the transition toward ***green agriculture***.

Results: An identified solution involves using a sniffer installed on the milking robot to monitor methane emissions while the cattle are stationary and positioned close to the sensor during this phase.
This approach allows for the collection of data under standardized conditions from a substantial number of subjects, enhancing both the representativeness and reliability of the information.
The use of the milking robot enables the seamless integration of methane emissions monitoring into the farm management cycle without disturbing the animals. Emission data can be cross-referenced with milk production and quality metrics, helping to develop models that optimize both efficiency and sustainability

In conclusion, methane is a byproduct of enteric fermentation and is closely linked to the animals' diet. Monitoring its emissions allows for the identification of dietary inefficiencies, the optimization of feeding through balanced additives or feed, and a reduction in methane production, thereby improving the environmental sustainability of the farm.

PhD thesis

A measurement system for CH4 e missions monitoring from ruminants in livestock farming

"Why is it original and scientifically sound?“

Originality

Italy is a leader in buffalo milk production and its derivatives, such as Buffalo Mozzarella DOP. This technology could position itself as a global example of excellence in the sustainable management of this production. It appears that no similar solution has been implemented elsewhere for buffalo farming.

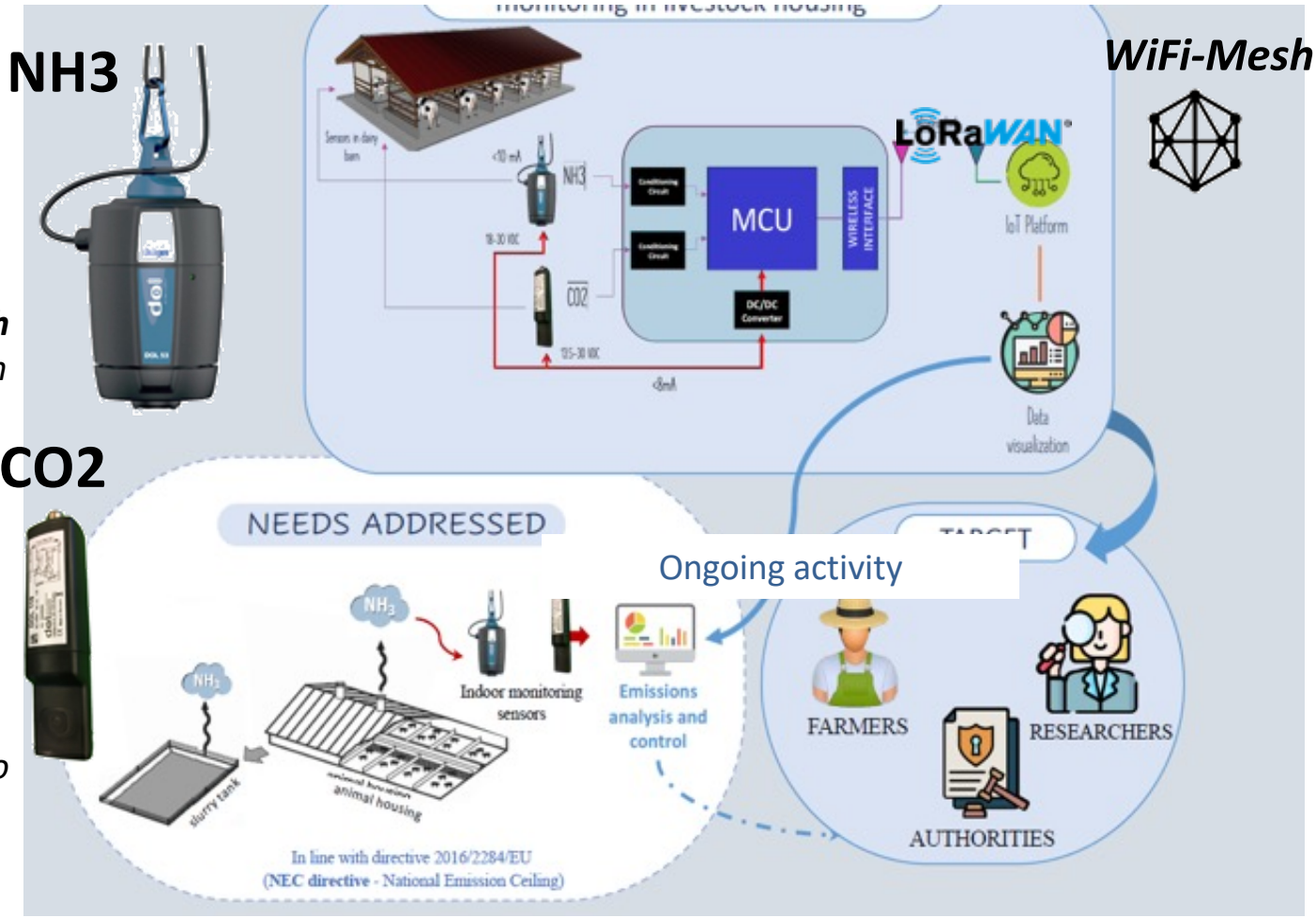
Scientifically Sound

- *Measuring emissions facilitates the development of innovative technologies and strategies, such as feed additives to reduce methane production, manure treatment systems to capture ammonia, and biogas systems for energy recovery.*
- *It also contributes to the collection of scientific data, supporting the transition toward more sustainable farming models*

PhD thesis

Development of a wireless sensor network for ammonia measurement in Italian Mediterranean buffalo farms

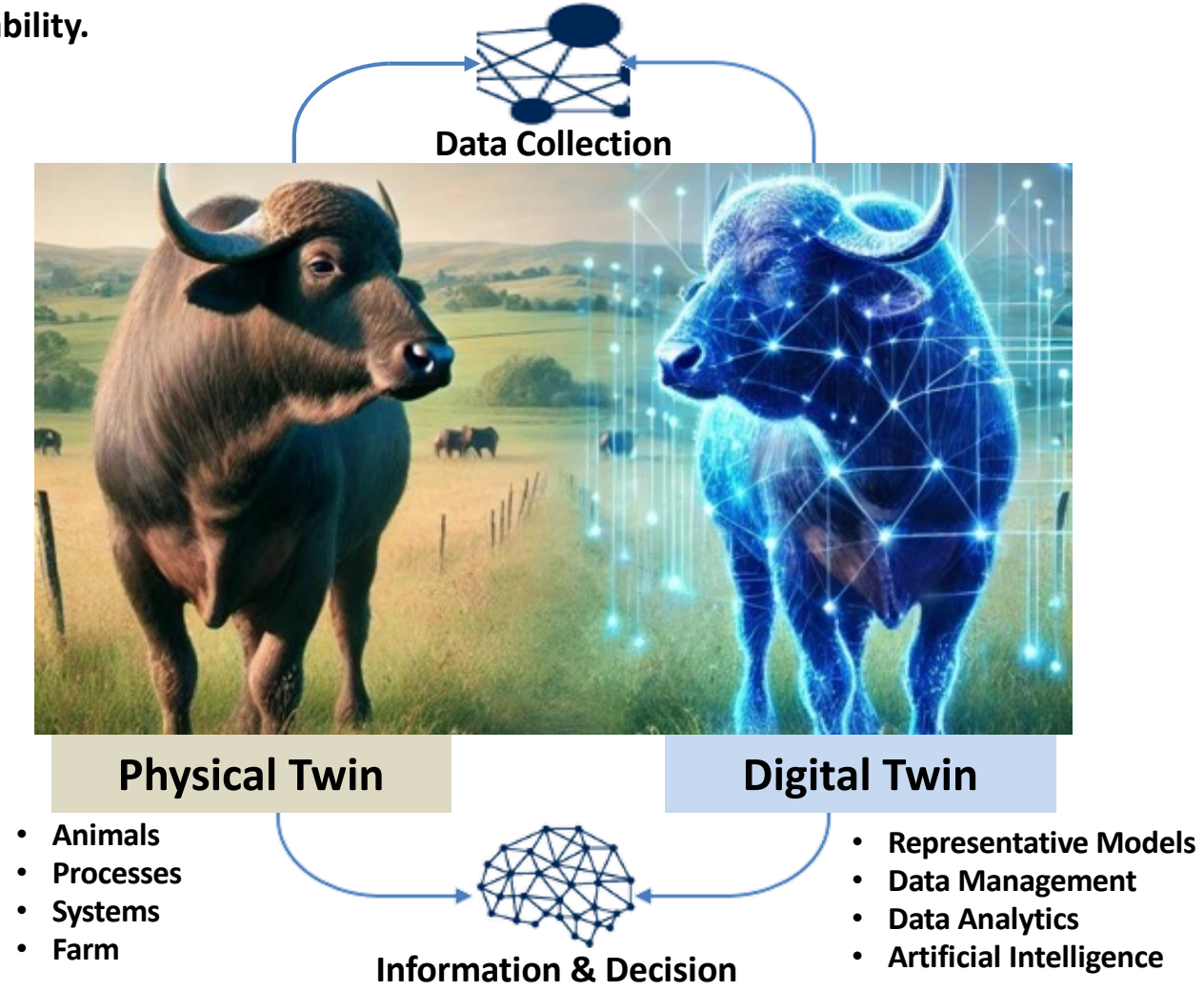
ARMONIA *(**A**utomated **R**emote **M**onitoring of **N**itrogen in Agriculture): A system has been designed to monitor real-time emissions of ammonia (**NH_3**) and carbon dioxide (**CO_2**) in livestock farms, utilizing a scalable network of wireless sensors based on **Wi-Fi Mesh** or **LoRaWAN** protocols, depending on specific requirements. This approach enables the continuous and accurate collection of environmental data within the barn, providing essential insights to improve air quality management and animal welfare while reducing environmental impact. The system is particularly valuable for continuous monitoring to comply with regulations on greenhouse gas and ammonia emissions.*



The NH_3 and CO_2 sensors are electrochemical devices designed for installation on the barn ceiling, where gas concentrations naturally accumulate.

PhD thesis

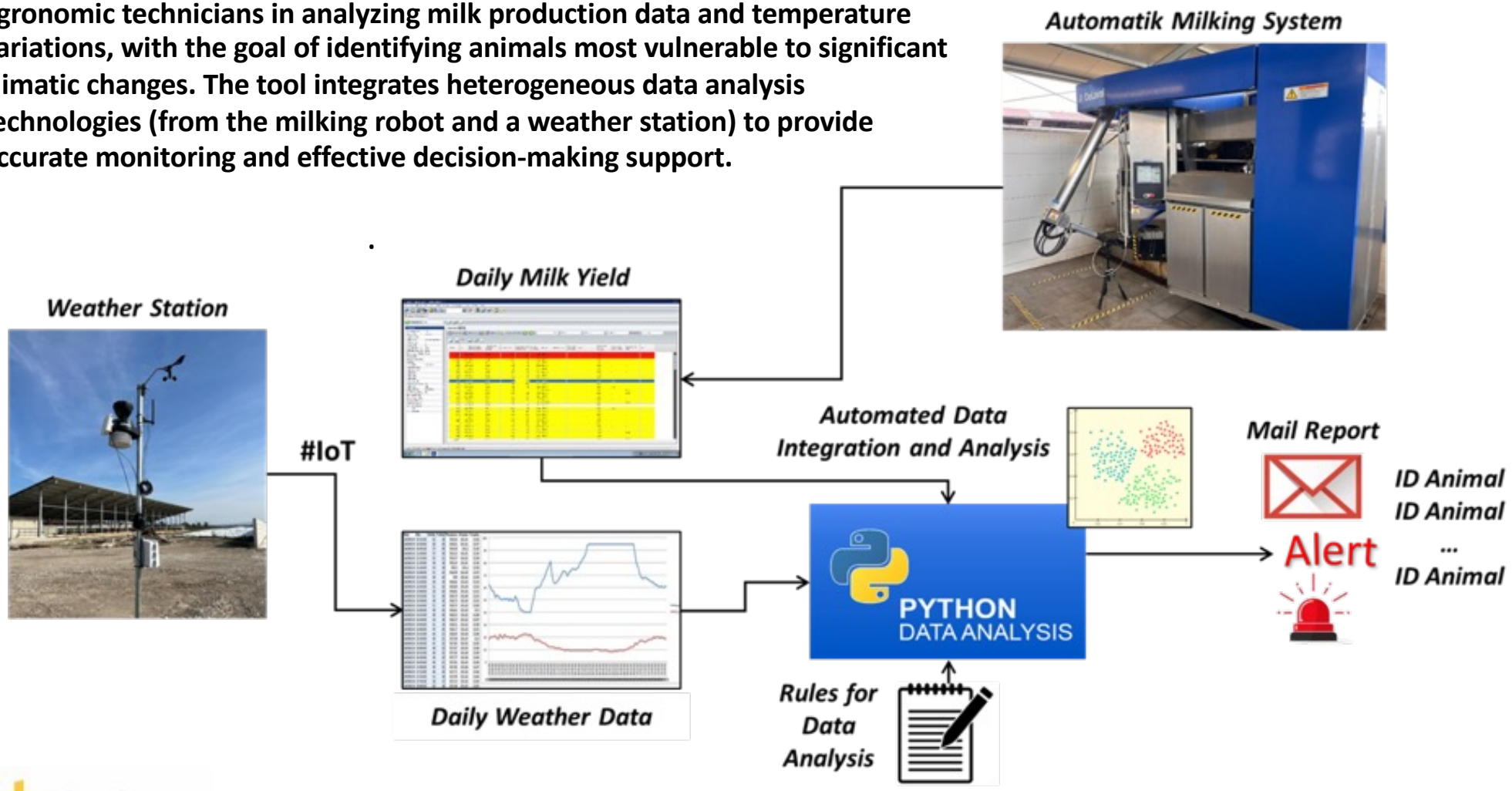
The integration of the developed data collection systems into a single platform marks a crucial step toward creating an integrated system, conceived according to a holistic vision. This approach aims to develop a *Digital Twin* of the Farm, a virtual model that represents the ideal farm, optimizing management processes, animal welfare, and environmental sustainability.



PhD thesis

An example of data integration from heterogeneous sources, automatically analyzed to provide effective decision support is... ThermalDrop: Software for automatic analysis of the correlation between temperature variation and production decline *(developed in collaboration with the hosting company, Castelluccia s.n.c.)***.**

This is an advanced software solution designed to support farmers and agronomic technicians in analyzing milk production data and temperature variations, with the goal of identifying animals most vulnerable to significant climatic changes. The tool integrates heterogeneous data analysis technologies (from the milking robot and a weather station) to provide accurate monitoring and effective decision-making support.



Conclusions

This thesis has demonstrated how the implementation and application of innovative technologies in the field of Precision Livestock Farming (PLF) can revolutionize the farming of Italian Mediterranean buffalo, delivering significant advancements in animal welfare, productivity, and environmental sustainability.

Notably, it stands out for:

- The first large-scale application of thermal imaging and artificial intelligence technologies for the early detection of subclinical mastitis in Italian Mediterranean buffalo;
- Integration of non-invasive sensors for monitoring animal welfare;
- Promoting reduced antibiotic usage and more sustainable farming practices;
- Introducing advanced methods (3D Camera) for monitoring individual feed intake in calves and systems for tracking emissions (CH_4 and NH_3) in farm processes;
- Developing methodologies based on real-world data collected in operational environments;
- Rigorous validation of results through statistical modeling and real-world testing;
- Expanding sensor integration to create a digital twin of the farm.

The buffalo farming sector has traditionally been less explored compared to other livestock industries (e.g., dairy cattle or swine farming) from both scientific and technological perspectives.
Applying PLF to this sector therefore represents a pioneering field of research.
Buffalo exhibit distinct physiological traits and behavioral patterns compared to other bovines, and applying PLF technologies to the unique characteristics of this species requires targeted scientific investigation.

Finally, this thesis highlights how the use of PLF can enhance the quality of buffalo milk and Buffalo Mozzarella DOP, thereby helping to improve the global competitiveness of buffalo farming.

Conferences and seminars attended

I attended the First and Second Edition **IEEE International Workshop on Measurement and Applications in Veterinary and Animal Sciences (MeAVeAS) in 2024** and **2023,** where:

- I held tutorial **Innovative Technologies for a Buffalo Smart Farm (MeAVeAS 2023)**
- I was chair of the **Special Session #6:** *IOT-BASED INNOVATIVE TECHNOLOGIES FOR PRECISION LIVESTOCK FARMING* **(MeAVeAS 2023)**
- I was chair of the **Special Session #13:** *New Technologies and Engineering Solutions to improve livestock farming (Precision Livestock Farming)* **(MeAVeAS 2024)**

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Scientific Research interactions/relations with other Research Center, Institutions, and companies established

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