Recent scientific advances in precision livestock farming

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International Workshop on Nondestructive Quality Evaluation of Agricultural, Livestock and Fishery Products

Animal team (multidisciplinary team)

Bio-Engineers
- 1 PhD → incubation technology
- 1 PhD → poultry housing technology
- 4 MSc → a bit of everything…

Computer Scientists
- PostDoc → Sound analyst: poultry
- PostDoc → Computer vision: pig
- 2 PhD → Computer vision: pig health/behaviour

Ethologist/Welfare scientist
- PostDoc → Stress responses: poultry

Veterinarian
- PhD→ Data analysis pig health

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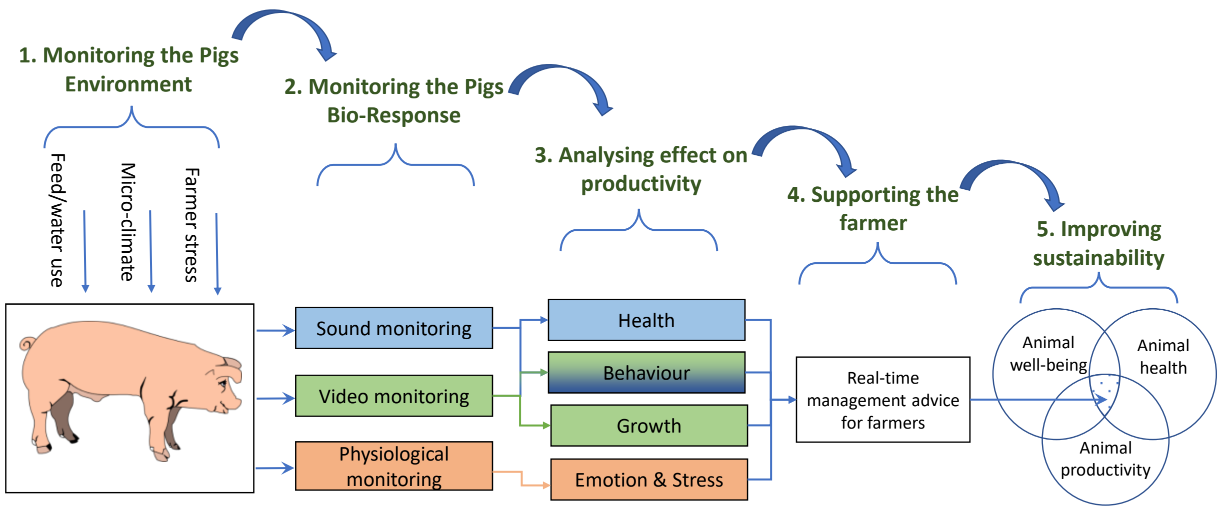
Creating a worthwhile digital twin of pigs



Why we need to help EU livestock producers

External

→Health: animal/human diseases looming

→Welfare: legislation on animal welfare changing

→Environmental: more restrictions across the EU

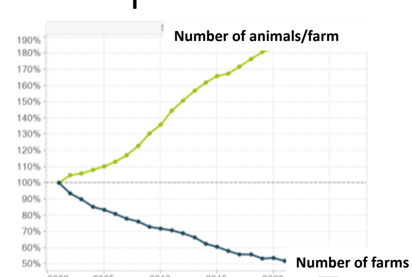
→Imports: reliance on soy protein

Internal

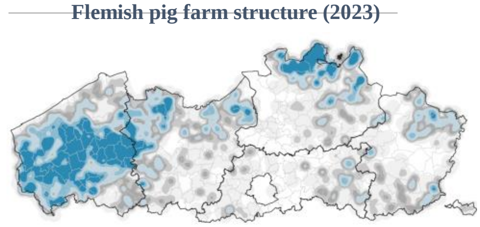
→Aging farmer demographic

→Increasing hard to get good people

→Animals are more efficient but also more "sensitive"



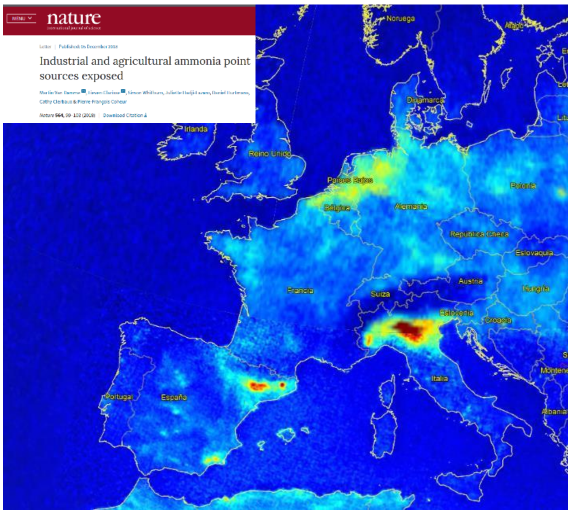
Flemish pig farm structure (2023)

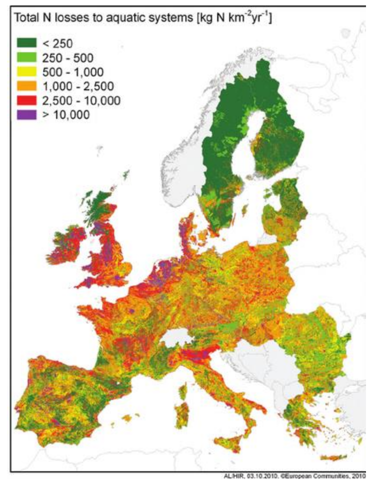


Flemish pig farm distribution (2023)

Flemish government | Department of Agriculture and Fisheries (2023)

Impact of livestock production on environment





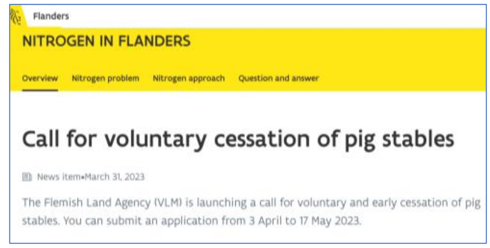
Sutton and Billen (2011)

Impact of livestock production on health and welfare

Reducing these impacts? → 2 ways

(1) Shrink the production sectors through government schemes

Flemish Pig Sector to reduce by 30% before 2030


Flanders

NITROGEN IN FLANDERS

Overview | Nitrogen problem | Nitrogen approach | Question and answer

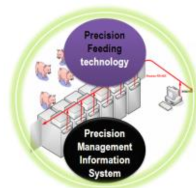
Call for voluntary cessation of pig stables

News item•March 31, 2023

The Flemish Land Agency (VLM) is launching a call for voluntary and early cessation of pig stables. You can submit an application from 3 April to 17 May 2023.

(2) Exploit multiple technologies:
- A. Emission reduction
- B. Feed efficiency
- C. Animal health and welfare


Environmental tech

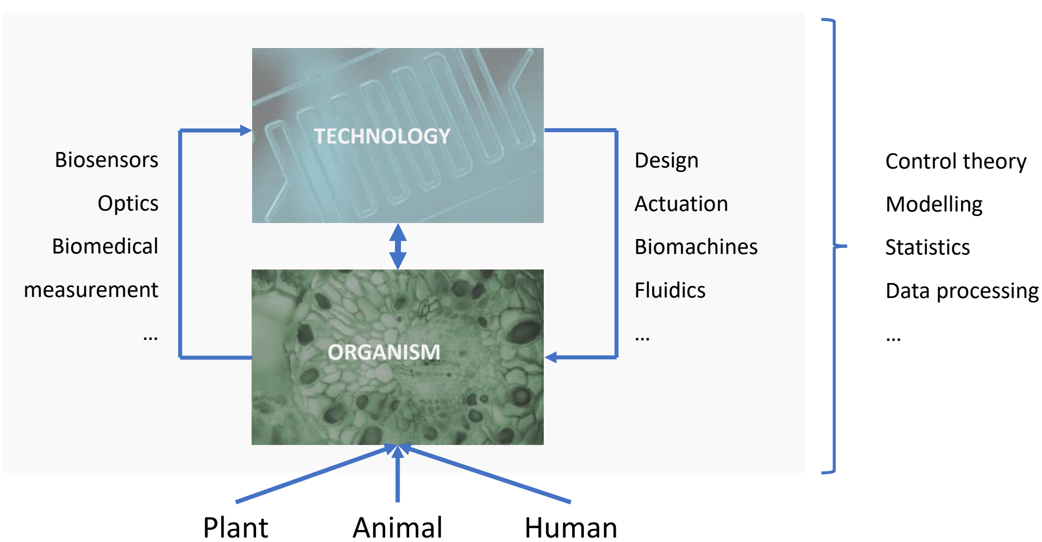


Feeding tech


Monitoring tech

Precision Livestock Farming

Biosystems Engineers needed to develop Precision Farming technology

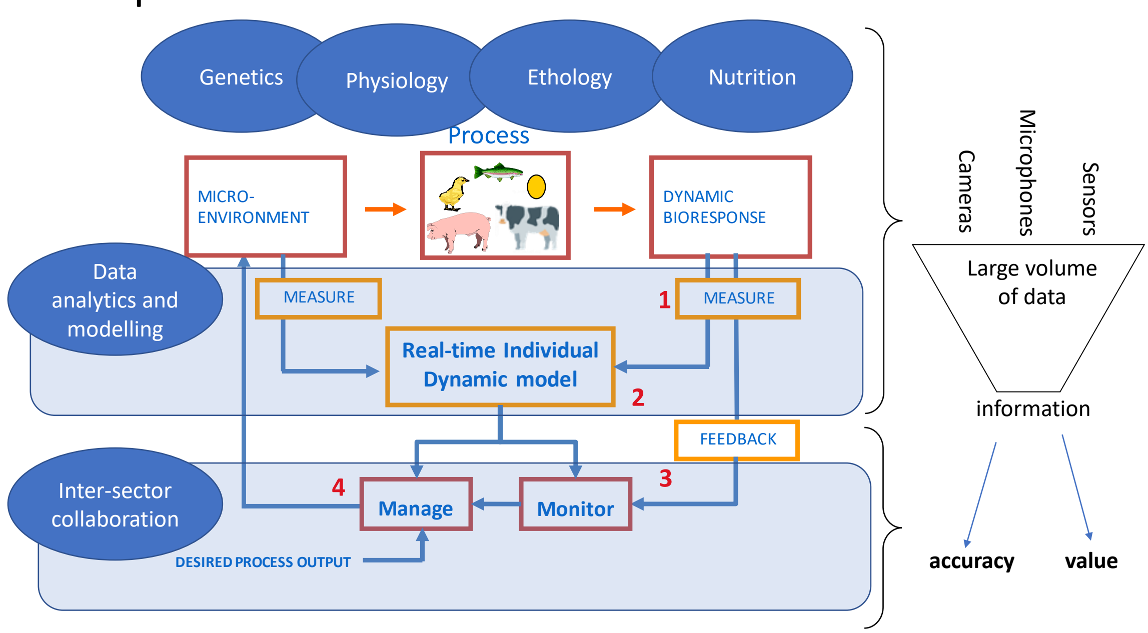


Definitions: Precision Agriculture (PA) versus Precision Livestock Farming (PLF)

Precision Agriculture *is a management **strategy that gathers, processes and analyses temporal, spatial and individual data** and combines it with other information to **support management decisions** according to estimated* variability *for improved resource use efficiency, productivity, quality, profitability and sustainability of agricultural production.* The International Society for Precision Agriculture (ISPA)

Precision livestock farming *is the management of livestock production using the principles and technology of process engineering* (Wathes et al., 2008).

Principles of PLF



Remote sensing of animals – what tool is best?

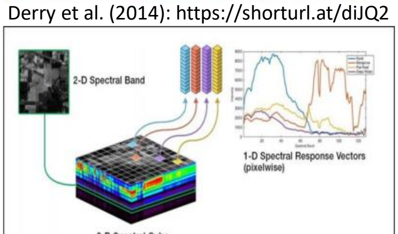
Racewicz et al (2021)

Equipment	Application	Advantages	Disadvantages
2D (RGB) cameras	Pig identification based on detection of colours in the image [67]. Automatically detecting pig locomotion [56]. • Automatically detecting pig position and posture [21]. • Monitoring the environment in a pig pen [21]. Analyse the group behaviour of pigs [21].	Non-invasive method [67]. Possibility of individual or group analysis [67]. • Helps to analyse how often animals visit the feeder [48]. • Helps determine time of animal feed intake [48].	Performance depends on lighting conditions [67]. Very similar appearances of pigs and varying statuses of the background [41]. Vulnerability to errors due to occlusion [15]. May require protective shielding against environmental factors [71]. • Requires filtering to obtain useful information [70].
3D (RGBD) cameras	Estimation of pig body weights [60]. • Identification of standing pigs [74]. Tail biting detection [67]. • Automatically detecting pig locomotion [61].	• Non-invasive method [67]. • Possibility of individual or group analysis [67]. • Ability to handle large datasets [35]. Ability to adapt to variable light and background conditions [74].	• May require protective shielding [71]. Limited depth measurement range [67]. • Vulnerability to errors due to occlusion [15].
Microphones	Detection of sickness and heat stress [2]. Cough detection [2]. Group behaviour monitoring [2].	Non-invasive method [2]. Monitoring of large groups of animals with a single sensor [2]. • Indirect detection of air pollution [85]. • Can be used indoor and outdoor [2].	Monitoring individual is not feasible Susceptibility to interference from environmental sounds [82]. • Environmental factors may interfere with the functioning of the microphone [82].
Camera vs microphone	**5 vs 3**	**3 vs 2**	**5 vs 2**

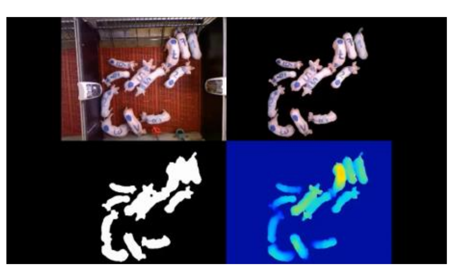
Camera able to monitoring on an individual animal level is a major advantage

Shared challenges: PA vs PLF

Derry et al. (2014): https://shorturl.at/diJQ2

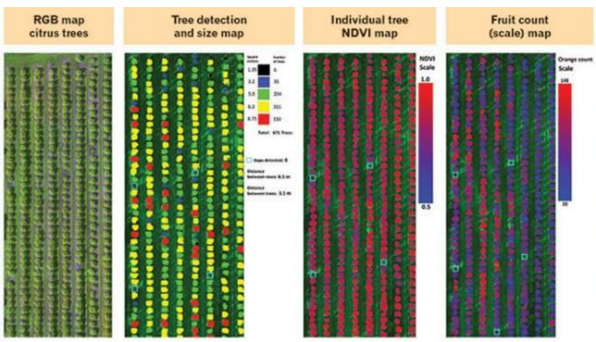


Sethy et al. (2022): https://shorturl.at/vSUZ1



- Large volumes of data
- Noisy data
- Poor contrast
- Redundancy
- Poor labels/unlabelled
- Time dependent
- Space dependent

Main difference: PA vs PLF

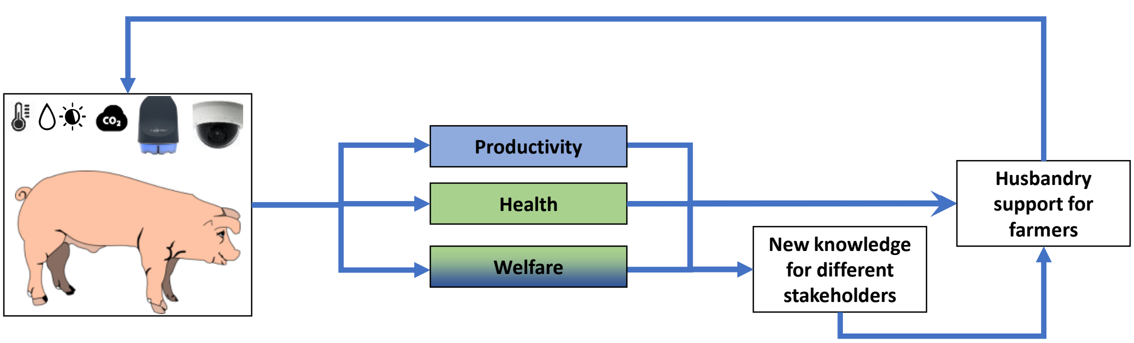


Ampatzidis et al. (2023): https://shorturl.at/uxCLP

Not Moving!

Moving!

Creating value with PLF technology



Socio-economic challenge → what indicators create the most impact?

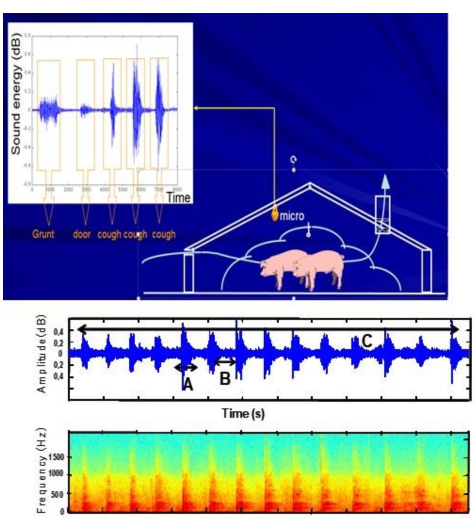
Technical challenge 1. → how easily can it be measured?
Technical challenge 2. → what is the <u>highest</u> resolution and accuracy?

Health: sound monitoring of respiratory health

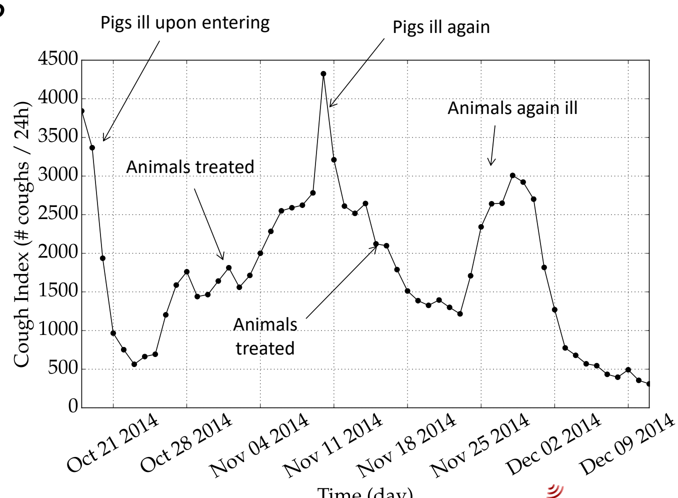
Available → yes
Primary stakeholder → Farmer
Secondary stakeholder → Veterinarian

Ease of measurement → microphone

Pig Cough Monitoring



(*) In collaboration with UNIMI (Italy)



Started by Van Hirtum and Berckmans (2000)

EU - PLF
FP7 2012-2016

Independent validation

Preventive Veterinary Medicine 186 (2021) 105208

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Preventive Veterinary Medicine

journal homepage: www.elsevier.com/locate/prevetmed

Managing respiratory disease in finisher pigs: Combining quantitative assessments of clinical signs and the prevalence of lung lesions at slaughter

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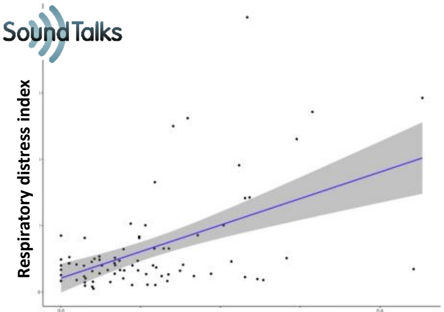
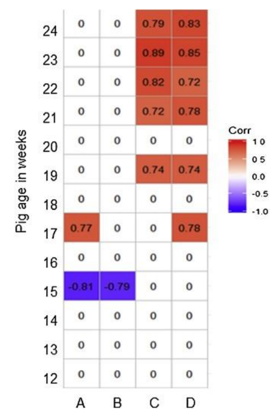
SoundTalks





(A) = Dorsocaudal pleurisy
(B) = Cranial pleurisy,
(C) = Lung scars,
(D) = Pneumonia

Teagasc
Agriculture and Food Development Authority

Benefit:

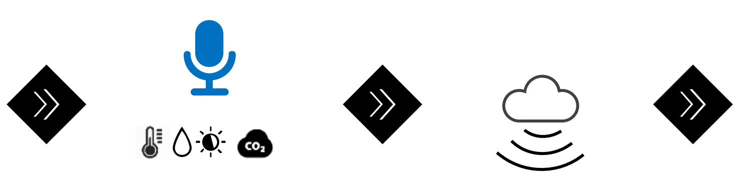
- Adapt vaccination and treatment protocols
- Coughing patterns can be related to primary aetiology

Challenge

- Resolution – group level is possible

Current solution

Boehringer Ingelheim | powered by SoundTalks®



Hardware
Objective measurement of a herd of fattening pigs

Algorithms Sound & Climate
Automated analysis of pig sounds
Climate sensors indicate cause

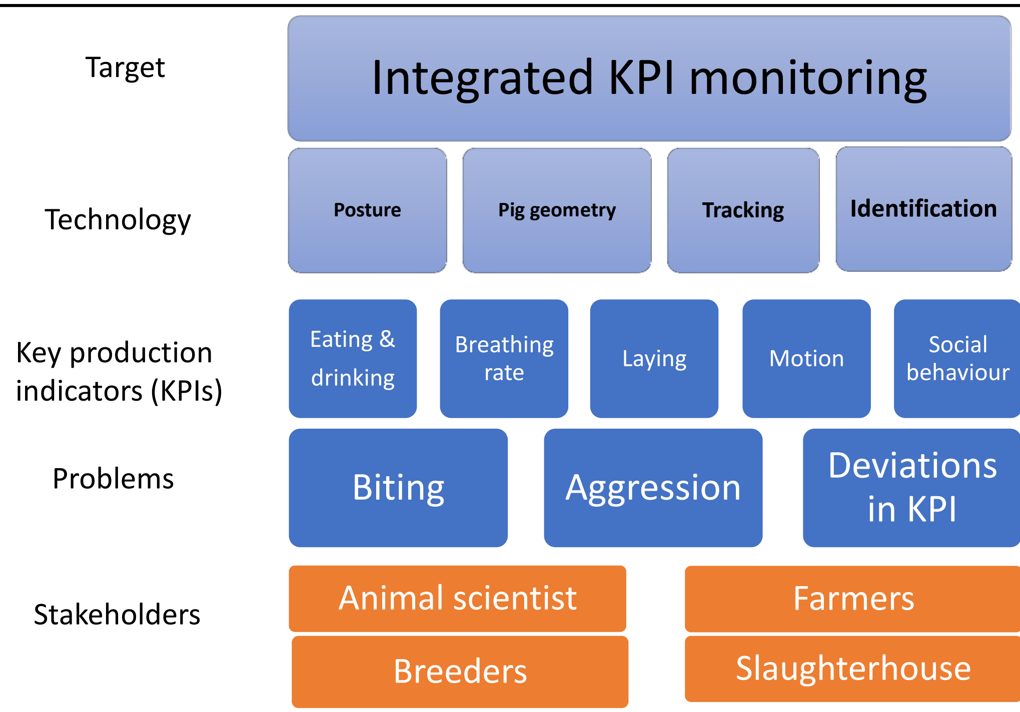
Cloud Based Solution
Excellent service in Scalable model
Remote monitoring
IP protection

Customer Intimacy
Useful Information
...for one specific farm
... for one specific customer

The FUTURE!

Integrated remote animal monitoring: health/welfare/productivity

Available → no
Primary stakeholder → Depends on application
Secondary stakeholder → Farmer/Veterinarian/Nutritionist/Scientists
Ease of measurement → **camera (1 device per pig pen)**



Group level monitoring with the camera

Challenges with Computer Vision…

What we need?

- Group to Individual level→ animal is a "time-varying" system
- General indicators to high resolution monitoring (activity index v.s. social interaction)
- ALL-in-one system → integration of coarse-to-fine applications

What are the Challenges?

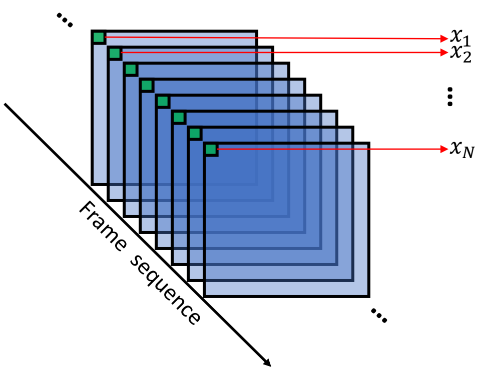
- Diversity of farm conditions → Generalization challenge
- Group size → Density/Occlusion challenge
- Homogeneous appearance → Re-identification/Tracking challenge
- Long-term monitoring → robustness challenge (hardware & software)
- Performance & efficiency → Light-weighted model, affordable computing device capable of processing large data

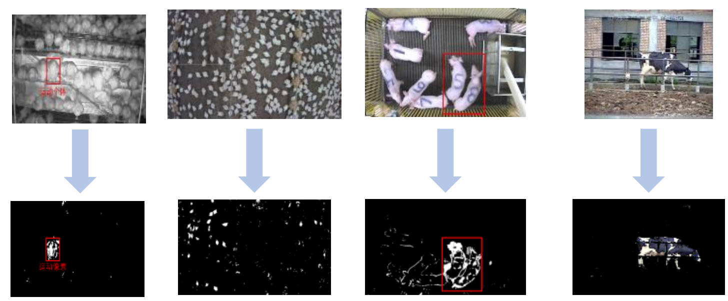
Basic image processing methodology for behaviour monitoring

<u>Gaussian mixture modelling approach for robust group-level activity monitoring</u>

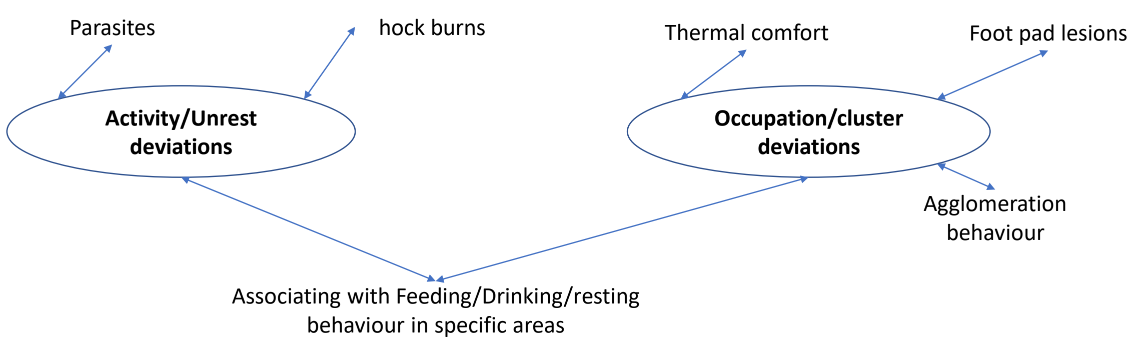
Parameterizing the background by distribution $p(X|\theta)$, and estimating θ via observed data

- If new observed data obey this distribution → output 0 (static background)
- Otherwise→ output 1 (moving animal)
- Updating model parameters θ





Associating group level monitoring with animal welfare



- Fernandez A P, Norton T, Tullo E, et al. Real-time monitoring of broiler flock's welfare status using camera-based technology[J]. Biosystems Engineering, 2018, 173: 103-114.
- Pereira D F, Lopes F A A, Gabriel Filho L R A, et al. Cluster index for estimating thermal poultry stress (gallus gallus domesticus)[J]. Computers and Electronics in Agriculture, 2020, 177: 105704.

Traditional Computer Vision: Pros & Cons

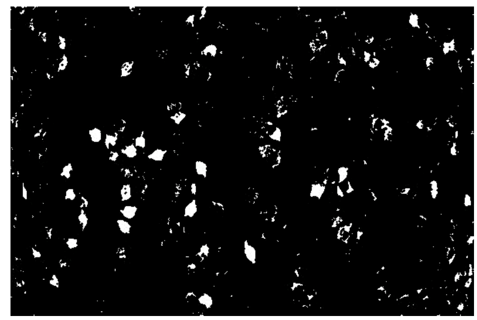
Pros.

- Light-weighted → Real-time in low-cost CPU
- Unsupervised method → no data annotation
- Illumination robustness → Long-term monitoring

Cons.

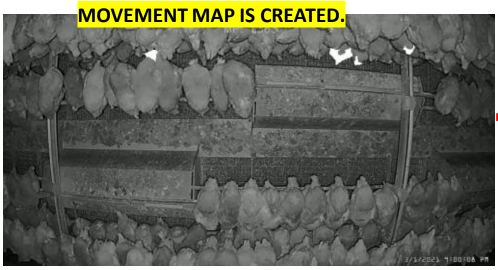
- Coarse indicators
- Group-level monitoring → sensitive to size
- Lack of identification

Limited phenotyping value

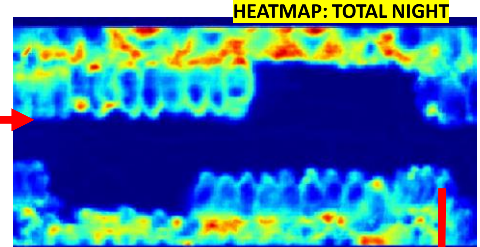


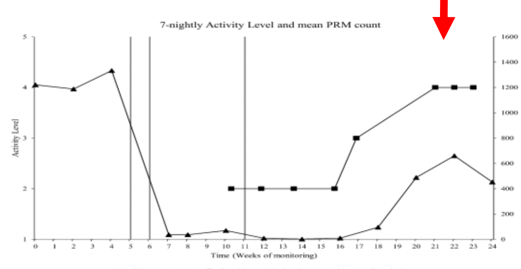
Restlessness monitoring of parasite effect on layer hens

MOVEMENT MAP IS CREATED.



HEATMAP: TOTAL NIGHT



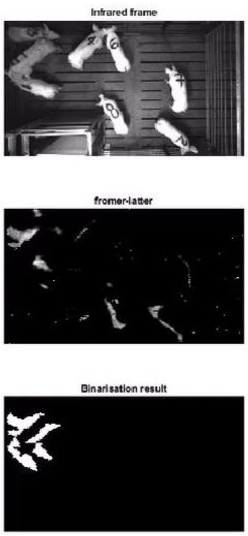


<u>Advantage</u>

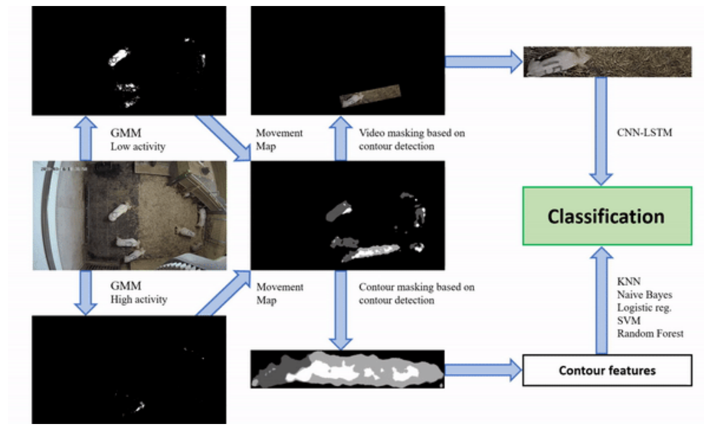
Activity level clearly represents the restlessness of the birds during the dark period

Willems et al (2022)

Monitoring aggression and playing between piglets



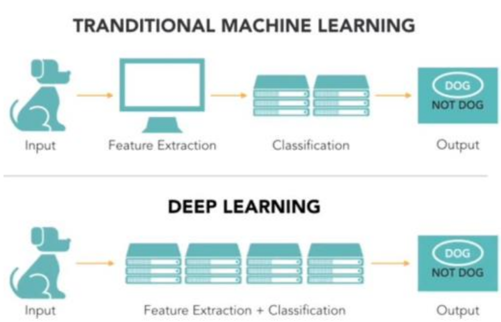
Chen et al. 2019



Larsen et al. submitted

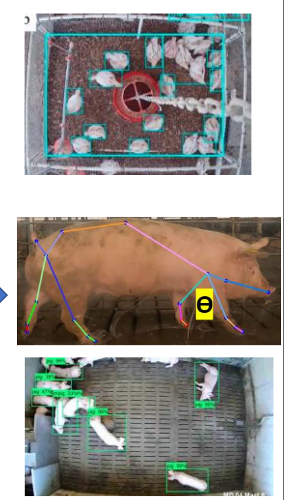
Deep Learning based Computer Vision

DL is *"a machine learning technique that teaches computers to do what comes naturally to humans: learn by example"* ref. Mathworks



DL compliments computer vision

- Object detection
- Multi-object tracking
- (Re-)identification
- Pose estimation
- Behavior understanding

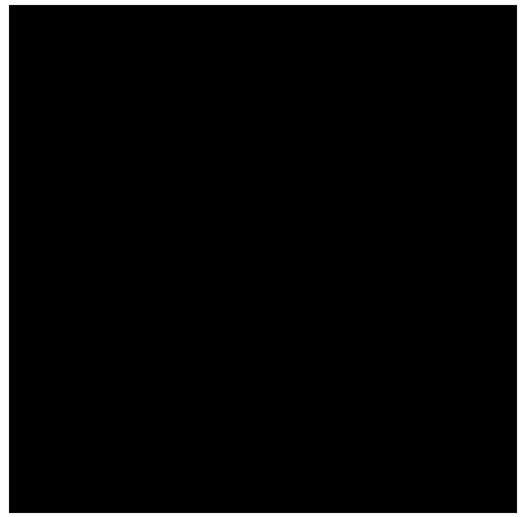


High resolution behaviour capture now possible

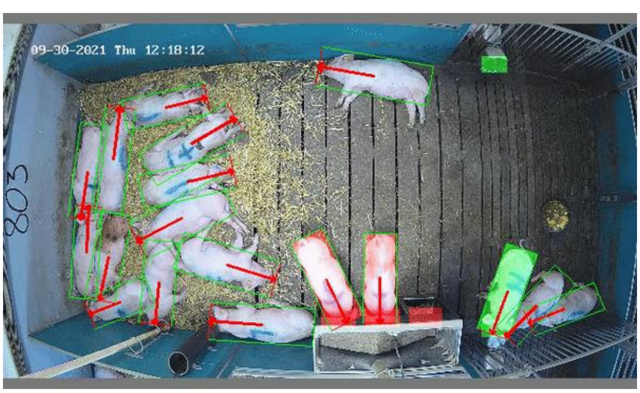
Pig detection - Locate each animal by Rotated Bounding Box

Innovations

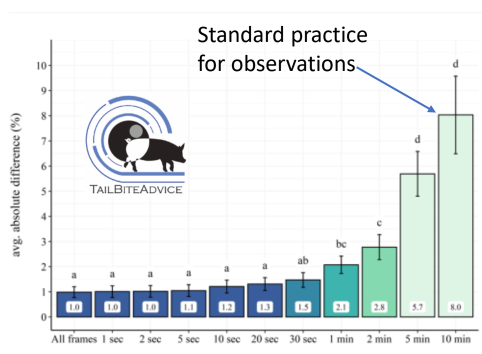
- ✓ *<u>Rotated bounding box</u> → Performs well in dense scenario*
- ✓ *<u>Direction vector</u> → enable inferring the yaw angle*
- ✓ *<u>Super lightweighted (1.7M)</u> → edge device → marketing*



Behaviour quantification (group level)



(Liu et al. under review)



(Larsen et al. 2023)

Production related behaviours

- ✓ Feeding (red box)

Health related behaviours

- ✓ Feeding (red box)
- ✓ Drinking (green box)

Welfare related behaviours

- ✓ Resting/dunging zones
- ✓ Activity levels

Individual pig tracking with the camera

Individuals level tracking is a challenge: Animal re-identification

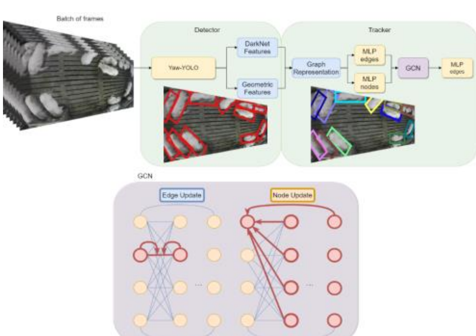
Re-identification

- Ear tag
- Body marker

Psota et al. (2020)

In collaboration with

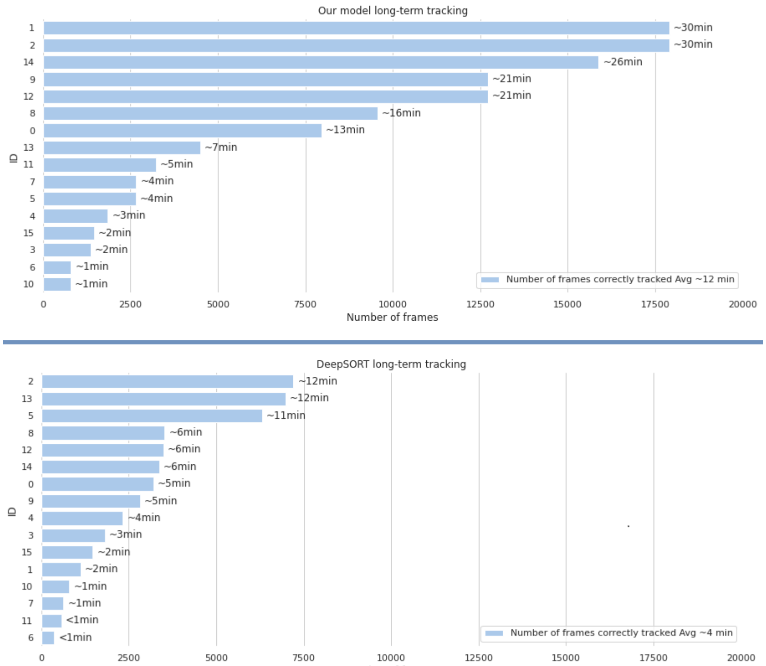
Multi-pigs tracking in real-time video using graph convolutions



Innovation

- ✓ *Accurate identity tracking*
- ✓ *Individual behaviour measurement*
- ✓ *Interactive behaviour recognition*
- ✓ *Real-time inferencing*

Parmiggiani et al. accepted



Parmigianni et al. under review

Quantitative tracking results

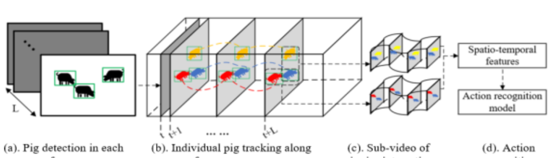
Tracks individual pigs for **3 times longer** than current state-of-the-art without the need for ear-tag.

Behavior detection - Tail biting (under development)

TAILBITEADVICE

Algorithm:

- Object detection
- Multi-object tracking
- Behaviour recognition



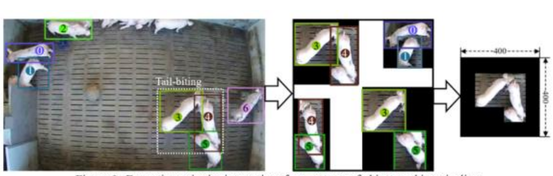
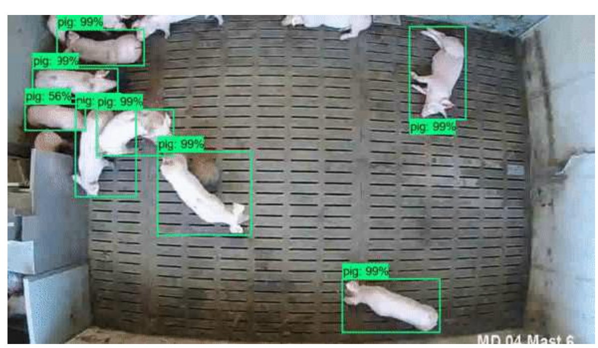


Figure 6. Extracting pairwise interactions from outputs of object tracking pipeline.



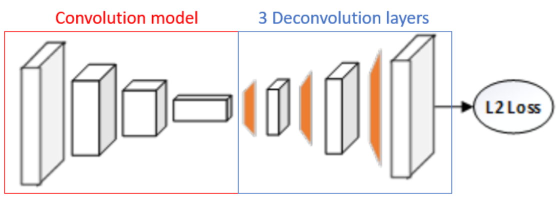
Liu et al (2020)

Performance:

- classification accuracy of 96.25%
- Localization accuracy of 92.71%

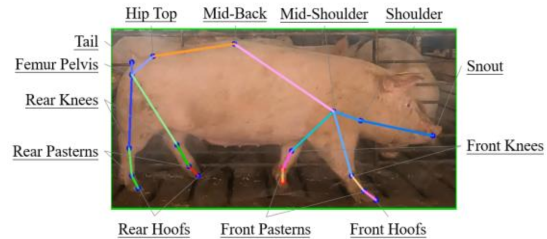
Gilt gait analysis

- Gilt selection
- Lameness assessment



Dataset:

- 1100 images (0.8:0.2 split for training and validation)

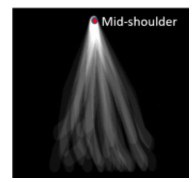


Dynamic gait feature – Skeleton Energy Image

- Inspired by Pathological Gait Analysis (e.g. Parkinson's disease)

Concatenate sequence into SEI:

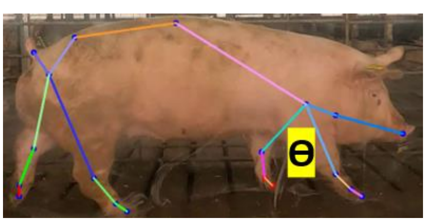
$$SEI(x, y) = \frac{1}{N}\sum_{t=1}^{N} S_t(x, y)$$

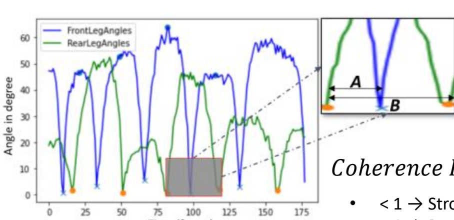


Liu et al (2022)

Interpretability

- Combination of DL with bio-mechanics





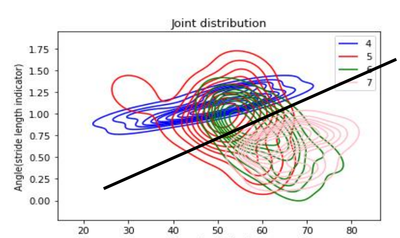
Gait feature

- Stride length
- Walking coherence

$$Coherence\ Indicator = 2 \times \frac{A}{B}$$

- < 1 → Strong leg
- > 1 → Poor leg

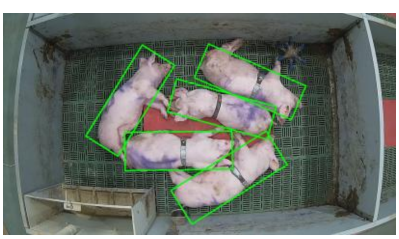
Two interpretable gait feature make lameness/healthy pigs linearly separable



Liu et al (2022)

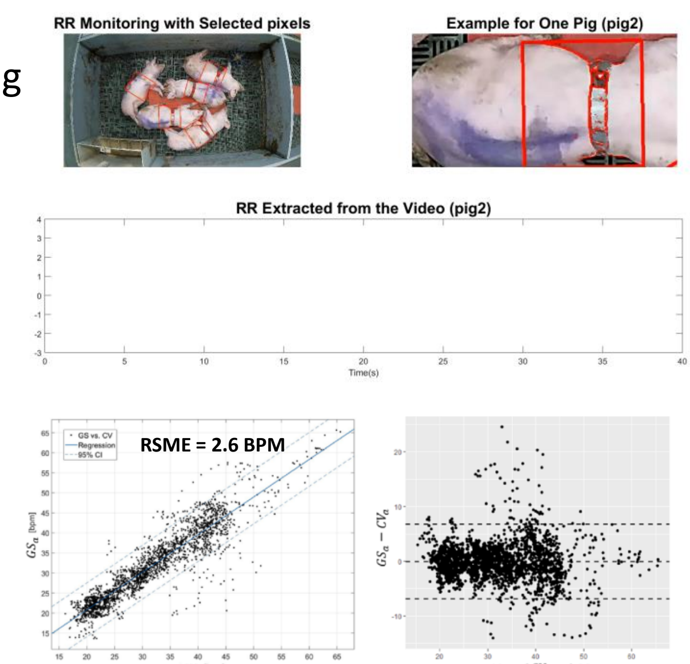
Monitoring health and production status with cameras

Respiration rate monitoring



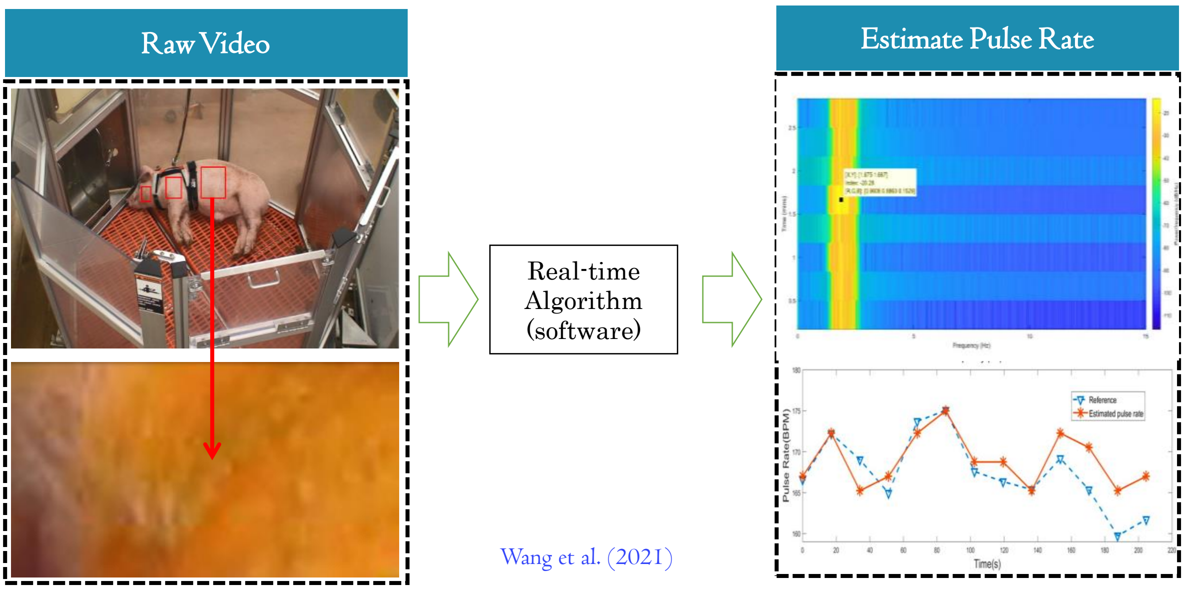
Detection

Select pixels in ROI



Wang et al. (2023)

Heart rate monitoring

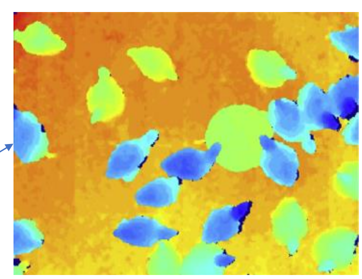


Wang et al. (2021)

Growth monitoring: poultry

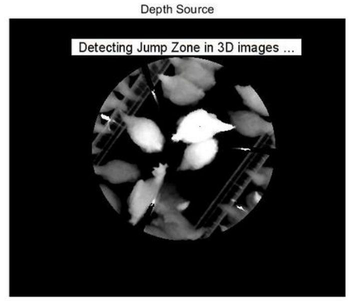
- Combination of CV with existing solutions
- Separate weighing hens and rosters in broiler breeder farm

Segmentation +
body mass estimation



Mortensen A K (2016)

Depth Source



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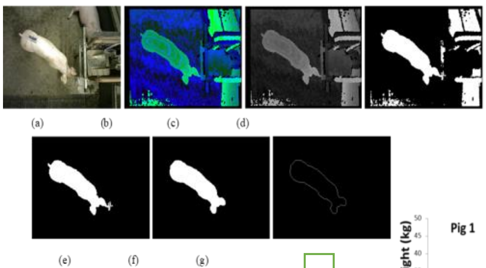
4490

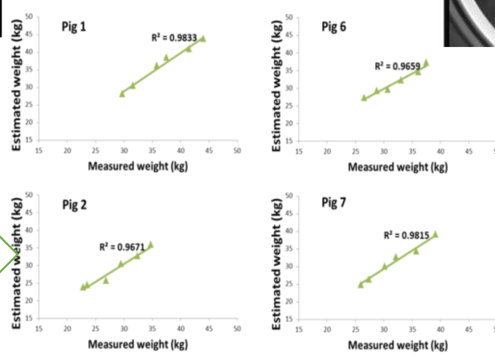
Combining CV with existing weighing system

Liu et al (2020)

Growth monitoring: pigs

Weight: contactless video-based weight estimation





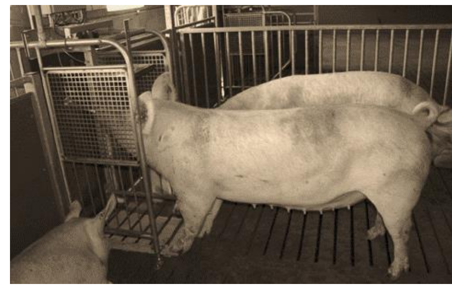
Kashisha et al. (2015)
Lu et al. (2019)

Integrated technologies for growth control

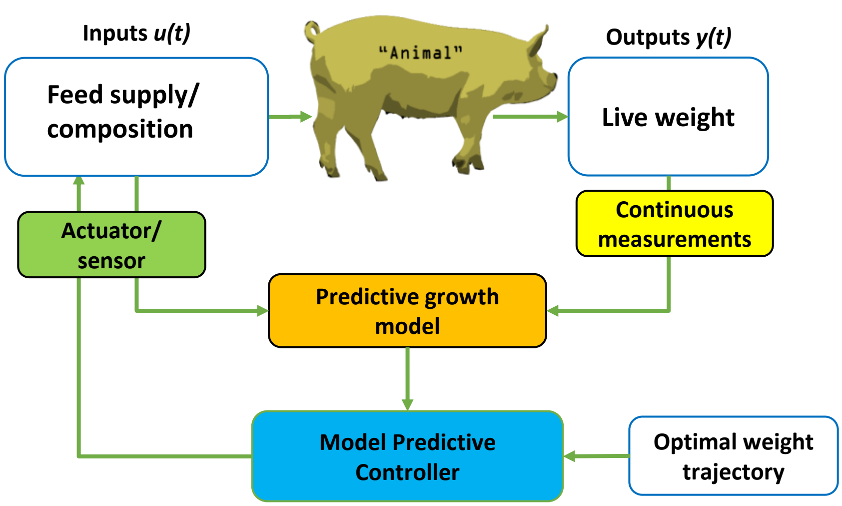
Software sensors: in precision feeding (control)

What?

- For each pig, **calculate and deliver** the economically optimal feed composition and feed supply:
  - Feed composition: is controlled by adjusting the ratio of number of feed components (A, B, …, N feeds).
  - Total feed supply: is the sum of feed supplies of individual components (A + B+ …+ N).

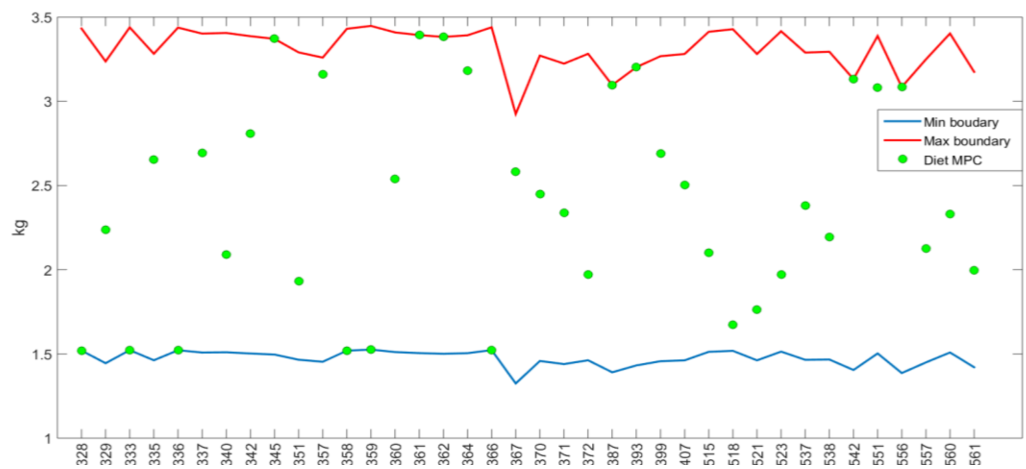


Software sensors: precision feeding (control)

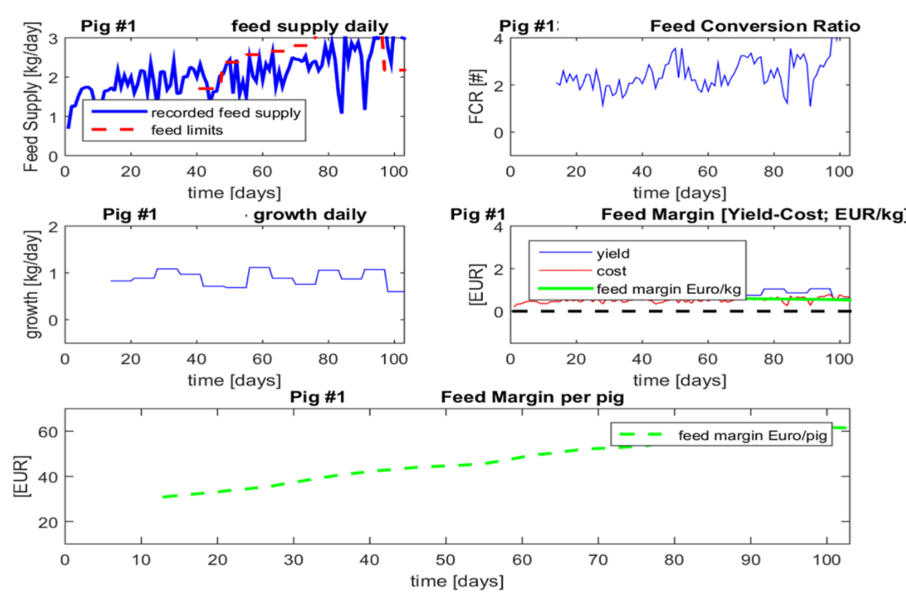


Software sensors: precision feeding (control)

Model Predictive Control – Suggestions



Software sensors: precision feeding (control)



Youssef et al.
(in prep)

Supporting the community!

FACT-CIN: A COORDINATED INNOVATION NETWORK FOR ADVANCING COMPUTER VISION IN PRECISION LIVESTOCK FARMING

PI: Juan Steibel

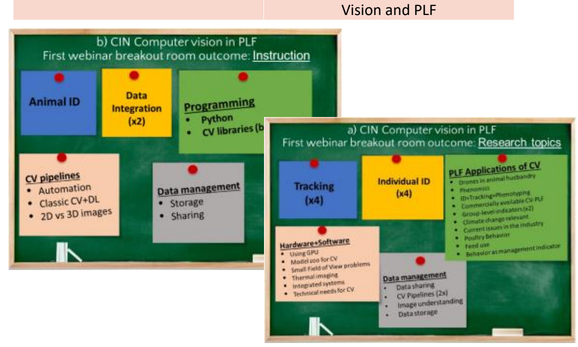
Objective 1. Generate reference datasets and benchmarking data for facilitating the development of computer vision applications that address key challenges in precision livestock farming		
a) Generate reference datasets for testing animal identification algorithms	b) Generate and distribute reference data for quantifying behavior using CV, in particular:	c) Provide a set of baseline performance results from applying existing analysis algorithms to the data generated in 1a and 1b

Public datasets for behavior recognition

Dataset	Species	Behavior types	Analysis unit	# Annotated
Newcastle Pig Posture	Pig	Standing, Lateral lying, Sternal lying, Sitting, Drinking	Single image	113,079 images
Edinburgh Pig Behavior	Pig	Eating, Drinking, Lying, Standing, Moving	Single image + image sequence	7,200 images from 12 videos
Pig Position and Posture	Pig	Lying, Not lying	Single image	305 images
Pig Novelty Preference	Pig	Investigating, Exploring	Image sequence	20 videos
PigTrace	Pig	Sitting, Standing	Single image	540 images from 29 videos
Cow Behavior	Cattle	Frontal, Lateral, and Vertical interaction; Crowding; Drinking; Exploring; Queuing; Normal	Single image	1,526,473 images from 253 videos

Han et al., in prep

Objective 2: Build a coordinated innovation network of stakeholders, researchers, and students to develop computer vision applications in precision livestock farming	
a) Organize a "Computer Vision-for-PLF challenge series"	b) Host a webinar series on translational topics in Computer Vision and PLF



Conclusions

- Animal production faces major challenges that Precision Agriculture can help to solve!
- New technology should have multiple functions to enable wider application opportunities: from behaviour through health to production monitoring and control
- Great opportunity for precision livestock farming to integrate different technologies for the future of sustainable animal production