Continuous and non-invasive monitoring of animals using sensors and computer vision analysis

Wageningen University & Research – Animal Science Group

Noldus Information Technology

WAGENINGEN UNIVERSITY & RESEARCH

NOLDUS INFORMATION TECHNOLOGY

DAIRY CAMPUS
Inspire to create

Outline

Current situation and future perspective

General description of the project

Data architecture at Dairy Campus

- Installation of hardware and software
- Data quality control

Tools to retrieve relevant information form raw sensor data

- Locomotion parameters of individual animals
- Continuous monitoring of behaviour in groups of animals
- Automated behaviour in the barn
- Transmission of Digital Dermatitis

Output

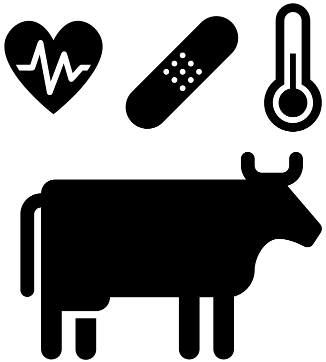
Current situation and future perspective

Animal health and welfare are one of the pillars for sustainable farming.

Animal health and welfare is often monitored through (deviant) behaviour

By farmers/experts/sensors:
No continuous information
Often more severe cases
Time consuming
Subjective
Indirect

Today



By camera/tracking
Continuous
Scalable
Objective
Non-invasive

Future

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General description of the project

Vision:

Non-invasive long-term continuous monitoring of health & welfare

Partners:

WUR-ASG and Noldus Information technology with financial support from the Dairy Campus Innovation Fund funded by SNN

Duration of the project:

June 1, 2021 – September 30, 2023

Location of research:

Dairy Campus and Wageningen, the Netherlands

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General description of the project

Focus of project:

Behaviour related to **Locomotion** and transmission of **Digital Dermatitis** using tracking data and computer vision

Research focus is 2-fold:

1. Develop **data architecture** at Dairy Campus (DC) for long-term continuous raw data collection and synchronisation with data quality control throughout the process

2. Develop **tools** to retrieve relevant information for (behaviour related to) locomotion and Digital Dermatitis from these raw sensor data

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Data architecture at Dairy Campus

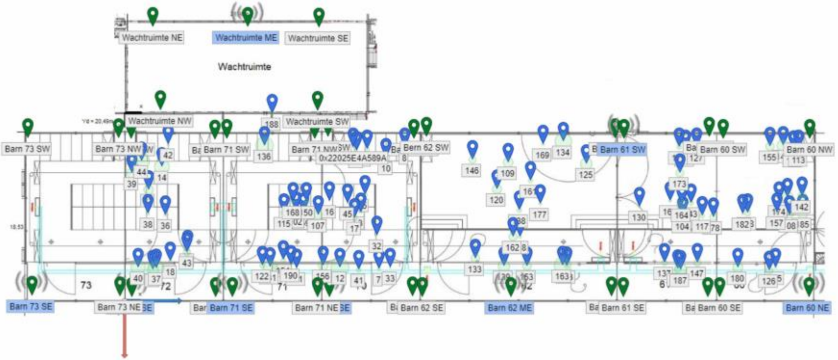
Objective

Develop architecture at Dairy Campus that allows long-term continuous collection and synchronisation of raw sensor data collected at different locations within DC. Ensure data quality is controlled throughout the process

What is achieved

Installation of hardware and software at different locations within DC

Pipelines for data quality control



Outline

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General description of the project

Data architecture at Dairy Campus

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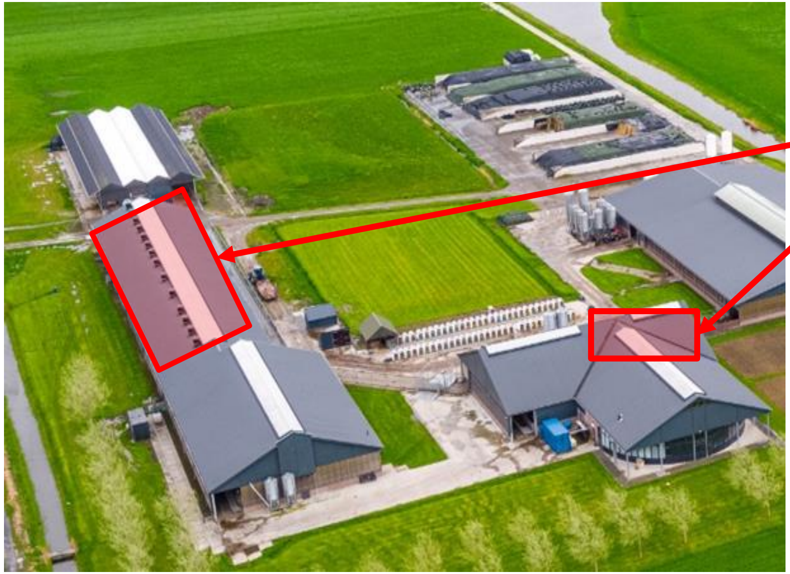
Output

Installation of hardware and software



UWB Tracking sensors

(TrackLab, Noldus Information Technology)

7 research units, 110 cows, 24/7 XY en accelerometer data

Waiting area, 110 cows, 2x/day XY en accelerometer data

Network extension for IP cameras and beacons

Installation of hardware and software

Cameras at three locations

8 camera's in 1 research unit, 16 cows, 24/7, birdview

(Viso systeem, Noldus Information Technology)

2 camera's in 'exit lane', 110 cows, sideview, 2x/day

2 camera's in milking parlour, >400 cows, hind view, 2x/day

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- *Data quality control*

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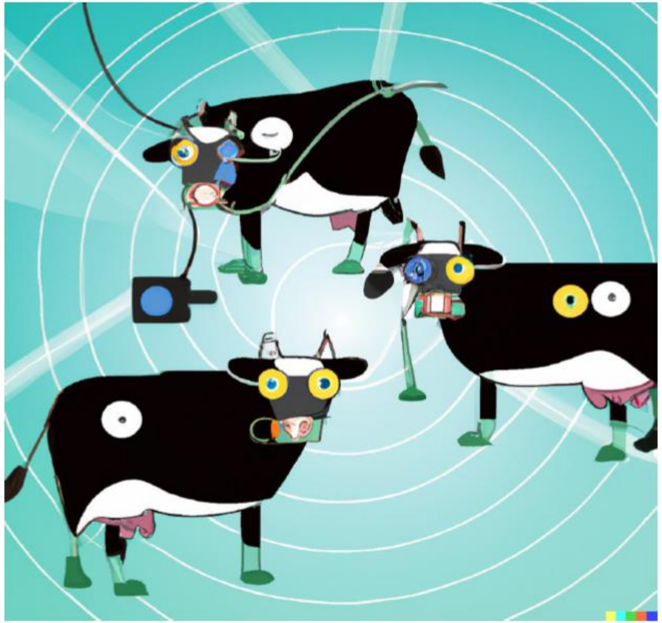
Output

Data quality control

Control of data quality is extremely important. Tools are developed to control quality at different locations and at different levels



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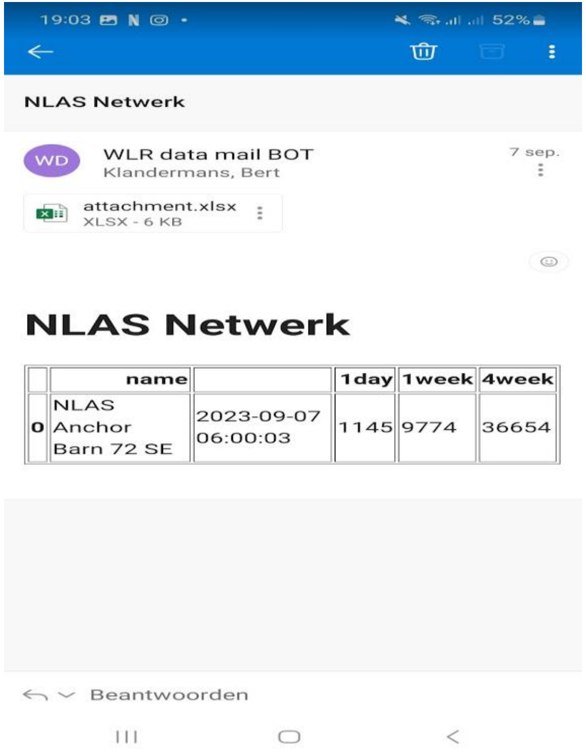

At network level

Continuous check (every minute a day) of the functioning of hardware

If not functioning: an email is generated and sent to the data engineer at Dairy Campus

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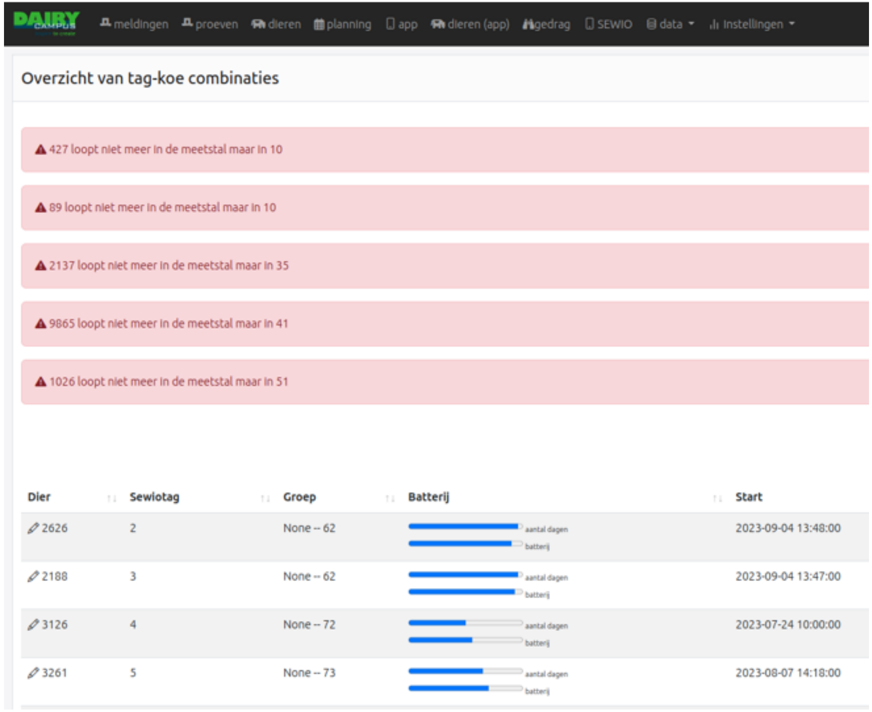
Data quality control

Control of data quality is extremely important. Tools are developed to control quality at different locations and at different levels

At tag level

digital tool to record which tag
fitted on which cow
are cows in the right research unit
battery status of tags



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Data quality control

Control of data quality is extremely important. Tools are developed to control quality at different locations and at different levels

At raw data level

pipelines developed to collect and store raw data, e.g. for tracking data

Pipeline in words: 1 export raw data from Sewio data base to WLR data base; 2 export datasets of one hour from WLR data base to secured location WLR; 3 aggregate data to 1 XY position per second, add cow identification; 4 create datasets of 24h; 5 Implement filters to clean data, impute missing values and classify position of cow in barn based on XY position. Based on position in barn define behaviour; 6 add average behaviour per minute per cow to Dairy Campus database

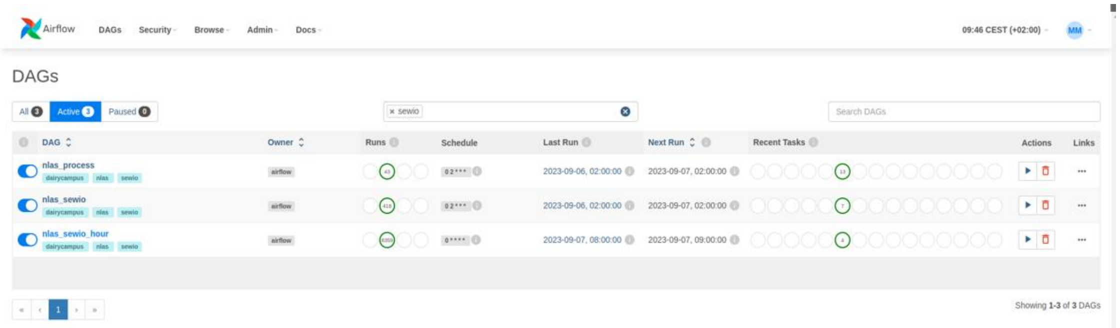
Data quality control

Control of data quality is extremely important. Tools are developed to control quality at different locations and at different levels

At raw data level

pipelines developed to collect and store raw data

steps within pipelines are monitored to check functioning of these pipelines



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Data quality control

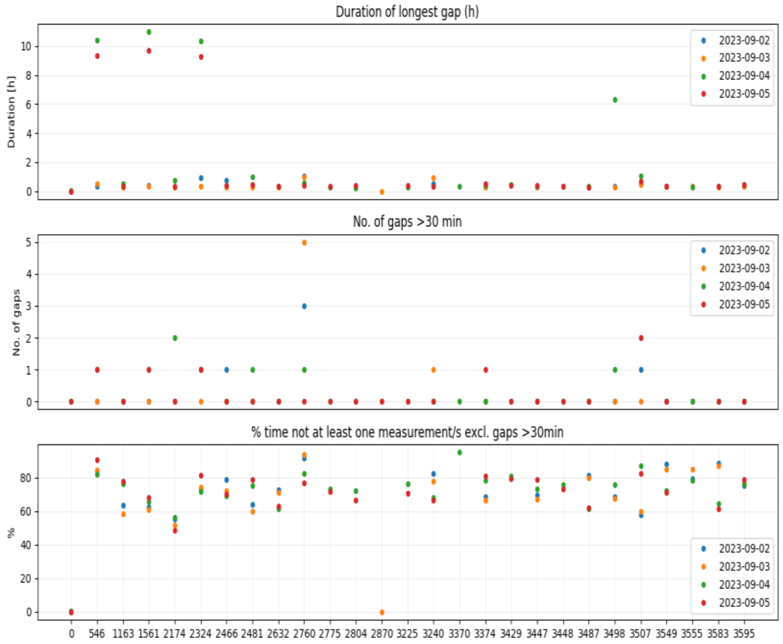
Control of data quality is extremely important. Tools are developed to control quality at different locations and at different levels

At processing of raw data

identify data gaps

impute gaps if possible

check tag position at cow



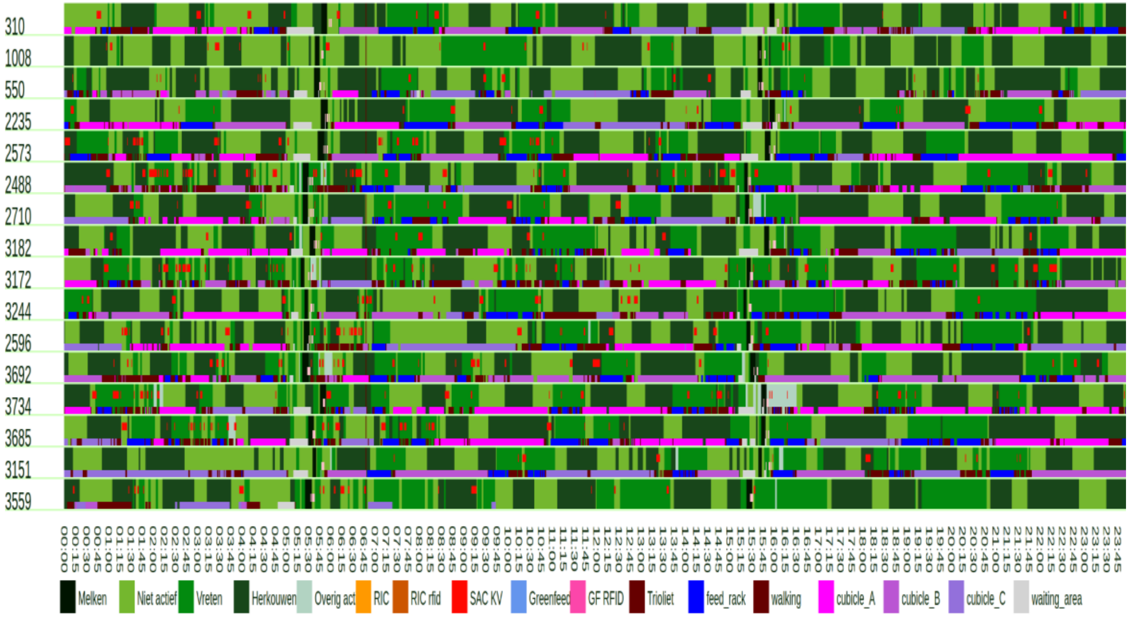
Data quality control

Control of data quality is extremely important. Tools are developed to control quality at different locations and at different levels

After processing of raw data

daily basis

From 7am onwards no data on feeding or cubicles from tag



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Output

Locomotion parameters of individual animals

Objective:

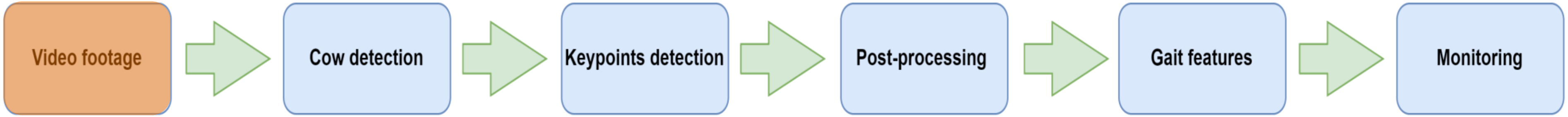
Develop tools that allows monitoring of locomotion of **individual animals** through **computer vision**

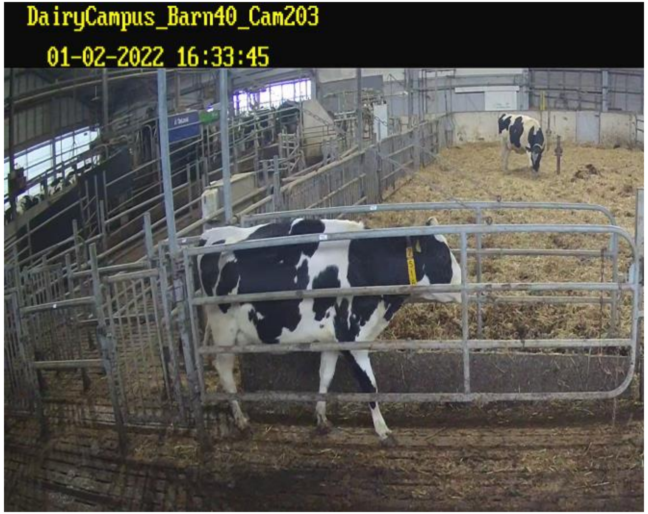
What is achieved:

From raw video footage via automatically detected anatomical key points to features related to locomotion that we can monitor over time

Locomotion parameters of individual animals

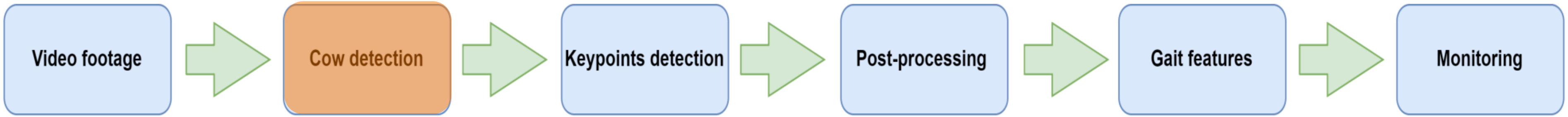
Pipeline:





Collecting and storing video footage, in 1-hour batches
2*3 hours/day

Locomotion parameters of individual animals



Video example

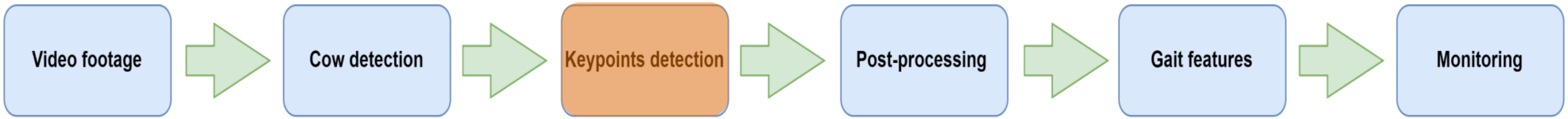
Train and validate on 200 frames with:

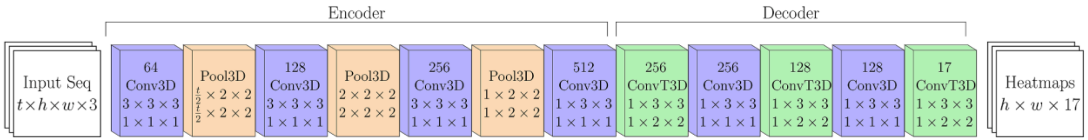
- *Yolo7 object detection*

Results: mean average precision (MAP): 0.95

Code available: https://git.wur.nl/dwz_ai/yolo_v8/-/commit/c74517b369bc466a3a75d77a48b91a305aeb1dbc

Locomotion parameters of individual animals





Using ***T-leap** model:

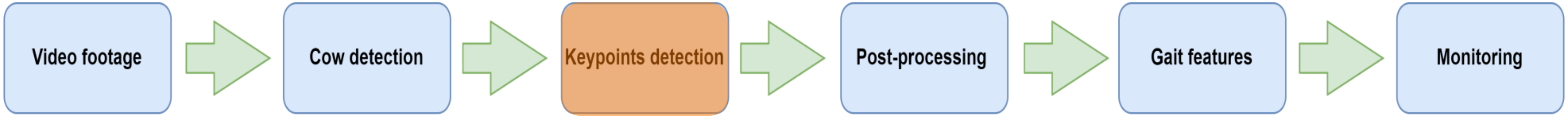
- Used the temporal information to detect the key-points
- Validated on occluded data

Code: https://github.com/hrussel/t-leap

Russello et al. 2022
T-leap model outside

T-leap model
retrained for inside

Locomotion parameters of individual animals



Frames annotated with free and open-source annotation tool CVAT

17 key points per cow per frame

1 left front (LF) hoof, 2 LF fetlock, 3 LF carpal,

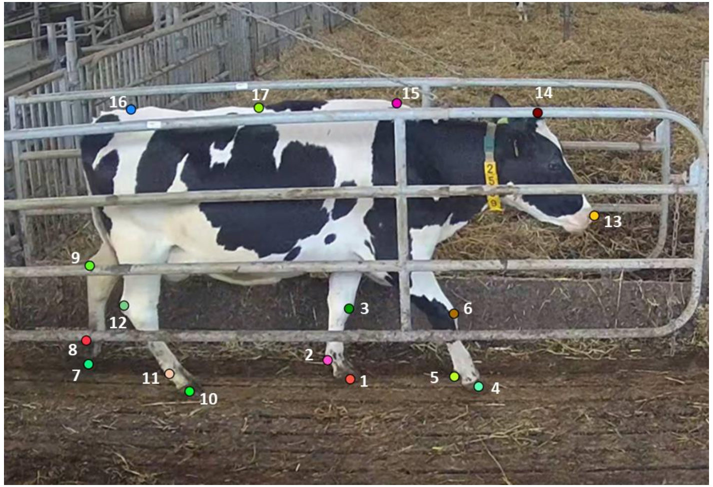
4 Right front (RF) hoof, 5 RF fetlock, 6 RF carpal,

7 Left hind (LH) hoof, 8 LH fetlock, 9 LH carpal,

10 Right hind (RH) hoof, 11 RH fetlock, 12 RH carpal,

13 nose, 14 forehead,

15 withers, 16 sacrum, and 1) caudal thoracic vertebrae.



Dataset:

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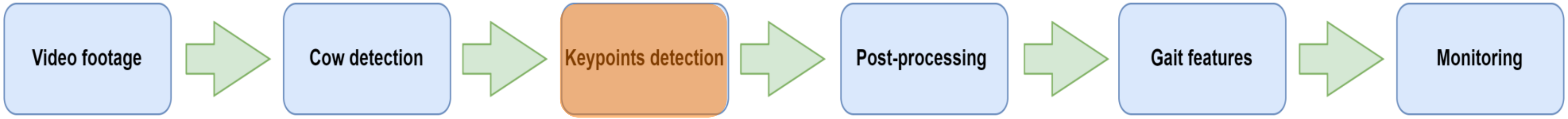
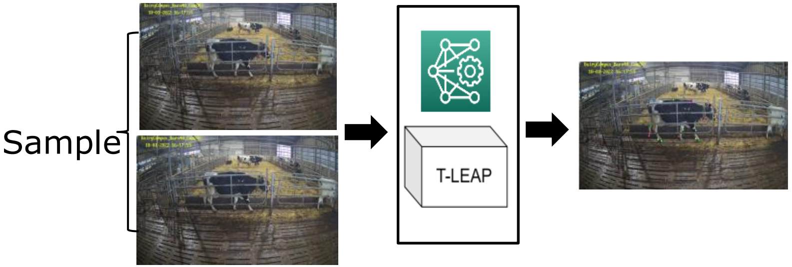
Locomotion parameters of individual animals



Train T-leap

Dataset:

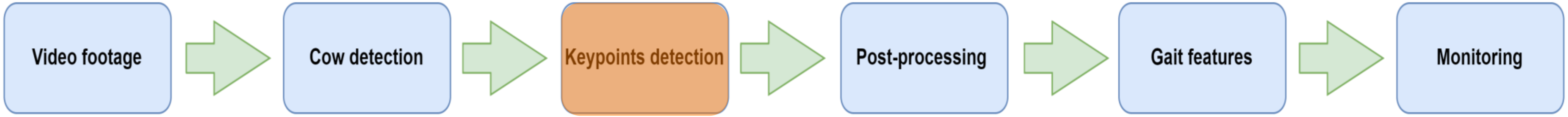
Dataset	Train	Validation	Test	Total
#Cows #Samples	22 388	7 108	15 262	44 758



Code:

https://git.wur.nl/ddht_ai/gait_analysis/keypoint_detection/-/tree/main/frame_selection?ref_type=heads

Locomotion parameters of individual animals



Quantify T-leap model performance – specific key points

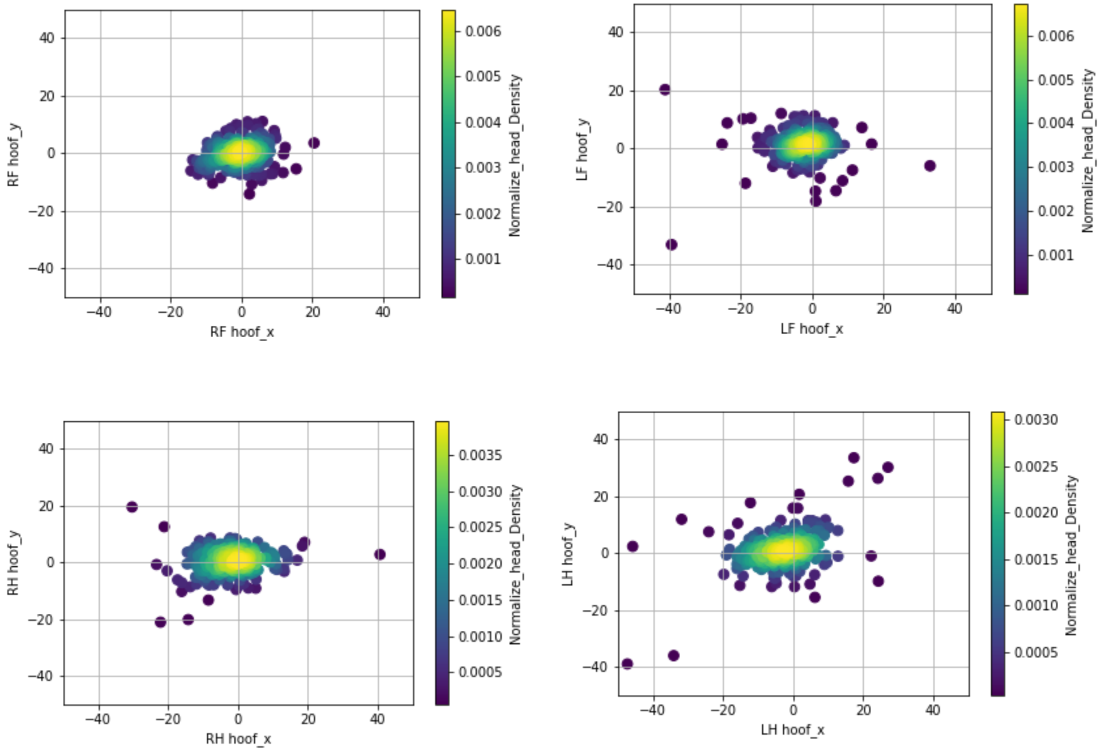
Body parts	Legs	Back	Head
PCkh@0.2	0.96	0.59	0.98
Error-x axis	5.59(±10.63)	28.34(±60.11)	4.52(±6.37)
Error-y axis	4.82(±4.79)	5.87(±6.55)	4.53(±4.66)
Error-x-y axis	8.39(±14.33)	29.85(±60.02)	7.22(+-7.15)

$$PCKh@\theta = 1/N \sum_{k=1}^{k=N} \delta(\|P_k - T_k\| - head\_size_k * \theta) \quad \text{(eq.1)}$$

$$\frac{1}{N}\sum_{K=1}^{k=N}\sqrt{\left(\frac{(\acute{x}_k - x_k)}{head\_size_k}\right)^2 + \left(\frac{(\acute{y}_k - y_k)}{head\_size_k}\right)^2} \quad \text{(eq.2)}$$

Locomotion parameters of individual animals

Error visualisation



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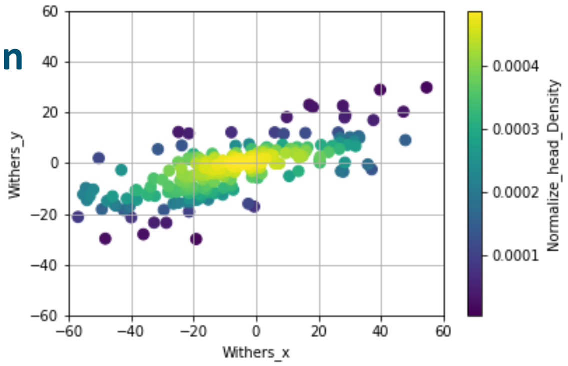
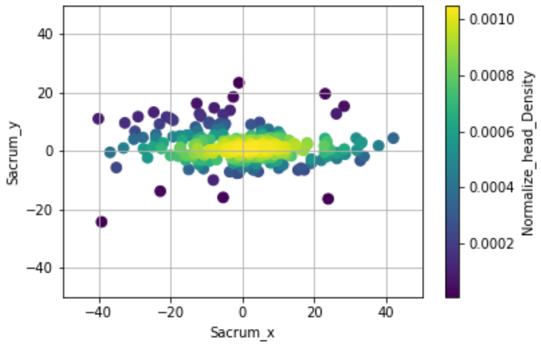
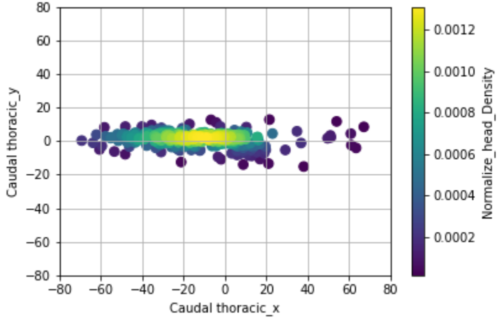
Locomotion parameters of individual animals

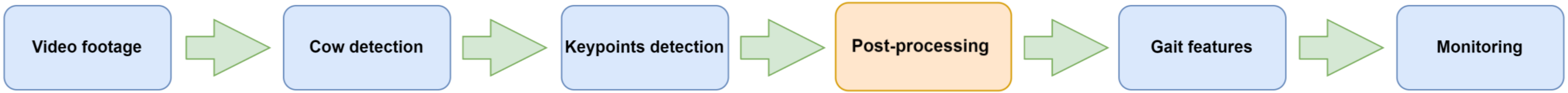
Error visualisation

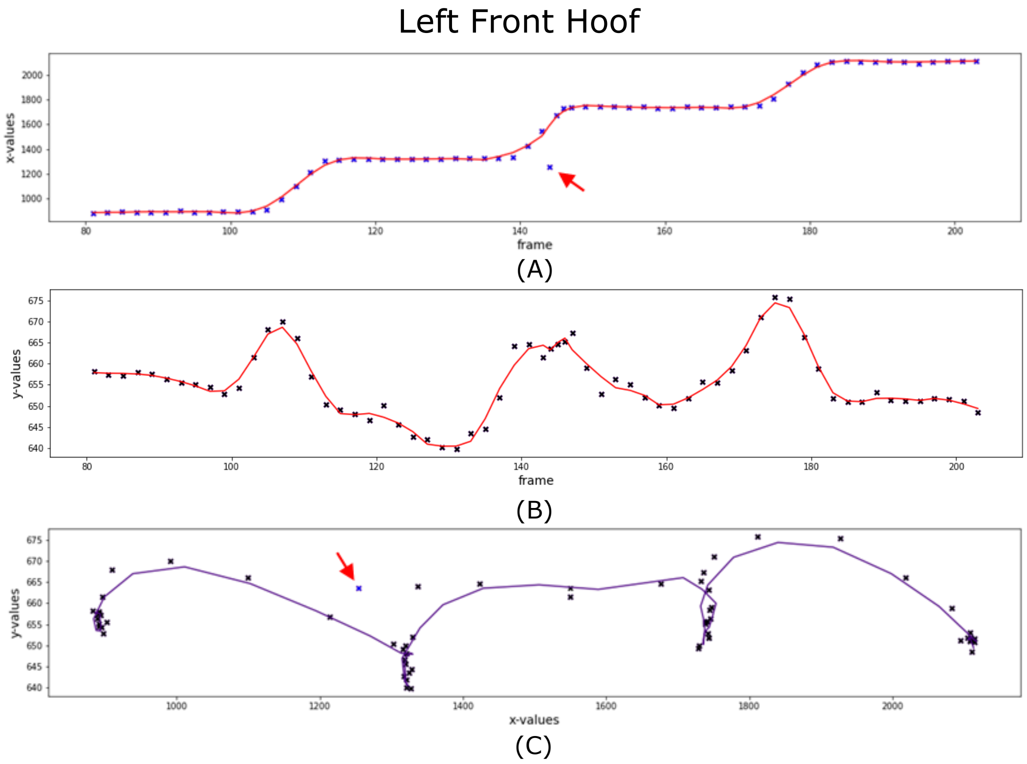






Locomotion parameters of individual animals





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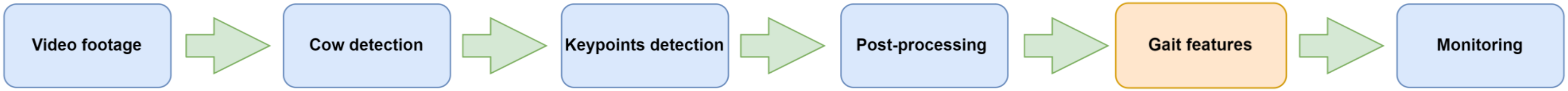
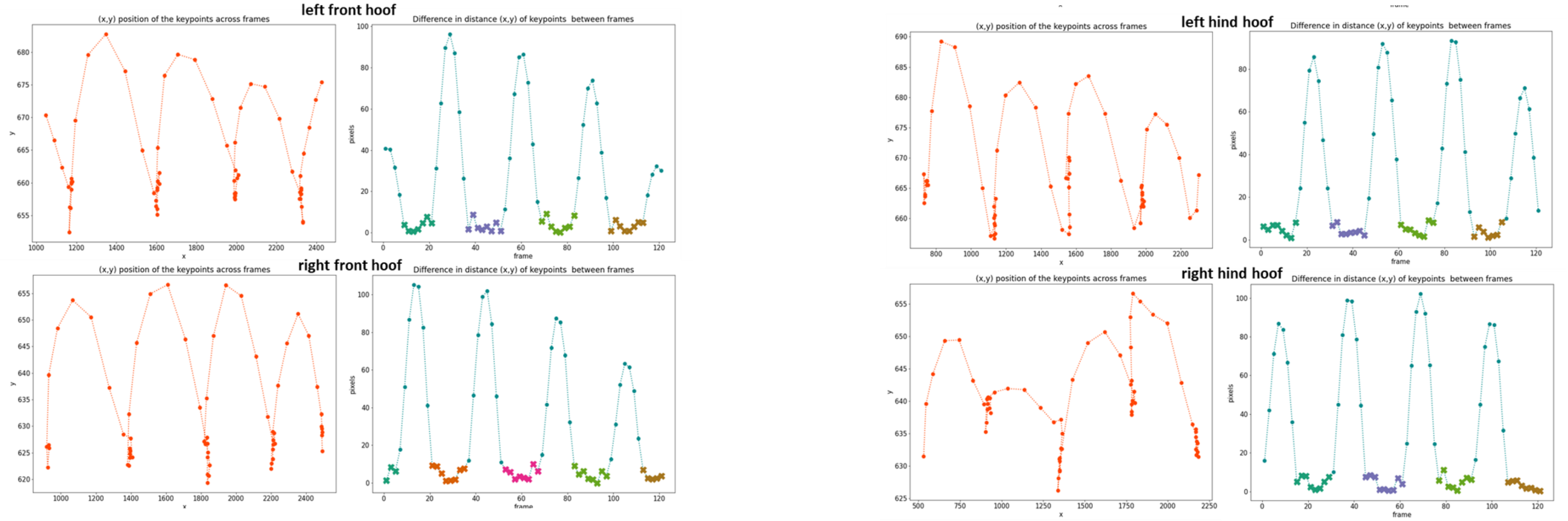
Locomotion parameters of individual animals





Code:
https://git.wur.nl/ddht_ai/gait_analysis/gait_features

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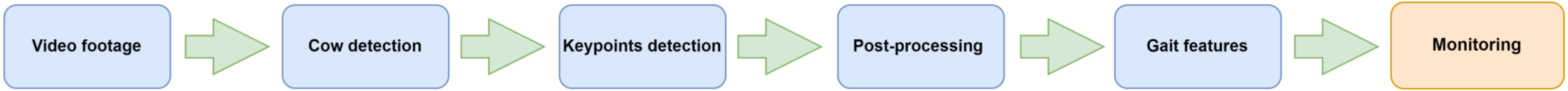
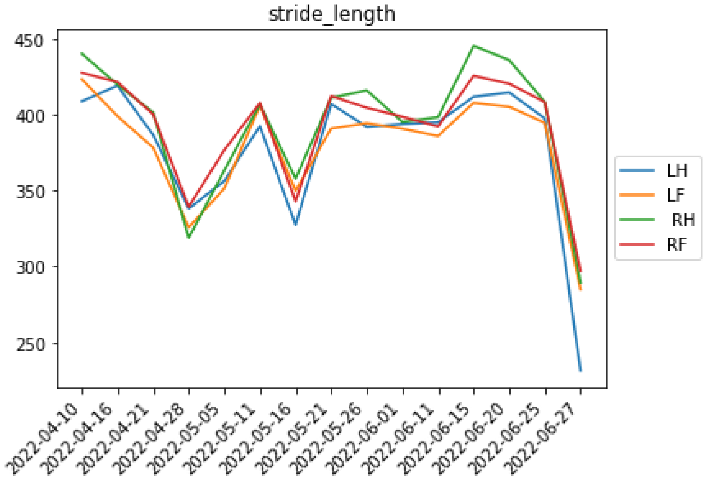
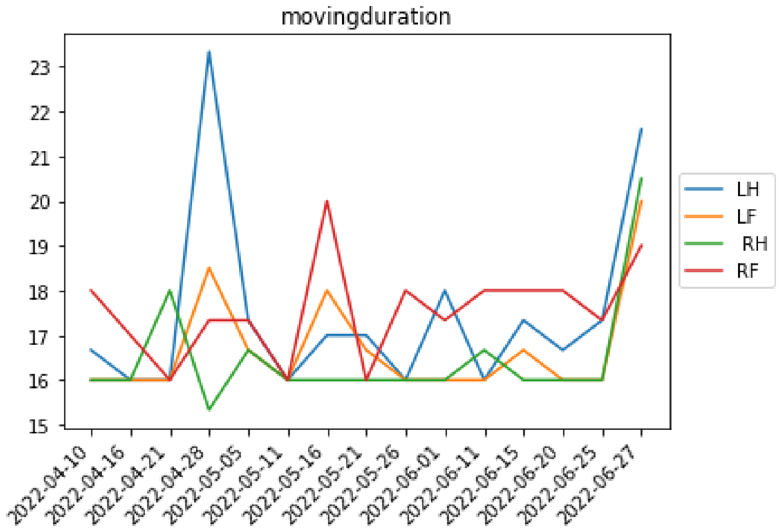
Locomotion parameters of individual animals



- Gait features from stationarity of hoofs within 15 weeks



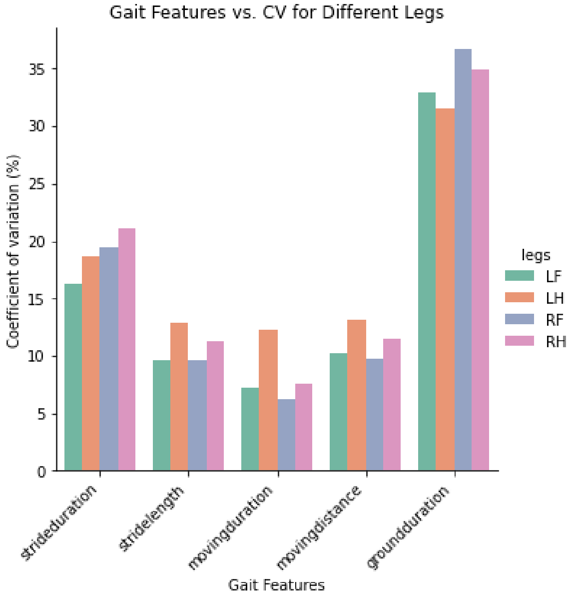


Locomotion parameters of individual animals

Repeatibility of gait features:

Coefficient of variation (CV)

$$CV\ (\%) = \left(\frac{Standard\ deviation}{Mean}\right) \times 100$$



Dataset:

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Locomotion parameters of individual animals

Lessons learned:

Inaccuracies in cow identification were assigned to the substantial physical distance between the point where cow identification is read by the selection gates and the point where the cow is passing the camera view.
Cow identification is not solved yet.

To monitor the locomotion of cows, continuous video footage of a cow walking past the camera without interruption is required

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Output

Monitoring behaviour of groups of animals

Objective:
Develop tools that allows continuous monitoring of behaviour of **groups of animals** through **computer vision** and **tracking sensors**

What is achieved:
Calibration of the camera setup and realignment of the cameras

Tools to obtain 3D positions of key points and identify individual cows in a group from raw video footage

Tools converting raw position data into behaviours

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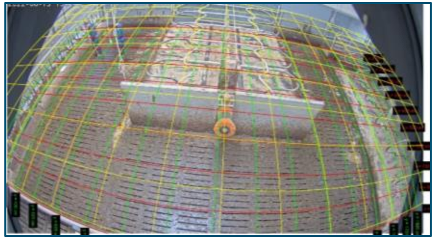
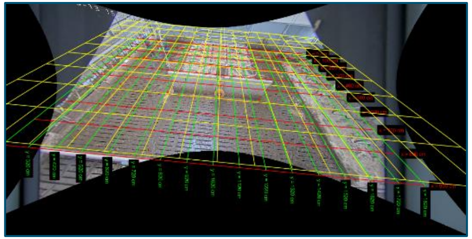
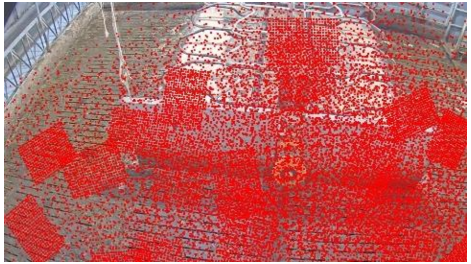
Monitoring behaviour of groups of animals

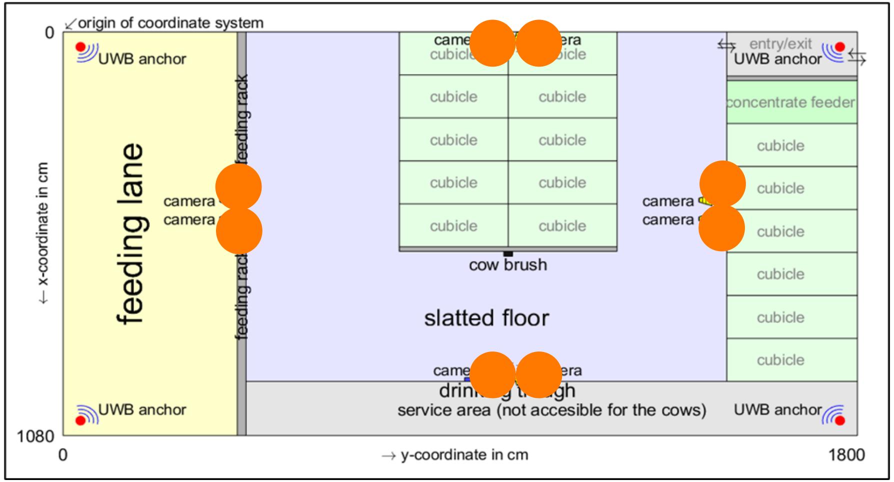
Through video footage

Calibration and synchronisation of a multi-camera system (individual and stereo)









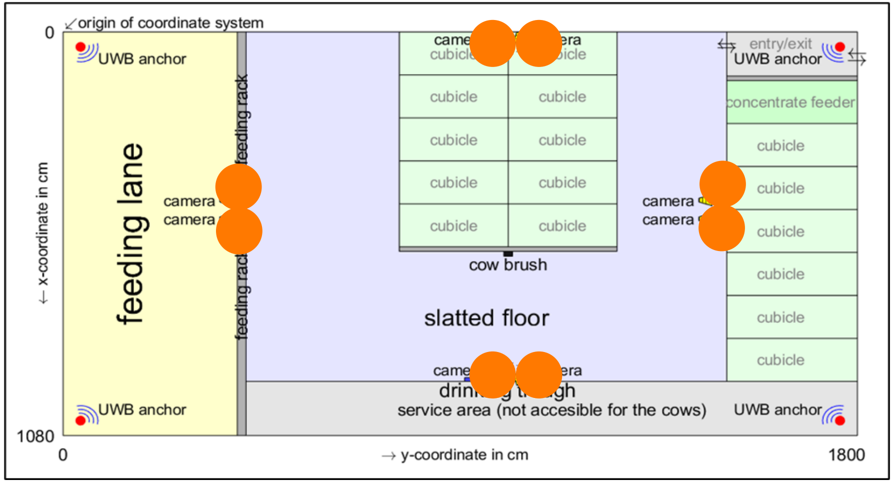
8 cameras (Viso, Noldus) in 1 of the research units (16 cows).

Monitoring behaviour of groups of animals

Through video footage

Calibration and synchronisation of a multi-camera system (individual and stereo)

Relate pixels to 3D positions (in 'real-world' coordinates) of each camera -> triangulation ->3D positions of keypoints

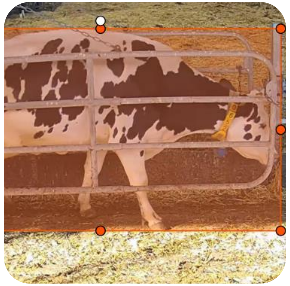


8 cameras (Viso, Noldus) in 1 of the research units (16 cows).

Monitoring behaviour of groups of animals

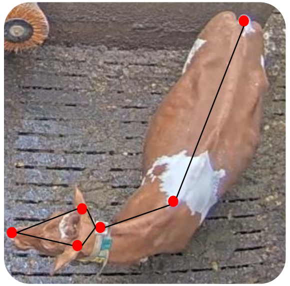
After calibration of the multi-camera system and relating pixels to real-world coordinates the following work flow to get to behaviour monitoring

Per camera step 1 and 2, and at step 3 multiple camera views are combined and integrated into 3D key points that are tracked over time. Step 4 is future work.



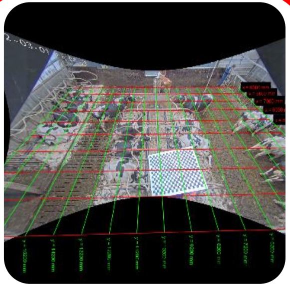
Stap 1

Object detection and tracker



Stap 2

Keypoint detection and tracker



Stap 3

Integration of multiple views to 3D tracker

Stap 4

Behaviour recognition (patterns)

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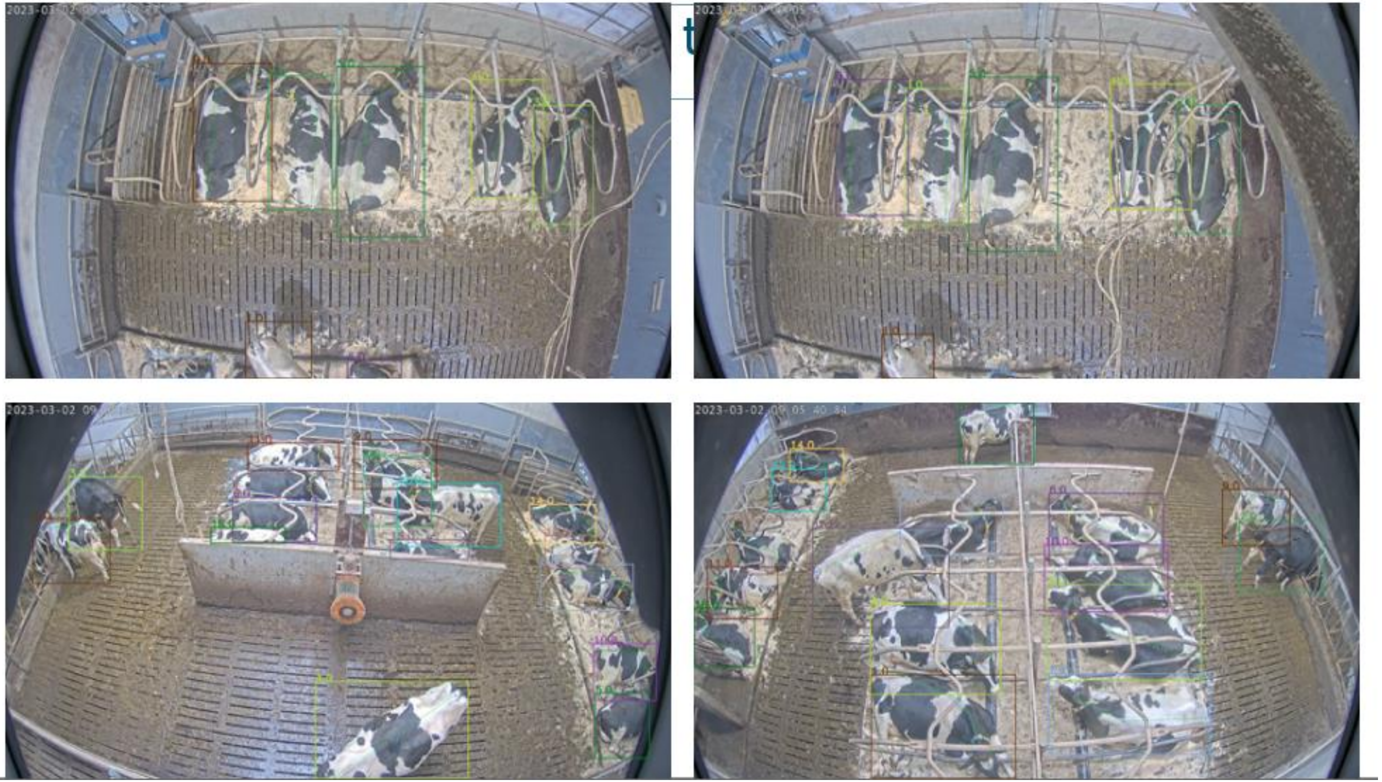
Monitoring behaviour of groups of animals



Input: synchronised video footage

Approach: for each camera
- cow detection (bounding boxes)
- keypoint detection

Integration: pixels to 3D coordinates

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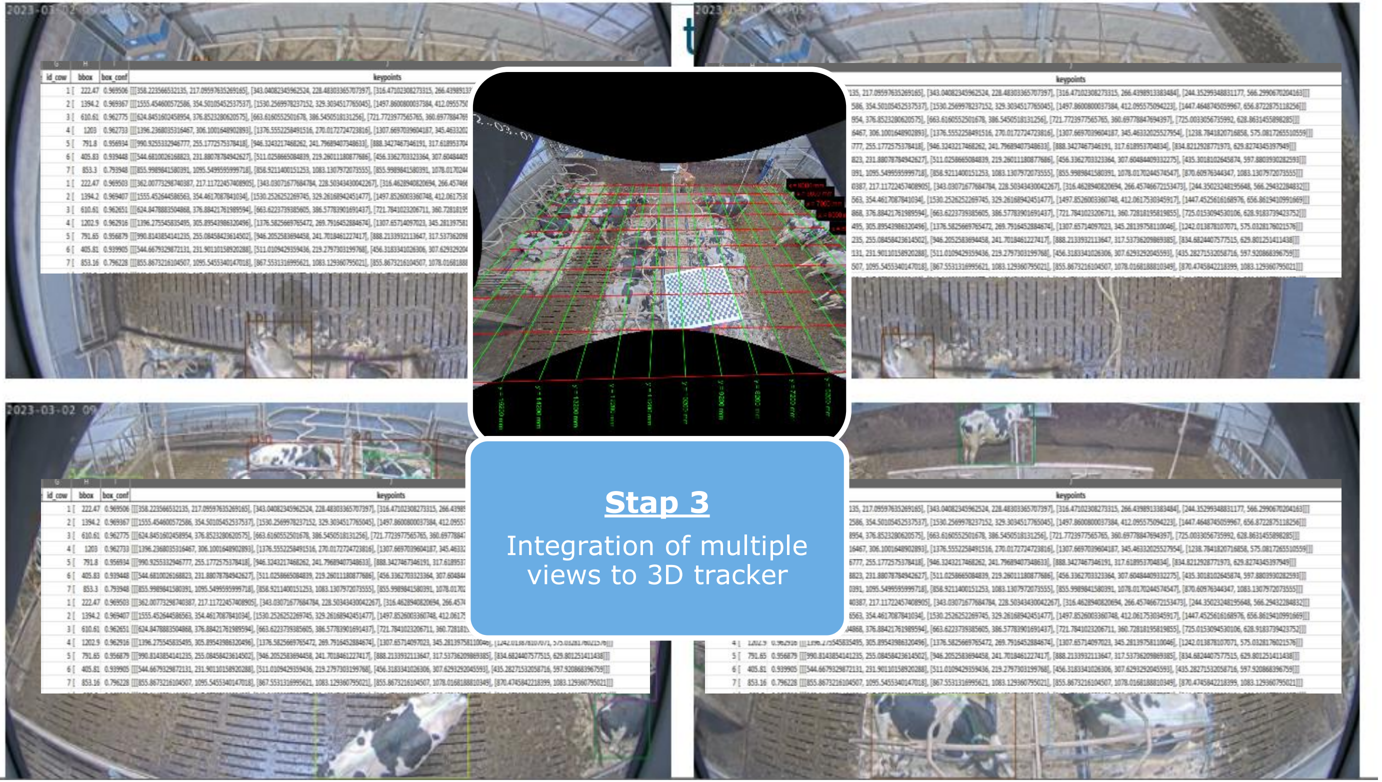
Monitoring behaviour of groups of animals



Output: numerical data for each timestamp (both per camera and combined)

Cow identification = work in progress

Monitoring behaviour of groups of animals

Through tracking

Raw postion data from hardware Sewio

7 research units and waiting area
110 cows (of which 32 with 10Hz/sec)

Pre-process raw XY data to 1 XY-position / cow ID / second

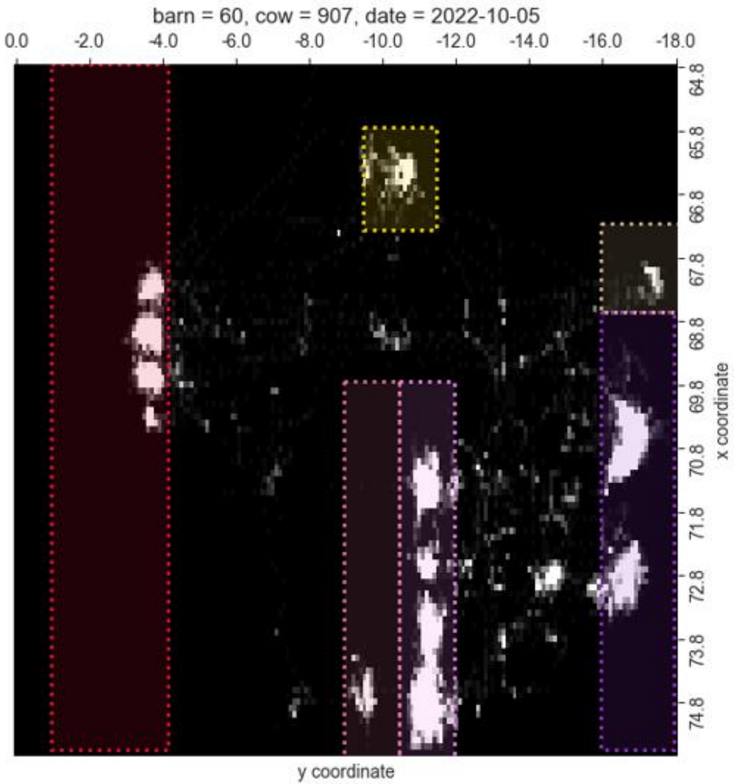
Median smoothed, rolling window filter

Minimum distance travelled filter, data

imputations, filter area edges,

add cow identification

Link XY-position with ‘real-world’ coordinates of resarch unit and waiting area

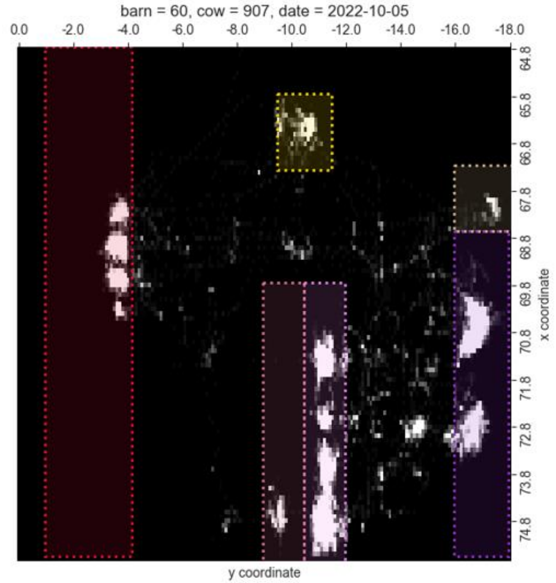


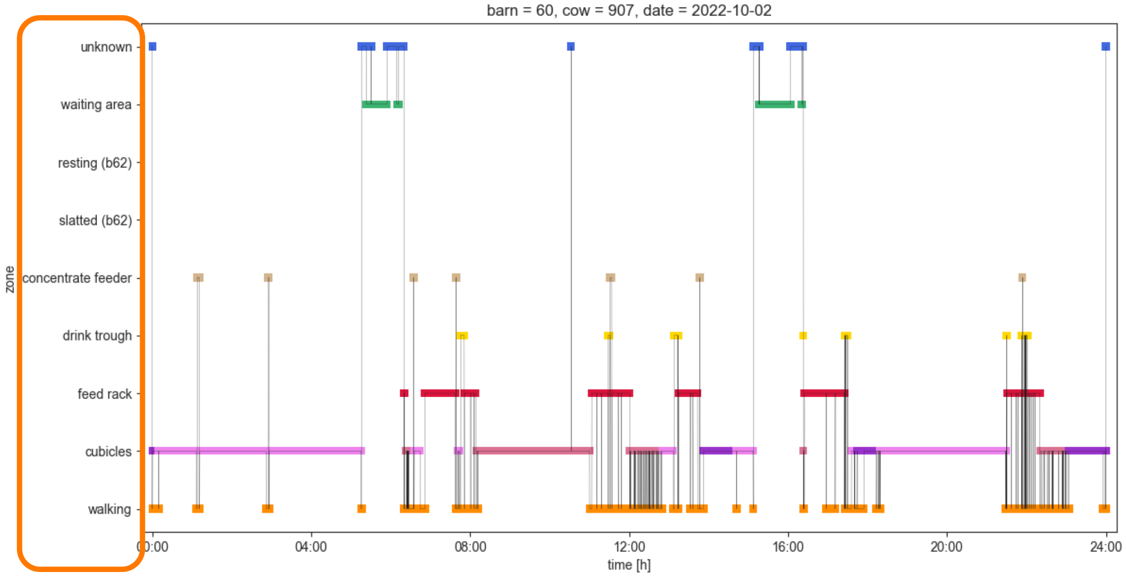
Heat map of XY positions of one cow during one day

Monitoring behaviour of groups of animals

Through tracking

XY-positions over the day are assigned to a location in the barn. Location can be used to assign behaviour per cow per day





Monitoring behaviour of groups of animals

Lessons learned:

Pre-installation preparation can be improved considerably

Camera calibration & multiple camera setup have advantages for processing

Annotation of video footage can best be done iteratively

Long term collection of sensordata with high temporal resolution with standard tracking sensors is considerably more difficult than expected

Accelerometer data collected with such devices has limited useability.

Outline

Current situation and future perspective

General description of the project

Data architecture at Dairy Campus

- Installation of hardware and software
- Data quality control

Tools to retrieve relevant information form raw sensor data

- Locomotion parameters of individual animals
- Continuous monitoring of behaviour of groups of animals
- *Automated behaviour in the barn*
- Transmission of Digital Dermatitis

Output

Automated behaviour in the barn

Objective:

Noldus main objective is to provide a large scale monitoring system to continously record location and activity data which facilitates researchers to get insights in movement and behavior patterns of dairy cattle in the different barns at the Dairy Campus.

Noldus provided two behavioral monitoring systems for cattle:

- TrackLab, a tag-based location and activity tracking system using Ultra Wide Band radio technology.
- Viso, a video camera system controlling and synchronizing multiple camera streams.

Automated behaviour in the barn

Achievements
Successful deployment of TrackLab, a large tracking system for analysis of dairy cow movement and behavior at Dairy Campus

8 departments/pens divided over two barns (environmental barn and waiting area)

Up to 130 dairy cows can be tracked continuously and visualized on a map in real-time

Accuracy of tag UWB location data has been validated. Accuracy and precision is <20 cm

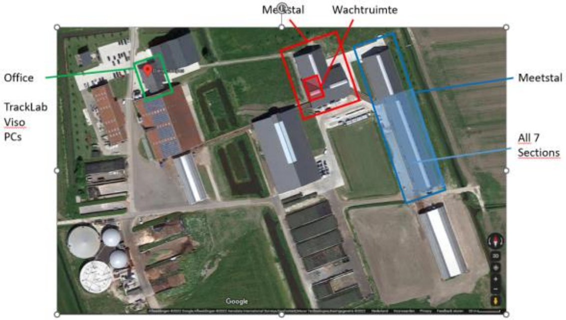
Optionally with individual accelerometer data (at sample rate ~10 Hz)

Succesfull deployment of Viso, a video and audio recording system

8 Axis IP cameras, 4 different views, in one barn (72)

Successful integration of both tools in Dairy Campus computer network

Data is directly available and streamed on WUR network



WAGENINGEN UNIVERSITY & RESEARCH

NOLDUS INFORMATION TECHNOLOGY

Automated behaviour in the barn

Achievements

TrackLab LIVE visualization of individual dairy cows

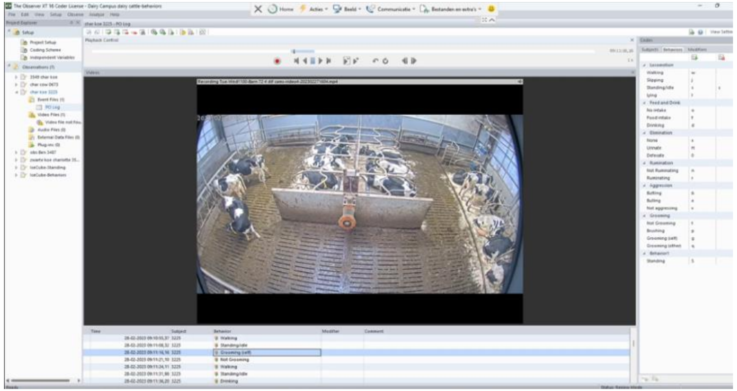
Automated behaviour in the barn

Multi model dairy cattle Data Set has been created for research purposes

- Data collected for a week from 16 dairy cows at Dairy Campus
  - Accelerometer and location data at high sample rate (20 Hz)
  - Detailed video recordings (5 different camera views including hay rack and waterbin)
- Human labeled/annotated behavior events using the video recording (partially)
- All data is imported and synchronized in The Observer XT software from Noldus

Objective to use the data set to develop (machine learning) algorithms for automatic detection and classification of cattle behavior.

Contact Noldus when interested in this data set: www.noldus.com/contact



WAGENINGEN UNIVERSITY & RESEARCH

NOLDUS INFORMATION TECHNOLOGY

Automated behaviour in the barn

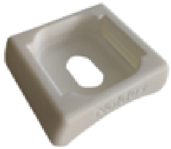
Lessons learned

Collaboration from people in the field, Dairy Campus employees, researchers from WUR and technical people from Noldus lead to optimal use and integration of the tools

Use of individual cow tags requires administration and human labor to attach and remove the tags from the cow neck collars to recharge the battery. Minimize human labor but get maximum data collected.

System hardware redesigns are made to cope with the barn environment

- New robust tag collar adapters
- New extended UWB anchor wall mounts for optimal tracking



Collected dairy cattle data is a very valuable source for research and development of (machine learning) algorithms that give insight of animal behavior and indicators for health. Ongoing and future work.

Automated behaviour in the barn

Lessons learned

TrackLab and Viso showed to be useful tools for Dairy Campus / researchers / farmers (from: BSc thesis by Rik Dekker)

- Precise location recording of cows, valuable for research and management
- Registration (history) of cows (research groups)
  - Where, which cow, what time (important for barn experiments)
- Continues monitoring enables detection of changes and alerts
- Reusable cow tags (individually rechargeable and reconfigurable)
- Analysis for research purposes
- Different built in standard analysis possibilities (activity, area or socially related)
- For user defined time periods

Outline

Current situation and future perspective

General description of the project

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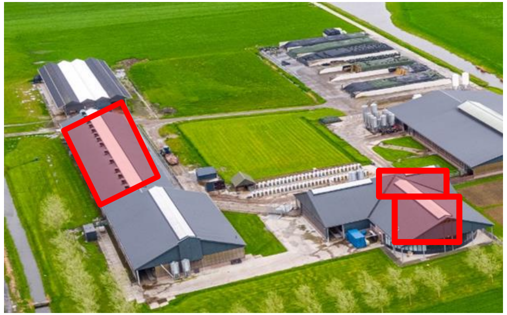
Tools to retrieve relevant information form raw sensor data

- Locomotion parameters of individual animals
- Continuous monitoring of behaviour of groups of animals
- Automated behaviour in the barn
- *Transmission of Digital Dermatitis*

Output

WAGENINGEN UNIVERSITY & RESEARCH

Detection and transmission of Digital Dermatitis



Objective:

1. Study transmission of the infectious claw disease Digital Dermatitis (DD) in dairy cattle
2. Investigate the genetic and environmental factors contributing to transmission

What is achieved:

Installation of hardware (cameras and protection box) at milking parlour within DC for normal functioning under troublesome conditions and limitations

A basic maintenance and cleaning protocol for hardware was implemented

A basic algorithm prototype for computer vision detection of DD-sick/healthy claws during milking

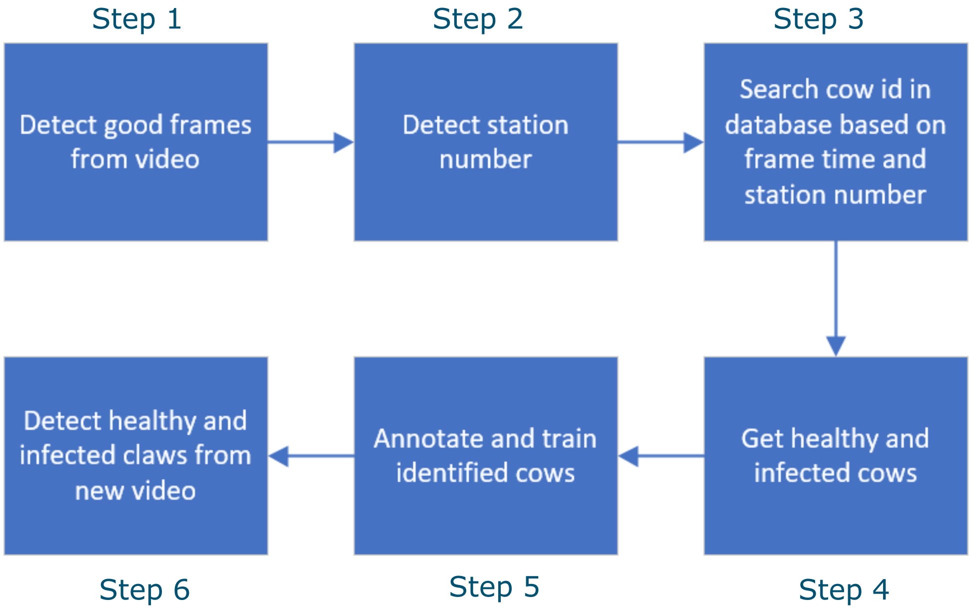
A discrete time and space agent-based model of SARS-COV-2 transmission (PeDVIS COVID) was adapted for modelling environmental transmission of DD within farm

Detection and Transmission of Digital Dermatitis

Hardware installed in the milking parlour for automated detection

Detection and Transmission of Digital Dermatitis

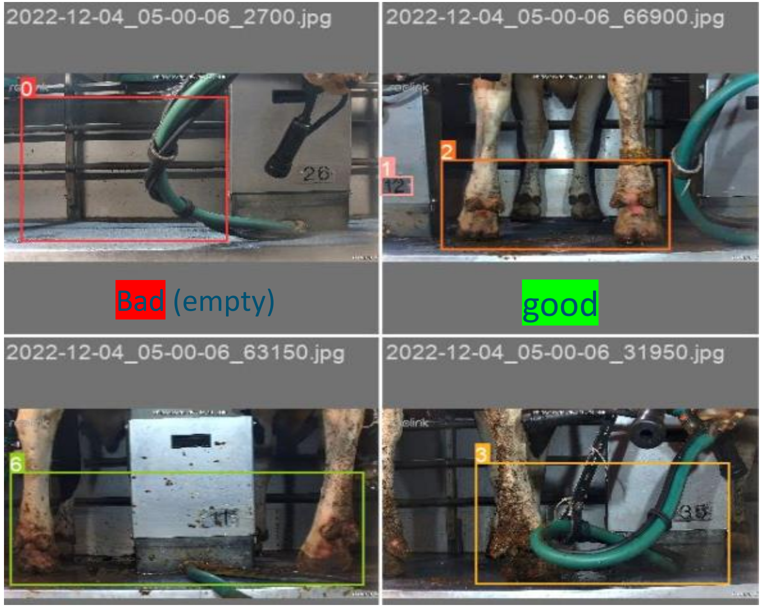
Algorithm for automated detection of DD through computer vision



Detection and Transmission of Digital Dermatitis

Results of detection algorithm

1. Detect good frame



Bad (claws of different cows) Bad (claws on wrong side)

2. Detect station number

3. Search cow Id

index	CowId	DateTime	Station
36	3295	2022-12-05 16:19:00	2
37	1586	2022-12-05 07:07:00	2
38	1133	2022-12-05 18:03:00	2
39	3314	2022-12-05 16:59:00	2
40	2725	2022-12-05 05:11:00	2
41	1427	2022-12-05 06:15:00	2
42	628	2022-12-05 17:28:00	2
43	1218	2022-12-05 15:43:00	3
44	3037	2022-12-05 06:13:00	3
45	2472	2022-12-05 07:51:00	3
46	3163	2022-12-05 16:32:00	3
47	1607	2022-12-05 18:03:00	3
48	2439	2022-12-05 17:32:00	3
49	8239	2022-12-05 07:05:00	3
50	2266	2022-12-05 07:23:00	3

Detection and Transmission of Digital Dermatitis

Results of detection algorithm

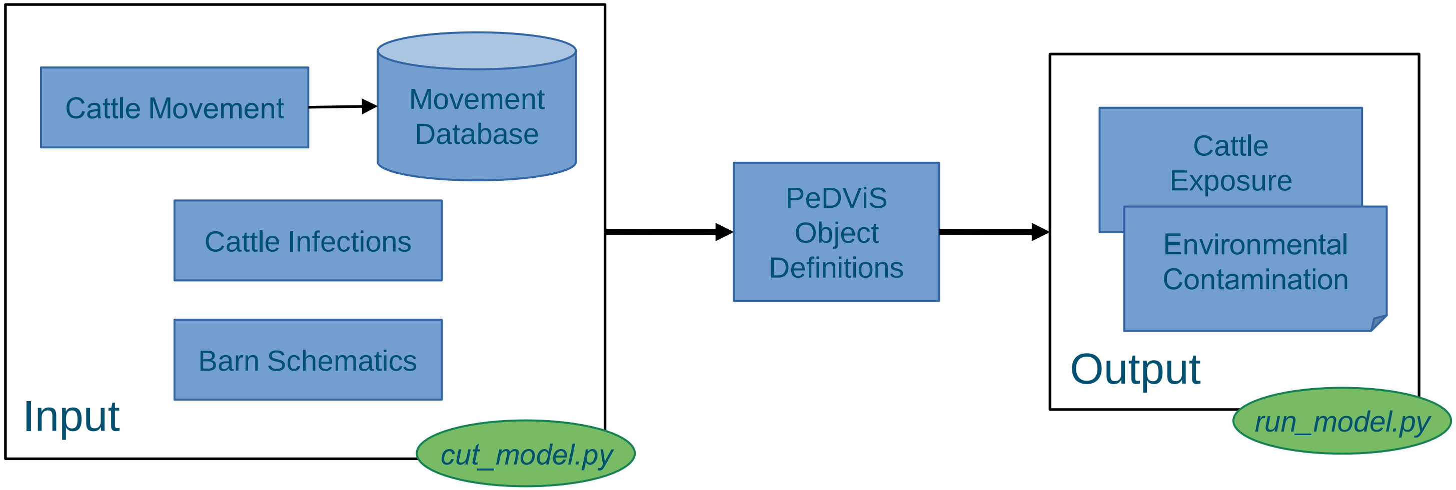
4. Detected infected claws

Left (healthy), Right(infected)

Detection and Transmission of Digital Dermatitis

Transmission model developed with cattle tracking data generated and collected during the project (n = 193 cows) and claw DD status obtained during three months of milking sessions

Model design



Detection and Transmission of Digital Dermatitis

Model design

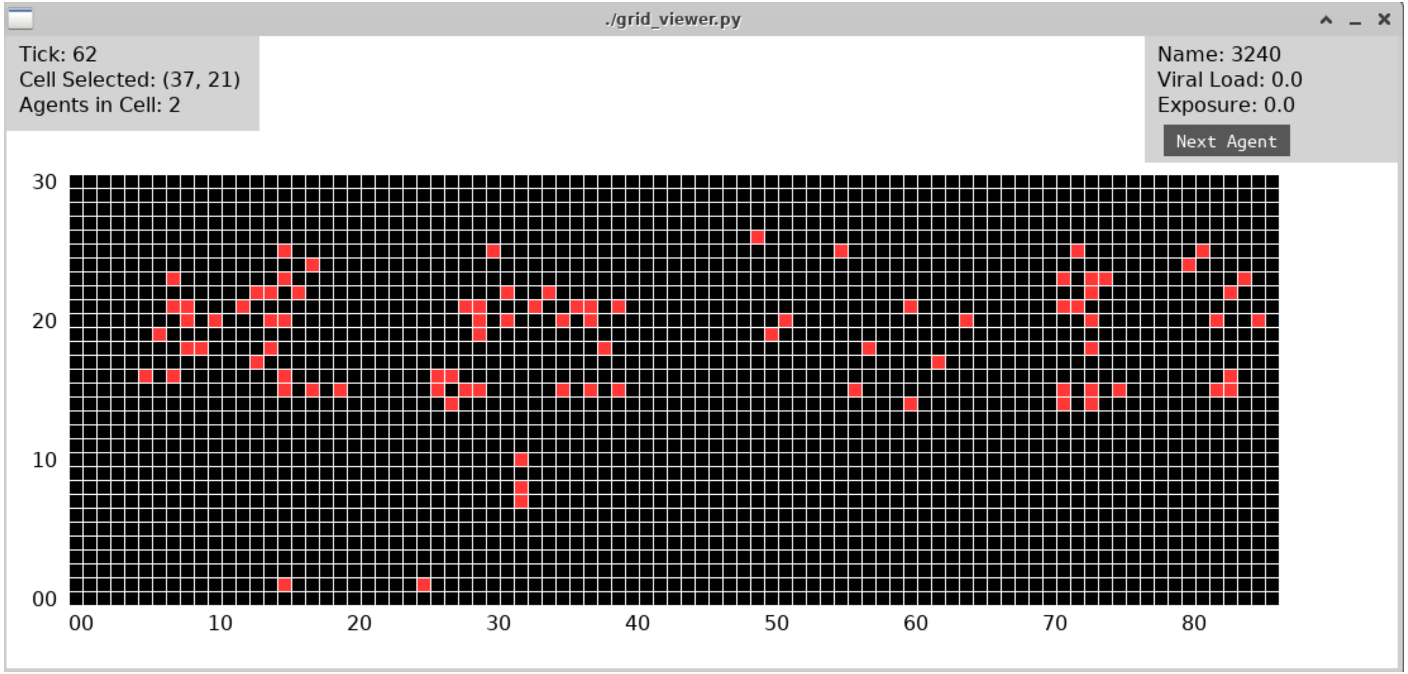
Environment

- Height x width grid of cells, units set by user
- Grid represents cattle movement over time
- Grid holds ‘contamination’ emitted by infected cattle

Agents

- Cattle themselves and their movement ‘script’
- Tracks contamination, total and location specific

Movement Grid



Detection and Transmission of Digital Dermatitis

Lessons learned:

Computer vision of specific lesions and disease stages under commercial operations presented several challenges and need more time and efforts to be optimized

Hardware adequacy needed for working conditions on commercial farms should be optimized and long-term use tested

Maintenance and lens cleanliness protocols should be optimized and adapted to many different farm conditions and settings

Our system was satisfactory for carrousel milking systems but should be adapted for herring-bone or robot systems

Detection and Transmission of Digital Dermatitis

Lessons learned:

We used limited cattle tracking data and claw DD status; however; we were able to show that environmental transmission can be detected

More data (coming from more animals and extended time-period) is needed for:

- calibrating the model in terms of bacterial emission, pickup, and decay onto the contamination layers
- grid refinement and integration of different sources of data (behaviour, animal direction, etc.)
- evaluate the genetic and environmental factors contributing to transmission

Outline

Output

Locomotion parameters of individual animals

A large amount of raw video footage at secured data storage WLR that is currently largely unexplored

Several annotated datasets at secured data storage WLR

- Key points for retraining T-leap
- Gait features

Several scripts stored at gitlab

- https://git.wur.nl/ddht_ai/gait_analysis/keypoint_detection/tree/main/frame_selection?ref_type=heads
- https://git.wur.nl/ddht_ai/gait_analysis/gait_features
- https://git.wur.nl/dwz_ai/yolo_v8/-/commit/c74517b369bc466a3a75d77a48b91a305aeb1dbc
- https://github.com/hrussel/t-leap
- https://git.wur.nl/dwz_ai/kb_ai (cow detector and keypoint detector for barn video footage)

Output

Continuous monitoring of behaviour of groups of animals

A large amount of raw sensor data (including video footage) at secured data storage WLR that is currently largely unexplored

Several annotated datasets at secured data storage of WLR

- Bounding boxes for training the cow detector model
- keypoints for training the keypoint detector model

Some examples of processed video footage at secured data storage of WLR

Several scripts stored at gitlab

- https://git.wur.nl/dwz_ai/kb_ai

Output

Automated behaviour in the barn

Multi model dairy cattle Data Set has been created for research purposes

- Data collected for a week from 16 dairy cows at Dairy Campus
  - Accelerometer and location data at high sample rate (20 Hz)
  - Detailed video recordings (5 different camera views including hay rack and waterbin)
- Human labeled/annotated behavior events using the video recording (partially)
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Output

Detection and transmission of Digital Dermatitis

A large dataset of cattle movement files were transformed into formatted agent *scripts*

sqlite database files containing daily movements of each cattle in the experimental barn
a movement visualization tool to check movement file transformation

All code is in a GIT version control repository hosted by the WUR Data Competence Center

A python script '*cut_model'* was written to produce both the environment definitions and the agents with their movement scripts

The model outputs data is a grid of contamination by coordinates across time and a list of contamination that an agent has been exposed to, across time

The output data is stored as such

Output

Other output

Thesis

Doornenbal, J., 2022. Adviesrapport drinkgedrag. Rapportage studentenonderzoek VHL.

Dekker R., 2022, Noldus TrackLab en Viso als managementtool voor Dairy Campus? Een verkenning naar de (on)mogelijkheden. BSc thesis. informatie@dairycampus.nl

Popular press

De technologie houdt een oogje in het zeil. Een zesde zintuig voor de boer. Nienke Beintema. 2022. WageningenWorld|3. https://edepot.wur.nl/582933

Camera’s verraden de gezondheid van de koe. Nienke Beintema. 2022. Resource. https://edepot.wur.nl/582175

Output

Popular press (continued)

Onderzoekers Dairy Campus willen kreupele koeien via camera's vroeg herkennen. Guus Daamen.2022 Melkvee. https://www.melkvee.nl/artikel/459072-onderzoekers-dairy-campus-willen-kreupele-koeien-via-cameras-vroeg-herkennen/

Smart technology helps track and improve cow health. 2022. https://www.youtube.com/watch?v=V_FPqSx0Upk&t=8s

Camera's voor gezonde hoeven. 2023. https://magazines.wur.nl/nlas-magazine-nl/cameras-voor-gezonde-hoeven

Een camerasysteem detecteert kreupele koeien automatisch. 2023. Een camerasysteem detecteert kreupele koeien automatisch – Dairycampus

Continue monitoren op gezondheid loont. Janet Beekman. 2023. Boerderij 108 – no 50 (13 September 2023)

Output

Presentations

Ouweltjes, W., Next level animal science: monitoring behaviour. Webinar Japan-Netherlands on digital dairy farming & AW assessment, January 28, 2022.

Taghavi M., Russello H., Ouweltjes W., Kamphuis C., Adriaens I. 2022. Automated gait analysis with a deep learning key point detection model. 10th European Conference on Precision Livestock Farming (ECPLF), Vienna, Austria

Koning de., C., C. Kamphuis, W. Ouweltjes, Digital Dairy Developments. 2022. World Agri-Food Innovation, Beijing, November 28, 2022

Kamphuis C., Data een blik in de toekomst. 2023. Data Dairy Dag bij Dairy Campus, Leeuwarden, September 19, 2023

Scientific output

Taghavi M., Russello H., Ouweltjes W., Kamphuis C., Adriaens I. 2023. Cow key point detection in indoor housing conditions with a deep learning model. Accepted for publication in Journal of Dairy Science.