Computer vision technology for automated lameness assessment

Presenter: Tom Van Hertem

Co-Authors: S. Viazzi, M. Steensels, C. Bahr, C.E.B. Romanini, C. Lokhorst, A. Schlageter Tello, E. Maltz, I. Halachmi and D. Berckmans
Acknowledgements

• Financial support:
  o Industrial Research Fund KU Leuven (IOFHB/13/016)
  o FP7-PEOPLE-ITN-2008

• Scientific support:

• Practical support:
  o Technicians Ludo Happaerts (KUL) & Aharon Antler (ARO)
  o Farmers and staff.
Outline

• Why is lameness detection important?
• Computer vision technology
• Implementation of camera technology
• Behaviour and performance sensing
• Multi-sensor lameness detection
• General conclusions
• EU-PLF project
What is lameness?

Why is lameness important?
## Dairy industry in Flanders

<table>
<thead>
<tr>
<th>Year</th>
<th># dairies</th>
<th># cows/dairy</th>
<th>Kg milk</th>
<th>Kg fat</th>
<th>Kg protein</th>
<th>ejr</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>3433</td>
<td>45</td>
<td>7942</td>
<td>332</td>
<td>271</td>
<td>1920</td>
</tr>
<tr>
<td>2008</td>
<td>3100</td>
<td>49</td>
<td>8014</td>
<td>336</td>
<td>276</td>
<td>1953</td>
</tr>
<tr>
<td>2010</td>
<td>2802</td>
<td>55</td>
<td>8175</td>
<td>342</td>
<td>280</td>
<td>1983</td>
</tr>
<tr>
<td>2012</td>
<td>2469</td>
<td>59</td>
<td>8317</td>
<td>347</td>
<td>287</td>
<td>2026</td>
</tr>
<tr>
<td>2014</td>
<td>2166</td>
<td>67</td>
<td>8392</td>
<td>344</td>
<td>289</td>
<td>2026</td>
</tr>
<tr>
<td></td>
<td>-27%</td>
<td>+49%</td>
<td>+6%</td>
<td>+4%</td>
<td>+7%</td>
<td>+6%</td>
</tr>
</tbody>
</table>

Source: mpr-uitslag 2014 (www.crv4all.be)

- **Intensification and up-scaling**
- **Less time per animal**
Introduction to lameness

• What is lameness?
  o … deviation in gait and posture due to pain or discomfort resulting from hoof and leg injuries and diseases.
Introduction to lameness

• Deviation in gait and posture...

**Gait**
- Asymmetry
- Reluctance Bear Weight
- Speed
- Stride length
- Tracking-up
  - Affected Leg Evident
  - Abduction-Adduction
  - Joint Flexion

**Posture**
- Back curvature
- Head-Bob
- Hip Hick

**Others**
- Difficult turning
- Difficult rising
- Tenderness
- Affected behaviour
Lameness assessment

- Locomotion score
  - Subjective
  - Time consuming
  - Expensive

- Aim: Lameness detection based on PLF
  - Automated
  - Objective
  - Continuous
  - (Early) warning
Computer vision technology
Why computer-vision?

• Replace eyes of farmer
• Biggest effects of lameness:
  o Not on cow behaviour
  o Not on cow performance
  o BUT on cow locomotion
• Non-invasive
• Cheap
• 1 sensor for entire herd
2D RGB computer vision

- Replace eyes of farmer
- Lameness → Recording of cow gait → after milking
2D Video preprocessing

C:\NotSynch\videos\setup.avi

Points Of Interest
2D side view computer vision

• Manual labeling of POI \(\rightarrow\) lameness classification model

Limitations:
• Robustness of segmentation
  o Foreground (cow) \(\leftrightarrow\) background
  o Need for static background
  o Computational power vs. real-time
• Side view
  o Interfered management practices
  o \(\rightarrow\) limit commercialization
Algorithm flowchart

3D Video

Cow segmentation

Back detection

Back spine extraction

Curvature parameters extraction

Classification
Algorithm flowchart

3D Video

Cow segmentation

Back detection

Back spine extraction

Curvature parameters extraction

Classification

Threshold on depth image
Algorithm flowchart

1. 3D Video
2. Cow segmentation
3. Back detection
4. Back spine extraction
5. Curvature parameters extraction
6. Classification

Pixel histogram along x-axis
Algorithm flowchart

3D Video

Cow segmentation

Back detection

Back spine extraction

Curvature parameters extraction

Classification

Back spine extraction
Algorithm flowchart

3D Video

Cow segmentation

Back detection

Back spine extraction

Curvature parameters extraction

Classification
Algorithm flowchart

3D Video

Cow segmentation

Back detection

Back spine extraction

Curvature parameters extraction

Classification

Not Lame

Lame
Algorithm output

- Back Posture Measurement BPM

Comparison of a three-dimensional and two-dimensional camera system for automated measurement of back posture in dairy cows

Computers and Electronics in Agriculture Volume 100 2014 139 - 147

Variables $\theta_1$, $\theta_2$, $\theta_3$ and $L_1$ extracted from the reconstructed back curvature of the cow.
Algorithm Verification I

- Verification matrix

<table>
<thead>
<tr>
<th></th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>Accuracy</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calibration</td>
<td>0.76</td>
<td>0.93</td>
<td>0.90</td>
<td>293</td>
</tr>
<tr>
<td>Verification</td>
<td>0.54</td>
<td>0.90</td>
<td>0.83</td>
<td>1100</td>
</tr>
</tbody>
</table>

Sensitivity = ability to detect lame animals
Specificity = ability to detect not-lame animals
Accuracy = ability to detect lame and not-lame animals (correct classification rate)
# Algorithm Verification II

<table>
<thead>
<tr>
<th>N = 744 (4x186)</th>
<th>Reference Live Score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Model Score</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>5</td>
</tr>
</tbody>
</table>

- **Model Score**
- **Reference Live Score**
- **DairyCare COST Cordoba- March 2015**

- **Accuracy**
  - 60.8%
  - 90.9%
Intermediate conclusions

• Strong relation between BPM and locomotion score
• Classification more robust when considering multiple recordings
• Difficulty in identifying mildly lame cows

➔ need for continuous measurements
On-farm implementation of camera technology
Commercial farm layout
Process automation

- Fully automatic video recording & processing
  - Automatic trigger → photocell + RFID
  - Automatic identification
    - RFID-antenna
    - Overlap window for timestamp correlation
      - Recording time stamp [recording pc]
      - RFID time stamp [farm pc]
      - Time delay (every session re-estimated!)
      - 100% accuracy!
  - Automatic analysis (BPM-measurement)
    - Offline
    - After the milking + recording session
    - Filter to select good videos
Video recording performance
On recording session level
Performance

- Collection period: 20/09/2013 – 19/08/2014
- 630+ recording sessions
- 111900+ BPM-scores

<table>
<thead>
<tr>
<th>Step in Process</th>
<th>Absolute number</th>
<th>Relative Number [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of cows milked</td>
<td>226 ± 9</td>
<td>100</td>
</tr>
<tr>
<td>Number of cows RFID</td>
<td>224 ± 10</td>
<td>99,1 ± 1,3</td>
</tr>
<tr>
<td>Number of recorded videos</td>
<td>197 ± 16</td>
<td>88,1 ± 6,6</td>
</tr>
<tr>
<td>Number of video-cowID links</td>
<td>178 ± 14</td>
<td>79,4 ± 5,5</td>
</tr>
<tr>
<td>Number of analysed videos</td>
<td>110 ± 24</td>
<td>49,3 ± 10,8</td>
</tr>
</tbody>
</table>
Performance per session: analysis

**Merging** = link cow-ID to video

**Analysis** = automatic BPM-score

**Scored videos**

**cowID linked videos** = $61.8\%$

DairyCare COST Cordoba - March 2015
Recording/Milking session performance

- Impact of cow traffic
- Impact of selection gate (setup)
- Hardware failure
  - Photocell
  - RFID

Video ID = 77.7%
BPM-score = 48.2%

DairyCare COST Cordoba - March 2015
Cow traffic: crowding in alley

Cow 1

Cow 2
Video recording performance

On cow individual level
Performance per cow

80% has at least 5 scores per week
Trade-off for selected window size
Example output of 1 cow

**Visual locomotion score**

**Automatic BPM-score**

- Visual locomotion score
- Automatic BPM-score

<table>
<thead>
<tr>
<th>Date</th>
<th>Visual locomotion score</th>
<th>Automatic BPM-score</th>
</tr>
</thead>
<tbody>
<tr>
<td>30/10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>06/11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13/11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20/11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>27/11</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Values:
- 6
- 5
- 5
- 7
- 4
Herd specific factors affecting analysis rate

• Parity
  o Parity 1: $r = -0.51$
  o Parity 4: $r = 0.38$

• Lactation stage
  o Late (271-305 days after calving): $r = -0.49$
  o Early (0 – 20 days after calving): $r = 0.25$

• Milking duration: $r = 0.43$

• Autumn & Spring < Winter & Summer

$r = \text{correlation coefficient with analysis rate}$
Discussion

- System performance ~ time of farmer
- Optimal traffic intervals for free cow traffic?
- How many scores do we need for lameness detection?
- Type of milking parlour ~ location of recording system
- Can other sensor data help?
Behaviour and performance sensing in dairy cows
Milk yield in relation to lameness treatment
Activity in relation to lameness treatment
Behaviour and performance sensors

- Milk meter MM27BC (DeLaval)
  - Milk yield
  - Milk conductivity
  - Milk flow rate

- Activity meter system (DeLaval)
  - Activity [bits/hour]

- Cow recognition
  - Milking time/order
Data analysis

• Univariate lameness classifiers
  ○ Receiver Operating Characteristic (ROC)-curve
  ○ Area Under Curve (AUC)

<table>
<thead>
<tr>
<th>AUC</th>
<th>Test performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>[0.9 – 1]</td>
<td>Excellent</td>
</tr>
<tr>
<td>[0.8 – 0.9]</td>
<td>Good</td>
</tr>
<tr>
<td>[0.7 – 0.8]</td>
<td>Fair</td>
</tr>
<tr>
<td>[0.6 – 0.7]</td>
<td>Poor</td>
</tr>
<tr>
<td>[0.5 – 0.6]</td>
<td>Fail</td>
</tr>
</tbody>
</table>

• Multivariate models
  ○ Forward stepwise binary logistic regression

Test performance

- Excellent: [0.9 – 1]
- Good: [0.8 – 0.9]
- Fair: [0.7 – 0.8]
- Poor: [0.6 – 0.7]
- Fail: [0.5 – 0.6]
Data analysis

• Gold standard
  o Human visual locomotion scoring (LS)
    • Discrete numerical 5-point score

• Binary reference
  o LAME
  o SEVLAME

• Dataset: n = 3439 cow-observations
## Univariate analysis

<table>
<thead>
<tr>
<th>Variable</th>
<th>Variable class</th>
<th>LAME - AUC</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theta2</td>
<td>Video</td>
<td>0.7199</td>
<td>1</td>
</tr>
<tr>
<td>Back Posture Measure</td>
<td>Video</td>
<td>0.7021</td>
<td>2</td>
</tr>
<tr>
<td>Theta3</td>
<td>Video</td>
<td>0.6745</td>
<td>3</td>
</tr>
<tr>
<td>Inverse radius</td>
<td>Video</td>
<td>0.6724</td>
<td>4</td>
</tr>
<tr>
<td>L-distance</td>
<td>Video</td>
<td>0.6715</td>
<td>5</td>
</tr>
<tr>
<td>Number of Frames</td>
<td>Video</td>
<td>0.5963</td>
<td>6</td>
</tr>
<tr>
<td>Walking Speed</td>
<td>Video</td>
<td>0.5722</td>
<td>7</td>
</tr>
<tr>
<td>Theta1</td>
<td>Video</td>
<td>0.5452</td>
<td>8</td>
</tr>
<tr>
<td>Daytime activity</td>
<td>Activity</td>
<td>0.6155</td>
<td>9</td>
</tr>
<tr>
<td>Daily activity</td>
<td>Activity</td>
<td>0.5898</td>
<td>10</td>
</tr>
<tr>
<td>Night-time activity</td>
<td>Activity</td>
<td>0.5397</td>
<td>11</td>
</tr>
<tr>
<td>Milk peak conductivity</td>
<td>Milk</td>
<td>0.5846</td>
<td>12</td>
</tr>
<tr>
<td>Milk conductivity</td>
<td>Milk</td>
<td>0.5789</td>
<td>13</td>
</tr>
<tr>
<td>Milking order</td>
<td>Milk</td>
<td>0.5560</td>
<td>14</td>
</tr>
<tr>
<td>Milk peak flow rate</td>
<td>Milk</td>
<td>0.5444</td>
<td>15</td>
</tr>
<tr>
<td>Daily milk yield</td>
<td>Milk</td>
<td>0.5372</td>
<td>16</td>
</tr>
<tr>
<td>Lactation stage</td>
<td>Milk</td>
<td>0.5359</td>
<td>17</td>
</tr>
</tbody>
</table>
Multi-sensor lameness detection
Multivariate binary logistic regression model

- Reference = LAME \((12)(345)\)
- Resulting model AUC = 0.76

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>Standard error</th>
<th>Step</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant term</td>
<td>-15.8804</td>
<td>1.5034</td>
<td>0</td>
</tr>
<tr>
<td>BPM</td>
<td>15.1437</td>
<td>0.8320</td>
<td>1</td>
</tr>
<tr>
<td>Daytime activity</td>
<td>0.0014</td>
<td>0.0003</td>
<td>2</td>
</tr>
<tr>
<td>Theta1</td>
<td>0.0658</td>
<td>0.0078</td>
<td>3</td>
</tr>
<tr>
<td>Walking Speed</td>
<td>-3.4867</td>
<td>0.6163</td>
<td>4</td>
</tr>
<tr>
<td>Daily activity</td>
<td>-0.0021</td>
<td>0.0002</td>
<td>5</td>
</tr>
<tr>
<td>Milk conductivity</td>
<td>0.2346</td>
<td>0.0835</td>
<td>6</td>
</tr>
<tr>
<td>Daily milk yield</td>
<td>-0.0664</td>
<td>0.0142</td>
<td>7</td>
</tr>
<tr>
<td>Milk peak flow rate</td>
<td>0.0996</td>
<td>0.0259</td>
<td>8</td>
</tr>
<tr>
<td>Milking order</td>
<td>0.4257</td>
<td>0.1399</td>
<td>9</td>
</tr>
<tr>
<td>Lactation stage</td>
<td>-0.0009(_{50})</td>
<td>0.0005</td>
<td>10</td>
</tr>
</tbody>
</table>
Does multivariate sensing improve lameness detection?

<table>
<thead>
<tr>
<th>Model</th>
<th>Included variables¹</th>
<th>AUC</th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
<th>Accuracy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>std</td>
<td>Mean</td>
<td>std</td>
</tr>
<tr>
<td>Single sensor systems</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Video</td>
<td>BPM, T1, T2, T3, L1, IR, WS, nFr</td>
<td>0.732</td>
<td>0.011</td>
<td>48.4</td>
<td>3.3</td>
</tr>
<tr>
<td>Activity</td>
<td>dACT, nACT</td>
<td>0.633</td>
<td>0.018</td>
<td>29.9</td>
<td>3.7</td>
</tr>
<tr>
<td>Milking</td>
<td>MY, MO, MCo, MPFR, DIM</td>
<td>0.604</td>
<td>0.026</td>
<td>19.2</td>
<td>2.7</td>
</tr>
<tr>
<td>Milk</td>
<td>MY, MO</td>
<td>0.562</td>
<td>0.037</td>
<td>7.0</td>
<td>2.1</td>
</tr>
</tbody>
</table>

¹ The included variables in the models are milk yield (MY), milking order (MO), lactation stage (DIM), milk conductivity (MCo), milk peak flow rate (MPFR), daytime activity (dACT), night-time activity (nACT), number of frames (nFr), walking speed (WS), back posture measure (BPM), Theta1 (T1), Theta2 (T2), Theta3 (T3), L-distance (L1) and inverse radius (IR).
Does multivariate sensing improve lameness detection?

<table>
<thead>
<tr>
<th>Model</th>
<th>Included variables</th>
<th>AUC</th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
<th>Accuracy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Single sensor systems</strong></td>
<td></td>
<td></td>
<td>Mean</td>
<td>std</td>
<td>Mean</td>
</tr>
<tr>
<td>Video</td>
<td>BPM, T1, T2, T3, L1, IR, WS, nFr</td>
<td>0.732</td>
<td>0.011</td>
<td></td>
<td>48.4</td>
</tr>
<tr>
<td>Activity</td>
<td>dACT, nACT</td>
<td>0.633</td>
<td>0.018</td>
<td></td>
<td>29.9</td>
</tr>
<tr>
<td>Milking</td>
<td>MY, MO, MCo, MPFR, DIM</td>
<td>0.604</td>
<td>0.026</td>
<td></td>
<td>19.2</td>
</tr>
<tr>
<td>Milk</td>
<td>MY, MO</td>
<td>0.562</td>
<td>0.037</td>
<td></td>
<td>7.0</td>
</tr>
<tr>
<td><strong>Double sensor systems</strong></td>
<td></td>
<td></td>
<td>Mean</td>
<td>std</td>
<td>Mean</td>
</tr>
<tr>
<td>Milking &amp; Video</td>
<td>MY, MO, DIM, MCo, MPFR, BPM, T1, T2, T3, L1, IR, WS, nFr</td>
<td>0.755</td>
<td>0.033</td>
<td></td>
<td>52.0</td>
</tr>
<tr>
<td>Activity &amp; Video</td>
<td>dACT, nACT, BPM, T1, T2, T3, L1, IR, WS, nFr</td>
<td>0.750</td>
<td>0.031</td>
<td></td>
<td>51.4</td>
</tr>
<tr>
<td>Milking &amp; Activity</td>
<td>MY, MO, DIM, MCo, MPFR, dACT, nACT</td>
<td>0.669</td>
<td>0.028</td>
<td></td>
<td>38.0</td>
</tr>
<tr>
<td>Milk &amp; Activity</td>
<td>MY, MO, dACT, nACT</td>
<td>0.649</td>
<td>0.028</td>
<td></td>
<td>34.8</td>
</tr>
<tr>
<td><strong>Multi-sensor system</strong></td>
<td></td>
<td></td>
<td>Mean</td>
<td>std</td>
<td>Mean</td>
</tr>
<tr>
<td>Milking, Activity &amp; Video</td>
<td>MY, MO, DIM, MCo, MPFR, dACT, nACT, WS, nFr, BPM, T1, T2, T3, L1, IR</td>
<td>0.757</td>
<td>0.029</td>
<td></td>
<td>52.1</td>
</tr>
</tbody>
</table>

1 The included variables in the models are milk yield (MY), milking order (MO), lactation stage (DIM), milk conductivity (MCo), milk peak flow rate (MPFR), daytime activity (dACT), night-time activity (nACT), number of frames (nFr), walking speed (WS), back posture measure (BPM), Theta1 (T1), Theta2 (T2), Theta3 (T3), L-distance (L1) and inverse radius (IR).
Discussion points

- Correct variable vs. Multivariate analysis
- How good is our gold standard method?
  - 5-point numerical score to quantify changes in *n* indicators

### Locomotion score

- **1** Not Lame
- **2** Not Lame
- **3** Lame
- **4** Lame
- **5** Lame

### Gait
- Asymmetry
- Reluctance to Bear
- Speed
- Stride length

### Posture
- Arched-Back
- Head-Bob

### Others
- Behaviour
- Difficult rising
General Conclusions

• Lameness affects cow locomotion, behaviour and performance
• Sensor technology can help us identify the changes
• Key feature variables for dairy cow locomotion assessment can be extracted from captured video recordings
• An automatic computer vision prototype-system was successfully installed in a commercial farm
• A multi-sensor system is not outperforming a single sensor system

• Questions?
  tom.vanhertem@biw.kuleuven.be
  claudia.bahr@biw.kuleuven.be
  daniel.berckmans@biw.kuleuven.be
Future research

• Impact of cow traffic on system implementation
• Changes from individual behaviour
  o Cow specific threshold
  o Large pool of historical data
• Warning list to farmer
  → value creation
EU-PLF project

Bright Farm by Precision Livestock Farming

www.eu-plf.eu
Title: Bright Farm by Precision Livestock Farming (EU-PLF)
Animal and farm-centric approach to Precision Livestock Farming in Europe

Objective: The objective is to deliver a validated Blueprint for an animal and farm-centric approach to innovative livestock farming in Europe proven through extensive field studies.

Project funding: EU – Collaborative project

Budget: 5.900 000 Euro

Time line: 4 years

Project Partners: 20
KULeuven, SLU, Bristol, INRA, Teagasc, ARO, UMIL, WU, DLO, RVC, FANCOM, SoundTalks, PLF AgritechEurope, Xenon, ABROX, M&M, Syntesa, VITAMEX, EAAP, GEA
Objectives of the EU-PLF project
Validated Blueprint

- Core deliverable: Validated Blueprint
  - “manual” for farmers, industry and stakeholders
  - website support

PLF → Operational system at farm level
Objectives of the EU-PLF project
Key Indicators and Gold Standards

- Core deliverable: **Validated Blueprint**
- Define **Key Indicators + Gold Standards**

- Animal welfare
- Animal health
- Environmental load
- Productivity
Objectives of the EU-PLF project
Value Creation

• Core deliverable: **Validated Blueprint**

• Define **Key Indicators + Gold Standards**

• Relate KIs on farm to Social and Economic value measures for **Value Creation**
Objectives of the EU-PLF project
SME Drive

• Core deliverable: **Validated Blueprint**
• Define **Key Indicators** + **Gold Standards**
• Relate KIs on farm to Social and Economic value measures for **Value Creation**
• SME drive

High-tech SMEs  ↔  Market players
Objectives of the EU-PLF project
Farm level

- Core deliverable: **Validated Blueprint**
- Define **Key Indicators + Gold Standards**
- Relate KIs on farm to Social and Economic value measures for **Value Creation**
- SME drive
- Realise all these in different farms
  - 10 Pig farms
  - 5 Broiler farms
  - 5 Cow farms
What is a Blueprint

A design plan, descriptions of concepts, schemes, technical drawings, plans, protocols, detailed working methods and descriptions that act as a model on how to realise the implementation of PLF-technologies in farms and how to create value with it.
Creation of the Blueprint

• Description of the different steps in the logic line
• Choices at the different steps and how they are made
• Link to value creation for the Farmer
• Validation via the SME drive
Validation of the Blueprint

• Info- and training- sessions for young entrepreneurs and potential spin-out activities
• Competition for a new PLF system
• Four winning teams will get funding to realise a prototype at farm level
  – They will use the Blueprint
    • They will validate the Blueprint
Thank you for your attention

www.eu-plf.eu
Acknowledgments and Disclaimer

This project has received funding from the European Union’s Seventh Framework Programme for research, technological development and demonstration under grant agreement no. 311825.

The views expressed in this presentation are the sole responsibility of the author(s) and do not necessarily reflect the views of the European Commission.