Leveraging accelerometer data for lameness detection in dairy cows — longitudinal study of 7 farms in Germany

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Motivation

Lameness is a common problem in dairy cows and can substantially affect the welfare and productivity of these animals. Lameness does not only impair the mobility of cows, but has major effects on behavioural patterns such as grooming behaviour and number of visits to the feed bunk [1]. Different types of statistical models were devised including variables and parameters which can be affected by lameness, such as rumination, feeding and movement patterns, milk production, days in milk (DIM) or weight and aimed to detect lameness in cows with a high accuracy[2,3].

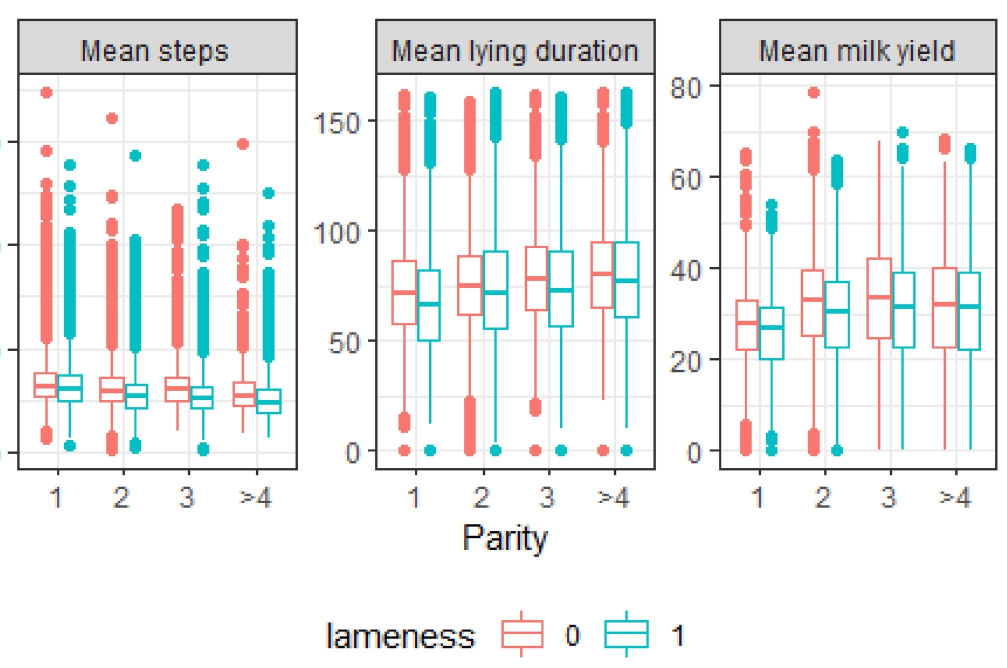
Our goal is to develop a lameness prognostic model for the data set collected from seven farms in Germany. It would be useful to develop several models, taking into account the different parameters affected by lameness and to select one most suitable model that could be universal in the future. The description of the data and its processing allows to explore the dynamics of daily activity patterns in dairy cows identified as being lame or non-lame by visual mobility scoring and choose appropriate parameters for developed models.

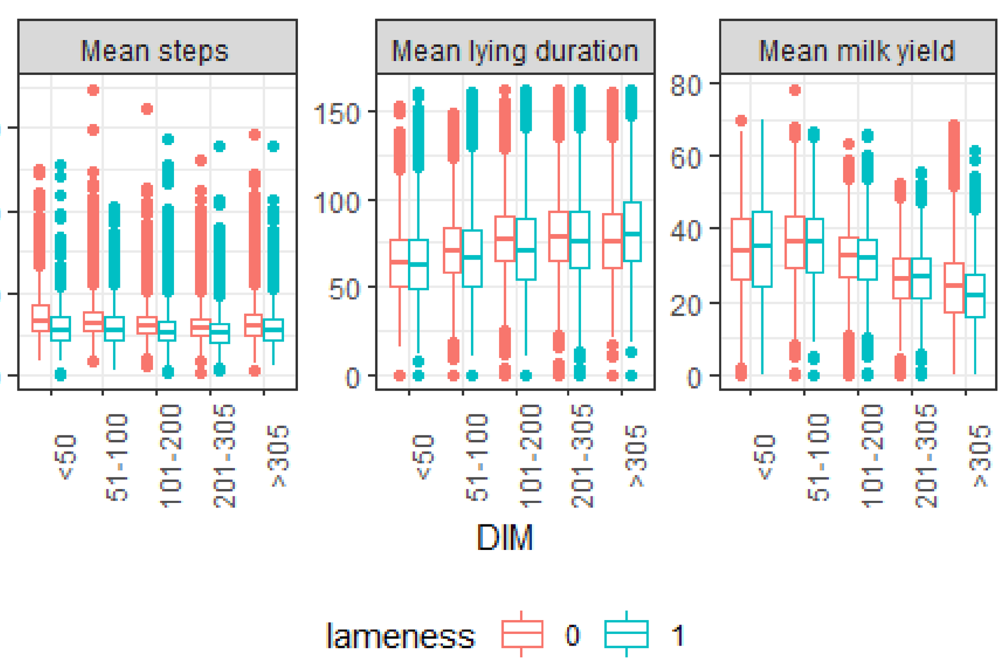
Data Processing

Mean measured parameters:

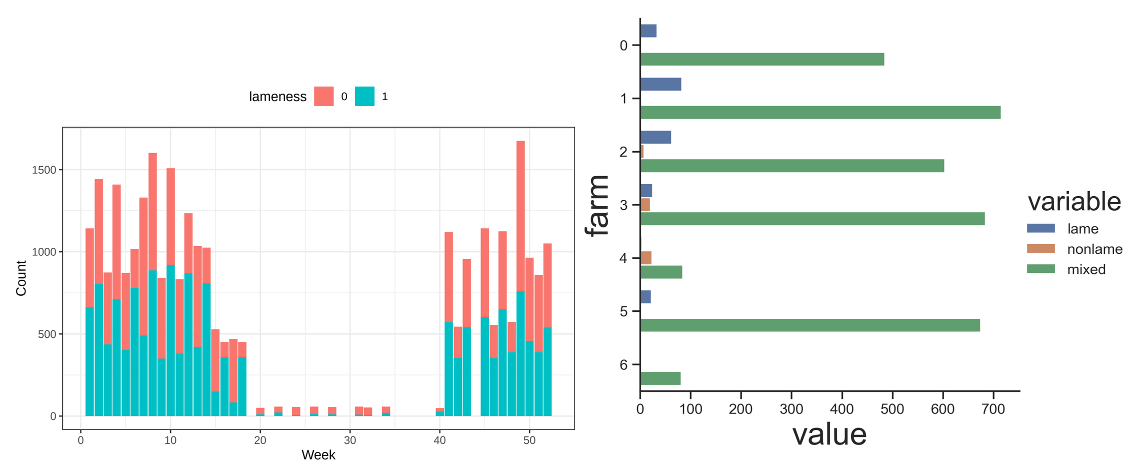
- daily averaged activity per hour from pedometer/accelerometer: number of steps per hour and lying duration (min/bout)
- parity
- lactation stage – days in milk (DIM)
- daily milk yield

Daily average activity and milk yield averaged over three days before locomotion scoring for lame (locomotion score ≥ 3) and non lame (locomotion score < 3) cows in dependence on the **cow parity** and **DIM**. The red and blue colors denote non-lame (0) and lame (1) cows.





Seasonality/farm dependence



Numbers of lame and non-lame cows per observation and over time. (**left**) The cases of lameness scoring per week represented by a stacked histogram. Non-lame (0) and lame (1) status is shown by colour. (**right**) The number of cows assigned to status (persistently) lame, non-lame, mixed) based on results of mobility scoring in seven farms. As mixed cows with interchanging lame/non-lame states were defined. Green, blue and brown colour correspond to mixed, persistent lame, and persistent non-lame cows correspondingly.

Logistic regression model

$$\log\left(\frac{\pi}{1-\pi}\right) = x_{it}\beta + u_i + \varepsilon_{it}, \qquad (1)$$

with β being a vector of regression coefficients (fixed effects) and x_{it} being a matrix of major independent or explanatory variables listed in Table. u_i are random effects of unit i from the overall mean β_0 and ε_{it} is the error vector (unobserved) which is uncorrelated with the random effects vector. $\pi = \mu_y$ is a conditional mean (i.e. the probability that the target variable $y_{it} = 1$ (lame) provided the existing x_{it} values). Then $\left(\frac{\pi}{1-\pi}\right)$ gives us the odds-ratio, that $y_{it} = 1$ and $\log\left(\frac{\pi}{1-\pi}\right)$ is *log odds* or *logit*.

Logistic regression model with mixed effects

Variables used in the model

Variable	Meaning
mean_steps_j	fixed effect referring to the individual cow's activity (number of steps) accounting for the j-th number of days between activity recording and locomotion scoring ($j = [1..3]$)
mean_lay_j	fixed effect referring to the individual cow's activity (lying duration) accounting for the j-th number of days between activity recording and locomotion scoring ($j = [1..3]$)
mean_yield_j	fixed effect referring to the individual cow's developments of daily milk yield accounting for the j-th number of days between yield measurement and locomotion scoring ($j = [1..3]$)
lact_k	fixed effect as well as random effect (random slope dependent on individual cow) of the k-th parity class ($k = [1..10]$) s
DIM	fixed effects of the stage of lactation or days in milk considered as a continuous variable
season	Season can take values: Spring, Summer, Autumn, and Winter
cow_i	random permanent environmental effect (random slope) of the i-th animal ($i = [1..2757]$)
ε	random residual

Results for logistic regression model with random effects for lameness status as dependent variable.
Interactions were taken into account ($var_i : var_j$) and all variables were re-scaled

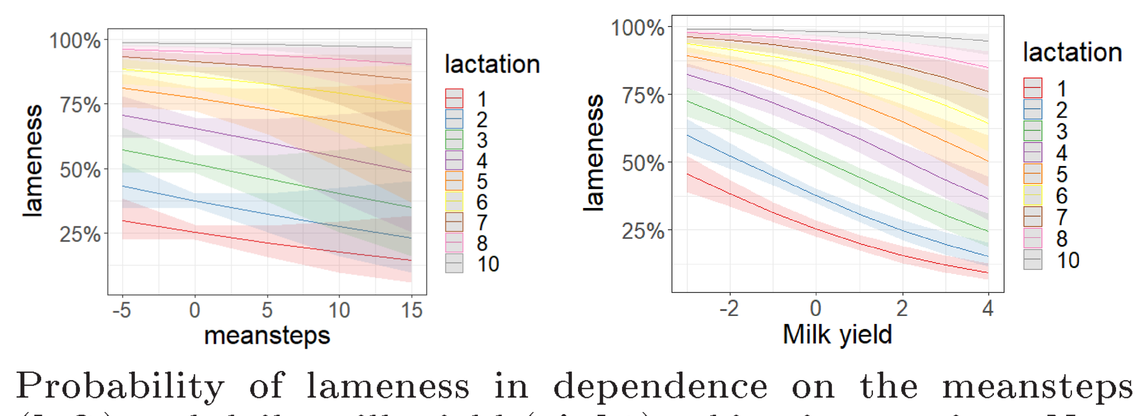
Fixed effects	Estimate	odd ratios	Std. Error	p–value	
Intercept	-1.648	0.192	0.114	$< 2e-16$	***
mean_steps	-0.046	0.955	0.034	0.18	
mean_lay	-0.083	0.92	0.038	0.029	*
lact	0.581	1.788	0.044	$< 2e-16$	***
DIM	-0.016	0.984	0.075	0.825	
mean_yield	-0.301	0.740	0.040	5.65e-14	***
season_Spring	-0.227	0.797	0.106	0.033	*
season_Summer	0.187	1.206	0.583	0.748	
season_Fall	0.049	1.050	0.121	0.687	
mean_steps:season_Spring	-0.008	0.992	0.050	0.876	
mean_steps:season_Summer	-0.338	0.713	0.167	0.043	*
mean_steps:season_Fall	0.121	1.128	0.061	0.050	*
mean_lay:DIM	0.055	1.057	0.026	0.032	*
mean_lay:season_Spring	0.058	1.059	0.049	0.236	
mean_lay:season_Summer	0.174	1.190	0.254	0.493	
mean_lay:season_Fall	0.119	1.127	0.064	0.062	.
lact:DIM	-0.114	0.892	0.0297	0.0001	***
lact:season_Spring	0.083	1.087	0.0396	0.035	*
lact:season_Summer	0.094	1.099	0.158	0.549	
lact:season_Fall	0.003	1.003	0.047	0.948	
mean_yield:season_Spring	0.141	1.152	0.05	0.005	**
mean_yield:season_Summer	1.026	2.790	0.313	0.001	**
mean_yield:season_Fall	0.166	1.180	0.074	0.025	*

Random effects

Groups	Names	Variance	Std. Error
cow	Intercept	5.23578	2.2882
	lact	0.08462	0.2909

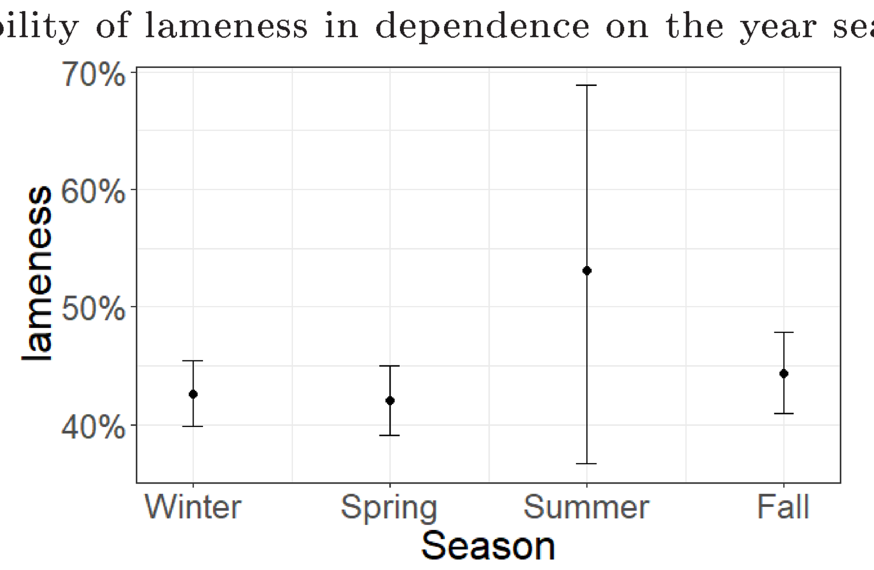
Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Quality of predictions

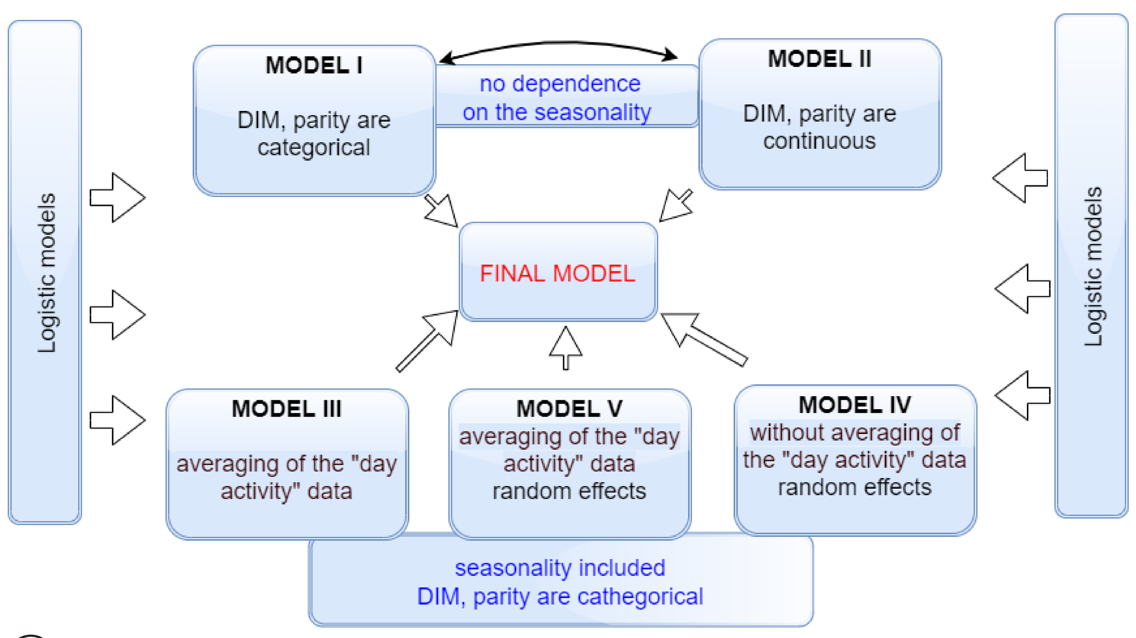


Probability of lameness in dependence on the meansteps (**left**) and daily milk yield (**right**) taking into parity . Note that continuous variables were re-scaled.

Probability of lameness in dependence on the year season:



Summary



① Based on the analysis of accelerometer activity data as well as cow-individual meta-data, it was built a statistical model (logistic regression with mixed effects) able to detect lameness with 86% sensitivity and 82% specificity.
② The resulting model includes a large number of easily measurable variables and can be used by any researcher, since the code in R is accessible and user-friendly written.
③ Model findings constitute a foundation for development of computer assisted decision support systems for automated surveillance and intervention planning in dairy industry.

References

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