Locomotion Traits of Dairy Cows from Overhead Three-Dimensional Video

K. ABDUL JABBAR, M. F. Hansen, M. L. Smith, and L. N. Smith
Centre for Machine Vision, Bristol Robotics Laboratory
University of the West of England, Bristol, United Kingdom
Email: khalid.abduljabbar@brl.ac.uk

***Abstract*—We investigate two locomotion traits in dairy cows from overhead 3D video to observe lameness trends. Detecting lameness -particularly at an early stage- is important in order to allow early treatment which maximizes detection benefits. The proposed physical setup is covert, non-intrusive and it facilitates full autonomy; therefore, it could be implemented on a large-scale or daily-basis with high accuracy. The algorithm automatically tracks features to key regions (i.e. spine, hook bones) using shape index and curvedness measure from the 3D map. The gait asymmetry trait is analysed in the form of a dynamic novel proxy derived from the pelvic height movements, as the animal walks. We have found this proxy sensitive to early lameness trends. The back arch trait is analysed using a fitted polynomial in the extracted spine region. The proposed methods in this paper could be implemented on other cattle breeds, equine or other quadruped animals for the purposes of locomotion assessment.**

I. Introduction

The importance of locomotion/lameness scoring (LS) of dairy cows lies mainly with its direct association with animal welfare. Lameness is still acknowledged as one of the most serious problems that affect an animal's well-being and thus, productivity [1]. It is estimated that lameness in UK's dairy cows accounts for financial losses up to GBP 127 million per year [2]. Regardless of causes (e.g. injury, sole ulcers), early detection allows herdsmen to intervene and apply the appropriate treatment, this will subsequently minimize losses and reduce animal suffering [3]. Based on these facts, there has been a growing demand in the dairy industry to utilize the latest technologies for an accurate daily based monitoring that will allow herdsmen detect small changes or minor abnormality trends, and act accordingly. The non-intrusive analysis of locomotion -in general- is a largely unexplored area of research that has the promise to deliver financial benefits to herdsmen and improve the welfare of dairy herds.

Presently, the conventional methods to assess the locomotion automatically are based on analyzing the kinematic measurements from the limbs (i.e. using force plates or accelerometer sensors). However, to date, manual scoring methods (i.e. human scoring such as Sprecher et al [4]) are still the more commonly used option in commercial farms. Besides the associated subjectivity [5], they could be costly, time-consuming or stressful to the animal. Automated vision based methods are in their infancy and are mainly based on static imagery. Previous vision-based back posture estimation methods such as [6] and [7] showed high classification rates in both experimental and commercial data capture conditions. However, the presented locomotion scores are coarse-grained (restricted to two or three levels). Hence, it is not possible to ascertain the sensitivity towards minor deviations from healthy gaits which is important to establish an early lameness identification.

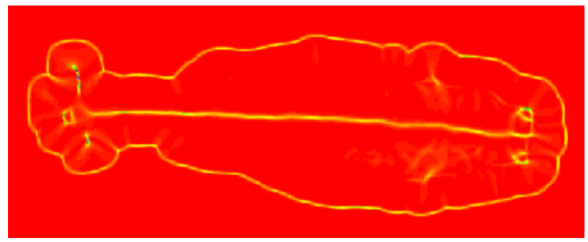

Fig. 1. Processed overhead image of a cow with a convex threshold applied. This image is used to track the prominently convex features (hook joints and spine).

II. Methodology

The data capturing setup is mainly designed to facilitate full autonomy. This is because in real world, farmers prefer a system with the least possible intervention in the daily routine of the herd. Due to the unpredictability and unconstrained movements of the animal, continuous 3D capturing offers a feasible solution as it enables data from the entire view of the animal to be captured in every frame. This 3D data also enables us to robustly track key features that we use in this analysis. An overhead view (on top of the herd) ensures that the system remains completely covert, allowing an option which is less prone to damage and noisy backgrounds. The 3D data presented here is captured using a standard depth sensor at a maximum height of 2 to 2.5 meters above the animals body. The horizontal Field of View (FOV) is around 6 meters. This has allowed the capture of at least two full animal strides on average. The camera operates at 30 frames per second. All cows are Holstein Friesian breed. The 3D data is recorded in a local farm at Glastonbury, UK. An expert observer scored all cows in this analysis using the Sprecher et al [4] LS system. (1-5 levels/scores, where LS 1 represents a healthy cow and LS 5 is a severely lame cow).

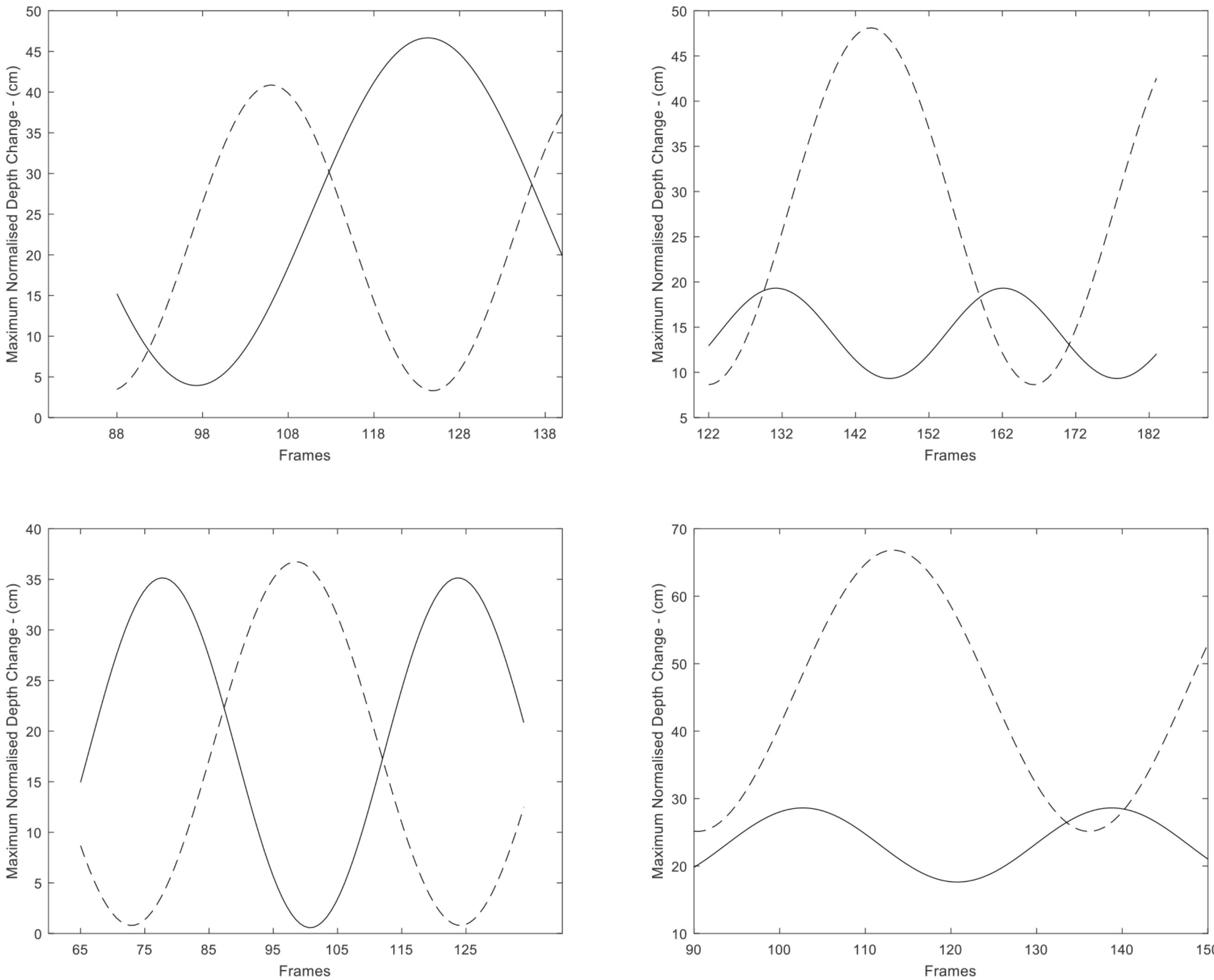

Fig. 2. Smoothed locomotion signals for this study. Slightly lame cows (LS 2/3 - right coloumn) and healthy cows (LS 1 - left coloumn). Right hook/side is solid and left hook/side is dotted. Notice how lameness (gait asymmetry) affects the amplitude and phase in the height locomotion signals.

A. Pre-processing and features

The pre-processing starts with background subtraction from the frame. A height threshold is used to eliminate surrounding object pixels. The noisy areas in the subtracted frame are filtered-out to discard the remaining extraneous information. A symmetric Gaussian low-pass filter is used to make the image smoother and remove quantization artifacts from the raw image.

Our algorithm automatically tracks key Regions of Interest (ROIs) in the animal's body (i.e. hook joints and spine). These ROIs reflect the regular movements resulted from the locomotion. Because of the spine and hook joint's pointy (convex) features -as shown in Fig. 1-, a shape index and curvedness measure [8] is a suitable descriptor to robustly track these ROIs from the 3D video. A curvedness measure/threshold represents the overall surface topology from the 3D map by calculating the principle curvatures at each point. Because these ROIs will always be the highest convex points, we use a high-peak finding algorithm, where the hooks are always the outermost peaks in the image. The spine represents the largest connected object in a binary converted image of the curvedness threshold. This approach allows us to track the key ROIs in each frame, as the animal walks freely beneath the 3D camera.

B. Gait asymmetry

Historically, the kinematic measurements (locomotion dynamics) are considered as highly reliable indicators for gait related studies [9]. Hildebrand et al. [10], classified the routine quadruped walk (which cows normally follow at slow pace) as a symmetrical gait, which means the footfall (or any given action) of the two feet of a pair are evenly spaced in time. Thus, the more lame the animal, the more asymmetrical its gait will become, and the greater the kinematic difference between its contralateral sides will be. We hypothesize that

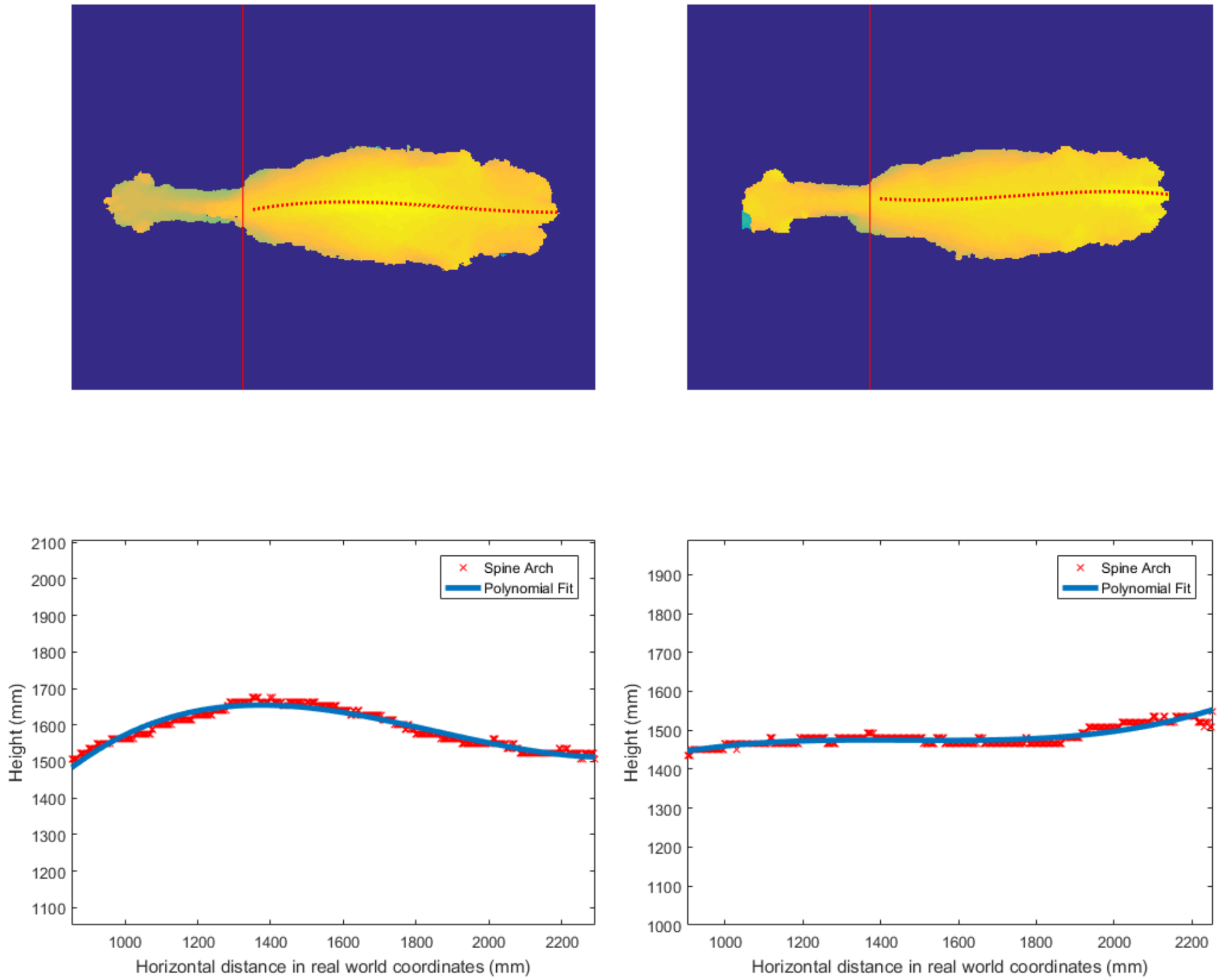

Fig. 3. Back arching examples for a lame cow (right coloumn) and a healthy cow (left coloumn). Top row shows both processed cows from a top-down view, with the spine features extracted and the neck area identified. Bottom row shows the back arch in each cow from a side view, with its polynomial fit. Notice how the clear arch in the lame cow.

the resulted height movements should also reveal symmetry. This means that a certain maximum height achieved on the right side should be shortly equalized on the left side.

This hypothesis benefits from the 3D depth data, because it allows us to estimate the height movements from each ROI. The ROIs are analyzed in terms of height variation symmetry between the right and left limb movements to predict locomotion soundness or potential lameness trends. By analyzing these minor height changes across the key ROIs, we are able to establish a pattern for a healthy locomotion. Subsequently, we can detect small deviations and predict locomotion abnormalities at an early stage. Our algorithm can pick up the early stage lameness (i.e. at LS 2, as explained in Fig 2) by further analysing and clustering the shapes of the signals [11].

C. *Back arch*

The majority of previous vision-based research is based on estimating the back's curvature to predict gait soundness. Because of the animals' natural resistance to pain caused by lameness; they tend to shift their body weight towards the contralateral limb [12]. This subsequently increases the back curvature. The spine's curvedness may also be affected when they use their head to shift the weight forward (counterbalance), in case the affected limb is at the rear. Hence, back posture is considered as a useful measure to predict if the cow is showing signs of discomfort, and subsequently is lame.

We have developed a different approach as compared to both [6] and [7] by fitting a cubic polynomial on the extracted spine ROI from the 3D depth map, as shown in Fig. 3. Furthermore, we detect the neck area in order to eliminate neck movements (head bobbing) effect on the back arch. The back arch is estimated using the curvature of the fitted polynomial. We have observed sensitive changes by taking the normalized minimum b-terms of the fitted polynomials (across all frames).

III. Discussion

The experimental work led to this paper was mainly focused at investigating whether there is a pattern in the morphological changes of the animal's back (from an overhead view) as she walks, and whether this pattern is different in lame and healthy animals. We believe that the hook-joints ROIs and the spine ROI are the most sensitive areas to lameness. Thus, our focus has been mainly towards these two regions in the above two traits.

Just like humans, cows walk in different ways. This also affects their reaction to lameness. Several cows have shown an arched back and gait asymmetry despite getting healthy scores. In some cases, initial analysis revealed that these cows might have a naturally arched back. This also applies to gait asymmetry as some healthy scored cows could have natural abnormalities in their footfalls. Thus, we believe that in terms of an accurate, early lameness detection, an overall system is needed which looks for various lameness traits (back arch, asymmetry, pelvic height difference, neck movements, walking speed) and calculates an estimated score based on results from all traits. This has been backed up recently [13], that different cows show different lameness traits and the most reliable lameness traits are back arch, gait asymmetry and the reluctance to bear weight.

Overall, the gait asymmetry method has been the most promising outcome because of the sensitivity it provides towards early lameness detection (e.g. the patterns of the signals in Fig 2, although all four cows are scored LS 1, 2 and 3). The resulting locomotion signals correlate with leg movements and subsequently, lameness. Thus, the patterns of both lame and healthy locomotions are noticeably dissimilar across the majority of the data. Our findings reveal that by observing the height changes of the animal's hooks and spine using 3D data, it is possible to establish a reliable proxy between the movement of the animal's limbs and the height of the hooks. By incorporating the individual animal's locomotion score over time, a reliable threshold for early stage lameness could be established. This will have a direct impact on animal welfare and productivity in commercial dairy farms as herdsmen will be able to intervene regularly.

The automated and non-intrusive system will enable large scale implementations in commercial farms allowing data to be captured after each milking session on a daily basis. Therefore, small developing lameness trends could be detected potentially even before a human observer could. This will improve the lack of robustness of existing methods and reduce reliance on expensive equipment and/or expertise in the dairy industry. Future work will focus on learning a better pattern from the entire locomotion signals by utilizing advanced pattern recognition and supervised machine learning techniques.

IV. Conclusion

The presented data of cow locomotion is acquired using an overhead depth camera in real farm conditions. Both locomotion traits are reliable indicators for lameness and useful for detecting lameness trends in dairy cows at early stages. That is important because these minor deviations could develop into a severe painful lameness condition. Gait asymmetry derived from the pelvic height movements is a promising trait especially for sensitive lameness detection. The cow's back arch is analysed by fitting a cubic polynomial to a representation of the extracted spine region. Expert-provided ground truth of locomotion soundness is used to evaluate the algorithms. Promising results are obtained by analysing the locomotion data from four cows.

Acknowledgment

This research is funded by the University of the West of England (Bristol, UK). The authors would like to thank to the observer, E. F. Wright and the staff of Kingshay Farming and Conservation Ltd. and Bridge Farm (Glastonbury, UK); for their help during data collection.

References

[1] J. Huxley, "Impact of lameness and claw lesions in cows on health and production," *Livestock Science*, vol. 156, no. 13, pp. 64 – 70, Sep. 2013.

[2] J. A. Willshire and N. J. Bell, "An economic review of cattle lameness." vol. 17. British Cattle Veterinary Association, 2009, pp. 136–141.

[3] K. Leach, D. Tisdall, N. Bell, D. Main, and L. Green, "The effects of early treatment for hindlimb lameness in dairy cows on four commercial UK farms," *The Veterinary Journal*, vol. 193, no. 3, pp. 626 – 632, Aug. 2012.

[4] D. J. Sprecher, D. E. Hostetler, and J. B. Kaneene, "A lameness scoring system that uses posture and gait to predict dairy cattle reproductive performance," *Theriogenology*, vol. 47, no. 6, pp. 1179–1187, Apr. 1997.

[5] F. C. Flower and D. M. Weary, "Gait assessment in dairy cattle," *animal*, vol. 3, pp. 87–95, 1 2009.

[6] S. Viazzi, C. Bahr, T. Van Hertem, A. Schlageter-Tello, C. Romanini, I. Halachmi, C. Lokhorst, and D. Berckmans, "Comparison of a three-dimensional and two-dimensional camera system for automated measurement of back posture in dairy cows," *Computers and Electronics in Agriculture*, vol. 100, pp. 139–147, Jan. 2014.

[7] T. Van Hertem, S. Viazzi, M. Steensels, E. Maltz, A. Antler, V. Alchanatis, A. A. Schlageter-Tello, K. Lokhorst, E. C. Romanini, C. Bahr, D. Berckmans, and I. Halachmi, "Automatic lameness detection based on consecutive 3d-video recordings," *Biosystems Engineering*, vol. 119, pp. 108–116, Mar. 2014.

[8] J. J. Koenderink and A. J. van Doorn, "Surface shape and curvature scales," *Image and Vision Computing*, vol. 10, no. 8, pp. 557 – 564, Oct. 1992.

[9] J. T. Manter, "The dynamics of quadrupedal walking," *Journal of Experimental Biology*, vol. 15, no. 4, pp. 522–540, Oct. 1938.

[10] M. Hildebrand, D. M. Bramble, K. F. Liem, and D. B. Wake, *Functional vertebrate morphology*. The Belknap Press of Harvard University Press, 1985.

[11] K. ABDUL JABBAR, M. F. Hansen, M. L. Smith, and L. N. Smith, "Early and non-intrusive lameness detection in dairy cows using 3-dimensional video," *Biosystems Engineering*, 2016, [In Press].

[12] S. Neveux, D. Weary, J. Rushen, M. von Keyserlingk, and A. de Passill, "Hoof discomfort changes how dairy cattle distribute their body weight," *Journal of Dairy Science*, vol. 89, no. 7, pp. 2503–2509, Jul. 2006.

[13] A. Schlageter-Tello, E. A. Bokkers, P. W. G. Koerkamp, T. Van Hertem, S. Viazzi, C. E. Romanini, I. Halachmi, C. Bahr, D. Berckmans, and K. Lokhorst, "Relation between observed locomotion traits and locomotion score in dairy cows," *Journal of Dairy Science*, Sep. 2015.