Quadruped Locomotion Analysis using Three-Dimensional Video

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***Abstract*— To date, there has not been a single method suitable for large-scale or regular-basis implementation to analyze the locomotion of quadruped animals. Existing methods are not sensitive enough for detecting minor deviations from healthy gaits. That is important because these minor deviations could develop into a severe painful lameness condition. We introduce a dynamic novel proxy for early stage lameness by analyzing the height movements from an overhead-view 3D video data. These movements are derived from key regions (e.g. spine, hook joints, and sacroiliac joint). The features to these key regions are automatically tracked using shape index and curvedness threshold from the 3D map. Our system is fully automated, covert and non-intrusive. This directly affects the accuracy of the analysis as we are able to observe the animals without spooking them. We believe that our proposed method could be used on other animals, i.e. predator quadrupeds where human presence is difficult.**

Keywords—quadruped locomotion; lameness detection; 3D computer vision;

I. INTRODUCTION

Lameness is one of the most serious problems in equine (horses, ponies) and livestock (cows, goats, sheep) animals. It can promptly affect the animal's well-being and productivity. The annual economic losses due to lameness in horses reach from USD 600 million to 1 billion in the US only [1]. In 2009, lameness in the UK's national cattle herd accounted for losses of up to GBP 127.8 million [2]. It has been proven that provided an early intervention [3], lameness can be treated. Thus, there has been a growing demand for an accurate, non-intrusive and sensitive method to analyze the locomotion and detect early lameness trends. Furthermore, an accurate locomotion analysis must consider dynamic factors; a largely unexplored area of research that has the promise to deliver financial benefits to herdsmen and improve the welfare of the animals.

Previous studies investigated the use of weight scales, body sensors or even lately, computer vision techniques to detect lameness. However, there are number of outstanding challenges in automating these methods on large-scale or regular-basis (i.e. in commercial livestock farms or equine stables). This paper introduces a novel method to observe the locomotion non-intrusively, aimed to improve the sensitivity towards early lameness detection. Ideally, before the lameness condition becomes severe, to provide appropriate treatment.

II. METHODOLOGY

Farmers and livestock owners tend to prefer a system with the least possible intervention in the daily routine of the herd. This subsequently leads to better accuracy and automated mechanism. 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. An overhead view (on top of the herd) ensure that the system remains completely covert, allowing an option which is less prone to damage and noisy backgrounds. As we are studying sensitive changes in motion, it is important that we observe as many possible cycles of the locomotion's resulting signals. The 3D data presented here is captured using a standard depth sensor at a maximum height of 2 to 2.5 meters above the animal's body. The horizontal 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.

A. Pre-processing and convex features

First the background is subtracted from the frame and a height threshold is applied. The threshold is used to eliminate surrounding object pixels. The noisy areas in the subtracted frame are filtered-out to discard the remaining extraneous information. We then use a symmetric Gaussian low-pass filter to make the image smoother and remove quantization artifacts from the raw image.

Our algorithm automatically tracks key Regions of Interests (ROIs) in the animal's body, i.e. from the top-down view. These ROIs reflect the regular movements resulted from the locomotion. Many quadrupeds -in general, with the exception of camels in this study- tend to have pointy (convex) features around the spine and hind-limb joint areas. Thus, we have found shape index [4] a suitable descriptor to represent the surface topology by calculating the principle curvatures. This allows us to apply a convex threshold on a processed and smoothened curvedness 3D map, as shown in Fig. 1. Thus, we are able to locate the key ROIs in each frame, as the animal walks beneath the 3D camera.

Presently, our features detection algorithm works better on larger quadrupeds (e.g. cow and horse) as compared the smaller quadrupeds (e.g. goat, sheep). However, modifications could be applied based on the animal's size/height- for other species.

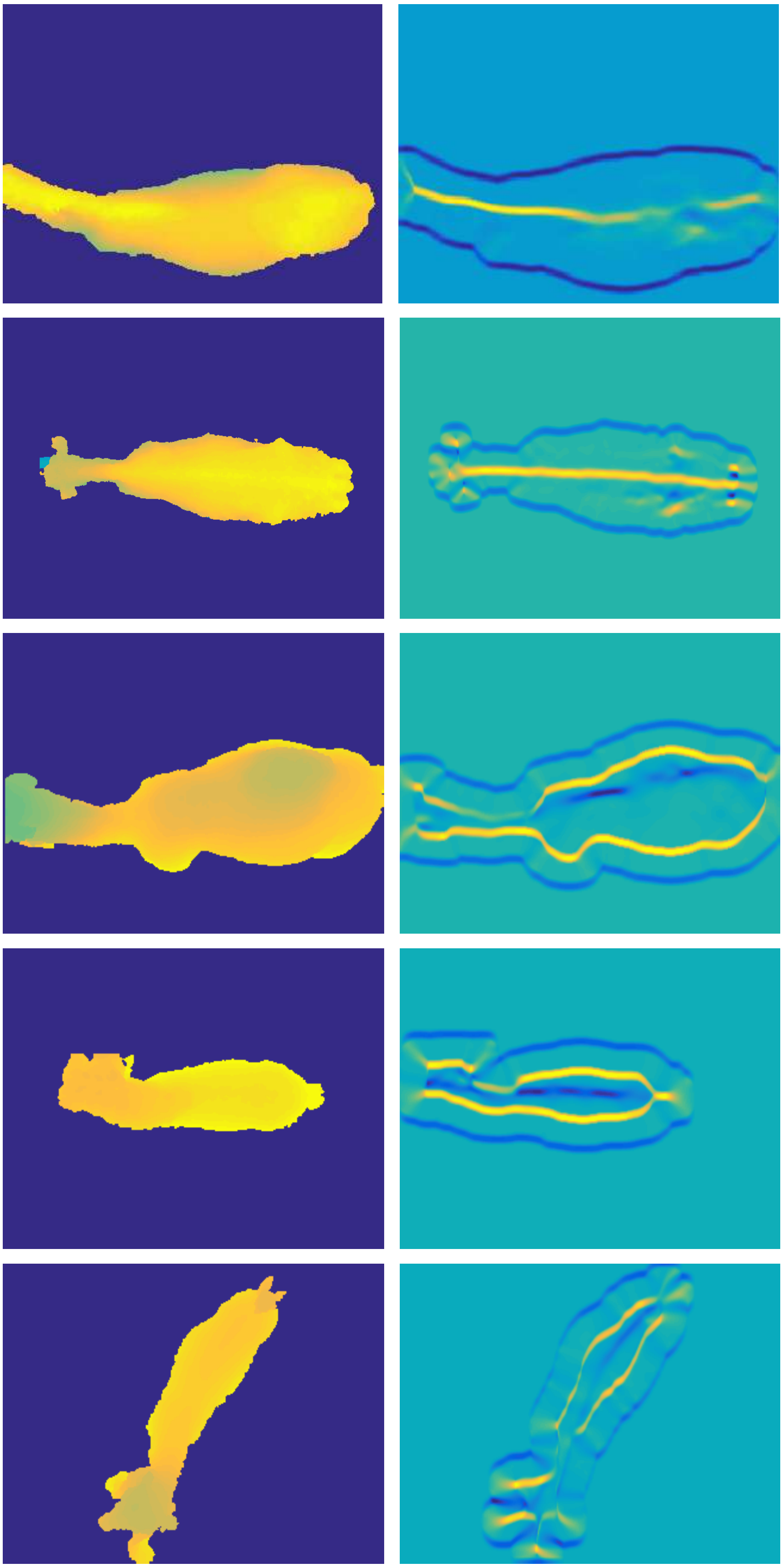

Fig. 1. Top-down convex features for five quadrupds. Left column shows processed 3D depth images for each animal, and the right column shows the prominent features extracted using shape index and curvedness (convex) threshold for the same animals. Top to bottom; Arabian horse, Holstein Friesian dairy cow, Arabian camel, pony, Ardi goat.

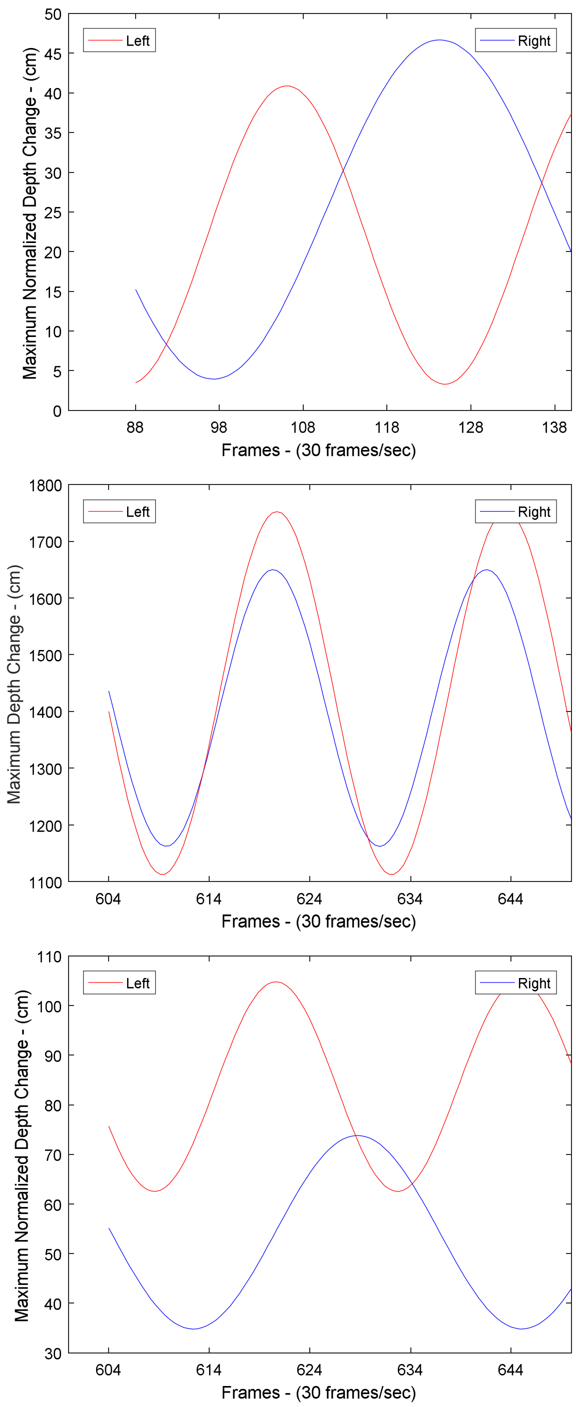

Fig. 2. Proposed locomotion signals. Top figure is hind limbs height movements for a cow. These are normalized by subtracting the sacrum height from each hook region. Middle figure is hind right and left regions of a horse. These regions are normalized in the bottom figure by subtracting the sacroiliac joint height for the same horse.

B. *Locomotion signals*

The 3D depth data further allows us to estimate the height movements from each ROI. Once a frame is processed, height changes are extracted from the ROIs to analyze the changes in the 3D surface for each ROI as the cow progresses under the camera. Given that most quadrupeds follow a symmetrical gait at slow speeds [5], we hypothesize that the resulted height movements should also reveal symmetry. This means that a certain maximum height achieved on the right side should be shortly equaled on the left side. By analyzing these minor height changes across the key ROIs (as explained in Fig. 2.), 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.

III. Results and Discussion

For dairy cows, we applied a Hilbert transform to analyze the locomotion signals. Given the nature of these signals (i.e. sinusoidal mono-components), Hilbert transform is a suitable technique to determine an instantaneous phase difference. In this case, we are interested in observing a full cycle of leg movements on the right side as compared to the same on the left side. On a 22-cow dataset (4 healthy, 4 mildly lame and 14 lame/severely lame), we used a reference manual scoring system [6]. The cows have all been manually scored by a local expert to establish the ground truth for this study. Our algorithm can pick up the early stage lameness (at manual locomotion score 2) by clustering the shapes of the signals, as shown in Fig. 3.

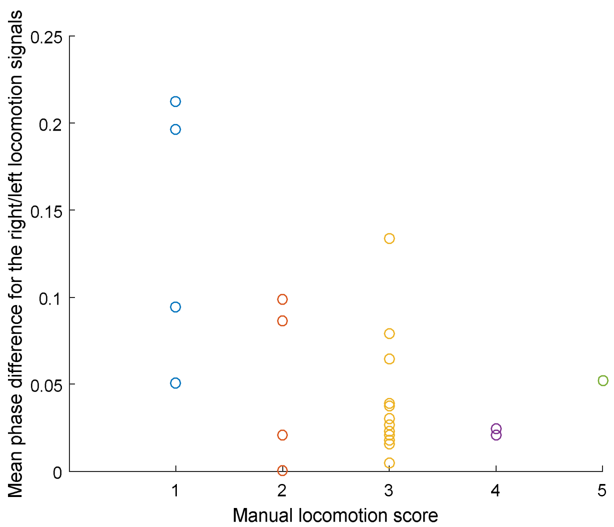

Fig. 3. Manual locomotion scores vs algorithm scores on 22 dairy cows. Manual locomotion score (1 healthy, 5 severely lame).

One of the major advantages of our proposed method is that we are able to capture data on a daily-basis, thus, 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 livestock industry.

IV. CONCLUSION

We have introduced a novel method to analyze the gait asymmetry of a quadruped animal, subsequently, assess the locomotion and detect lameness at an early stage. Given a suitable set of features, our algorithm tracks the regular limb movements as the animal walks beneath a 3D camera. The proposed data capturing method facilitates an automated system to be implemented on regular-basis, large-scale or in areas where human presence is difficult.

The presented locomotion signals from cows and horses correlate well with the actual locomotion and subsequently, we are able to detect minor lameness trends. Our findings reveal that by observing the height changes of the animal's rear limb joints and spine using 3D data, it is possible to establish a reliable relationship between the movement of the animal's limbs and the height of the 3D surface. This further allows us to analyze the locomotion signals in terms of symmetry, and establish a threshold for early stage lameness. Thus, a call for close intervention could be applied. This will have a direct impact on animal welfare and productivity in commercial farms and stables.

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