Wireless Transmission of Torso Acceleration and Fault Detection to Evaluate Lameness in Horses

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Abstract. Lameness is the most common clinical problem affecting horses. In cases of mild lameness, experienced veterinarians do not consistently detect lameness using subjective evaluation. The classic methods of kinematics and kinetics for objective detection of lameness are effective but not practical for the clinical setting. An inertial sensor system has been developed for objective lameness detection in horses. The sensors sample vertical acceleration of the head and pelvis and angular velocity of the right forelimb at 200 Hz. Data is transmitted in real time to a hand-held tablet computer. Using an adaptation of vibration analysis for fault detection vertical torso movement is processed and analyzed. Evaluation of lameness with the inertial sensor system is precise, accurate, and more sensitive than traditional subjective evaluation.

1 Background

Lameness is a change in the gait due to a functional or structural change in the locomotor system [3]; [19]. Lameness is the most common clinical problems that affects the horses' wellbeing and causes severe losses to the equine industry [8]; [1]. In many cases, the initial condition causing lameness is reversible if promptly diagnosed and treated. Delayed diagnosis and treatment may lead to progression of disease and delayed recovery. In many cases, without prompt diagnosis and treatment, irreversible lesions may develop, which can incapacitate the horse for further use [3]; [9].

The first step for lameness diagnosis is lameness detection, which is identification of the affected limb(s). This is a crucial step, which is then followed by other diagnostic procedures for locating the affected structure(s) and the pathologic process(s) associated with lameness. Traditionally, veterinarians identify lameness in horses by

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observing the horse moving at the walk and at the trot and then subjectively grading lameness severity using an integer scale [20]; [3]. Small changes in severity of lameness may be missed. The naked eye has limited temporal resolution and small changes in movement with mild or early dysfunction may be missed [18]; [21]. The limitations of the human eye explain the limited results of subjective evaluation of lameness even when performed by experts [6]; [7]; [10]; [12]. The human brain stores limited visual information [22]; [23] so that effective comparisons of sequential evaluations (e.g., before and after flexion, before and after nerve block, before and after treatment) cannot be performed. Also, subjective evaluation can be biased [2].

Objective evaluation of lameness lacks many deficiencies of subjective evaluation. Objective evaluation for detection of lameness in horses has been performed with both kinetic and kinematic approaches [11]; [13]. The use of a stationary force plate, a kinetic approach which measures the ground reaction forces to one limb at a time, is considered by some to be a gold standard for lameness detection in horses. However, kinematic evaluation using cameras to record motion has also been shown to be useful as an objective method for lameness detection. Although accepted as accurate methods to objectively study lameness, current kinetic and kinematic evaluation approaches are limited. The artificial conditions required for data collection affect normal locomotion. Current methods are laborious and time consuming. Specialized equipment, facility and expertise are required. These limitations generally restrict objective lameness evaluation in horses to the laboratory environment and make traditional kinetic and kinematic methods not practical for routine clinical use [11].

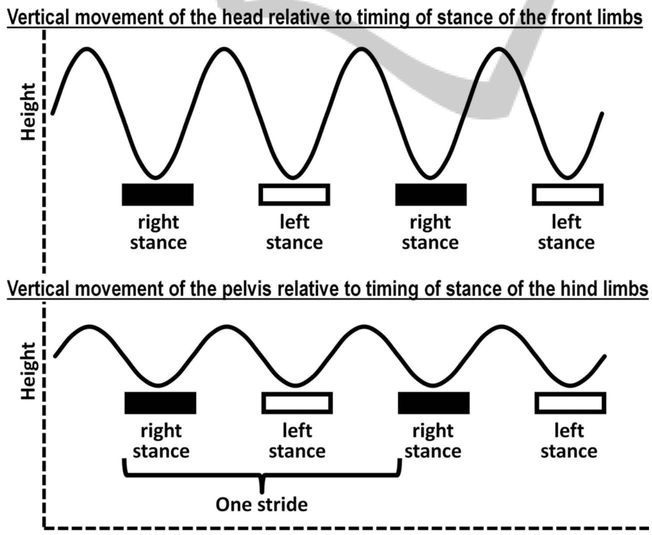

Fig. 1. Periodic signal representing normal vertical movement of the head or pelvis of horses moving at the trot. Local minimums are reached at middle of the stance of each limb (i.e., front limb for head movement, hind limb for pelvic movement) and local maximums occur after stance of each limb.

Kinematic studies of normal horses and lame horses moving at the trot have demonstrated that the head and pelvis move up and down twice during each stride.

Head and pelvic height reach lowest position in the middle of and highest position after the stance phase of each diagonal pair (Figure 1) [5]; [4]; [13]. Lameness manifests as perturbation of the normal sinusoidal-like vertical movement of the head and pelvis (at twice stride frequency) by a recurring component (at 1x stride rate) (Figure 2) [13].The aim of this article is to describe this approach of objective lameness evaluation using wireless transmission of body mounted inertial sensors and to demonstrate that it can be used practically in clinical cases trotting naturally over ground.

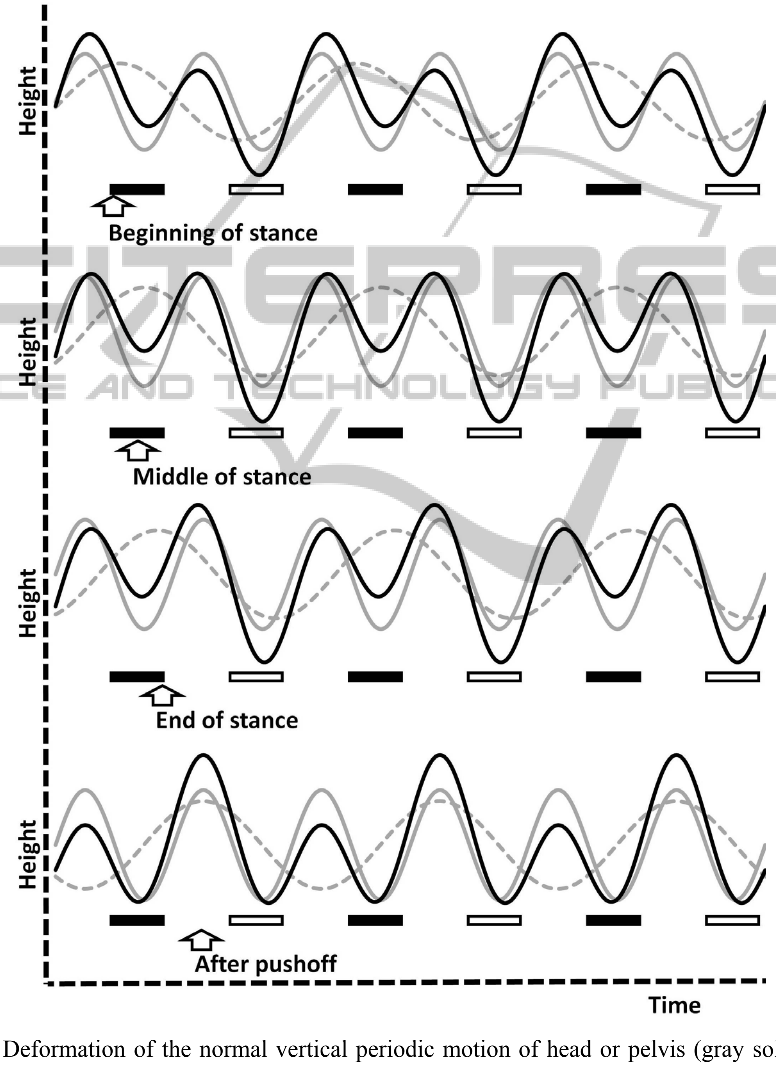

Fig. 2. Deformation of the normal vertical periodic motion of head or pelvis (gray solid line) by a component at 1x stride rate (gray dashed line) in lame horses moving at the trot. The black wave line represents the deformed periodic motion of a lame horse. Timing of lameness component relative to the phase of stride (arrows) indicates affected limb and phase of stance (beginning, middle, end) affected. The stances of the front limbs (if graphs represent head movement) or hind limbs (if graphs represent pelvic movement) are indicated as black (right limb) and white (left limb) rectangular figures.

2 Features of the Inertial Sensor-based System for Lameness Detection in Horses

2.1 Sensors

This device is composed of three small wireless inertial sensors each weighing 32 g and measuring 3.2 x 3.8 x 1.9 cm. Each sensor consists of a surface-mounted, microelectrical-mechanical device (accelerometer[1] or gyroscope[2]), radio transceiver (open wireless technology standard) and antenna[3], 4.2-V lithium-polymer battery[4], microcontroller,[5] and associated circuitry. The sensors are sampled synchronously at 200 Hz. Two of the sensors are uniaxial accelerometers, one attached to the head (Figure 3A) and one to the pelvis (Figure 3C). A third sensor is a gyroscope attached to the dorsal aspect of the right front distal limb (Figure 3B), measuring rotation of the digit on the sagittal plane. Fault detection algorithms are implemented to quantify vertical torso perturbation. This perturbation causes asymmetry of vertical torso movement, which is measured and reported to the user.

2.2 Computer

A tablet PC equipped with a class 1 Bluetooth receiver (Figure 4) receives and stores raw data, conducts data analysis, generates a report of the analysis, and stores the results of data analysis.

2.3 Software

Data acquisition and analysis software were custom written[6,7] to perform multiple tasks including a moving window error correction, double integration and decomposition into periodic and random components (Figure 5). After the random component is extracted, asymmetry of vertical torso movement (i.e., lameness) is quantified by calculating the ratio of the amplitude of the first harmonic (a1) to the amplitude of the second harmonic (a2) (Figure 5) and by calculating differences in local head and pelvis maximums and minimums between right and left strides (Figure 6). Means and standard deviations are calculated over all strides collected. Peak detection algorithms are used to automatically select strides to be analyzed. A report is generated at the end of data analysis (Figure 7).

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1 MMA7260QT, ± 1.5 to 6 g, Freescale Semiconductor, Austin TX, USA.
2 Gyrostar ENC-03M, Murata Electronics North America, Smyrna, GA, USA.
3 EYSF1SAJJ, Taiyo Yuden Co Ltd, Tokyo, Japan.
4 Hyper Power Co Ltd, Shenzhen, China.
5 PIC18LF452/PQ(44), Microchip Technology Inc, Chandler, AZ, USA.
6 Delphi, Borland Software Corp, Austin, Tex.
7 MATLAB, The Mathworks Inc, Natick, Mass.

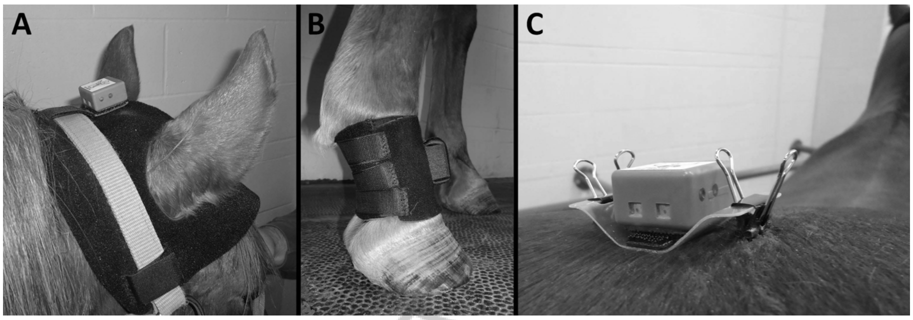

Fig. 3. Inertial sensor based system for lameness detection in horses: A and C - Vertical accelerometer positioned on the top of the head (poll) and top of the croup (between the sacral tuberosities); B – Gyroscope positioned on the dorsal aspect of the pastern of the right front limb.

Fig. 4. Data collection with the inertial sensor based system for lameness detection in horses: A tablet PC equipped with a long-range class 9 Bluetooth receiver stores and analyses data obtained by the inertial sensors.

3 Validation of the Inertial Sensor-based System for Lameness Detection in Horses

This system has been validated by comparison with traditional kinematics using horses with and without lameness trotting on the treadmill, with stationary force plate evaluations (kinetics) and with subjective evaluation by expert veterinarians. The inertial sensor system has shown to be precise [14], accurate [15]; [16] and more sensitive than subjective evaluation performed by experienced veterinarians [17]. Results of evaluation with the inertial sensor system correlate with results of traditional kinematic evaluation [16] and, for forelimb evaluation, with the results of evaluation with the stationary force plate [15]. Correlation between the evaluation with the inertial sensor system and evaluation with the stationary force plate has not been investigated yet.

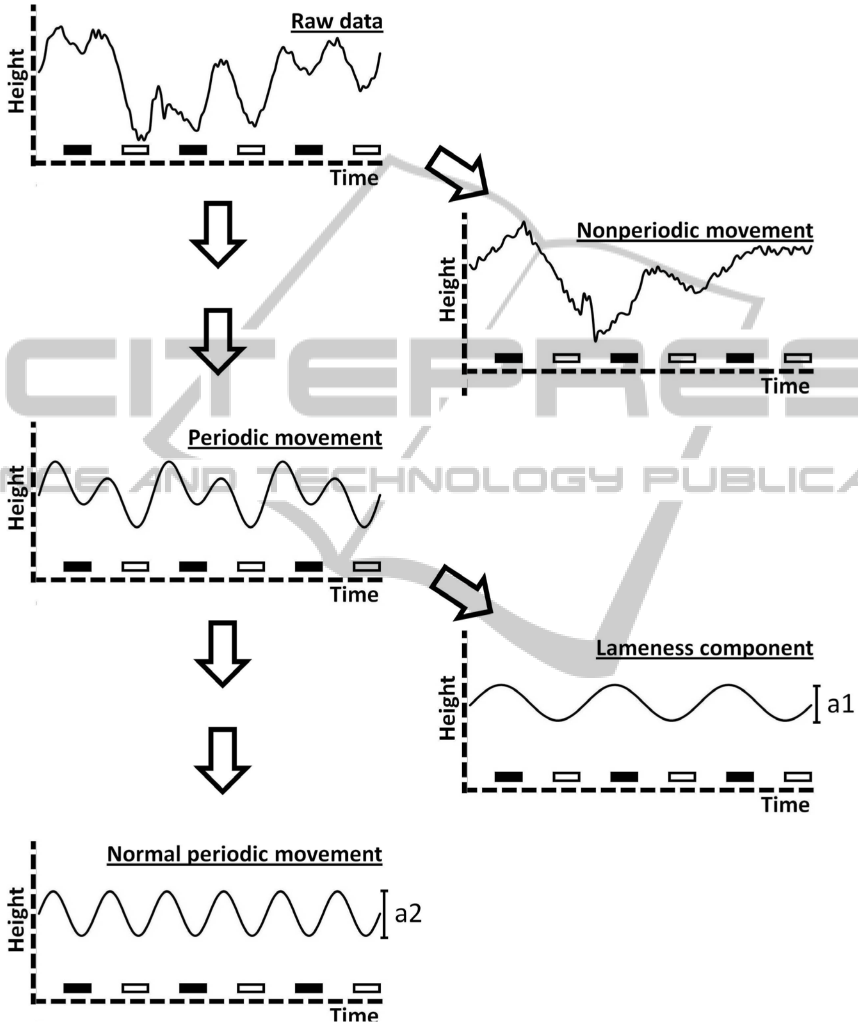

Fig. 5. Decomposition of the sinusoidal-like curves of vertical displacement signals of the head or pelvis into periodic components and random moving average. The stances of the front limbs (if graphs represent head movement) or hind limbs (if graphs represent pelvic movement) are indicated as black (right limb) and white (left limb) rectangular figures under the horizontal axis. The first periodic harmonic with frequency equal to frequency of the stride is the lameness component. The second harmonic with frequency equal to twice the frequency of the stride represents the normal vertical oscillation of the head or pelvis. Lameness severity is proportional to the ratio between the amplitude of the lameness component and the normal component (a1/a2).

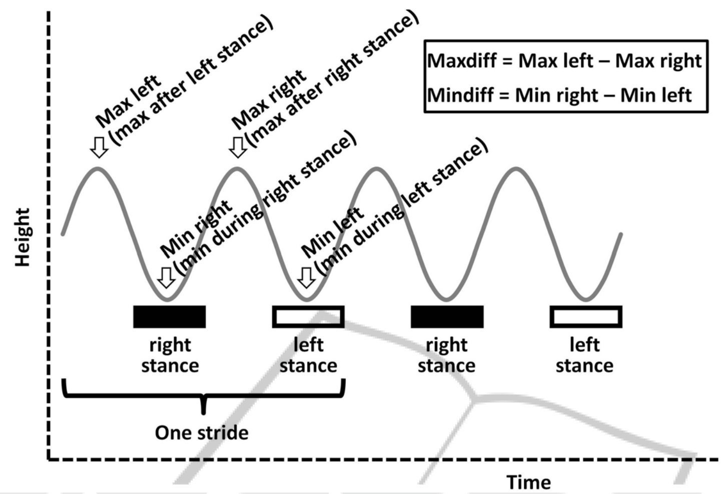

Fig. 6. Calculation of the difference between the maximal positions of the head or pelvis (maxdiff) after the stance of each diagonal limb pair. Calculation of the difference between the minimal positions of the head or pelvis (mindiff) during the stance of each diagonal limb pair.

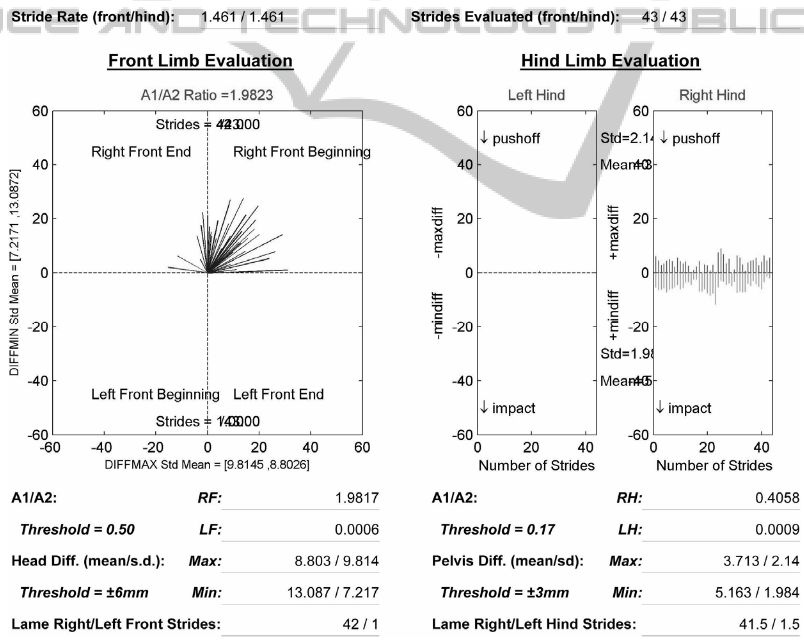

Fig. 7. Report of an evaluation performed with the inertial sensor system. Results of the front limbs are on the left side and results of the hind limbs are on the right side. Graphs and the data reported below each graph should be considered while interpreting the results.

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