Gait Analysis in Horse Sports

Jessica Maria Echterhoff
Technical University Munich
Munich, Germany
contact@jessicaechterhoff.com

Juan Haladjian
Technical University Munich
Munich, Germany
haladjia@in.tum.de

Bernd Brügge
Technical University Munich
Munich, Germany
bruegge@in.tum.de

ABSTRACT
In modern showjumping and cross-country riding, horse-rider-pairs have to jump a series of obstacles in a given time. A jump is considered successful (penalty-free) if a horse can comfortably jump the fence without elements of the fence falling down. If any of the elements of the fence falls down or the horse refuses to jump, the rider obtains penalty points or can be disqualified from the competition. An unsuccessful jump can lead to injury and loss in trust of the rider. The success of a jump is determined by the number, length and harmony of strides a horse performs before a fence. We propose a system for tracking horse strides and jumps using a smartphone attached to the horse's saddle.

Our system detects and segments individual strides and computes the length of a stride using signal processing and machine learning methods. We collected data from 9 horses who performed several jumps. Our results indicate that our system can detect horse strides with a precision of 96.3%, a recall of 95.7% and a pearson correlation of 0.73 with respect to our ground truth data set. We further describe a method to characterise the canter gait of the horse. Our system is intended to be used by riders to adapt their training and competition strategies to the physical limitations of the horse. The rider can thus prevent accidents due to an overtaxing of the horse or miscalculation of canter strides by the rider.

ACM Classification Keywords
H.5.2. Information Interfaces and Presentation: Miscellaneous

Author Keywords
Wearable Sensing; Showjumping; Cross-Country; Motion Characteristics; Activity Recognition

INTRODUCTION
Horses served humans for the entirety of modern history. They helped humans to carry weights, farm fields and transport people to different locations. In the modern western culture, most heavy work is done by cars, trucks and agricultural tractors. Humans and horses can thus enjoy athletic and leisure time together, which contributes to a positive life quality of the two companions. Showjumping and cross-country riding are sports based on a deep confidence between the rider and the horse and strengthen the bonding between them.

Showjumping as well cross-country riding require a rider and a horse to jump over a course of fences in a specific order within a given time. The order of fences, course length and optimal speed is given by the course designer and known before riding the course. Inside the course, fences are placed separately or in close distance to each other. The horse has to make a specific amount of strides between fences in order to perform a successful jump.

We propose a system to keep track of gait characteristics and present statistics of the ridden course to the rider with its details for specific canter strides made before each jump. We study the horse's motion signal collected with a sensor on the horse's body to obtain canter characteristics for showjumping and cross-country riding. Our system assesses the stride length to measure the equality of canter strides between the jumps. The system provides the average stride length of each horse to the rider to enable planning a strategy for the course and measures the horse's ability to reduce or extend the stride length. Reducing the stride length means that the horse shortens the stride - it collects itself to cover less ground in the same rhythm. Extending the stride length means that the horse's rhythm stays the same but the horse stretches itself to cover more ground. The variability in stride length is an indicator of the physical condition and training status of the horse. For example, if a sequence of jumps is designed to have the horse put two strides between them, but the horse's stride is too short, it will add a small extra stride. The horse will subsequently take off too close to the second element of the jump combination. Because the takeoff spot is too close to the jump, the horse risks knocking the poles, or worse, tripping over the jump and possibly even falling. Therefore, knowing the correct number of strides between jump elements is not just a performance issue, but a safety issue. Our system supports riders in decisions regarding the right amount of strides to make in order to perform more successful jumps and decrease the probability of severe injury of the horse.

BACKGROUND
An average sport horse is able to move in three different gaits - walk, trot and canter, which differ in the intensity of speed, frequency, and vertical swing. We define the frequency of the horses gait as the amount of steps made in a specific amount of time and the vertical swing as the up-and-down movement of the horse's back. Walk is four-beat movement, trot a two-beat movement with diagonal pairs simultaneously on the ground

ACI18, December 4–6, 2018, Atlanta, GA, USA

DOI: https://doi.org/10.1145/3295598.3295601

Figure 1. Horse performing three equal canter strides before a jump. Canter strides (a), (b), (c) are of equal length and lead to a successful takeoff point (d) and jump (e). Same horse performing three canter strides before a different jump. Canter strides (g), (h) are significantly longer than (f) and lead to a takeoff point to far from the fence (i) and a jump, where the horse has to distort its body to jump the fence (j).

and canter is a three-beat movement. One canter stride is a full sequence of a hind foot strike, diagonal pair and a front foot strike in the 3-beat rhythm. Horses typically jump all fences in a course running towards them in canter. While it is possible to jump fences when trotting, it is not common in competition and training scenarios.

Riders usually walk the course beforehand to measure distances between the fences and determine the amount of strides to make between them. To successfully find a strategy for riding the course, it is essential to know the horse's stride length and how far the horse is able to reduce or extend its stride length. Depending on its training status and physical conditions, a horse's stride length and variability is different and not always visually predictable. Riders need to prepare the distribution of canter strides in front of a fence equally so that the horse can jump a fence comfortably. This includes bringing the horse towards the fence in an approximately 90 degree angle, so that it can jump the fence straight and close to its centre. If fences are placed in short distance to each other, it is required to make a specific amount of strides between the fences. The rider needs to decide beforehand how many strides to make with the horse. Inside a jumping course, two fences can have no canter strides between them (so called in-and-out), 1-2 strides between them (so called combination), or 3-7 strides between them (so called distances). A well prepared distance reduces the amount of interference between the rider and the horse.

Throughout the course, the rider needs to keep harmony and equality in the frequency, speed and length of canter strides. If the horse increases or decreases the stride length right before the jump more than a certain degree, the probability of an unsuccessful jump increases. Figure 1 compares the strides a rider determined and the horse performed before a proper and a poor jump. In picture (i) and (j), we observe a tilted body position of the horse to the left, performing a jump unorthogonal to the fence jumping to the right side. The horse is scrambling over the jump which can be seen because its head is up and its neck is inverted (not round) to compensate for taking off too far away from the jump. This position results from the rider not determining the last canter strides before the jump correctly ((f)-(h)). The takeoff point before the jump is too far away from the fence and the horse is forced to jump in a different flight curve than physically comfortable. In contrast, picture (a)-(c) show a correct determination of canter strides, leading to good takeoff point a natural flight curve of the horse over the fence ((d)-(e)). We observe the horse to have a round and balanced neck over the jump.

RELATED WORK

Previous research studies in the field of Animal-Computer Interaction (ACI) have investigated the use of wearable technologies for different animal species. Research was done with dogs and the respective dog-human interaction using wearable sensors. Ladha et al. [6] focused on activity recognition for dogs, and classified jumping and walking for measuring the dogs' well being. Similarly, Valentin et al. [14] studied how to classify different dog gestures for the dog's communication with humans using wearable sensors. Thompson et al. [12] classified and quantified postures and posture transitions for enhancing welfare and productivity of pigs. Haladjian et al. and Pastell et al. [4, 9] developed an approach to detect anomalies in the gait of cows that might be caused by a lameness-related disease.

Previous research on horses includes using wearable sensors both for the kinematic analysis of horses as well as for tracking the rider's posture. Low et al. [8] studied how to prevent lamenesses in racehorses using a wireless sensor system attached to the horse's limbs, whereas Uhlir et al. [13] used a wearable motion sensor in the horse's neck to detect lamenesses in horses. Thompson et al. [11] developed a system for automated feedback for dressage riders. They used several sensors on the horse's limbs to classify different gaits and specific exercises in the domain of dressage. Green et al. [5] provided a system for tracking positions, velocity and physiological data of horses using wearable sensors in equestrian training. Barrey and Galloux studied the kinematics of a horse's gait and found that the penalty rate increased if the horse was ridden in a low stride frequency and suddenly reduced its stride frequency at takeoff [1, 3]. Other studies track the rider's behaviour and posture. Li et al. [7] investigated how to correct an equestrians posture using a wearable sensor system. A similar study quantifies the horse-rider-expertise using inertial sensors in show jumping to classify their performance level [10].

In comparison to other approaches, our system focuses on tracking and gathering information on the canter pattern of the horse relevant for the respective rider in the context of horse sports.

METHODS

Our system computes specific characteristics for the canter gait of a horse. We perform computations on the horse motion signal acquired by a smartphone. All further processing and evaluation methods are based on the collected motion signal.

Study Design

We collected motion data from 9 different horses in their regular showjumping or cross-country training. All horses completed one or two full jumping courses, including 4 cross-country courses and 5 showjumping courses. Our recordings include gait motion such as walking and trotting before and after the actual execution of the course. The horse-rider-pairs jumped different fences such as verticals (see Figure 1), oxers (two verticals in close distance to each other, to make the jump wider) or tree trunks in different heights, widths and shapes depending on the experience of the pair. These different fences require different takeoff points to accomodate the width of the respective jump. The horse-rider-pairs we selected ranged in their levels of expertise. Some horse-rider-pairs were able to jump 100 cm (± 5 cm) fences and others jumped 125 cm (± 5 cm) fences. We chose horses of different heights to represent a broad variety of stride lengths. All horses and their information is shown in Table 1. We recorded the signals produced by the accelerometer, gyroscope and magnetometer available in an iPhone 7 with a sampling rate of 100 Hz.

We placed the smartphone in a bag attached to the right side of the saddle pad, with its display facing the horse's body. Figure 2 shows how the iPhone was attached and illustrates the sensor coordinate system. We mounted the bag on the horse's torso to capture its vertical and horizontal body movement. If the rider had a stable and balanced posture inside the saddle, contact to the smartphone with the rider's leg was not possible. We constructed the bag to fit the iPhone tightly to avoid noise in the signal caused by shaking. We gathered the movement of all 9 horses in four different riding arenas. Our data set contains movements from two indoor arenas with a size of 20x30m and 20x60m as well as two outdoor arenas with a size of 50x60m and 200x400m. Outdoor arenas enable horses to gain more speed, which potentially leads to an increased stride length and frequency compared to smaller indoor arenas. We video recorded all horse-rider pairs during the data collection and annotated start and end points for all canter strides according to the video protocol.

Figure 2. Placement of the smartphone on the horse's body for measuring body movements during jump training.

#	*Fence height*	*Horse Height*	*Discipline*
1	110	164	CC
2	110	145	CC
3	110	145	CC
4	110	164	CC
5	120	170	SJ
6	100	175	SJ
7	100	165	SJ
8	115	167	SJ
9	125	170	SJ

Table 1. Overview of the participants including parameters such as fence height of the course (± 5 cm). Different horse heights were chosen to represent different stride lengths according to physical conditions of the horse. Performed disciplines were Showjumping (SJ) and Cross-Country (CC).

Extraction of Canter Strides

Signal Preprocessing

To evaluate specific canter characteristics, we attenuated walk and trot segments in the recorded data using the approach described by Echterhoff et al. [2]. This approach detects canter strides and jumps with a precision of 94.6% and classifies them with an accuracy of up to 95.4%. We use this method to detect the respective gait and jump segments for further detailed processing.

To calculate the length of a canter stride, we determine the start and end of each stride. For this purpose, we filter the data with a first order Butterworth low-pass filter at 20 Hz to eliminate noise from the signal. The raw signal $S1_{raw}$ is transformed to the filtered signal $S1_{filt}$ within the signal length m:

$$S1_{filt}(x_i) = Butter(S1_{raw}(x_i)) \qquad 1 \leq i \leq m \tag{1}$$

Peak Detection

The canter gait pattern is determined by two local minima representing the start and end point as well as one local maximum. To obtain the local maximum for each stride, we run a peak detection on $S1_{filt}$. To get the start and end of each canter stride, we run another peak detection on the inverse filtered acceleration x-axis signal $S1_{filtinv}$, which is defined as:

$$S1_{filtinv}(x_i) = S1_{filt}(x_i) * (-1) \qquad 1 \leq i \leq m \tag{2}$$

The threshold h and minimal peak distance r for the peak detection were chosen by visual observation of the raw signal and set to 0.5 and 40. We detect peaks $P_j(x_i)$ for $j \in \{filtinv, filt\}$ for canter strides as follows:

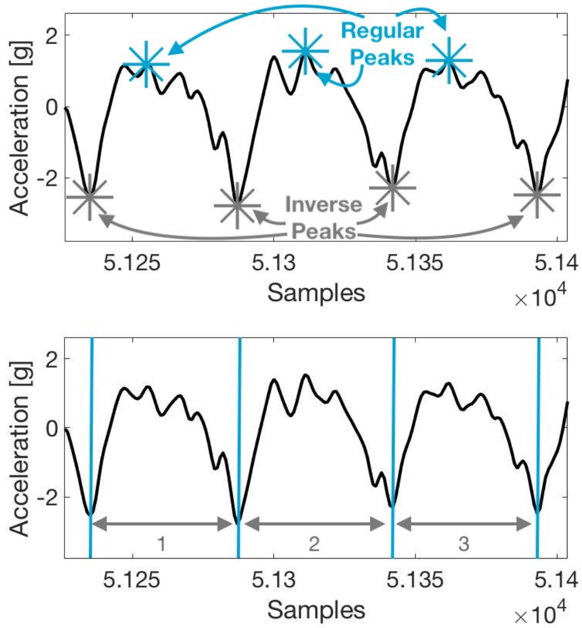

Figure 3. Stride segmentation performed on the filtered x-axis acceleration signal by detecting peaks (blue) and inverse peaks (grey) (top). Final canter stride segments 1,2,3 based on the peak detection (bottom).

$$P_j(x_i) = \begin{cases} 1, & \text{if } s \geq h. \forall s \in \{S_{1_{filtinv}}(x_i), S_{1_{filt}}(x_i)\} \\ 0, & \text{otherwise} \end{cases} \quad (3)$$

Stride Segmentation

To map each detected canter stride $P_{filt}(x_i)$ to one detected start $P_{start}(x_i)$ and one detected end peak $P_{end}(x_i)$, the two peaks around $P_{filt}(x_i)$ were chosen:

$$\begin{aligned} P_{start}(x_i) &= P_{filtinv}(y_i). \\ \forall P_{filtinv}(y_i) < P_{filt}(x_i) \wedge P_{filtinv}(y_i) &> P_{filt}(x_{i-1}) \end{aligned} \quad (4)$$

$$\begin{aligned} P_{end}(x_i) &= P_{filtinv}(y_i). \\ \forall P_{filtinv}(y_i) > P_{filt}(x_i) \wedge P_{filtinv}(y_i) &< P_{filt}(x_{i+1}) \end{aligned} \quad (5)$$

If there were more than one $P_{filtinv}(x_i)$ detected between two $P_{filt}(x_i)$ and $P_{filt}(x_{i+1})$, we chose the one closest to the respective $P_{filt}(x_i)$.

The canter stride segments k, detected with our peak detection, are defined by:

$$k = [P_{start}(x_i), P_{end}(x_i)] \quad (6)$$

Figure 3 shows three canter strides of the filtered signal $S_{1_{filt}}$ and explains how the peaks were detected (top) and segmented (bottom).

Stride Length Evaluation

The segments are characterised by the duration D in samples:

$$D(x_i) = P_{end}(x_i) - P_{start}(x_i) \quad (7)$$

The average stride duration d in samples and seconds of each horse is defined by

$$d_{samples} = \frac{\sum_{i=1}^{n} D(x_i)}{n} \quad (8)$$

$$d_{sec} = \frac{d_{samples}}{f} \quad (9)$$

for the overall amount of canter strides n in seconds with sampling frequency $f = 100$.

For each horse, the average canter stride length $d_{samples}$ is linearly compared with the horse's height h using a pearson correlation ρ to measure the strength of relationship between the two characteristics.

$$\rho = \frac{\mathrm{cov}(h,d)}{\sigma_h \sigma_d} \quad (10)$$

with standard deviation σ_h, σ_d and covariance $\mathrm{cov}(h,d)$ of the horse height and canter stride length. A pearson correlation coefficient of 1 indicates a strong positive relationship, -1 indicates a strong negative relationship. A coefficient of 0 describes the absence of a linear relation.

Finding the Number of Canter Strides before Fences

Based on our stride extraction method, we detect the last canter strides before a jump. To find the relevant strides, we first detect jumps inside the horse motion signal using [2]. We subsequently process the preceding 6 seconds before a jump occurred. If this preceding time interval contains another jump we trim the interval to fit between the respective fences. If the time interval does not contain another jump, the interval is trimmed to evaluate the last 7 canter strides before the jump. We further process the interval with our stride segmentation algorithm. The number and distribution of the detected canter strides between two fences is then displayed inside the user interface as an overview of the critical segments inside a jumping course.

USER INTERFACE

All gait characteristics are evaluated in real time inside the system, so that riders can see their training statistics for each jump. Inside the user interface, we show three different components. To evaluate the ridden path, an overview of the course is shown. The rider can see the path to evaluate the route to the respective fences (Figure 4 (a)). The user interface shows if the curves to the fences were ridden correctly and if the fences were reached in the right angle. Based on this course overview, the rider can zoom into specific sections of the course. The system shows the specific amount of strides made between fences for distances and combinations as well as the last canter strides before every single fence. The rider is thus able to evaluate the canter strides before a fence and see if the last strides were equally distributed. Figure 4 (b) shows this distribution of canter strides between fences, which helps the rider to post-evaluate problems of the jumping course. Riders can furthermore observe canter characteristics of their

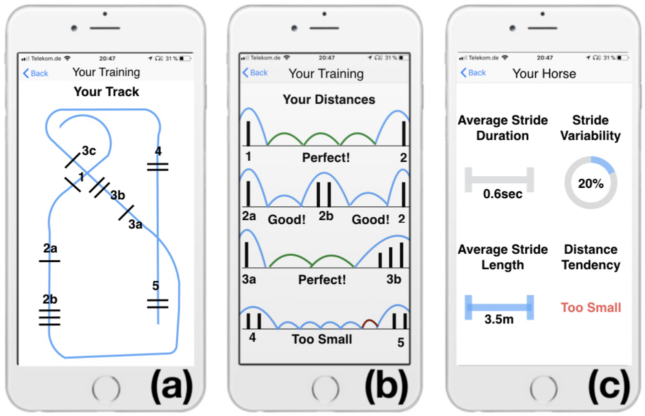

Figure 4. Bird's eye view of the course jumped (left) and obtained horse characteristics (right). Distribution of canter strides between fences. Green color indicates an equal distribution of canter strides before the fence, red color indicates that the canter strides before the jump were not equally distributed (middle).

horse inside the application. We enable the rider to consider the horse's training status by its gait characteristics. The displayed characteristics are a basis for for recommendations regarding possible training and competition strategies. For instance, if the rider gets information on the horse's small stride length from our system, she can consider making one canter stride more between the fences in the future. By knowing the amounts of strides to be performed before specific fences, riders can lead horses to find better takeoff points and gain trust in the rider. The system supports the rider by offering a post-evaluation of the ridden course. The rider can review the horse's performance and development over time and conclude further training steps. The user interface was designed and assembled by an experienced rider and enriched by the study participants suggestions.

RESULTS

Extraction of Canter Strides

Due to the rolling up and down movement of the horse in each canter stride we can detect the beginning and end of each stride. To evaluate the canter stride detection method, all beginnings and endings of canter strides in our data set were previously labeled according to a collected video protocol. In total, 3349 canter strides were labeled and used as our ground truth. A canter stride was detected correctly and marked as a True Positive (TP) if the maximum difference d of the detected to the labeled inverse peak $P_{filtinvstart}(x_i)$ and $P_{filtinvend}(x_i)$ is $d \leq 0.1$ s and the segment k contained a labeled peak $P_{filt}(x_i)$. The maximum difference d was chosen narrowly to ensure a precise calculation of the stride length. Detected strides or jumps were marked as False Positives (FP), if no label was found within range $d > 10$ samples. Labeled, but undetected strides were marked as False Negatives (FN). Correctly undetected instances are referred to as True Negatives (TN). An overview and the respective share to the ground truth is shown in Table 2.

#TP	*%*	*#FP*	*%*	*#FN*	*%*
3204	95.7	122	3.6	145	4.3

Table 2. True Positives, False Positives, False Negatives and their respective share of the overall data set.

#Instances	*Precision*	*Recall*	*F-Measure*
3349	96.3	95.7	96.0

Table 3. Performance of our canter stride detection approach in %.

Figure 5 shows a comparison of every ground truth canter stride length and the respective canter stride length detected by our system. This figure shows that every horse has a tendency towards a certain stride length. To explain the difference in canter stride lengths of different horses, Table 4 shows these two characteristics of the observed horses. We further compared the extracted stride length to the horse's height using the pearson correlation, since a smaller horse typically has a smaller stride length. The horse's stride length and the horse's height are positively correlated with a pearson correlation coefficient of 0.73.

CONCLUSION

This paper provides an evaluation of canter stride characteristics for showjumping and cross-country riding. Our stride detection algorithm extracts strides with a precision of 96.3% and a recall of 95.7%. Our peak detection method is thus

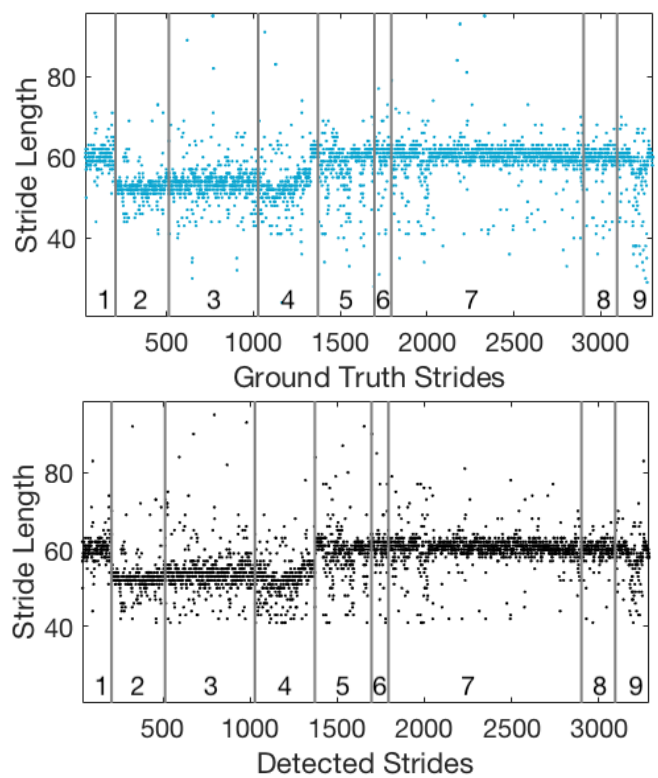

Figure 5. Comparison of the real and detected canter stride length. The vertical sections indicate the canter strides made by each different horse.

#	*Stride Length*	*Horse Height*
1	60.4	164
2	52.7	145
3	54.4	145
4	52.6	164
5	59.5	170
6	60.8	175
7	60.3	165
8	59.8	167
9	58.4	170

Table 4. Average stride length in samples per horse and horse height in cm.

suitable to provide feedback to the rider in real life. The misdetection rate of 3.6% and 4.3% for undetected instances of our system indicates that the system's prediction of the average stride length will not differ significantly when tracking the gait for an entire training session. We evaluate the ridden strides by their length, which can help the rider to get an overview of the training status and physical condition of a horse. This can be used as a reference to plan the amount of strides to make between fences for a successful course strategy. The pearson correlation between the horse's height and the stride length is positively correlated with a correlation coefficient of 0.73. The horse's height is thus an indicator of its average stride length.

In the future, we would like to investigate which other parameters have an impact on the horse's average stride length. Furthermore, we would like to study the importance of a correct takeoff point before a fence and its significance for a successful jump. Some horses tend to get too close to the fence before taking-off, and others takeoff to early before the fence. This can lead to the horse touching or even falling into the fence. Typically, these mistakes can be corrected by proper training. We would like to study how to evaluate the jumping tendency of the horse and provide this information as a training suggestion to the rider.

To enhance the rider's experience with the system, we would like to evaluate the user interface in a study to improve the impact of the user interface on the rider's decision making and consequently the horse-rider-pair's performance.

REFERENCES

1. E. Barrey and P. Galloux. 1997. Analysis of the equine jumping technique by accelerometry. *Equine Veterinary Journal* 29, 23 (1997), 45–49.
2. J. Echterhoff, J. Haladjian, and B. Brügge. 2018. Gait and jump classification in modern equestrian sports. In *Proceedings of the 2018 ACM International Symposium on Wearable Computers*. ACM, To appear.
3. P. Galloux and E. Barrey. 1997. Components of the total kinetic moment in jumping horses. *Equine Veterinary Journal* 29, 23 (1997), 41–44.
4. J. Haladjian, B. Brügge, and S. Nüske. 2017. An approach for early lameness detection in dairy cattle. In *Proceedings of the 2017 ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2017 ACM International Symposium on Wearable Computers*. ACM, 53–56.
5. A. Hill, A. Slamka, Y. Morton, M. Miller, and J. Campbell. 2007. A real-time position, velocity, and physiological monitoring and tracking device for equestian and race training. In *Proceedings of the ION GNSS*.
6. C. Ladha, N. Hammerla, E. Hughes, P. Olivier, and T. Plötz. 2013. Dog's life: Wearable activity recognition for dogs. In *Proceedings of the 2013 ACM International Joint Conference on Pervasive and Ubiquitous Computing*. ACM, 415–418.
7. J. Li, Z. Wang, J. Wang, H. Zhao, S. Qiu, and M. Guo. 2017. Study on the attitude of equestrian sport based on body sensor network. In *2017 IEEE International Conference on Systems, Man, and Cybernetics (SMC)*. IEEE, 3653–3658.
8. J. Low, V. Mak, B. Forbes, F. Sepulveda, and C. Yeow. 2016. Development of a wearable gait detection system for racehorses. In *ISBS-Conference Proceedings Archive*, Vol. 33.
9. M. Pastell, M. Kujala, A. Aisla, M. Hautala, V. Poikalainen, J. Praks, I. Veermäe, and J. Ahokas. 2008. Detecting cow's lameness using force sensors. *Computers and Electronics in Agriculture* 64, 1 (2008), 34–38.
10. M. Patterson, J. Doyle, E. Cahill, B. Caulfield, and U. Persson. 2010. Quantifying show jumping horse rider expertise using IMUs. In *Engineering in Medicine and Biology Society (EMBC), 2010 Annual International Conference of the IEEE*. IEEE, 684–687.
11. R. Thompson, I. Kyriazakis, A. Holden, P. Olivier, and T. Plötz. 2015. Dancing with horses: Automated quality feedback for dressage riders. In *Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing*. ACM, 325–336.
12. R. Thompson, S. Matheson, T. Plötz, S. Edwards, and I. Kyriazakis. 2016. Porcine lie detectors: Automatic quantification of posture state and transitions in sows using inertial sensors. *Computers and Electronics in Agriculture* 127 (2016), 521–530.
13. C. Uhlir, T. Licka, P. Kübber, C. Peham, M. Scheidl, and D. Girtler. 1997. Compensatory movements of horses with a stance phase lameness. *Equine Veterinary Journal* 29, 23 (1997), 102–105.
14. G. Valentin, J. Alcaidinho, A. Howard, M. Jackson, and T. Starner. 2016. Creating collar-sensed motion gestures for dog-human communication in service applications. In *Proceedings of the 2016 ACM International Symposium on Wearable Computers*. ACM, 100–107.