Equimetrics: An Open-Source Wearable System for Real-Time Feedback in Equestrian Sports

Jonas Pöhler
University of Siegen
Siegen, Germany
jonas.poehler@uni-siegen.de

Kristof Van Laerhoven
University of Siegen
Siegen, Germany

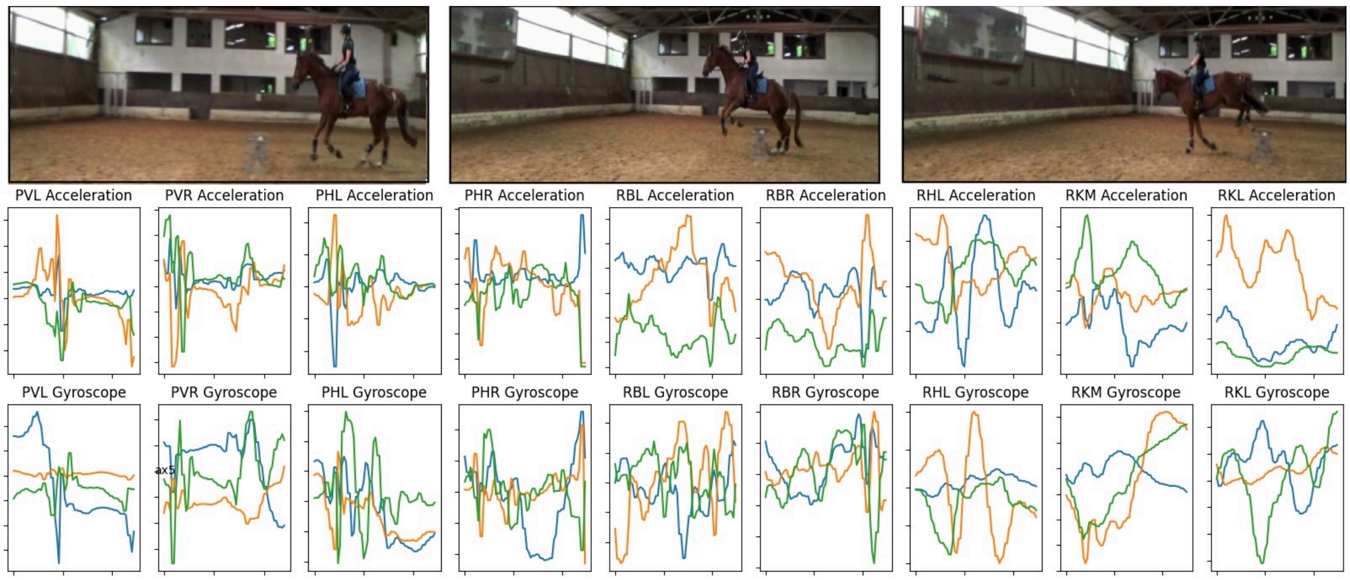

Figure 1: Exemplary 5-second data windows captured by the Equimetrics system during a jump over an obstacle. The top row shows 3-axis accelerometer data (in g) and the bottom row shows gyroscope data (in dps) from nine sensor locations on the horse and rider. The synchronized video frames are shown above the plots.

Abstract

This paper presents Equimetrics, an open-source wearable system for real-time equestrian analysis. We detail its design, implementation, and validation through a case study where the system provided live audio feedback to riders. The study demonstrates that the data captured by Equimetrics is robust enough to drive effective, in-the-moment coaching interventions, with findings showing that structured, data-driven feedback catalyzed tangible improvements in skill execution, particularly for less-experienced riders. By fusing objective, sensor-based analytics with traditional coaching expertise, this work offers a promising new approach to enhance equestrian training.

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CCS Concepts

• **Human-centered computing → Ubiquitous and mobile computing systems and tools**; *Empirical studies in ubiquitous and mobile computing*.

Keywords

Wearable Sensors, Equestrian Sports, Activity Recognition, Real-Time Feedback, Open-Source Hardware

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1 Introduction

Effective performance in equestrian sports requires precise coordination between horse and rider, where precision during transitions and movements is paramount. Traditionally, performance assessment has relied on the subjective feedback of coaches and judges, whose qualitative evaluations are susceptible to bias and limited in their ability to capture the fine-grained biomechanics of the horse-rider partnership. While valuable, this approach lacks the objective, repeatable data needed for systematic analysis and targeted training interventions.

Recent advances in wearable technology and Human Activity Recognition (HAR) offer a powerful opportunity to move beyond these limitations. By using networks of wearable inertial sensors, it is possible to capture detailed, quantitative data on the complex interplay of movements between horse and rider in real-time. This data-driven approach, common in other sports and human motion analysis, can provide unprecedented insights into equestrian performance.

To bring these capabilities to the equestrian domain in an accessible manner, we present Equimetrics, the primary contribution of this paper. Equimetrics is an open-source, cost-effective wearable system designed for the comprehensive capture and analysis of horse-rider dynamics. It utilizes a network of strategically placed inertial sensors on both horse and rider to create a holistic view of their interaction, leveraging open-source hardware and software to ensure the platform is affordable and reproducible for researchers and trainers alike.

A sensor platform's true value, however, is demonstrated through its practical application. As this paper's second key contribution, we present a case study that validates the Equimetrics system's utility in a real-world training scenario. We developed and evaluated a closed-loop system that provides riders with real-time audio feedback to improve their accuracy when performing specific dressage patterns. This study demonstrates that the data captured by Equimetrics is not only descriptive but also robust enough to drive effective, in-the-moment coaching interventions.

This paper will first detail the architecture and open-source nature of the Equimetrics system. We then describe its core analytical capabilities, including gait classification and the novel separation of rider and horse movements. Following this, we present the methodology and results of our real-time audio feedback study. We conclude with a discussion of our findings, the system's current limitations, and avenues for future work, highlighting how open-source wearable systems can improve equestrian training.

2 Related Work

The use of wearable sensors, particularly Inertial Measurement Units (IMUs), for human motion analysis is well-established, with wide-ranging applications in sports science, healthcare, and activity recognition [8, 12, 13]. These systems have proven effective for quantifying athletic performance, analyzing gait, and providing insights into biomechanics. Building on this foundation, researchers have increasingly applied similar sensor-based approaches to the complex domain of equestrian sports.

In equestrian science, a substantial body of work has focused on using IMUs for the objective analysis of the horse. A primary application is in veterinary medicine for gait analysis and objective lameness detection [4, 5, 7]. Systems, often validated against optical motion capture gold standards, use sensors placed on the poll, withers, and pelvis to measure movement asymmetries indicative of lameness [7]. Other studies have focused on characterizing gait quality, measuring spatiotemporal parameters like stride length and frequency, and classifying gaits such as walk, trot, and canter [6, 11]. While powerful, these systems are frequently either high-cost, proprietary commercial products (e.g., Equinosis Q, Lameness Locator) or closed-source research prototypes. This "black box" nature limits their accessibility for the broader research community and hinders customization and further innovation.

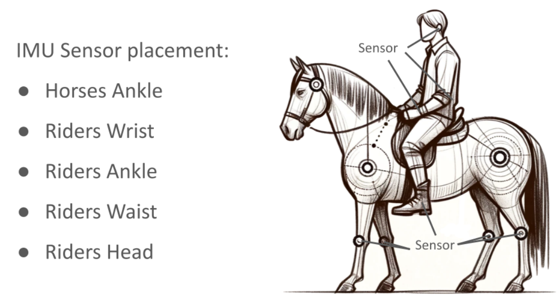

Figure 2: Positions of the IMU sensors.

Beyond analyzing the horse in isolation, another thread of research investigates the rider's impact on equine movement. Studies have used IMUs to quantify rider posture, stability, and the influence of rider asymmetries on the horse [3]. This work underscores the importance of the rider in the horse-rider dyad, yet it often treats the rider as a separate entity rather than as part of a tightly coupled system. Our work aligns with a more holistic view, recognizing that a comprehensive understanding requires capturing the dynamic interaction between both athletes simultaneously [10].

The final crucial element, largely absent in the existing equestrian literature, is the integration of real-time, actionable feedback for motor learning. Research in sports science has repeatedly shown that augmented feedback—delivered visually, audibly, or haptically—can significantly accelerate skill acquisition by enabling immediate error correction [14]. While some equestrian systems provide post-ride analysis, very few offer the real-time, closed-loop feedback necessary to guide a rider during a training session. This is a critical gap, as the potential to correct movements at the moment they occur is a cornerstone of effective coaching.

Synthesizing these points reveals a clear gap in the available tools: the field lacks an open-source, low-cost, yet high-precision system capable of capturing the holistic horse-rider dyad and robust enough to support real-time feedback interventions. Existing solutions are often proprietary, expensive, focused on a single aspect (e.g., lameness), or limited to post-hoc analysis. Our work, Equimetrics, directly addresses this gap by providing an accessible, open platform and demonstrating its utility through a real-time coaching application, thereby bridging the divide between data capture and practical training enhancement.

3 The Equimetrics System

The Equimetrics system was designed from the ground up to be a cost-effective, adaptable, and fully open-source platform for equestrian motion analysis. Its core architecture consists of a network of up to 10 wireless Inertial Measurement Unit (IMU) sensor nodes

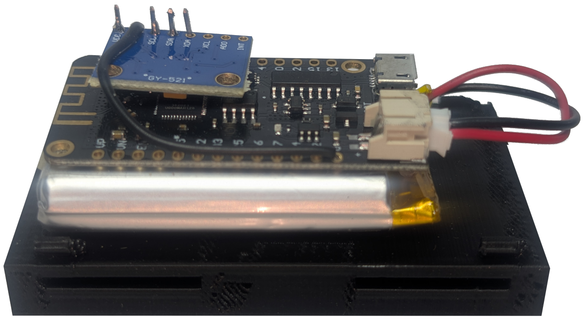

Figure 3: IMU Sensor Node

that stream time-synchronized data from both the horse and rider to a central processing unit for storage and real-time analysis.

Each sensor node is built using widely available and low-cost components to maximize accessibility. An ESP32 microcontroller serves as the brain of each node, managing data acquisition and wireless communication. Motion is captured by an MPU-6050, a MEMS device containing a 3-axis accelerometer and a 3-axis gyroscope. To provide a comprehensive view of the horse-rider dyad, these sensors are strategically placed on the rider's head, torso, wrists, and ankles, as well as on all four of the horse's lower limbs, as illustrated in Figure 2. This distributed configuration allows for the capture of both individual limb movements and the overall dynamics of the combined system.

Data is streamed from each sensor node at a high sampling rate of 130 Hz, which is sufficient to capture the rapid movements characteristic of equestrian activities, including jumping. The accelerometer is configured with a range of ±16g and the gyroscope with a range of ±2000 dps to avoid clipping during high-impact events. Data transmission is handled via Wi-Fi using the User Datagram Protocol (UDP), which provides the low-latency stream necessary for real-time applications.

In line with the principles of the OpenWearables community, the entire Equimetrics platform is open-source. The hardware designs and the software for data collection, synchronization, and processing are publicly available [2], enabling other researchers to replicate, modify, and build upon our work. To demonstrate the system's flexibility, the core IMU network was augmented for the real-time feedback study described in Section 5. For that use case, the IMU data was fused with positional data from a camera-based tracking system to provide a robust, real-time estimate of the rider's absolute location within the arena.

4 Data Analysis and Performance Metrics

The high-frequency, multi-point data captured by the Equimetrics system enables a rich, multi-layered approach to analysis, ranging from detailed kinematic event detection to high-level activity classification and quantitative performance scoring. The platform's foundational analyses provide deep insights into the horse-rider interaction. Leveraging the data from sensors on the horse's limbs, the system can automatically detect the precise timing of hoof-on and hoof-off events [15]. By fusing accelerometer and gyroscope data into quaternion representations, the algorithm identifies individual hoof placements with an average precision of 8.98 milliseconds, offering valuable data on gait patterns essential for assessing performance and health. Building on this, we address the challenge of distinguishing the rider's actions from the horse's movements by using the sensor on the rider's hip as a proxy for the horse's core motion [16]. By subtracting this movement from the rider's limb sensor data, we can isolate the rider's independent actions and calculate a comprehensive Movement Magnitude Index (MMI) to quantify their body control. At a higher level, we use this kinematic data to train two distinct Transformer-based models for automated activity recognition [9]. The first model identifies the horse's gait (walk, trot, canter) with an F1 score of 0.9324, while the second recognizes more complex dressage tasks with an F1 score of 0.7601 [6, 11]. The confusion matrices confirm reliable gait classification, with slightly lower performance on movements like the "Half Pass," likely due to its unique motion and fewer training samples.

To quantitatively evaluate and improve rider performance in our real-time feedback study, we developed specific metrics. Standard dressage tests require riders to execute gait transitions at designated points within the arena [1]. For our analysis, we expanded these points into "Activity Zones," defined as circular or elliptical boundaries around the ideal transition location. The system logs the precise location where each transition occurs and calculates the Euclidean distance between this point and the center of the target Activity Zone. This single value, the Distance to Activity Zone Center (DAZC), serves as our primary objective metric for measuring the accuracy of a rider's transitions, where a lower score signifies a more precise execution.

5 Use Case: A Real-Time Audio Feedback Intervention

To validate the Equimetrics platform's capability to do more than just record data, we designed and conducted a study to see if it could be used to actively improve rider performance in real-time. This use case demonstrates that the system is not only robust enough for detailed post-hoc analysis but also precise enough to drive a closed-loop feedback system for live coaching.

We conducted a pilot study with five experienced female riders, aged 18-25. To investigate the effects of sensor-based feedback, each rider participated in three distinct sessions performing the same dressage test pattern: a control session with no automated system, a session where they received real-time audio prompts guiding each transition, and a final judgment-only session where performance was tracked without live feedback. The primary outcome measure was the riders' ability to execute transitions within predefined "Activity Zones," quantified by the DAZC metric. Subjective data on the system's usability and effectiveness were also collected via post-session questionnaires.

The real-time tracking and feedback loop was enabled by fusing the data from the Equimetrics IMU network with a camera-based system that provided the rider's absolute position within the arena. A Kalman filter was used to create a smooth and continuous estimate of the rider's location. As a rider approached a designated Activity Zone, the system automatically triggered pre-recorded audio cues delivered through a discreet wireless earpiece. These cues consisted of a preparatory command, such as "Prepare to canter," followed by an execution command, "Transition now," at the zone's boundary, designed to minimize reaction time and improve precision.

The intervention had a clear and positive effect on rider accuracy. Statistical analysis of the DAZC metric revealed that riders performed transitions significantly more accurately when guided by the real-time audio cues compared to the control session, with the most substantial decrease in error occurring with live feedback. Less-experienced riders showed the greatest benefit from this audio guidance. These quantitative findings were corroborated by the post-session questionnaires, in which riders generally perceived the system as helpful and non-intrusive. Many described the audio prompts as a "natural" form of guidance, stating that it helped them maintain focus and prepare for movements more effectively.

The results of this study serve as a strong validation for the Equimetrics platform. The significant improvement in rider accuracy during the audio-cued session demonstrates that the data captured by our open-source system is sufficiently timely, reliable, and precise to drive a real-time, interactive coaching application. It demonstrates that Equimetrics can be a powerful tool not just for analysis but for active training, bridging the gap between data collection and actionable, performance-enhancing feedback.

6 Discussion

This paper presents the dual contribution of Equimetrics, an open-source wearable system for equestrian analysis, and a real-world validation of its capabilities through a real-time feedback intervention. The primary contribution is the system itself, a low-cost, accessible platform designed to empower researchers and trainers with objective data. The successful real-time coaching study serves as powerful evidence of the system's utility, demonstrating that the data it captures is not only descriptive but also sufficiently robust to drive performance-enhancing applications. While the core technologies used in Equimetrics, such as IMU sensors and wireless data transmission, are well-established, the primary contribution of this work is not the invention of a new type of sensor. Instead, its novelty lies in the integration of these components into a cost-effective, open-source, and end-to-end system designed and validated specifically for the equestrian domain.

Our findings have significant implications for equestrian training. The quantitative results, particularly the consistent reduction in the DAZC metric, show that immediate, data-driven audio feedback can lead to more precise and accurate movements. This suggests a pathway to supplement traditional, subjective coaching with objective, personalized insights. By providing riders with a tool that can quantify their performance and offer targeted guidance, we can provide riders with the objective feedback needed to refine their skills and improve their precision. Furthermore, the ability of the system to separate rider from horse movement and automatically classify gaits offers more detailed analytical possibilities. For instance, the ability to separate rider from horse movement allows for a more nuanced understanding of how a rider's specific actions influence the horse's gait.

Despite these promising results, we acknowledge several limitations that frame the scope of this work. The validation study was conducted with a small sample size of five riders, which limits the statistical power and generalizability of the findings. The entire experiment took place in a single, controlled indoor arena; performance in outdoor environments with variable lighting, terrain, and GPS availability may differ. Additionally, while our analysis accounted for rider experience, we did not deeply investigate horse-specific factors, such as breed or temperament, which could influence outcomes. Finally, while our sensor fusion approach was effective, robustly managing potential occlusions or signal drift in more complex scenarios remains a challenge for broader adoption. Additionally, our study did not focus on long-term deployment challenges such as battery life, which is a critical factor for usability in daily training, or the potential for IMU sensor drift over extended recording sessions. While our sensor fusion approach was effective for the duration of this study, robustly managing potential occlusions or signal drift in more complex scenarios remains a challenge for broader adoption.

These limitations highlight several exciting avenues for future work. The next logical step is to conduct longitudinal studies with a larger, more diverse group of horse-rider pairs to determine if the initial gains from real-time feedback translate into sustained skill development. There is also great potential in developing adaptive feedback algorithms that could personalize the timing, frequency, and content of cues based on a rider's real-time performance or predefined skill level. Expanding the system's analytical metrics to include rider posture, horse gait symmetry, or other biomechanical parameters could offer even deeper insights. Finally, future iterations could explore multi-rider scenarios for group lessons or tackle the challenges of deploying the system in outdoor and competitive environments.

7 Conclusion

This research successfully demonstrates the design, implementation, and validation of Equimetrics, an open-source wearable system for enhancing equestrian performance. We have presented two key contributions: first, an accessible, low-cost platform for capturing the complex dynamics of the horse-rider partnership, and second, a real-world validation showing that this system can drive a real-time audio feedback loop to significantly improve rider accuracy. Our findings underscore that structured, data-driven feedback can catalyze tangible improvements in skill execution, particularly for less-experienced riders.

By making the entire platform open-source, this work directly addresses a critical gap in the field and aligns with the core mission of the OpenWearables community. We provide an accessible, reproducible tool that empowers others to build upon our methods and further investigate the nuances of athletic performance. Ultimately, the fusion of objective, sensor-based analytics with traditional coaching expertise offers a promising new approach to equestrian training, helping riders refine their skills with enhanced precision and real-time insight.

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