

Design framework for bio-logging devices for monitoring grazing ruminants

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Abstract

Grazing is known to be a cost-effective feeding strategy that improves product quality, animal welfare, and the sustainability of livestock systems. Improving grazing management is therefore crucial and requires a deep understanding of grazing animal behaviour to derive management strategies. In this context, Precision Livestock Farming (PLF) offers significant opportunities to monitor continuously the grazing behaviour of ruminants. Numerous reviews have already synthesized aspects of PLF in general, sensing technologies, and their applications in grazing systems, but each with different focuses. This paper consolidates insights from recent reviews and provides: (i) a concise classification of technologies used to study grazing behaviour; (ii) a framework to support PLF device design for grazing contexts; (iii) an illustrative case study applying these principles. This document primarily aims to support decision-making during the design of PLF sensing devices in grazing management research.

Keywords: PLF, sensors, design, framework, grazing.

Introduction

In the context of climate change, gaining a better understanding of the interactions between grazing herbivores and pasture is crucial for developing sustainable management practices (Ding et al., 2025; Marchegiani et al., 2025). PLF offers significant potential for identifying optimal feeding strategies (Marchegiani et al., 2025). Although numerous reviews address the monitoring of grazing behaviour, none provides clear guidance on selecting appropriate technologies according to specific research questions and experimental constraints. Rather than providing an in-depth comparison of existing technologies, we propose a four-step, question-driven framework to guide the development of PLF tools for grazing management research. It is inspired by frameworks in ecology (Williams et al., 2020) and dairy lameness detection (Norton & Berckmans, 2017). It is illustrated with a practical example comparing grazing management methods.

Method development

A literature search was conducted in November 2025 using Google Scholar and Scopus. Various combinations of keywords were used, including: “review”, “overview”, “meta-analysis”, “framework”, “PLF”, “precision livestock farming”, “collar”, “sensor”, “IMU”, “accelerometer”, “GNSS”, “feed intake”, “behaviour”, “grazing”, “cattle”, “ruminants”, “sheep”, and “livestock”. Reviews published before 2020 or focusing solely

on welfare, health, indoor systems, omnivorous species, post-processing, or algorithm development were excluded. Reviews served as a consolidated knowledge base to identify recurring technologies, limitations, and design constraints, which were subsequently synthesized into a question-driven framework. As terminology in the literature was often inconsistent (“tools,” “sensors,” “technologies” ...), a three-category classification of technologies was first established, distinguishing between sensors, communication technologies, and integrated systems (Figure 1). The selection framework was then established. Rather than prescribing a specific technology, it adopts a progressive filtering question-driven approach. Starting from the research question (Figure 2, STEP 1), it first assesses whether an existing database can address it, although such datasets are rare in grazing systems due to the effort required to generate them (Chelotti et al., 2024). Technologies are then evaluated based on the object to be monitored and the type of information to be collected (STEP 2). Once these needs are defined, spatial, temporal, and object-related constraints are identified (STEP 3). If no commercial solution meets these requirements -as such solutions are often poorly suited for research applications due to limited algorithm transparency, insufficient validation, and high costs (Chelotti et al., 2024)- the framework guides the necessary design trade-offs and ultimately supports the definition of bio-logging device specifications (STEP 4).

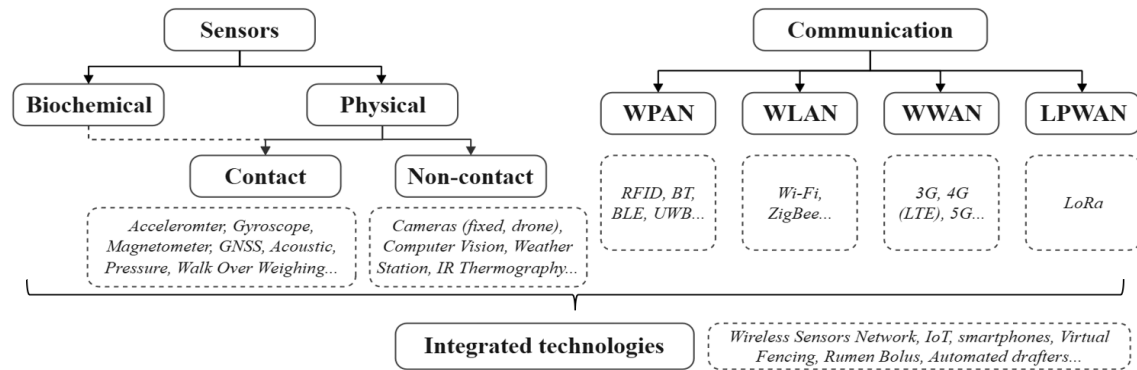


Figure 1: Functional classification of main technologies used in grazing systems.

Results – Case study

This section presents the results of applying the developed framework to a specific case study conducted at the University of Liège (Belgium) in 2025-2026. The research question was: “How does grazing management influence sheep grazing behaviour in a pasture composed of legume and grass strips?” (STEP 1). This defined the experimental objectives: monitoring individual animals (Object 1) (*Who*), their location (*Where*), behaviour (*What*), and the environment (Object 2), namely pasture biomass, structure, and composition (external *Why*) (STEP 2). Regarding dimensional constraints, the experimental site consisted of a 2-ha field divided into 84 & 168 m² paddocks. Groups of four lambs grazed at two stocking rates for two months in spring, with a grazing duration of 3 days per paddock, resulting in two levels of sward height reduction. Device constraints were: (1) a maximum weight corresponding to 1.2% of the sheep live weight (30 kg), and (2) a 24-h autonomy, as animals were handled daily (STEP 3). For environmental monitoring, a DJI Mavic 3M UAV (DJI, Shenzhen, China) was used as this commercial solution fulfilled the requirements (STEP 4). For animal monitoring, GNSS was chosen to derive animal positions at 1 Hz, as this technology is the most

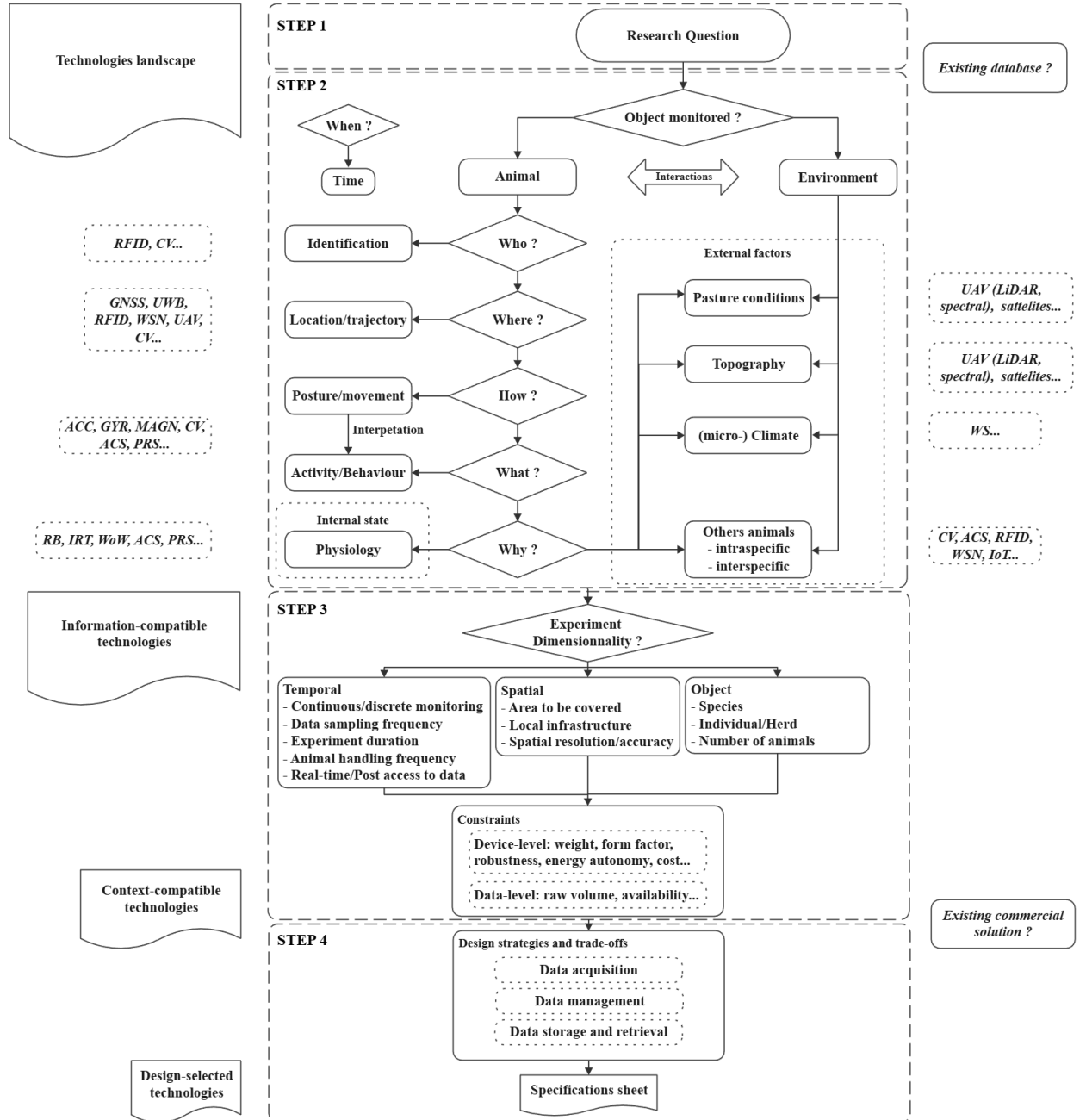


Figure 2: Four-step question-driven framework.

reliable for large outdoor areas. A 6-DOF IMU (tri-axial accelerometer and gyroscope at 50 Hz) was chosen to capture both static and dynamic movements. The device, built around a ZED-F9R chip (U-blox, Thalwil, Switzerland) with a SPK-6E Multi-Band L1/L2/L5 Helical antenna (SparkFun Electronics, Boulder, USA), was positioned on the nape. In ideal conditions, a 6 Ah carbon battery ensured a 24-h autonomy while respecting the weight constraint. The total device weight was 330 g. Anticipating future data processing, raw GNSS data was stored to allow centimetric positioning using PPK (Post-Processing Kinematics) with a CORS (Continuously Operating Reference Station) network. Due to the absence of embedded interpretation algorithms and limited computational resources of the Arduino Nano 33 (Arduino, Ivrea, Italy), edge computing and wireless data transfer were not implemented. Data was manually retrieved every day.

Preliminary results confirmed the suitability of the system, reaching a technology readiness level (TRL) of ~4-5. Behaviour classification algorithms developed using a 13-h reference dataset using 1-s time windows achieved 85.1% accuracy with a random forest model, with remaining limitations attributed rather to data labelling, post-processing and algorithm optimisation than data acquisition itself. Concerning animal location, during the first 3-day deployment on one sheep per grazing treatment, 99% of GNSS positions were retained after PPK processing with only *single* position points discarded. Average standard deviations were 0.095 m (North), 0.063 m (East), and 0.14 m (Altitude), providing the desired centimetre-level position accuracy. These results support the suitability of the devices for finely comparing selectivity among grazing treatments, with preliminary differences already observed in the time spent grazing each plant species. Future analyses will investigate selectivity differences among treatments in greater depth using data collected over the two-month grazing period. Future work will also focus on improving device connections to prevent power loss and increasing energy autonomy, although this remains challenging with continuous 1-Hz GNSS acquisition under such weight constraints. Cloud storage and computing are also under investigation to improve user experience and move towards an IoT platform.

Conclusions

This paper proposes a question-driven framework to develop devices specifically tailored for research in grazing management. Given the wide range of possible technological configurations, it is essential that researchers clearly report device characteristics to ensure reproducibility, enable meaningful comparisons between studies, and promote greater standardization of protocols.

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