PHENO3D: 3D phenotyping of beef calves — scaling image processing into edge-AI and extending predictions across breeds

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Initiated to bring beef cattle selection into the era of high-throughput phenotyping, the PHENO3D project aims to operationalize a non-invasive 3D imaging system enabling real-time estimation of body weight and morphological scores at weaning (Bruyas et al., 2022). The objective is to deliver standardized, robust phenotypes integrated into existing genetic evaluation programs, ensuring continuity with historical data while accelerating and harmonizing phenotypic recordings.

The PHENO3D system combines a dismountable gantry equipped with 10 RGB-D cameras, 3D image preprocessing, and predictive models. The scanner was tested in 50 configurations and demonstrated with end users, leading to major improvements toward a user-friendly system. Preprocessing converts the 10 RGB-D images into a single whole-animal 3D mesh, from which phenotypic indicators are extracted to feed machine learning models, as described by Do et al. (2024). Prediction models for Body Weight (BW), Skeletal Development (SKE), and Muscular Development (MUS) were initially developed for the Charolais breed (Dechaux et al., 2024) and have now been extended to 9 French beef breeds using the same methodology. In total, models were trained on more than 8,500 3D images from 5,000 calves, paired with reference body weights and expert linear scores. The preprocessing stage was implemented as a Python pipeline running directly on the 3D scanner, enabling fully on-device computation without cloud dependency. The edge-AI system was evaluated under external field conditions on 92 calves to assess image quality and pipeline completeness.

Using the same evaluation framework as Dechaux et al., models exceeded the targeted Spearman correlation objectives, achieving a Spearman's ρ of 0.76 for both SKE and MUS. BW prediction reached a mean absolute percentage error (MAPE) of 4.5% across animals. Some models' performances variability was observed, likely due to breed and operational effects, and improvement perspectives will be discussed. PHENO3D demonstrates that automated 3D imaging can deliver reliable phenotypes for large-scale beef cattle recording. By reaching an operational level compatible with routine use, this approach supports the integration of precision phenotyping into genetic evaluation systems.