PHENO3D: Phenotyping calves at weaning through automatic 3D image collection and instantaneous processing

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Abstract

The Pheno3D project aims to bring the selection of beef cattle into high-throughput phenotyping by relying on the non-invasive technology of three-dimensional (3D) imaging. Thanks to artificial intelligence, the automation of 3D image analysis is now possible. Thus, from an existing 3D "scanner", the PHENO3D project aims to develop an automated processing device (artificial intelligence) and in real time of 3D images to extract phenotypes used in the bovine meat sector (weight and scoring notes). To develop and validate the PHENO3D artificial intelligence, the project will first have to build a database comprising 3D images of the animals and their phenotypes (weight and scores) of approximately 500 images for each of the 10 involved breeds in beef recording. Artificial intelligence (Machine Learning, Deep Learning) will be optimized on its phenotype prediction performance but also on its ability to be embedded in a 3D scanner. The project will go beyond proof of concept by building a 3D imaging phenotyping service and its business models, and developing the skills needed for these use cases. To achieve its objectives, the PHENO3D project will rely on a network of actors covering the entire animal selection sector (RandD actors, performance control actors, breeding organisations). This use case in beef cattle will be a first step towards the deployment of high-throughput phenotyping by 3D imaging.

Keywords: 3D imaging, phenotype, performance, cattle, weighing, scoring, genetic.

Introduction

In France and in the beef cattle sector, genetic improvement is based on performance monitoring (also called phenotyping) of a large population of animals (Griffon *et al*., 2017). Phenotyping is based in part on a network of farmers affiliated to breeding organisations. For beef calves a first phenotyping is done around weaning. This collection of performances is carried out by advisers from Eliance network or from breeding organisations on farm. It includes animal weighing and scoring morphological traits. The morphological assessment comprises 19 scores on muscular and skeletal development or functional traits (see Figure 1). The compilation of performances allows, based on the phenotypic characterization of the breeders, the reasoned choice of mattings to meet the objectives of breed evolution. Even if the scoring by visual scores remains the most reliable, fast and less expensive technique compared to taking manual measurements on animals, the beef sector has expressed its need

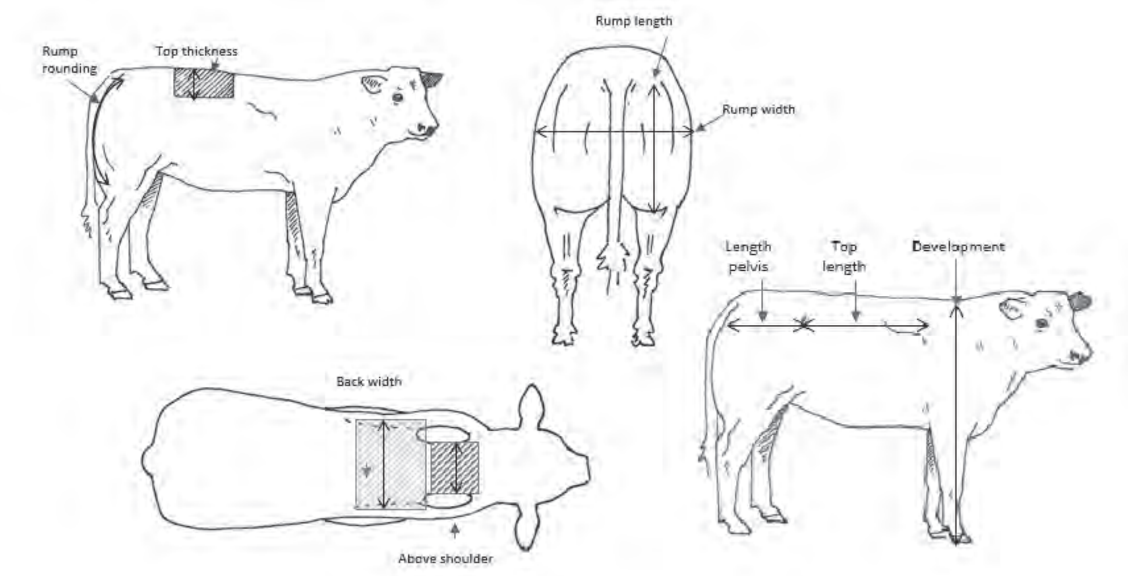

Figure 1. Syntheses of the positions of muscular development on the left and skeletal development on the right of beef cattle at weaning.

for an automatized digital solution to lower the very significant training costs and to reduce the human subjectivity effect on measurements.

The project partners have significant background and experience in the field of 3D imaging. At the scientific level, IDELE in partnership with INRAE and 3D Ouest led the morpho3D project. The objective was to estimate the weight and morphological measurements of dairy cows from 3D images of the entire animal (Le Cozler *et al*., 2019a; Le Cozler *et al*., 2019b). Another project involving the same partners aimed to obtain the body condition score of dairy cows from the cows' back 3D images (Fischer *et al*., 2015).

At the field level, FCEL, IDELE and Ingenera have developed a system (BodyMat M) to measure dairy cows BCS using a cane equipped with a 3D camera. Another project (BodyMat X) carried out with the same partners aimed to carry out morphological scoring of beef cattle using a scanner equipped with 3D cameras. Unfortunately, these initiatives failed to be industrialised with success because of difficulties with the industrial partner.

Finally, 3D imaging is a technology that has been proven to be the basis of prediction models for both simple metric measurements such as weight (Le Cozler *et al*., 2019a; Le Cozler *et al*., 2019b) or more qualitative notations. complex such as the body condition score (Fischer *et al*., 2015). If the collection of 3D images has been the subject of convincing proofs of concept, the processing of these images is not yet automatic and remains time-consuming. However, the application of finer artificial intelligence methods (such as simple or deep neural networks) on these images makes it possible to automate 3D image processing and analysis.

Considering the real needs and the past scientific, technical, and commercial experiences, we decided to run our own project from the development to the commercial phase.

The objectives of the Pheno3D project are to:

1. define the specification of the 3D scanner adapted to young beef cattle and for a mobile use;
2. define the best logistical arrangements for the installation and the passage of animals;
3. validate the ability of the system to gather good quality 3D images of entire beef cattle in movements:
4. develop and validate AI algorithms to estimate automatically morphological scores and weights of young beef cattle.

General project's road map

Main objectives

The tool must produce one or several 3D images to reconstitute an entire animal as a whole or partly. From this reconstruction, features will be extracted automatically. From the features or directly from the images, models and algorithm will estimate:

- The morphological scores for the traits described in figure 1.
- The weight with a prediction error or 3% max.

Device specifications

The device must be portable or transportable (and in this case be installed and ready to collect data in 30' and uninstalled in 20'). The dimensions of the device should not exceed 3m wide and 3.5m high which corresponds to the dimensions necessary to obtain qualitive 3D images (the smaller the distance between the animal and the sensor, the better the image quality) while avoiding scaring the animal to go inside. It must be transportable in a vehicle usually used by technicians and advisors. It will also have to be light (15kg of simultaneous load maximum) so that a single person can handle it. Indeed, it will be used by technicians who will move it from one farm to another.

The device must be able to produce a 3D image from a moving animal that will be guided within the device (using cables or fences). Indeed, the idea is to capture the data during the passage of animals (walking/running), one after the other, in a containment corridor.

The 3D cameras must be able to take a picture indoor or outdoor so they mustn't be too much sensitive to sunlight. The activation of the device can be done from human intervention. It will then have to be able to connect with an electronic animal identification device for farms where the animals are equipped with electronic loops.

The device will have to provide the expected score estimates in real time without internet access. The data must be exportable to another system.

The technical characteristics of the tool will be refined in the various specifications written throughout the project.

Targeted animals

The system will be used on beef calves at weaning (currently between 5 and 9 months). The algorithms will be developed for the French fallowing breeds: Charolaise and Limousine to start the project (being the 2 most developed breeds in France) then Aubrac, Bazadaise, Blanc Bleu, Blonde d'Aquitaine, Gasconne, Parthenaise, Rouge des Près and Salers will be integrated.

Conditions of use and measurement

The animals will have to pass through the device and the images will be taken on the moving cattle. The animals will therefore have to pass in motion, without running, without jumping, and perpendicular to the gantry to obtain clear images by the 5 pairs of sensors present on the device. To achieve this goal, field tests will be organized to optimize the speed and position of the animals. Several configurations will be tested to obtain the best results in order to validate the tool.

Device test and linear measures validation

The objectives will be to validate the ergonomics and the robustness of the device, the quality of the recorded images, the speediness of the images collection, in different conditions. This action must make it possible to adjust the prototype if necessary.

To validate the accuracy of the device, this action will aim to compare the measurements estimated by the prototype with reference measurements (like withers height, hips width, chest depth etc., see Figure 2) done manually on the animals and under different conditions.

This action will make it possible to estimate the prediction errors, repeatability and reproducibility of the 3D image collection and will validate the ability of the device to take a representative image of the real cattle. The exigence criteria for the validation are presented in table 1.

Development and validation of AI algorithms to estimate morphological scores and weight

The automatic processing of 3D images will be a revolution since in this project we want to achieve high-throughput phenotyping. Previously, image processing was largely manual, took much time and was not compatible with high-throughput phenotyping. In a performance monitoring use case, it is necessary to have a direct information in the 3D image quality to eventually make the animal pass a second time under the 3D scanner device. Having an automatic processing of the images, will allow advisers and

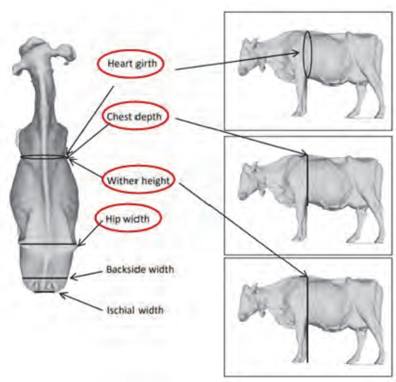

Figure 2. Morphological parameters tested to assess the quality of the image and measurements (in red).

Table 1. Exigency criteria for the device's validation.

Criteria	Values
Image quality	We will use the notion of completeness of the image. For this, we will look at the part of the animal that fits in a virtual box going from the hocks to the withers and from the tip of the buttocks to the end of the neck. This image should be complete. That is to say that if all the measurements defined above are feasible, the image will be considered complete and usable. 80% of the images must be usable on the first pass and 95% after 2 passes through the device.
Measurement precision	Correlation coefficient (Pearson) between manual measurements and measurements estimated on the 3D image > 0.7
Repeatability and reproducibility	Coefficients of variation of repeatability and reproducibility < 4%

farmers to have access to weight and scores quickly and discuss the results to adjust the monitoring of the herd in a unique session. Deep learning or machine learning models will be used to predict the weight and each morphological scores that are part of the scoring. The models will be built on a large dataset (more than 500 animals scanned, weighted and scored) built on farm to calibrate and then validate every models. The building of the dataset will be done on several farms during the current performance monitoring done by trained morphological scorers to ensure to capture the whole variability of the breed and thus having reproducible models.

The development of models by breed will be an important step since each breed has its morphological specificity and its own variability so the scoring has to be done based on breed standards. Because of this intra-breed specificities, models will have to take a breed effect or to have a model by traits to predict. The idea is to see if models can be efficiently adapted to one breed to another and if breed with a lower population (and probably a lower dataset) can benefit of the datasets from other breeds.

Prototype adjustment and development of the final version

Possible adjustments to be used routinely and safely (robustness, sensor protection, rugged boxes, data transmission and storage protocols, user manuals, transport cases, etc.) will be necessary as well as optimizations to limit construction costs. Development of the complete application for the end user will be done and will integrate their needs and requests. The final prototype integrating hardware and software adjustments will lead to the pre-industrial version of the device.

First results and achievements

Development of the first prototype

A first prototype was developed and tested on the field. The picture 3 below shows the main features and characteristics of the device.

Figure 3. On the right, the plan of the prototype; on the left, the prototype tested on the field; the prototype includes 5 pairs of cameras; the height is 2.6 m; width is 3 m

A few images were taken on the first trial. The first version tested only had two 3D sensors on the top of the scanner. A sample of the images taken are presented in figure 4 below. Images processing will allow a smoothing of the surface. Will all the sensors, the 3D images quality seems promising for extracting phenotypes.

Figure 3. On the right, the plan of the prototype; on the left, the prototype tested on the field; the prototype includes 5 pairs of cameras; the height is 2.6 m; width is 3 m

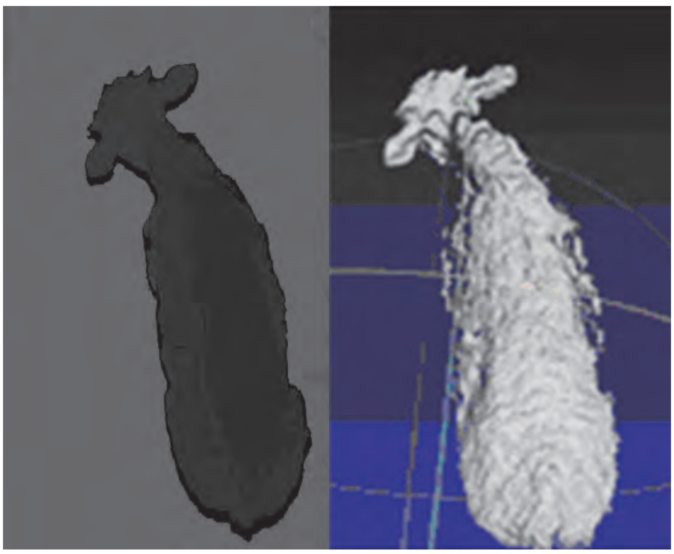

Figure 4. Depth and 3D images taken from the first prototype.

Optimization of the passage of animals in the scanner

The objective was to define scanning organizations to have animals that:

- Will pass under the device walking or trotting in the most standard position.
- Will not deteriorate the 3D sensors

On-farm tests allow us to define 2 organizations for scanning the animals. One, where the device is directly placed at the exit of a weighting scale without any additional fences or restraining elements (figure 5). The animals are managed in the way defined on the farm for weighting. The other requires two empty and adjacent pens of a barn or of a contention system. The device is placed in the first pen with additional fences that create a “funnel” from the width of the pen to a gate of 1.5 m (figure 6). Then the animal pass under the device and an operator guides it in the second pen where the animal will wait the end of the operation

Figure 5. Organisation of the scanning at the exit of the weighting scale.

Figure 6. Organisation of the scanning in a pen. White fences are additional fences added to form a funnel.

Summary of the road maps

Below the provisional schedule of the PHENO3D project is described:

- Spring to fall 2022: prototype testing phase in various situations to find the best way to pass animals in the device and obtain the best results
- Fall 2022: validation of the prototype: having good results passing animals
- Fall 2022 to spring 2023: data collection with several prototype to have lots of data by breed and to create algorithms.
- Spring 2023: validation of algorithms by breeding organisations. Each organisation will validate the algorithms concerning its own breed.
- During 2023: industrialization of the tool. 3D Ouest or another IOT manufacturer will industrialize the tool. We have estimated a need for more than 100 tools for France
- During 2024: routine use in the field

Conclusion

Automated morphological scoring based on 3D imaging will meet the sector's demand for an alternative to the current costly method: visual observation by technician scorer. The tool will be designed to obtain scoring and weighing data in a single scan of the

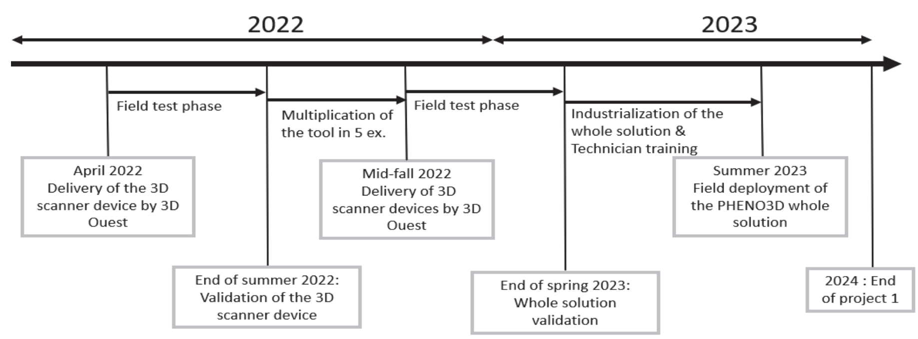

Figure 7. Project road map.

animal. Today the weighing is carried out 2 to 3 times before weaning, the score only once. By adapting the system on the weighing sites, we will be able to collect more data on the morphology of the animal, at different ages, and new phenotypes like volume and body surface of the animal. This could improve selection schemes and advice services on sorting animals on farms.

We also want to export the device internationally for weighing cattle without restraint, as the French scoring system is not used internationally.

In the medium term, artificial intelligence developed in the project will facilitate research on new phenotypes for beef cattle. Exporting the technology and the artificial intelligence developed in PHENO3D to animal other ages, other types of animals, or other sectors will make it possible to make significant advances in the collection and development of phenotypes for multi-performance breeding.

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