Animal 15 (2021) 100212

Contents lists available at ScienceDirect

Animal

The international journal of animal biosciences

Lambs' live weight estimation using 3D images

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A R T I C L E I N F O

Article history:
Received 12 July 2020
Revised 16 February 2021
Accepted 19 February 2021
Available online 23 May 2021

Keywords:
3D sensor
Animal production
Animal welfare
Machine learning
Sheep livestock

A B S T R A C T

The sheep sector has not suffered the technification that other livestock sectors have. The lack of technological knowledge of the farmers and the economic limitations of the sector have made this technification difficult. One of the most widely used technologies is Precision Livestock Farming (**PLF**). PLF has already been used in other livestock sectors to improve farming efficiency. In the light of the problem that sheep farmers have in weighing lambs and their low precision, this paper proposes a system for estimating weight by means of 3D image capture. Thus, zenithal images of 272 lambs have been recorded. They have been processed using the capture of the upper area and the average depth of the pixels of the lamb. This estimates the weight of the animal with an error of less than 6%. This technology has a low economic cost and is easy to operate, helping farmers to be more willing to use it. This method manages to reduce the duration of the process, the stress of the animal and to improve the overall accuracy in weight estimation. Thus, it will help to have a greater control of the weight of the animal and to improve the economic profitability that the farmer obtains for the lambs.

Implications

The accuracy of weight measurement in sheep farming is not reliable due to the manual methods that are still used. Weighing methods, apart from being inefficient, mean that farmers do not obtain the desired economic profitability from each individual animal. For this reason, a weight estimation system has been developed by means of 3D image capture that improves the accuracy of the weighing on lamb farms. In addition, the system improves animal welfare, reducing stress on the lambs and facilitating the process for the farmer, by reducing time and effort.

Introduction

Livestock farming has undergone a great technification in recent decades, mainly within the intensive livestock sector. This phenomenon has come primarily from veterinary intervention in the care of diseases, feeding and animal husbandry. However, technology is increasingly being used to improve livestock farms in aspects such as the handling, production and marketing of animal products. In the research of Tullo et al. (2019), multiple experiences are shown that have demonstrated a remarkable improvement of their results thanks to the introduction of technological improvements in these fields.

Among all the tools and techniques used within this technification of livestock farming, and more specifically those used in Precision Livestock Farming (**PLF**) (Berckmans, 2014), one of the most important and relevant in recent years is image processing. Thus, in recent years, these techniques have been used to achieve different objectives such as measurement using 3D technology for morphological analysis (Le Cozler et al., 2019), the estimation of muscle mass (Alsahaf et al., 2019), the detection of groups of animals for monitoring (Li et al., 2019), or weight control using thermal cameras to monitor growth (Stajnko et al., 2008). All of this shows that image processing is a technique that helps to improve different aspects of the management and control of livestock farms.

Despite the fact that these technological advances are increasingly widespread, not all species have been introduced in the same way, with the sheep sector being one of the least technological advances. Sheep farming does not have the resources that other species may have. Profitability in terms of production and sale of products is lower compared to products from other sectors such as beef and pork, and their price has not increased in the same way in recent years. This, together with the fact that farmers are not very well prepared, has slowed down the progress of technification on sheep farms. For all these reasons, low-cost technological solutions are needed in this sector to facilitate daily tasks. Easy to

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https://doi.org/10.1016/j.animal.2021.100212

use applications must be developed so that adaptation to new systems does not result in problems for the farmer. Within these tasks, one of the most interesting variables is weighing. In all species, including the sheep sector, weight is an indicator that allows the farmer to control the growth, nutrition, reproductive capacity or even muscle capacity of their animals.

Due to the importance of weight monitoring in cattle, different alternatives to traditional weighing are currently being studied that do not stress the animal and do not interfere with its daily routine. Therefore, image processing has become one of the most interesting techniques for this type of work, as it is faster and less invasive than traditional techniques (Vranken and Berckmans, 2017). Studies of pigs using image capture and processing to estimate their weight can be found in the literature (Wang et al., 2006), and even with the application of artificial neural networks to improve the accuracy of the estimation (Wang et al., 2008). The use of 3D images of the back of cows has also been used to identify the weight of the animal and the properties of the milk (Kuzuhara et al., 2015). On the other hand, another study used image capture by a Kinect V2 camera to estimate hip height and live weight in calves (Nir et al., 2018). With a similar technology, BCS has been estimated in cows using zenithal images (Spoliansky et al., 2016) and body weight has also been estimated in Holstein cows (Song et al., 2014). In the case of lamb, sheep or goats, studies have been found that use a camera from a mobile device can be used for weight estimation in sheep (Bhatt et al., 2018) or weight can be estimated through images of the back of dairy goats (Vieira et al., 2015).

In the more specific case of the sheep sector, it has been demonstrated that controlling the weight at all stages of sheep growth would be beneficial for the development of the animal (Brown et al., 2015). In the case of lambs intended for meat production, a correct estimation of the weight can have an economic impact on the farmer. Lambs above or below the weight thresholds set by the distributor will be paid less than those within the given range. On the other hand, the difference in weight during the gestation period can influence the subsequent growth of the lamb. For example, a lamb with a high birth weight tends to grow faster than a lamb with a lower weight up to 20 kg (Greenwood et al., 1998). Similarly, it has been found that a lamb with low weight has more than twice the chance of not surviving compared to a lamb with a higher weight in the lactation period (Hatcher et al., 2008).

Despite the importance of weight in sheep, currently only 17% of farmers weigh animals regularly, of which 96% do so by some manual method or by estimation with the naked eye (Jones et al., 2011). In the case of the former, the process is quite tedious and generates a high level of stress in the animal, which could cause a deterioration in the quality of the meat (Ferguson and Warner, 2008; Adzitey, 2011), as well as fatigue of the farmer. In the latter case, accuracy is low, as it depends on the farmer's experience. Hence, a correct monitoring of the weight would notably improve the profitability of the farm, allow a better control of growth, avoid diseases and help to control feeding, which, in the case of pregnant ewes, would serve to obtain lambs at the optimal weight for correct growth.

Therefore, the aim of this article was to develop a noninvasive weighing method which is fast and convenient through the use of image processing, helping the process of technification of sheep farming. A weight estimation is proposed by capturing images with a 3D camera from a zenithal plane of the lamb. The real live weight of the animal will be estimated using different image processing techniques trying to improve the results found in the literature in this field. The innovation of this study is the incorporation to the sheep sector, more specifically to the lambs, of techniques and technologies that have already been found in other research articles and successful experiments but in other species of animals, because in this sector, they are not correctly developed thus, trying to solve the problems of the sector described above. The present article presents the materials and methods used, the experiment carried out and its results.

Material and methods

To carry out this work, zenithal photographs have been taken of 272 lambs of the Rasa Aragonesa breed. This breed is distributed in 97% in Aragon, as it is mainly spread within the Ebro Valley. On 31st December 2018, the census of animals was over 1.3 million, of which more than 374 000 animals were reproducers on 454 farms. This is a breed with a semi-extensive production system that has the qualities of high hardiness, gregarious instinct, good maternal instinct all year round, sufficient milk capacity, grazing capacity and adaptation to the difficult environment in which it is farmed.

It has been shown that one of the most important factors in the profitability of farms for the Rasa Aragonesa breed is the number of lambs sold per sheep per year. In this sense, it is clear that an alternative way of increasing the profitability of the farms would be to improve the efficiency of the sheep, increasing both the productivity per birth and the economic profitability obtained from the sale of meat. In both cases, weight is a key factor.

If we focus on meat production, this is a breed that produces a type of lamb characteristic of the region called "Ternasco", with a minimum of 40 days in lactation, and a live weight between 18 and 26 kg (8–12.5 kg of cold carcass weight).

For this reason, an attempt was made to have all the lambs recorded within this weight range. On the other hand, all the lambs studied were of a similar age and wool quantity as they are intended for meat sales and do not reach a mature age. The lambs studied had an average live weight of 22.64 kg with a standard deviation of 3.6 kg, a maximum weight of 27.7 kg and a minimum weight of 13.5 kg.

Materials

All the lambs were recorded under the same conditions. Two technicians assisted by two veterinarians recorded all the images obtained in all cases so that the sample was not affected by the way the animals were treated. The same order was always followed in the recording process. First the lamb was weighed on an electronic scale that measured 20 weights in six seconds and averaged these measurements. In the same process, they were selected by sex and identified. Later, they were introduced into a small yard in groups of three so that the recording would be cleaner, while the technician took the images from the adjacent yard so as not to have any kind of contact with the animal, and thus making the animals calmer.

The equipment used for the capture of the images, which is the same as the device developed, can be seen in Fig. 1. This means a single user can operate the device with complete autonomy. The computer used for the recordings had IntelQR CoreTM i7 8550U CPU, Touchscreen FHD IPS 13.3″, Resolution 1 920 × 1 080 and IntelQR UHD 620 GPU while the camera was an IntelQR RealSense D435 USB powered-camera.

The device has been designed so that it does not represent a great cost for the farmer. The software works on any conventional computer, and the camera is low cost. The rest of the elements do not represent a significant cost with respect to the cost of the computer and the camera. The camera, which is the main element of the device, costs around 200 euros, while the computer does not have to be a specific computer. So, understanding the average cost of a computer as being between 800 and 1 200 euros, and

Fig. 1. Elements of the device, positioning in relation to the lamb and the actual device.

assuming that the farmers do not already have their own computer, the total cost of the device would be between 1 000 and 1 400 euros depending on the cost of the computer.

The lambs are recorded using the system described above pursuing a zenithal point of view while the animal is standing up without movement restrictions. The recordings are saved using ROSBAG file format that collects all the information from the camera in operation. This allows us to use these recordings as virtual devices in the analysis phase.

Methods

Computer image vision methods

The files obtained in ROSBAG format were processed to extract the RGB images and the depth images. These files were processed using image processing libraries that facilitate the functions necessary for the segmentation and classification of the images (Bradski, 2000; Van Der Walt et al., 2014). The first step in selecting the images was to perform morphological operations. Among these operations, as we can observe in Fig. 2, first, the ground was removed by the selection of points by depth. The next step was to remove small objects from the image to eliminate noise, and the remaining connected objects were labelled. The last step was to remove all objects that went beyond the image boundaries. After that, from the resulting mask, the physical real area of the lamb in mm^2 was obtained using the mean depths of the mask pixel. This average was obtained thanks to a library belonging to the camera that made it easy to obtain the coordinates of the lamb and therefore the area of the zenithal image.

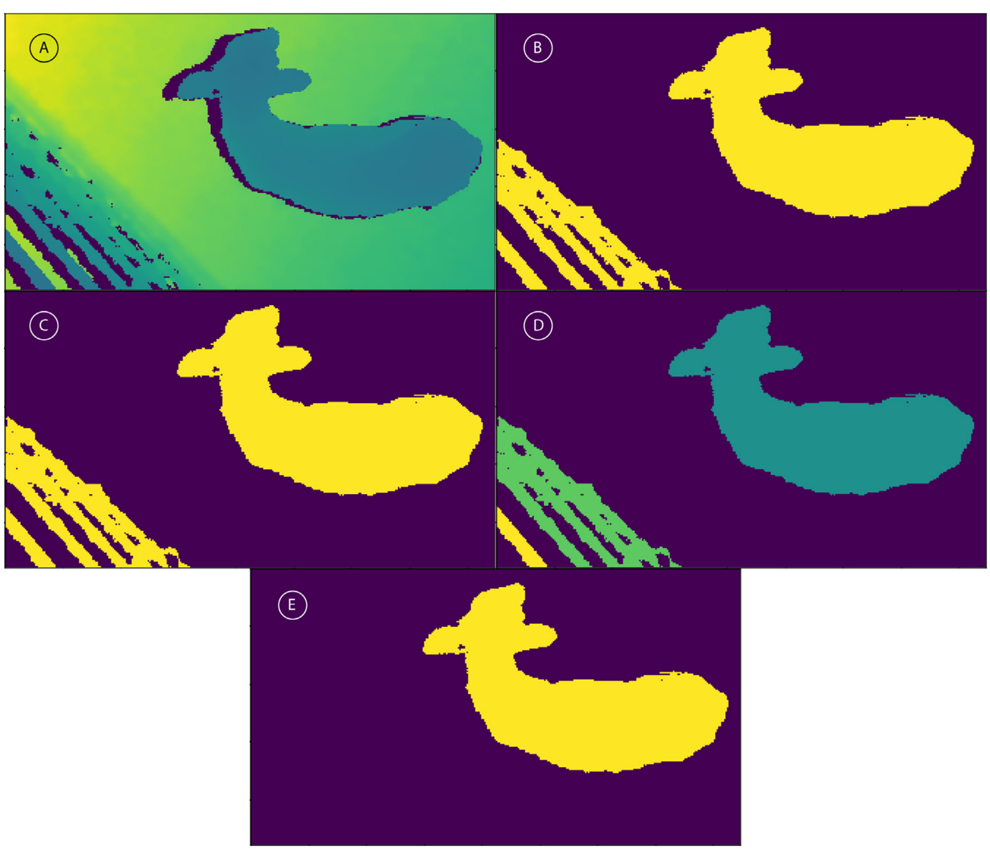

Fig. 2. Morphological operations performed on the lambs' top view images. (A) Original depth image. (B) Ground removal using depth. (C) Small object removal. (D) Labelled connected components. (E) Mask.

A screening is performed to discard those frames in which: a lamb is not present, a lamb is not entirely within the photograph limits, multiple lambs appear in the same picture, the point of view of the camera is lateral instead of zenithal, or the walls and fences interfere and are wrongfully detected as part of the animal.

The median of area of the zenithal shot for each lamb is considered, along with the sex feature, as predictors. The actual weight as measured by an electronic scale is used as a target value in the subsequent machine learning phase.

Machine learning algorithms

The computation of the regression algorithms is carried out using a Python 3.6 environment (van Rossum, 1995). The main libraries used are Scikit-Learn (Varoquaux et al., 2015) and PipeGraph. The dataset is split into a training set and a test set. The latter is used as a holdout set for assessing the capability of the best regressor to generalize when presented with new cases. The former is used to train a collection of regressors using an exhaustive grid search with a cross-validation strategy. The regressors are modelled as a PipeGraph object following the design displayed in Fig. 3. The five steps of this PipeGraph that can be seen in Fig. 3 are explained below:

1. Selector: A splitter that breaks down the input data array into selected components. In the experiments reported in this paper, it splits the sex feature from the area feature so that the former can be used in the "Multiple Class regressor" step as selector in order to multiplex the input data and train a different model for each sex.
2. Polynomial features: This step expands the dimensionality of its input data by adding the feature powers and by-products in order to fit polynomial predictive models.
3. Scaler: A preprocessing step that scales the input data features to a common interval.
4. Multiple class Regressor: A step capable of providing a different regression model for male and female.
5. Neutral scorer: A step that allows the graph to provide a score value when requested by Scikit-Learn's GridSearchCV function.

The regression algorithms to assess are as follows: linear regression, ridge, lasso, elastic net, support vector machines and random forest.

Results

Experimentation (statistical analysis of results)

A total of 272 lambs were recorded using the 3D system described above. The video recordings were comprised of 147 879 frames. The presence of a lamb was detected in 13 406 frames because the animals' reaction to the presence of the camera operator was frequently to move relentlessly at high speed which made it difficult to obtain clean shots. Out of those, 8 392 frames contained a lamb with their whole body within the photograph limits, again reducing the number of valid frames due to the difficulties associated with filming animals running in random patterns. Out of those, 520 frames from 64 lambs were obtained after filtering multiple lamb appearances or wall interferences. This initial filtering was done manually under the supervision of an investigator, not by the farmers. Fig. 4 displays two examples from those valid frames. Notice how different shapes were allowed in the experiment, not limiting the training to only straight shapes.

The dataset was split into a training set comprising 60% of the samples and a test set comprising 40% of the samples. Fig. 5 shows the weight vs. area scatter plot using the training set. The hyperparameter grid search with cross-validation was performed considering 10-fold cross-validation. The polynomial feature degree parameter was assessed with values ranging from 1 to 5. For the grid search with 10-fold cross-validation, six different models have been compared. These models were as follows: Linear Regression, Ridge regression, Lasso regression, Elastic Net, Support Vector Machines (SVM/SVR) and Random Forest (RF regressor).

Table 1 shows the results from performing the grid search with 10-fold cross-validation. With this we can see which of the methods evaluated has the best performance when a new weight measurement enters the model. As we can see in Table 1, the simplest model; the linear regression, is the model that achieves the best performance. The mean absolute error for the linear regressor is 1.15 kg in the training set and 1.37 kg in the test set. And mean relative absolute error (**MRAE**) is 5% and 6%, respectively. The algorithm developed for the model described above has made it possible to design software that estimates the weight of a lamb with an average error of less than 6% in real time.

The software has been developed in Python 3.6 and the interface has been designed with the Kivy library. As can be seen in Fig. 6, the interface is very clear, with the fields well delimited so

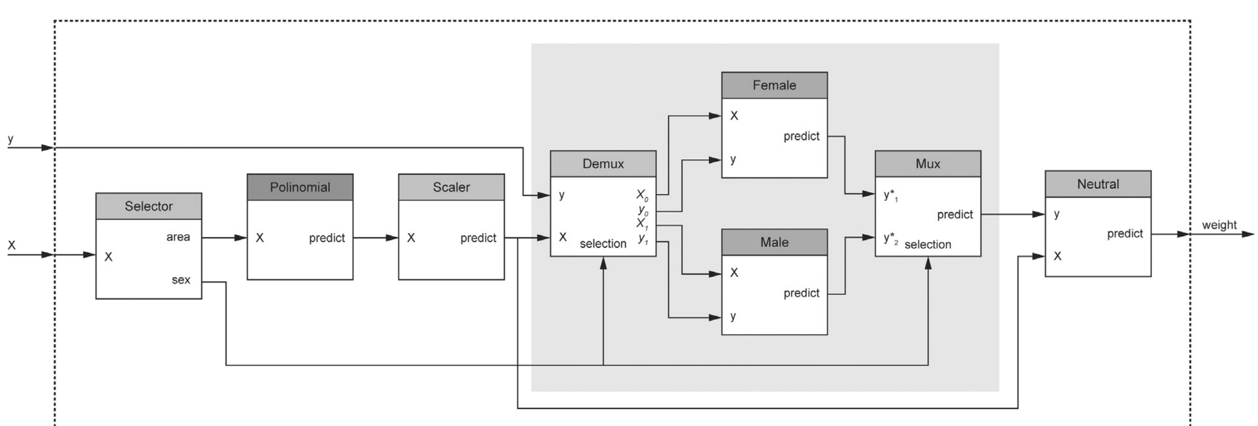

Fig. 3. The system of the figure details the flow of the data through the different processes that build up the predictive model. First, the input data features are separated in the "Selector" block. The powers of the area values are calculated in the "Polynomial". The values of the different powers are scaled in order to ease and speed up the training algorithms. Depending on the "sex" values, the data samples are split in the "Demux" block that forwards the observations of the lamb area either to the "Female" or "Male" predictive model. Then the "Mux" block joins the observations preserving the input order. Finally, the "Neutral" block contributes to select the output signal of the system and provides the ability to compute error metrics.

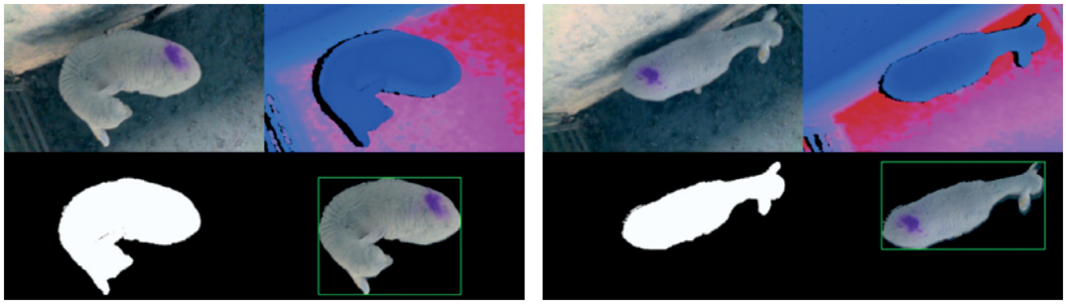

Fig. 4. RGB (Additive colour model), depth, mask and segmented images from two different lambs.

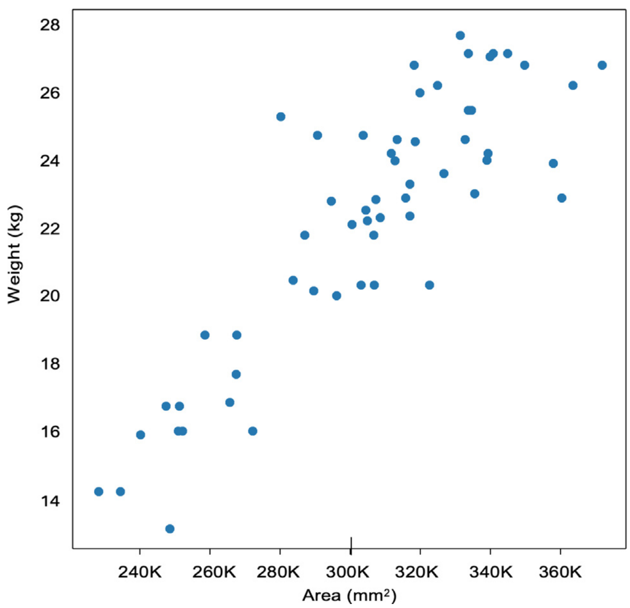

Fig. 5. Training data set comparing zenithal area with lamb weight.

Table 1
Learning performance comparison for predicting lamb weight based on the negative mean squared error obtained from 10-fold cross-validation (the higher the better).

Mean Test	
Regressors	Score
LinearRegressor	−6.69
SVR	−7.18
RandomForestRegressor	−8.96
Ridge	−8.97
ElasticNet	−13.50
Lasso	−13.50

Abbreviations: SVR = Support Vector Regression.

that the farmer has no difficulty in interacting with the application. Taking into account the environment in which the activity and mobility of the lambs take place, the buttons of the application have been designed with a large size allowing the farmer to avoid having to look at the buttons to press them and to focus his attention on the display. In order, for the farmer, to have good feedback of when a captured image is correct for the weight estimation, each time the software captures a correct image, the background is attenuated and the lamb is inscribed in a green square.

Discussion

The technification of other sectors and the application of PLF specifically improve the performance of livestock farms (Berckmans, 2014; Tullo et al., 2019). As a first step in this technification of the sheep sector, a device is proposed that is easy to operate and quick to learn, and which solves some of the problems currently faced by the farmer. This will contribute to an improvement in the predisposition of the farmer to use new technologies (Kaler and Ruston, 2019). The device must be adapted to the farmer's knowledge (Hostiou et al., 2017). Therefore, a system that does not require advanced knowledge and which utilizes tools that the farmer already uses has been proposed.

As described above, the device only needs a low-cost 3D camera at around 200 euros, and the software works on any conventional computer such as the one livestock farmer have on their farms. This, together with a simple and user-friendly graphic interface, makes the device a good incentive to improve the weighing process without involving a disproportionate investment, in line with the economy of the sector.

Besides the fact that the device is adapted to the knowledge and faculties of the farmer, for a successful technological implantation, it is necessary for the device to have a factor that encourages its use. It has been proven that one of the greatest incentives for the use of technology is the cost/benefit ratio generated by these devices (Bewley and Russell, 2010). For this reason, it was necessary to generate this technological improvement on a factor that generates direct benefits to the farmer and which currently does not have the necessary resources for its correct measurement. This factor is weight.

Current weighing methods are not most optimal. It generates too much stress in the animal and causes significant fatigue in the farmer. With the method proposed in this paper, weight measurement error improves to below 6% with an accuracy of 86%. In addition, the farmer can observe the weight of the lamb on the computer at the same moment because the process is done in real time, considerably reducing the current time of weighing.

A comparison with studies found in literature

In Table 2 you can see a comparison of the study carried out with the studies found in the literature above. As can be seen, most of the studies have similar results to the current study with respect to MRAE (Wang et al., 2006; Song et al., 2014; Nir et al., 2018). In terms of accuracy in weight estimation, our study only improves on one of the studies analysed (Kuzuhara et al., 2015). However, and despite the fact that it seems that the results are not much better than those analysed, we can consider that comparing the sector in which it has been carried out, it is a very good start. Most of the studies analysed were performed on cows or pigs, while in this case it has been developed on lambs. If we compare the main char-

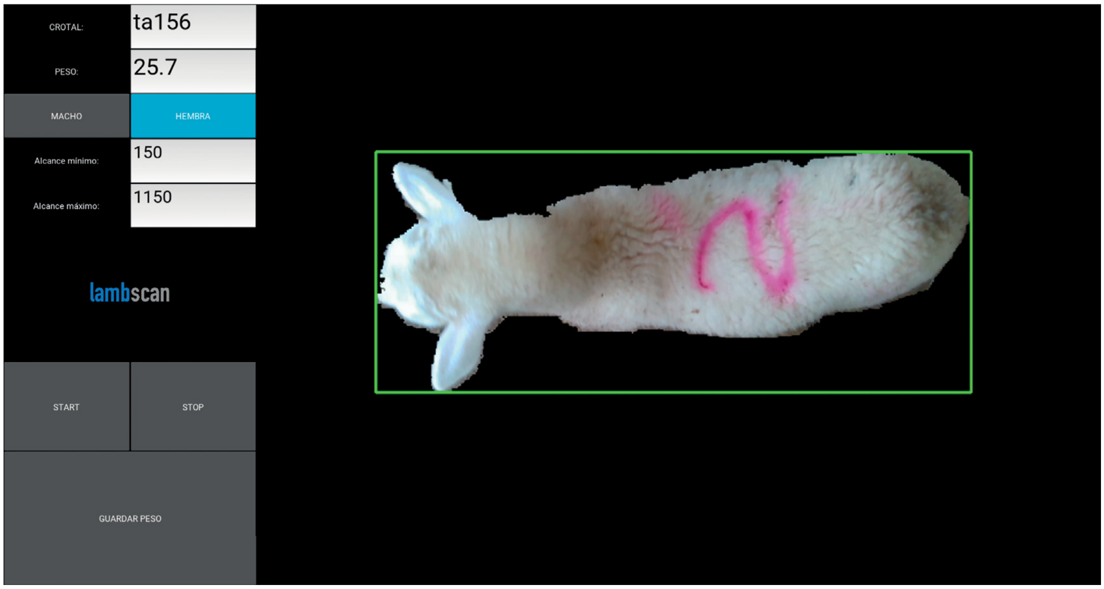

Fig. 6. Top view of a lamb in the final interface of the developed software.

Table 2
Comparison of MRAE in weight estimation in different species (lambs, pigs and cows) among the studies found in the literature.

R^2 and MRAE Comparison		
Studies analysed	R^2 (%)	MRAE (%)
This study	86	6
Wang et al. (2006)[1]	94	6
Song et al. (2014)[1]	91	6.5
Kuzuhara et al. (2015)[1]	80	–
Nir et al. (2018)[1]	94.6	5.598

Abbreviations: MRAE = Mean Relative Absolute Error.
[1] The research with which the study is compared has different datasets from the one used in the current experiment.

acteristics that influence weight estimation by capturing images of each animal in relation to the others, we can see that the lamb is an animal with much more mobility and activity than the previous ones, with hair and is usually grouped on top of each other. These characteristics make it more difficult for a lamb to capture a quality image and make it difficult to process the image. For all of these reasons, the results obtained are considered to be good as they are very close to the results obtained in other species with different characteristics and with similar image capturing techniques. According to the proposal of one of the reviewers, it was checked if results were better by ignoring the sex of the animal. It was observed that although the result was slightly worse, it was close enough to continue exploring this but with a larger dataset as it seems that both (with and without sex) can improve their ability to generalize.

The importance of weight

On the other hand, accuracy in weight estimation is of the utmost importance during different phases of the animal's growth (Greenwood et al., 1998; Hatcher et al., 2008). Furthermore, a lamb with a specific weight will be sold to the marketer for more money than a lamb that is underweight or overweight. Currently, it is estimated that lambs above the correct weight sell for one euro less than lambs at the correct weight and the feed cost is estimated to be 3.5 euros more than usual, while a lamb below the correct weight consumes two euros less per feed but sells for almost 10 euro less. With these data, a farm of 700 sheep would save 2 700 euros per year. These factors give the developed device the necessary characteristics for the farmer to start considering the introduction of this technology on their farm.

Nowadays, in the best-case scenario, with the use of an electronic scale, the lamb should be isolated from the other animals and locked in a room where it cannot be moved and can be weighed. In the case of the Roman scale, or dynamometer, the lamb is also isolated and is usually hung from harnesses not well adapted to the animal. In both cases, the stress suffered by the animal is very high. With the use of the weighing device developed by means of 3D image capture, the stress of the animal in this process is considerably reduced (Ferguson and Warner, 2008; Adzitey, 2011) as it is not even necessary to share space with the lamb.

This is important because sheep, unlike other species such as pigs or cows, have slightly different characteristics that make this type of process more complicated. Lamb, for example, is a species with a lot of movement, while pigs and cows are a quieter species and less afraid of humans. It is very difficult for lambs to be calm in the same position and they tend to move when a human approaches, except when they are in a group. In terms of image capture, wool is a disadvantage as it is very difficult to predict the amount and thickness of wool to improve measurement error. However, in this case, since the lambs are of the same age in most cases and of the same breed, the variation in the fleece was minimal, although it represented some difficulty when segmenting the images. The distance for carrying out the process reduces the time in the weighing and the effort that the farmer makes, since he does not have to interact with the lamb in the process with this new method. All this will help the farmer to perform other activities better and therefore help improve their mental health and the treatment of their animals (Hostiou et al., 2017).

Limitations and future challenges

The system designed will have to overcome some current limitations in order to correctly cover all the needs of the farmers.

Although it obviously improves the current state of lamb farms, it has some functional needs that could be the object of study. Currently it is necessary for the lamb to be isolated at the scene or have no direct interaction with the elements of the scene. However, lambs tend to be in groups, and when separated from the rest of the group they generate too much stress. Being able to capture the lamb in groups or next to a wall or fence would reduce the stress they suffer. To do this, it is proposed to study more methods of image segmentation, such as using Graphics Processing Units on the colour image and the depth image obtained from the 3D camera. This is necessary because by using the 3D images, as is currently the case, we are using very light algorithms with respect to the calculation time. The use of colour images would require a Graphics Processing Unit to be able to perform the operations in a competitive or acceptable time. All this would reduce duration of the process, reduce stress and make the job much easier for the farmer, further improving this process.

Ethics approval

No animal was harmed during the video recordings carried out for this research. Not applicable.

Data and model availability statement

In the following GitHub link, you can execute the public code where the calculation, construction and verification of the tested models are shown, as well as the training of the dataset and the estimation error. Additionally, you can see other codes about different steps in the image processing, results with other cross-validation parameters or models without sex segmentation: https://github.com/ULE-Informatica/lambscan-depth-unizar-ule.

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Rubén Rebollar: Conceptualization, Data curation, Formal analysis, Project administration, Validation, Writing - original draft.
Manuel Castejón-Limas: Formal analysis, Investigation, Project administration, Software, Validation, Visualization, Writing - original draft, Writing – review & editing.
Claudia Ávarez-Aparicio: Formal analysis, Investigation, Software, Visualization, Writing - original draft.

Declaration of interest

None.

Acknowledgements

The authors are grateful for the collaboration of the "Asociación Nacional de Criadores de Ganado Ovino de Raza Rasa Aragonesa (ANGRA)" and "Casa Ganaderos", among other colleagues and technicians who have participated directly or indirectly by providing data for the elaboration of the work.

Financial support statement

This research was funded from the Aragonese government and the "Asociación Nacional de Criadores de Ganado Ovino de Raza Rasa Aragonesa (ANGRA) via the "Programa de Desarrollo Rural de Aragón para el periodo 2014-2020 (GCP2017-2700)".

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