Advances in horse morphometric measurements using LiDAR

M. Pérez-Ruiz[1,2]; D. Tarrrat-Martín[1]; M. J. Sánchez-Guerrero[3]; M. Valera[3]

1. Universidad de Sevilla. Área de Ingeniería Agroforestal
Dpto. de Ingeniería Aeroespacial y Mecánica de Fluidos, Spain.
2. Corresponding Author's contact information:
ETSIA. Ctra. Sevilla-Utrera km 1
Sevilla, Spain 41013
Phone: 954 481 389
Fax: 954 486 436
E-mail: manuelperez@us.es
3. Universidad de Sevilla. Dpto. de Ciencias Agroforestales, Spain

***Abstract*.**

Zoometric measurements have a potential value in differentialing between individuals and within populations. The measurement of body size in horses and livestock plays a significant role in functional longevity, production, and reproductive performance and health. In this context, the measurements obtained without contact by detection systems and visualized by computers could represent a great advance over conventional measurements that are tedious, time consuming and stressful for the animals. This study presents a new approach to taking zoometric measurements of an animal's body based on digital three-dimensional modelling. The capture of the data series was carried out by a LiDAR sensor. The 16 laser beams of the sensor were able to fully scan a horse, performing a 3D reconstruction of the horse's side, through which body measurements were obtained. Five Pura Raza Española horses (PRE) (3 stallions and 2 mares) with ages ranging between 5 and 18 years old were scanned. The PRE is the most recognized native Spanish horse population for its census (national and international), cultural and socioeconomic importance. For each horse, 17 zoometric measurements (linear and angular) were taken both manually and using the LiDAR-based system to check the usefullness of this non-invasive technology in obtaining quick livestock measurements while causing minimal stress to the animals. Of the 17 zoometric measurements obtained manually and with the sensor, 10 (58.82%) had a mean relative error that ranged between > 0 and <10; 5 (29.41%) had an error that ranged ≥10 and <20; and two (As and ACr) had an error ≥20 (11.76%). A total of 82.5% of the traits studied had an accuracy (v^2) lower than 5%. Therefore, although this approach could still be improved, it verifies the viability of noncontact measurements of large livestock.

Keywords. Zoometric measurements, digital three-dimensional modelling, LiDAR sensor, Velodyne VLP-16

1. Introduction

The use of remote sensing in agriculture is not new; it dates back decades. However, recent technological advances in sensors, instrumentation, and wireless networks have brought innovative levels of monitoring into raising livestock (Guo et al., 2017, 2019; Le Cozler et al., 2019). Sensors measuring animal welfare, health, growth rate, and physiological features, including shape, size, and weight, either alone or in combinations, have been applied in animal breeding. Kawasue et al. (2013) used three Kinect sensors to investigate the weight and size of cattle, as well as their postures and shapes, with accuracies of up to 93% relative to manual measurements. Other authors have also evaluated the body shape and temperature of black cattle using a thermal camera and a Kinect sensor (Kawasue et al., 2017), the correlation between manual measurements and stereo vision in horses (Pallottino et al., 2015), and the combination of a binocular stereo vision system with the LabView development platform to estimate pig body size and weight in indoor farm conditions (Shi et al., 2016).

The horse industry plays a part in national, state, and local economies in Europe, North America, and Canada (Cross, 2019). The equine sector is diverse, involving agriculture, business, recreation, racing, competitions, and the generation of specialized skills and general employment across the board. Breeding, competition, and leisure activities involving horses are important business concerns, and while horses are no longer used for primary transport, they remain important assets. Although not currently popular in most countries, the consumption of horse meat is increasing in several Western European countries due to its availability and recognized nutritional value and mainly as an alternative to the traditional consumption of red meat (Belaunzaran et al., 2015).

Equine production is one of the main agricultural activities in Spain, responsible for 0.5% of the gross national product (Sánchez-Guerrero et al., 2018), with the Pura Raza Española horse (PRE) being the most important breed in terms of historical census (328,706 horses in 65 countries) and economic impact on international trade (Sánchez-Guerrero et al., 2016). Typical genetic selection programmes are based on functionality (dressage) and morphological characteristics. Therefore, obtaining accurate zoometric measurements, characterized by high repeatability and low variance among observers, can be considered ideal conditions in the context of an animal breeding programme (Duensign et al., 2014). In the case of horses, the close connection between biometric parameters, locomotion characteristics, and sports performance is often the only tool for genetic improvement (Pallottino et al., 2015) and as an indicator of functional longevity. In recent decades, indirect conformation assessment systems based on linear morphological traits have been implemented for many equine breeds (Kuhnke et al., 2019; Folla et al., 2019). This system has a series of advantages, as the scoring scale of each region covers its biological range and a wide range of numerical classes can be used, which allows subsequent statistical treatment of the data in a continuous scale. However, highly trained qualifiers are required to apply the linear morphological system, and the relationship between zoometric measurements and the linear scale used has not been established. The main goal of the PRE breeding programme is to improve not only animal functionality but also its conformation for sport performance (Sánchez-Guerrero et al., 2016). Therefore, in the PRE, the importance of conformation has been shown in studies carried out to demonstrate its relationship with dressage (Sánchez-Guerrero et al., 2017; Solé et al., 2013), functional longevity (Solé et al., 2017), and genetic improvement of morphofunctional traits (Sánchez-Guerrero et al., 2017).

In the last decade, several computerized techniques have been proposed for the collection of biometric data through images (Wu et al., 2004; Viazzi et al., 2014). Novel three-dimensional systems can solve the problems posed by conventional two-dimensional vision systems, including stereo photogrammetric techniques. However, these photogrammetric systems are difficult to implement.

In recent years, new techniques that provide point clouds in a fast, non-invasive and inexpensive way, such as the Kinect v2® (Microsoft Corp., Redmond, Washington) or Xtion Pro (USUSTeK COMPUTER Inc., Taipei, Taiwan), as well as infrared (IR) light (Salau et al., 2017; Kawasue et al., 2017; Viazzi et al., 2014; Mortensen et al., 2016; Guo et al., 2017; Pezzuolo et al., 2018; Song et al., 2018; Guo et al., 2019), are being used to develop new method to automate the collection of morphological information from livestock. In fact, Pezzuolo et al. (2019) performed a metrological analysis of the Structure from Motion (SfM) approach, low-cost LiDAR scanning, and the Microsoft Kinect v1 depth camera for three-dimensional measurement of an animal's body, with specific reference to pigs. The results obtained demonstrated the high potential of the 3D Kinect and a higher root mean square (RMS) value of LiDAR with respect to Kinect and SfM, probably due to the collection approach based on individual profiles instead of surfaces.

However, despite progress in the three-dimensional reconstruction of the bodies of animals, no robust descriptor for the automatic estimation of conformation has currently been found in equine species. Therefore, the main objective of this study is to explore a 3D reconstruction approach for body measurements in horses using point cloud analysis. Our specific objectives were (1) to develop a portable scanning system for domesticated animals; (2) to obtain valuable zootechnical information through 3D point cloud analysis (that would avoiding wasting time and money); and (3) to compare the accuracy between the digital and conventional manual measurements on five PRE horses.

2. Materials and methods

2.1. Animals and morphological variables under study

Five PRE horses, belonging to the breeding programme of the "Yeguada Cartujana del Hierro del Bocado" (Jerez de la Frontera, Cádiz, Spain), situated at latitude 36°41′ north and longitude 06°09′ west, were analysed (Table 1).

Table 1. Ages and coat colours of the five Pura Raza Española horses used in this study.

	Stallion 1	**Stallion 2**	**Stallion 3**	**Mare 1**	**Mare 2**
Age	5 years old	6 years old	8 years old	12 years old	18 years old
Coat Colour	Grey	Bay	Grey	Grey	Grey

The animals had been used for breeding and dressage exhibitions. To reduce possible variations, the zoometric measurements taken by the manual method were always carried out by the same veterinarian. For each horse, 17 zoometric measurements (15 linear and 2 angular) relating to sport performance (Sánchez-Guerrero et al., 2016, 2017) were collected (Fig. 1).

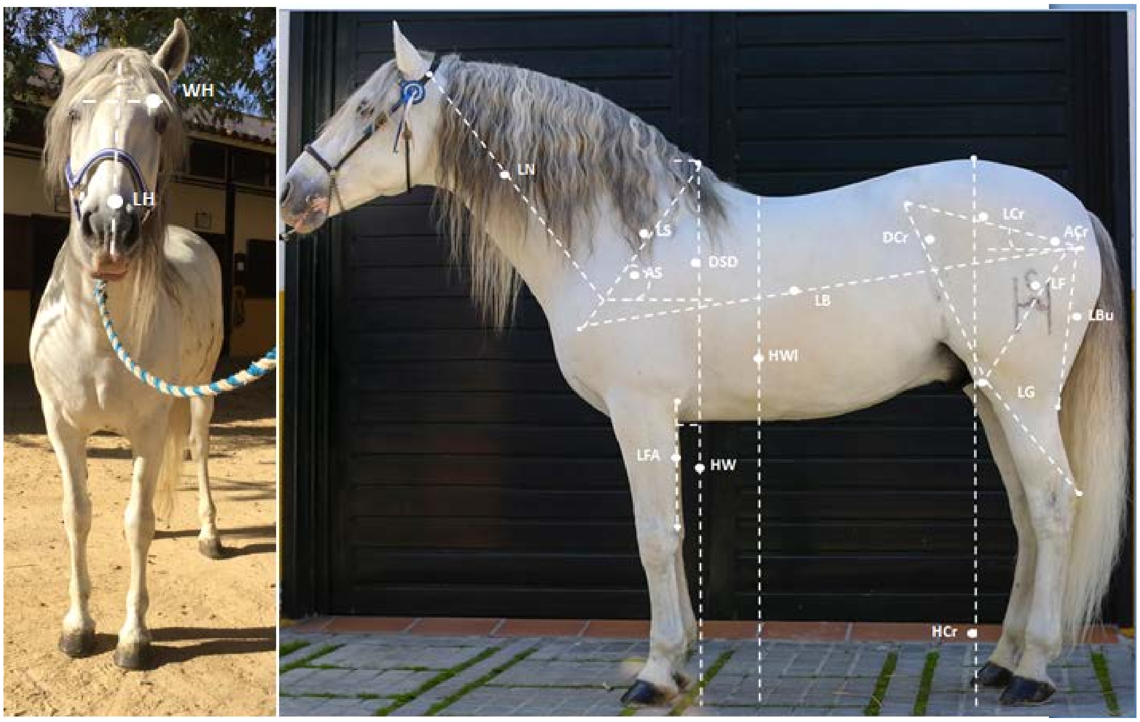


Figure. 1. Graphical representation of the morphological measurements taken in the Pura Raza Espanola stallion 1 of the *Yeguada Cartujana del Hierro del Bocado*. Height at the withers (HW); Height to the lowest point at the withers (HWl); Height at the croup (HCr); Length of the body (LB); Length of the head (LH); Width of the head (WH); Length of the neck (LN); Length of the shoulder (LS); Length of the forearm (LFA); Dorso-sternum diameter (DSD); Length of the croup (LCr); Length of the femur (LF); Depth of the croup (DCr); Length of the gaskin (LG); Length of the buttock (LBu); Angle of the shoulder (AS); Angle of the croup (ACr).

The morphological measurements taken were as follows:

1. Height at the withers (HW): measured from the ground to the highest point of the withers.
2. Height to the lowest point at the withers (HWl): measured from the ground to the lowest point of the withers.
3. Height at the croup (HCr): measured from the ground to the highest point of the tuber coxae.
4. Length of the body (LB): measured between the tubercle of the humerus and the ischial tuberosity.

5. Length of the head (LH): distance from the nape to the cranial border of the snout.
6. Width of the head (WH): distance between the most protruding edge of the zygomatic arches.
7. Length of the neck (LN): distance between the base of the ear and the middle point of the spine of the scapula.
8. Length of the scapula (LS): distance between the wither and shoulder.
9. Length of the forearm (LFA): distance between the parallel straight lines drawn down from the elbow and carpal joint midpoint.
10. Dorso-sternum diameter (DSD): distance measured from the lowest point in the wither decline to the sternal area.
11. Length of the croup (LCr): distance between the coxal tuberosity at its midpoint and the ischial tuberosity.
12. Length of the femur (LF): distance between the buttock and stifle
13. Depth of the croup (DCr): distance between the hip and stifle.
14. Length of the gaskin (LG): distance between the stifle and the hock
15. Length of the buttock (LBu): distance between the coxal tuberosity of the ilium and the ischial tuberosity.
16. Angle of the shoulder (AS): angle formed by the line from the withers to the shoulder with the horizontal.
17. Angle of the croup (ACr): angle formed by the line from the ischial tuberosity to the tuber coxae with the horizontal.

2.2. Data acquisition and data processing

2.2.1 Conventional measurement system

For each horse, zoometric measurements were systematically collected using standard measuring sticks, non-elastic measuring tape and zoometric compasses (Sánchez-Guerrero et al., 2016). All measurements were taken from the left side of the horse while it was standing on a hard surface and flat ground, assuming a natural position. The horses were positioned for measurement with the front legs and hind feet parallel and as near to perpendicular as possible; the toes were in line. No sedatives were used.

2.2.2. Measurements based on the point cloud system

The zoometric measurements were acquired through an optical remote sensing technique using a LiDAR sensor. The sensor uses laser light to obtain a dense sampling of the target, producing accurate measurements in three dimensions. The reflection of laser light off the target is detected and analysed by the receivers in the LiDAR sensor. These receivers, consisting of a receiver telescope, filters, and an optical detector, record the precise time between when the laser pulse left the system and when it returned to calculate the limit distance between the sensor and the target. These spatially organized post-processed LiDAR data are known as point cloud data, which is a large data set consisting of 3D point data. Each LiDAR point can have an assigned classification defining the type of object that reflected the laser pulse.

The LiDAR used was a Velodyne VLP-16 (Velodyne Lidar, Inc., California, EEUU), which is a high-precision 3D laser sensor LiDAR with a rotating head containing a certain number of semiconductor lasers or laser diodes. Each of the lasers has its own detector (Fig. 2).

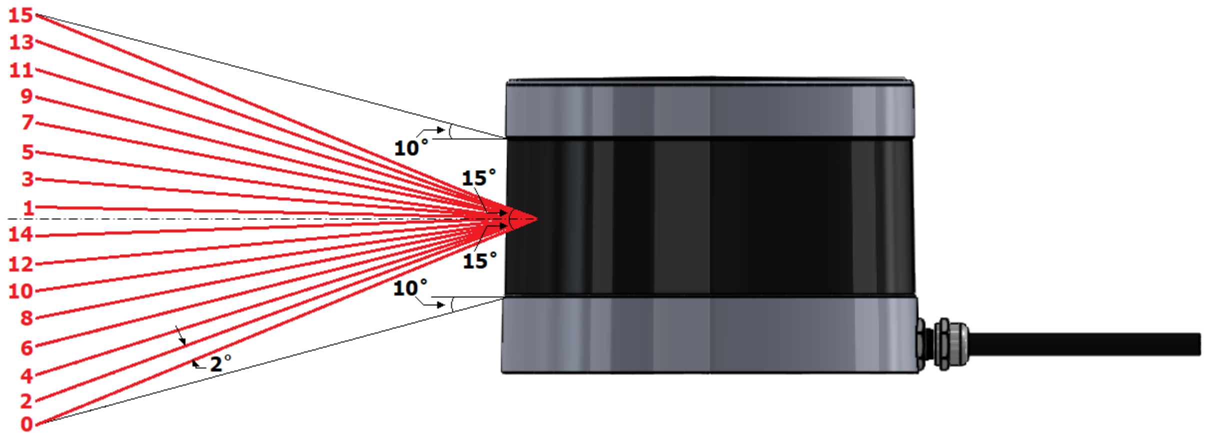


Figure 2. Representation of the lasers of the Velodyne VLP-16

The VLP-16 sensor measures the reflectivity of an object with 256-bit resolution independent of laser power and distance within an interval of 1-100 m. Commercially available reflectivity standards were used for absolute reflectivity calibration, which are stored in a calibration table within the field-programmable gate array (FPGA) of the VLP-16.

The VLP-16 scanner has 16 individual lasers/detectors arranged in a 30° FOV, which yields a vertical resolution of 2.0°. This sensor has an FOV symmetrical with the respect to the horizontal plane, and points can be obtained up to 100 m away at a rate of approximately 300,000 per second in single return and 600,000 for dual return. The horizontal FOV is 360°, with an adjustable rotation frequency between 5 and 20 Hz.

Thanks to the divergence of the laser beam, a single shot can hit multiple objects, and different returns will occur. The VLP-16 has the ability to analsze the multiple returns and report the strongest return, the last return, or both (dual return or dual mode). Multiple returns occur when a laser pulse strikes the horse in a location that does not completely block the path of the pulse, allowing the remaining portion of the pulse to continue to the next seen object.

Communication between the sensor and the computer performing the data analysis was performed was carried out through an interface box with an Ethernet cables and user-assigned IP addresses.

As a robust and easily portable solution, the mini PC used was a Raspberry Pi, a small, low-cost, single-board computer. This system (Fig. 3) is very versatile and allows the installation of several operating systems, whether official or otherwise, as well as different content managers depending on the use for which it is intended.

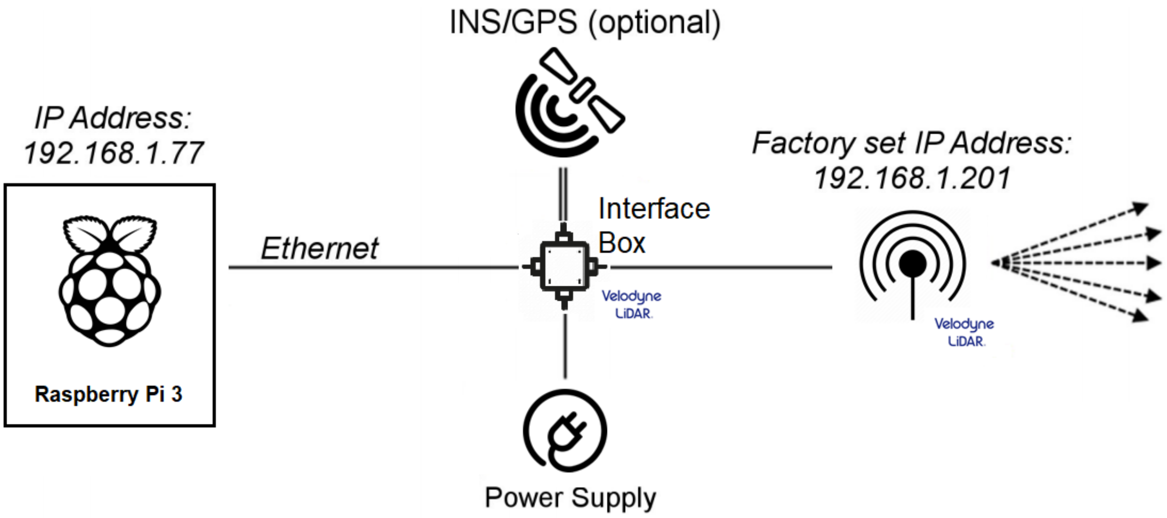


Figure 3. Hardware connections.

The operating system used was UBUNTU 18.04.2 (Bionic). Ubuntu was chosen because it is an open operating system and the preferred software for development under Linux, especially in terms of artificial intelligence solutions, automatic learning, and deep learning, because it offers a wide breadth of libraries, tutorials, and examples; furthermore, no other operating system offers the same level of support for the latest versions of software and free open source platforms. Additionally, UBUNTU is one of the best optimal platforms for robotics operating systems (ROS) to function correctly and simply.

An ROS is an operating meta-system, as it includes an operating system that is installed over another one. This flexible framework has a wide variety of tools, libraries, and packages that considerably simplify the creation of applications for robots.

Working with the Ubuntu operating system along with the ROS allows us to obtain information through a command terminal, configure the sensor, the interface and execution time, and work with a simple graphical interface (such as ROS visualization (RViz)), among other functions.

RViz is a 3D visualization tool that can represent robots, point clouds, sensor data, and so on. RViz simply reads and interprets the different data contained in the ROS messages. Therefore, it is necessary to have an external generator for these messages, such as a robot, or in this case, a LiDAR sensor.

Once RViz was configured, the horse could be scanned. A tripod was used to stabilize the sensor and regulate its height. Once screwed to the tripod, the sensor must be placed far enough away from the horse to capture the animal completely and through as many acquisition channels as possible. The LiDAR is placed on the tripod at a height of 90 cm for the ground, enough height to obtain a complete scan of the horse. This height favors that the sensors rays strike as as little as possible on the ground and on the top of the horse.

As the vertical field of view of the sensor covers an angle from -15° below to 15° above the horizontal, the laser was installed in the horizontal orientation, perpendicular to the ground, ensuring a complete sweep of the horse (Fig. 4). The horse was only restrained by a halter and a rope, and the handler attempted to keep it as stationary as possible.

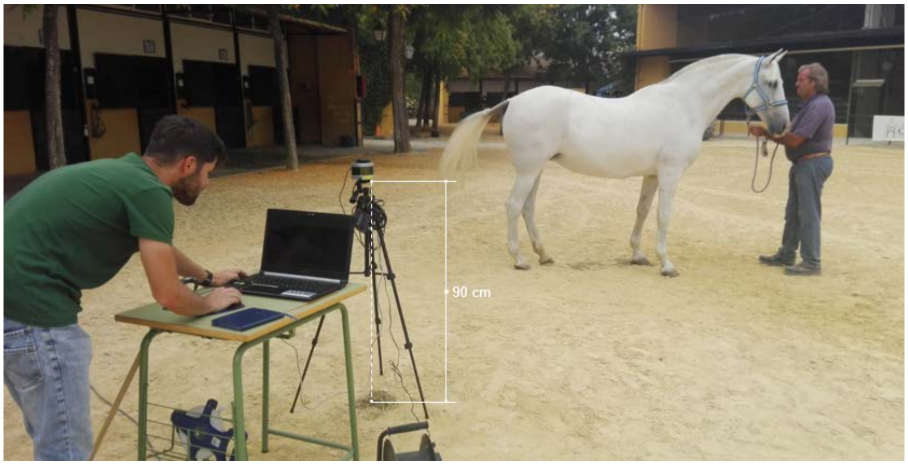
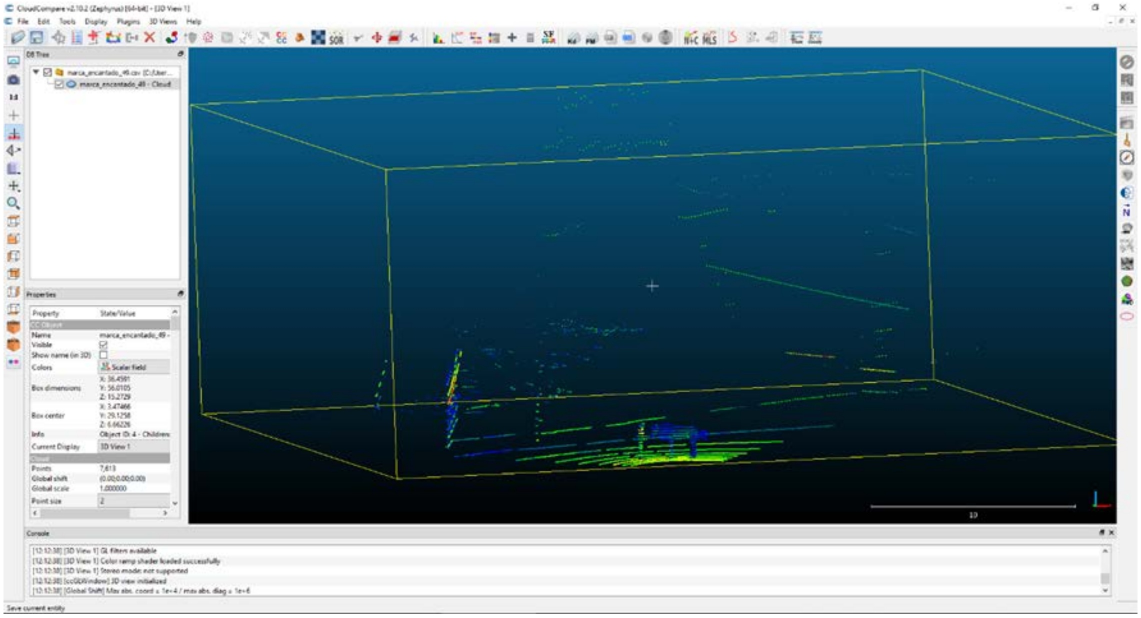


Figure 4. Measuring a mare with the LiDAR system at the *Yeguada Cartujana Hierro del Hierro del Bocado*.

From the LiDAR sensor configuration screen, it is possible to reduce the vertical field of view, preventing the sensor from scanning the background, focusing only on the surface of the horse. The point cloud was generated by the RViz visualization tool. Through this point cloud, we could find the surface and reflectance of the materials scanned (Fig. 5).



Property	State/Value
CC Object	
Name	marca_encantado_49 -
Visible	☑
Show name (in 3D)	☐
Colors	Scalar field
Box dimensions	X: 36.4581 Y: 56.0105 Z: 15.2729
Box center	X: 3.47466 Y: 29.1258 Z: 6.66226
Info	Object ID: 4 - Children
Current Display	3D View 1
Cloud	
Points	7,613
Global shift	(0.00;0.00;0.00)
Global scale	1.000000
Point size	2

```
[12:12:38] [3D View 1] GL filters available
[12:12:38] [3D View 1] Color ramp shader loaded successfully
[12:12:38] [3D View 1] Stereo mode: not supported
[12:12:38] [ccGLWindow] 3D view initialized
[12:12:38] [Global Shift] Max abs. coord = 1e+4 / max abs. diag = 1e+6
```

Save current entity

Figure 5. Point cloud from a test scan of a Pura Raza Espanola stallion of the *Yeguada Cartujana del Hierro del Bocado*.

To be able to work with data in the CloudCompare point cloud processing software, it was necessary to convert the .bag file recorded in RViz into either a comma separated value (.csv) or a .pcd file format. CloudCompare is a free software for processing 3D point clouds and triangulation meshes. It is designed to cope with huge point clouds typically consisting of more than 10 million points and up to 120 million points with 2 gigabytes of memory.

As the data were taken in one of the yards of the *Yeguada Cartujana del Hierro del Bocado*, it was necessary to perform manual filtering of the point cloud to facilitate the extraction of the measurements of zoometric variables. The filtering consisted of removing all objects that surrounded the horse from the complete point cloud that made it difficult to take measurements, such as the trees in the yard or the operator steadying the horse. From the point cloud generated and filtered through the CloudCompare program described above, measurements of the racial and functional zoometric variables were manually obtained in cm (Fig. 7).

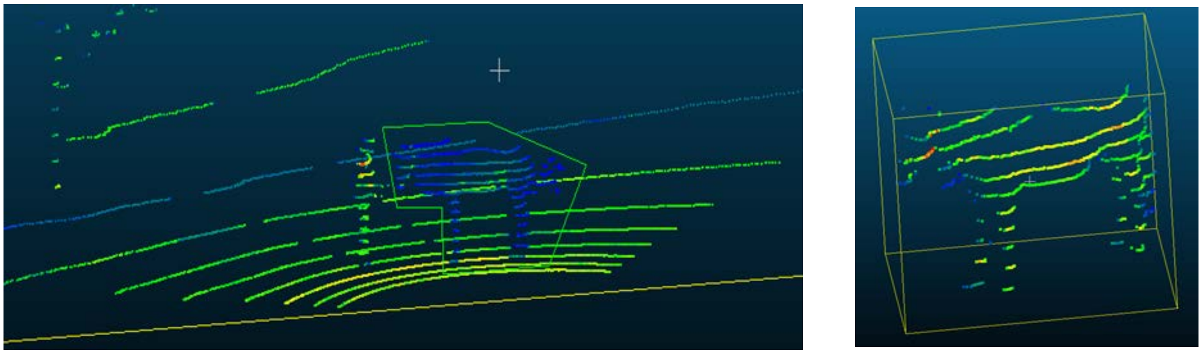


Figure 6. Point cloud filtering.

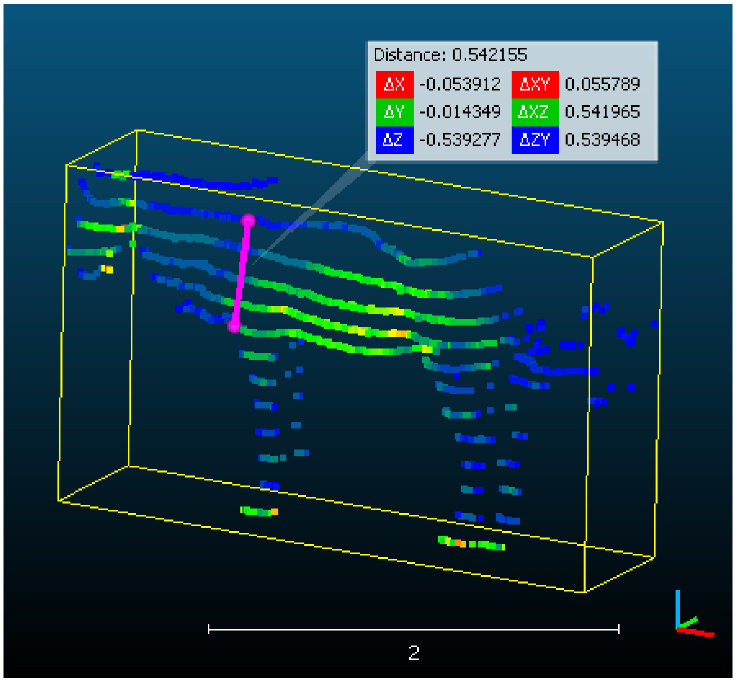


Figure 7. Zoometric measurements of the back length of the Pura Raza Espanola stallion obtained at the *Yeguada Cartujana del Hierro del Bocado*.

2.3. Statistical analysis

The relative error formula was used to compare the measurements taken manually and by the sensor to discern the errors made with this latter method for the noncontact measurements of animals:

$$\text{Relative error (\%)} = ((\text{Manually Measurement} - \text{Sensor Measurement})*100)/\text{Manual Measurement}$$

The accuracy of this method (v^2) was estimated by calculating the percentage of error of the sensor method with respect to the variance (Poly et al., 1967).

$$v^2\ (\%) = (\text{Variance}_{(\text{Manually Measurement - Sensor Measurement})})*100)/\text{Variance}_{\text{Manual Measurement}}$$

In addition to the relative error and v2, the mean, maximun, and minimun errors were also calculated. The relative error only indicates the deviation over the manual measurements, while v2 also analyses the variance of these differences between the manual and sensor measurements. Therefore, v2 is more precise than the relative error, especially when several animals are studied. A low value of v2 and relative error were desirable. The Pearson correlation coefficient (r) was calculated between the measurements taken manually and by the sensor. Finally, a regression analysis between the coefficient of determination (R^2) and the root-mean-square error (RMSE) between zoometric measurements performed using the conventional procedure (manual) and the LiDAR system (sensor) was also calculated. The procedures were analysed using Statistica 10.0 for Windows package.

3. Results and discussion

In general, morphology is considered more important in horse breeding than in other livestock species due to the horse's relationship with sports performance and meat production (Preisinger et al., 1991). To obtain data for the genetic evaluations, all the PRE horses registred in the PRE studbook are tested morphologically. Although manual measurements in equids are the most precise, they often involve a risk for the assessor (as wild, young, and stressed animals could cuase them injury) and consuming excessive time and money. In the last decade, 71,349 PRE horses have been tested with manual measurements and linear morphological traits with the consequent expense of time and money that this entails. In addition, only PRE over two years old could be tested, since younger foals are often incapable of standing still while the veterinarian takes the zoometric measurements. This problem also prevents studies of growth in the breed. Therefore, a new methodology, that could be applied quickly, systematically and without touching the animal (even with animals in the field) would be of great benefit to PRE breeding programmes. Therefore, the zoometric measurements in this paper were obtained twice, once manually and once using the Velodyne LiDAR sensor, as shown in Table 2.

Table 2. Zoometric measurements, relative error, v^2 error and Pearson correlations in five Pura Raza Española horses from Estrepe Cartujana obtained using the conventional procedure (manual) and the LiDAR system (sensor)

M	Stallions 1			Stallions 2			Stallions 3			Mare 1			Mare 2			Global v^2	r
	m	**s**	**r.e.**	**m**	**s**	**r.e.**	**m**	**s**	**r.e.**	**m**	**s**	**r.e.**	**m**	**s**	**r.e.**		
HW	156	160	-2.56	159	149	6.29	164	156	4.88	160	149	6.88	163	150	7.98	1.14	-0.32
HWl	151	141	6.62	150	148	1.33	153	155	-1.31	149	146	2.01	153	150	1.96	3.59	0.60
HCr	158	145	8.23	159	155	2.52	159	140	11.95	160	154	3.75	162	161	0.62	23.17	0.77
LB	156	150	3.85	155	155	0.00	159	153	3.77	159	158	0.63	170	156	8.24	0.86	0.39
LH	60	63	-5.00	58	57	1.72	59	62	-5.08	61	57	6.56	62	60	3.23	0.52	0.06
WH	23	29	-26.09	23	22	4.35	24	23	4.17	21	17	19.05	23	25	-8.70	3.92	0.64
LN	74	78	-5.41	73	70	4.11	79	73	7.59	78	78	0.00	78	75	3.85	0.64	0.25
LS	62	53	14.52	62	54	12.9	62	67	-8,06	66	73	10.61	69	70	-1.45	0.98	0.71
LFA	54	54	0.00	47	56	19.15	49	40	18.37	44	37	15,91	47	51	8.51	1.07	0.48
DSD	72	54	25.00	71	54	23.94	74	62	16.22	74	66	10.81	77	67	12.99	3.58	0.90
LCr	56	50	10.71	54	54	0.00	52	51	1.92	52	54	3.85	53	55	3.77	1.86	-0.45
LF	53	44	16.98	50	42	16.00	51	48	5.88	48	41	14.58	45	42	6.67	0.86	0.53
DCR	52	48	7.69	49	39	20.41	52	53	1.92	52	35	32.69	53	49	7.55	17.70	0.47
LG	51	64	25.49	48	49	2.08	50	50	0	57	62	8.77	54	55	1.85	2.32	0.62
LBu	47	45	4.26	45	41	8.89	48	47	2.08	42	39	7.14	45	47	4.44	0.25	0.79
AS	57	66	15.79	57	86	50.88	56	62	10.71	58	83	43.1	57	65	14.04	230.60	0.66
ACr	14	25	78.57	18	10	44.44	18	23	27.78	17	21	23.53	18	20	11.11	4.17	-0.55

Measurements (M); conventional procedure (m) and the LiDAR system (s); relative error (r.e.); Pearson correlations coefficient (r); MHeight at withers^1 (HW); Height at croup^1 (HCr); Length of head^1 (LH); Width of head^1 (WH); Length of neck^1 (LN); Length of shoulder^1 (LS); Length of forearm^1 (LFA); Length of body^1 (LB); Length of croup^1 (LCr); Length of femur^1 (LF); Length of gaskin^1 (LG); Depth of croup^1 (DCr); Length of buttock^1 (LBu); Dorso-sternum diameter^1 (DSD); Angle of shoulder^2 (AS); Angle of croup^2 (ACr). ^{1}Centimters ^{2}Degrees

Size and body conformation are critically important traits in nearly all horses breeds, which are presumably subject to a strict process of selection over time (Brooks et al., 2010). The zoometric measurements recorded during this study were similar to those obtained previously in the same breed (Molina et al., 1999; Gómez et al., 2009). Although the bay PRE horses are the tallest in this study, the height of stallion 2 was between that of stallions 1 and 3.

The measurements were taken both in mares and stallions to measure the possible difference in accuracy of the measurement at the horse's mane; in mares, the mane is usually cut, and in stallions it is usually left long (Fig. 1 and 4). In our results, stallions had a higher relative error than mares (10.83 and 8.80, respectively) and a higher average v^2 value.

Among the three stallions, the relative error ranged between 0 (HC, LFA, LCr and LC) and 78.57 (Acr). A total of 7.84% of the zoometric measurements studied had a relative error of 0; for 52.94% had an error > 0 and <10; for 21.57% had an error ≥10 and <20; for 11.76% had an error ≥20 and <30; and for 5.88% had an error ≥ 30. For the two mares studied, the relative error ranged between 0 (LN) and 43.10 (AS). A total of 2.94% of the zoometric measurements studied had a relative error of 0; for 64.71% had an error > 0 and <10; for 23.53% had an error ≥10 and <20; for 2.94% had an error ≥20 and <30; and for 5.88% had an error ≥ 30 (Table 2). The mean relative error was 10.83% and 8.00% without angle measurements. A total of 82.5% of the studied features had an accuracy (v2) of less than 5%; only one of the angle meaurements (AS) had a higher v2 value. The Pearson correlation between the manual and sensor measurements ranged from 0.90 (DSD) to -0.55 (Acr) or -0.45 (LCr) if the angles were no taken into account (Table 3). The angles are, in general, very difficult to measure also in the traditional system and in the linear morphological assesments since they are influenced by the horse's posture (Sánchez et al., 2013). We suggest that perhaps this problem could be solved with the use of LiDAR or a similar technique, since the scan could be performed when the animal is perfectly poised, and in real life, the horse is always moving to some degree while zoometric measurements are being taken. The R^2

and RMSE estimated by comparing the zoometric measurements obtained using the conventional procedure (manual) and the LiDAR system (sensor) were 0.97 and 7.62, respectively (Figure 8).

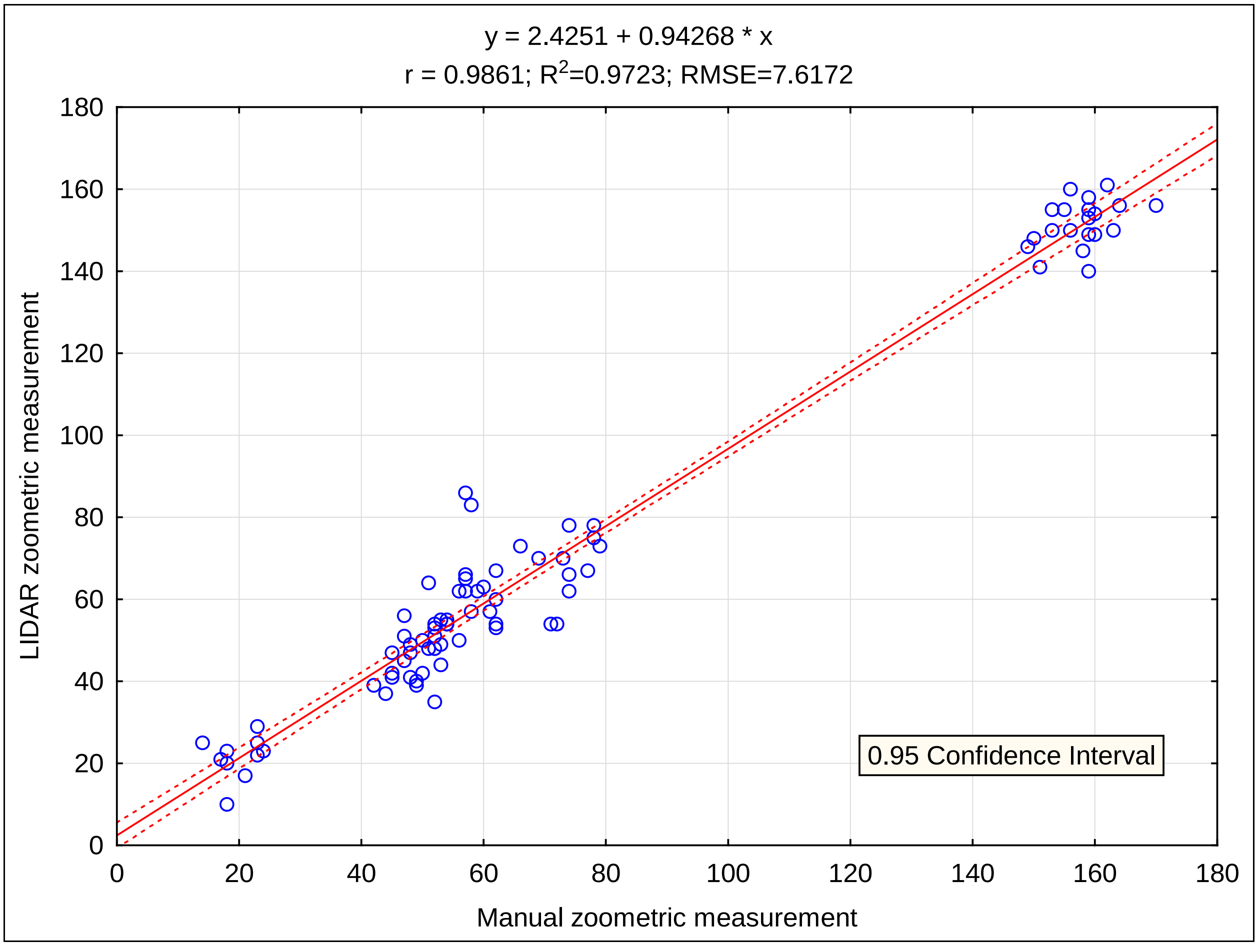


Figure 8. A scatter plot with regression analysis between the coefficient of determination (R^2) and root-mean-square error (RMSE) comparing zoometric measurements obtained for five Pura Raza Española horses from Estrepe Cartujana performed using the conventional procedure (manual) and the LiDAR system (sensor)

Thus, our results differ from those reported for different body measures on Mediterranean buffaloes (Negretti et al., 2007), correlating traditional measures with predicted ones using image analysis and obtaining coeficients ranging between 0.91 and 0.99 depending on the measured trait. Moreover, Pallottino et al. (2015) correlated traditional measurements with those obtained with a dual web-camera system (r = 0.998) in Lipizzan horses. In any case, It is important to highlight that the Pearson correlation coefficients are not the best way to detect the differences between two methods of measurement, since we are not as interested in whether they increase or decrease in the same direction. The main interest is to ensure that the difference between the two measures is as small as possible. This could be better estimated with the relative error. For the body size measurements of sheep, a low-cost dual web camera was used, yielding a mean relative error of 5% (Menesatti et al., 2014). In addition, 16 adult dairy cows were studied with pairs of pictures, taken with a portable instrument incorporating two synchronized cameras, with photogrammetric measurements having an accuracy within 0.5 cm (Gaudioso et al., 2014). The use of a structured light depth camera for three-dimensional body measurements of dairy cows in free-stall barns has also been evaluated (Pezzuolo et al., 2018), obtaining coefficients of determination of R2 > 0.84 and deviations lower than 6% with respect to manual measurements. As in our case, lower performances were obtained for the angle measurements (back slope: $R^2 = 0.12$). In our study, the AS measurement had a very high v^2 value, while ACr had a low v^2 value in both genders. This is the first study in which 17 zoometric measurements were analysed, with the majority of the previous studies having fewer traits analysed (ranging from 3 to 8 body measurements (Huang et al., 2018; Pezzuolo et al., 2018)). Taking accurate manual measurement data as validation criteria, LiDAR methodology was used in another study to measure three live cattle, and the experimental results showed that the final deviations were close to 2 mm and within approximately 2% (Huang et al., 2018). The reproducibility of these traits in the linear morphological system ranged from 0.86 to 0.99 in PRE (Sánchez et al., 2013). In studying another group of zoometric measurements, Gaudioso et al. (2014) found a standard deviation of 2.0 cm. It shold be noted that we have not been able to study the precision of these 17 zoomometric measurements since replications were not carried out.

Once the methodology proposed in this project has been presented and the results obtained from this process have been analysed, the final development of two conclusions can be presented, one from a generic point of view and another from a specific point of view, in addition to a roadmap for future developments.

4. Conclusions

A general methodology has been created that establishes a data evaluation process, so that in the future, applications can be developed in which we can encompass the entire process. The use of a LiDAR system has simplified the taking of measurements, giving rise to a method that can obtain optimal results in monitoring the growth of the livestock. This methodology specifies a clear, precise and logical process.

In theory, this method can be extrapolated to any equine breed, as well as to other livestock species. Although it is a pilot study and its accuracy must be improved, it could help in preventing excess spending and stressing animals with the current manual zoometric measurement. More specificically, the following conclusions can be drawn based on the results obtained from implementing the methodology. The approach carried out in this work verifies the viability of the noncontact measurement of large livestock. Knowledge of the scalable growth and animal welfare at the location where the animals are housed will improve the quality of the animals and genetic breeding. However, as can be seen in the results section, due to the constant movement of the horses and the limitation of single-frame analysis, it is not possible to fully analyse the three-dimensional image of the horse. The geometric accuracy of these sensors is closely related to the quality of their external orientation. This external orientation is what we will obtain from the integrated navigation systems (GNSS and INS). The laser scanner measures only the vector oriented from the opening of the laser system to an object point normally on the ground, the horse. Three-dimensional points can only be calculated if at any moment the position and orientation of the LiDAR sensor with respect to a coordinate system is known. A future study will try to improve these drawbacks by integrating two synchronized point clouds through two LiDARs positioned on each side of the animal and performing repeated measurements with the conventional procedure (manual) and the LiDAR system (sensor).

For this problem, in the near future this system will continue to be optimized by activating the LiDAR sensor and an integrated navigation system that will allow the sensor to move so that the horse can be rotated while it is being scanned. This will further allow a complete reconstruction of the horse in 3D for greater accuracy in obtaining the zoometric variables.

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