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Visual Image Analysis for a new classification method of bovine carcasses according to EU legislation criteria

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A R T I C L E I N F O

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A B S T R A C T

In the European Community, conformation and fat cover of bovine carcasses is assessed using the SEUROP grading system. In this study we pursued the development of an application software (App) based on Visual Image Analysis, useful for SEUROP and Fat Cover grading of bovine carcasses using a smartphone. The App was trained using 500 bovine carcasses. Carcass conformation and Fat Cover classes were assessed in parallel by expert evaluators and by App. Overall, a high correspondence was found between the measurements of carcasses parameters by operators and by the App, as high as 84.2% for SEUROP and 86.4% for the Fat Cover. In the 15.8% of samples with discordant SEUROP evaluation, and in the 13.6% of samples with discordant Fat Cover evaluation, the operators' and App measurements deviated by only one class. All values also aligned with the requirements expected by the current legislation for the use of automated and/or semi-automated systems able to determine the market value of carcasses.

1. Introduction

Regulation (EEC) No. 1208/81 (EC, 1981) and Regulation (EEC) No. 3220/84 (EC, 1984) established the system for the classification, identification, and presentation of carcasses in the meat sector (cattle and pigs). Currently, Regulation (EU) No. 1308/2013 (EC, 2013) on the classification of carcasses, entered into force in July 2018, and Commission Implementing Regulation (EU) No. 2017/1184 (EC, 2017a), governs this system. From the outset, EU legislation has aimed both at harmonizing meat prices within the EU single market, and at improving transparency for both Food Business Operator (FBO) and consumers.

The above-mentioned Regulation (EC, 2013) was based on the use of a common language to describe carcasses using commercially significant characteristics. In particular (ANNEX IV), carcasses or half-carcasses of bovine aged ≥8 months must be classified by evaluating the development of their profiles, back and shoulders and assessing their fattening status (visible surface including inner thoracic cavity) to assign them one of the six *Conformation Class* (*S, E, U, R, O, P*) and one of the five *Fat Cover* (FC) (*1, 2, 3, 4, 5*) respectively. In the first case, the upper class (*S*) includes the higher quality carcasses, while in the second case the fat cover increases from class 1 to class 5. Moreover, slaughterhouse operators are adequately trained to use these classification criteria associated with official reference images.

The classification of carcasses is compulsory, with some exceptions reported in Article 2 of the Commission Delegated Regulation (EU) No. 2017/1182 (EC, 2017b). However, the possible error of the classifiers often represents a subject of legal contention (Craigie et al., 2012). For these reasons, alternative measurement systems have been developed to address the limitations of empirical evaluation. In fact, progress in the field of digital images has now led to the development of Visual Image Analysis (VIA) (Computer Vision System). This is an inspection approach, in which images are acquired with a physical image sensor and analysed by hardware and software (Brosnan & Sun, 2004; Craigie et al., 2012; Gunasekaran, 1996). Also techniques have been used in different ways throughout the food chain. They have often been applied to estimate the weight of live animals indirectly from their size (Menesatti et al., 2014; Mollah, Hasan, Salam, & Ali, 2010; Negretti & Bianconi, 2005; Negretti & Bianconi, 2007; Negretti, Bianconi, Bartocci,

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Terramoccia, & Verna, 2008; Negretti, Bianconi, D'Angelo, Gaviraghi, & Noè, 2004; White, Schofield, Green, Parsons, & Whittemore, 2004), to authenticate fish fillets (Grassi, Casiraghi, & Alamprese, 2018; Mathiassen, Misimi, Bondø, Veliyulin, & Østvik, 2011), or to predict some significant quality parameters and to classify meat foods (Cheng, Nicolai, & Sun, 2017).

From the 1980s to the present, the development and use of VIA has been extensively described (Cannell et al., 2002; Costa et al., 2014; Craigie et al., 2012; Craigie et al., 2013; Cross, Gilliland, Durland, & Seideman, 1983; Pabiou et al., 2011). Its strength has been linked to its non-destructive, non-invasive, and objective nature and even to the possibility of automating it according to the work flow of the slaughterhouse (Craigie et al., 2012). Transforming this technique into an easy-to-use application for tablets and mobile phone to be used by slaughterhouse classifiers, could represent a valid and economical alternative to maximize the accuracy of the carcass assessment process even in small establishments. A dedicated Application software (App-SEUROP), developed for an Android device and easily accessible from mobile phone, could represent a valid, objective, and economical tool to support slaughterhouse qualified classifiers. Therefore, given that the classification of carcasses could be carried out using automated and/or semi-automated grading techniques (EC, 2017a), the aim of the study was to create a new VIA-based tool for the objective classification of bovine carcasses based on the criteria of Commission Implementing Regulation (EU) No. 2017/1184.

2. Materials and methods

2.1. Parameters for carcasses classification

The official reference images representing the six conformation classes (S, E, U, R, O, P) and the five fat cover (1, 2, 3, 4, 5) were visually analysed to screen and select objective parameters that could be measured and used for carcass classification by VIA. The selected parameters were evaluated only on the external part of the carcass, that allows an optimal observation of the roundness of conformation with the imaging system.

2.1.1. Angular parameters associated to the conformation class

The amplitudes of the five angles were selected as parameters on the official images related to the conformation classes. These are illustrated and described in Fig. 1.

2.1.2. Surface parameter associated to the fat cover class

The ratio between the entire carcass surface and the surfaces covered by fat (visualised on the official images related to the fat cover classes) was selected as parameter to objectively establish the carcass fat cover percentage and unequivocally assign it to a fat cover class (Fig. 2).

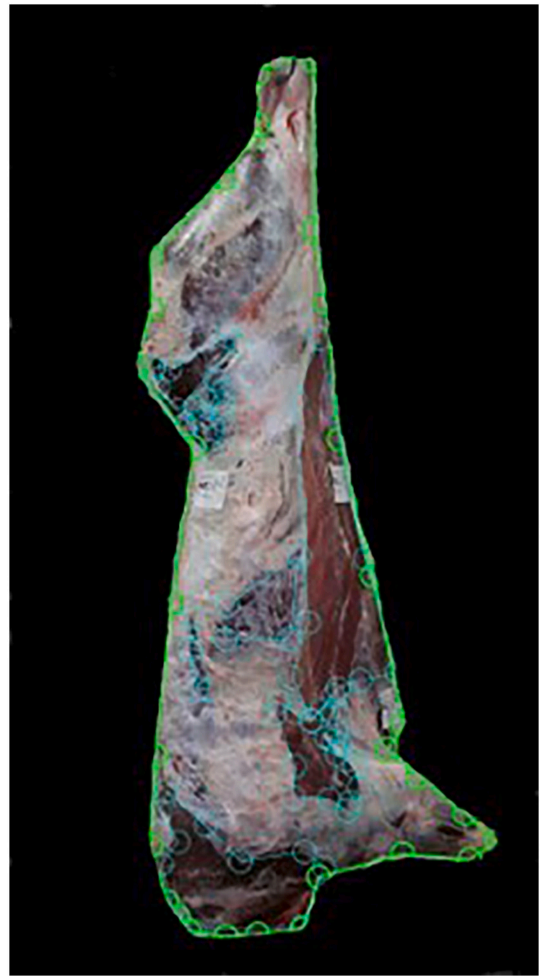

Fig. 2. Representation of the fat cover (FC) detection.

Fig. 1. Representation of the selected parameters (AC, AC1, AC2, AC3, AC4).
AC: the roundness of the thigh at the base of gluteal region. AC1: the depth at the base of the ileum. AC2: the width of the hind. AC3: the hind roundness. AC4: the roundness of the thigh at the point of attachment of the tendon. P–P4: point of origin of the two segments T and V, which determines the angle. T and T4: the two segments that follow the profile of the thighs starting from the base of the gluteal region. T1: originates at the depth of the ileum and goes to the point of greatest curvature of the thigh. T2 and T3: segments that mark the profile of the thighs starting from the shin. V: originates at the base of the gluteal region.V1: originates at the base of the ileum and goes to the base of gluteal region. V2: originates at the shin and goes to the profile of the abdomen. V3: originates at the base of the shin. V4: originates at the base of the gluteal region.

2.2. Measurement of the identified parameters and reference tables

The angular and surface parameters were first measured (Patent n. 1413532, Negretti-Bianconi) on the official reference images of the conformation and fat cover classes. They represent unequivocal classes, and consequently the evaluators must refer to them in the formulation of their assessment. It was then possible to obtain discriminating values between one class and another (S vs E vs U vs R vs O vs P) for the identified parameters as shown in Fig. 1 and Table 1, regardless of breed, age and sex.

The threshold values of Table 1 were used to identify, for each introduced angular parameter, a SEUROP conformation class with respect to the accepted reference standard images of carcasses. The calculation between the different parameters was simply obtained by adding each individual class identified by the measurement of parameters and then calculating the average. Given that it was not possible to add letters, a single decreasing numerical value was matched to each single letter in order to perform a statistical mathematical calculation S (6), E (5), U (4), R (3), O (2), P (1). For instance, if the parameter AC (roundness of the thigh at the base of gluteal region), measured on a given carcass, provides a value that according to the Table 1 belongs to class U (4), while the parameter AC1 belongs to class R (3), AC2 to class U (4), AC3 to class E (5) and AC4 to class U (4), the overall value will be given by the average of the different classes that is $4 + 3 + 4 + 5 + 4 = 20/5 = 4$ and, therefore, the carcass classification will correspond to class U.

A similar methodology was applied for the FC. In this case the ratio between the surface of the carcass and the lean parts results in the percentage of fat cover. These measurements were performed on the official images and reliably provided a measurable discriminant between one class and another (5 vs 4 vs 3 vs 2 vs 1) as shown in Fig. 2 and Table 2.

The use of angular values and the percentage of fat cover which defines the state of fattening, allowed us to overcome the calibration problems that the VIA system based on biometric measurements requires, besides pure numbers. The use of angular values and fat percentages do not require image calibration to establish the pixel/cm ratio.

Table 2
Correspondence between the class evaluation of the state of fattening and measure of the coverage in fat with the Visual Image Analysis.

	Fat cover classes				
	1	2	3	4	5
Fat surface/total surface (%)	<33–70	71–77	78–82	83–86	> 87

2.3. Development of instrumentation in the field of Visual Image Analysis

2.3.1. Graphic interface and functionality

In the field of VIA techniques, an Android-based App (copyright No. 2017003117) was designed and developed to acquire the angular and surface parameters of bovine carcasses. The acquisition is performed quickly and without the support of dedicated equipment in order to determine the carcass SEUROP classification. The App used the mobile phone's wide-angle camera. This allowed acquiring a good image of the carcasses, despite space constraints at the slaughterhouse. Furthermore, to avoid distortions altering the accuracy of the measurements, the images were taken perpendicular to the carcass.

The App allowed on-line and off-line processing, as well as the capturing of a photo of the carcass for immediate analysis, or the import and processing of a previously acquired photo. The measurement phase is based on the determination of the values of the angular parameters AC, AC1, AC2, AC3 and AC4 (Fig. 1) and the percentage of fat surface (ratio between lean mass surface/total surface of the carcass).

To make its use functional and intuitive, a simple graphical interface (GUI) was created. The App superimposes reference points mapped to the carcass, which the operator can immediately identify. The GUI allowed the insertion of data points (i.e. the significant points that define angles and surfaces) with a simple touch in the relative chosen point of the photo. Precise positioning and adding of data points for carcass outline and angle location can also be managed later via drag & drop interactions. The App was designed to be used with a large number of different smartphone models with medium-sized displays, in order to ensure high compatibility with the devices currently present on the market.

The main sections of the App were three: (i) measurement list, (ii) parameter definition and (iii) data display. All sections are interconnected by the logical flow of operation. In the first section it is possible to view, consult and manage the measurements made previously. These measurements can in fact be displayed, stored or deleted by the user. In this section it is also possible to either acquire a new photo or import an existing one from the gallery to proceed with its elaboration. In the second section it is possible to insert the data points on the image to define the angular and surface parameters. The App automatically overlays a standard carcass outline to render the process faster and easier. Specific graphical tools allow the adaptation and modification of the carcass silhouette to achieve the best possible precision. Finally, in the third section, data relating to the measurement of angles and % surface fat and the final result of the processing are shown in tabular format. Figs. 3, 4 and 5 show examples of the relevant App screen of the three sections, respectively.

2.3.2. Architecture and data organization

The logical architecture of the App is organized according to an accurate scheme (Fig. 6):

- Presentation Layer: it handles the user input and sends it to the underlying layers for processing and storage. It can be partitioned into User Interface (UI) and Export Layer.

- UI: the module within the Presentation Layer that manages the user interface. The purpose is to present the screens, respond to the user's interaction and acquire data and commands; it also handles the navigation between the different sections of the App.

- Export Layer: the module within the Presentation Layer that takes care of exporting data in xlsx format.

- Data Manipulation Layer: it takes care of processing the input and output data to support the core functionality of the App. In particular, it takes care of acquiring the raw data provided by the Presentation Layer and converts them into the internal data model. It also carries out all the necessary processing on the data to feed the Presentation Layer with the results of interest to the user. The specific features of the App are as

Table 1
Correspondence between the S (6) E (5) U (4) R (3) O (2) P (1) evaluation class and the experimental parameters measured with the Visual Image Analysis.

Angular parameters	Conformation classes					
	S (6)	E (5)	U (4)	R (3)	O (2)	P (1)
AC	>78–73	72–61	60–47	46–41	40–36	≤ 35
AC1	> 45–41	40–36	35–32	31	30–29	≤ 28
AC2	> 56–51	50–47	46–42	41	40–38	≤ 37
AC3	> 44–41	40–36	35–33	32	31–29	≤ 28
AC4	> 167–156	155–147	146–132	131–127	126–122	≤121

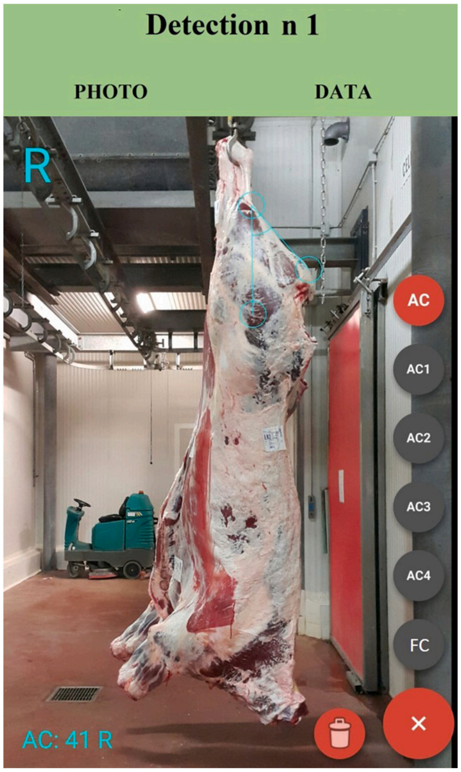

Fig. 3. App screen of the section“definition of parameters”.

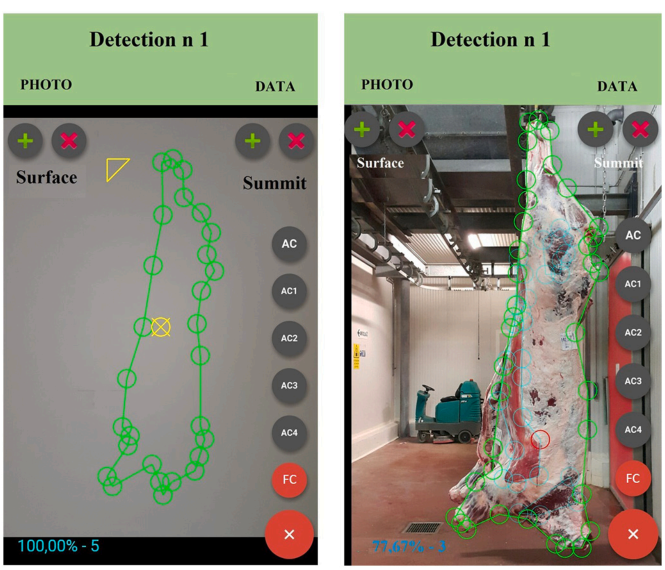

Fig. 4. App screen of the automatic overlay section of the carcass silhouette.

follows: (i) conversion of the user inserted points into angular values, (ii) computations on the user inserted areas and (iii) mapping of the angular and surface values on the corresponding SEUROP and FC classifications.

- Data Access Layer: it manages the access to the database.

- Database: the physical archive on which the data are recorded and retrieved by the user.

2.4. Validation of the parameters on carcasses

To verify the reliability of the selected parameters and of the methodology developed with the detection of official images (Section 2.2), a survey was performed on a sample of 500 bovine carcasses of different breeds. The carcasses were classified by three certified expert classifiers holding the necessary licenses obtained after passing special courses for these inspections, according to the SEUROP conformation and were divided into the following categories, on the basis of the Regulation (EU) No. 1308/2013:

A: carcasses of uncastrated male animals aged from 12 months to less than 24 months.

B: carcasses of uncastrated male animals aged from 24 months.

D: carcasses of female animals that have calved.

E: carcasses of other female animals aged from 12 months.

The tests were carried out in an Italian slaughterhouse and included all the classes identified by the legislation. The 500 carcasses were assessed with the App simultaneously with the official assessments conducted by 3 experts to correct the error due to the subjectivity of the eye evaluations. The measurements obtained with the SEUROP App were compared with the average of the SEUROP classifications assigned by the experts.

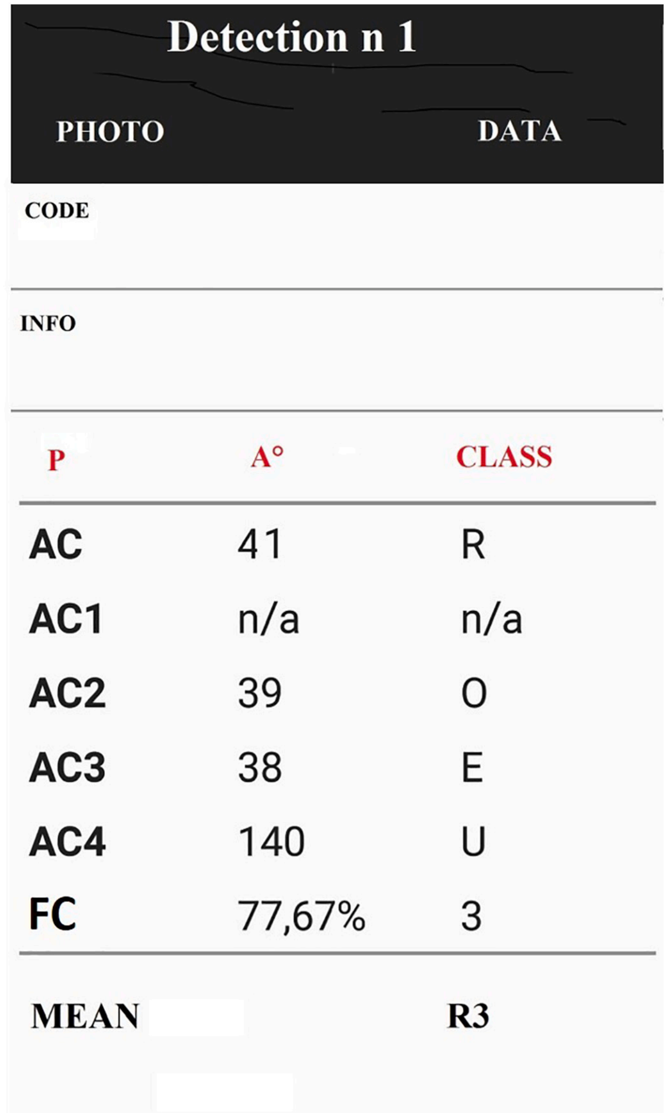

Fig. 5. Screen of processed data.

2.5. Statistical analysis

Degree of concordance between official methodology and app

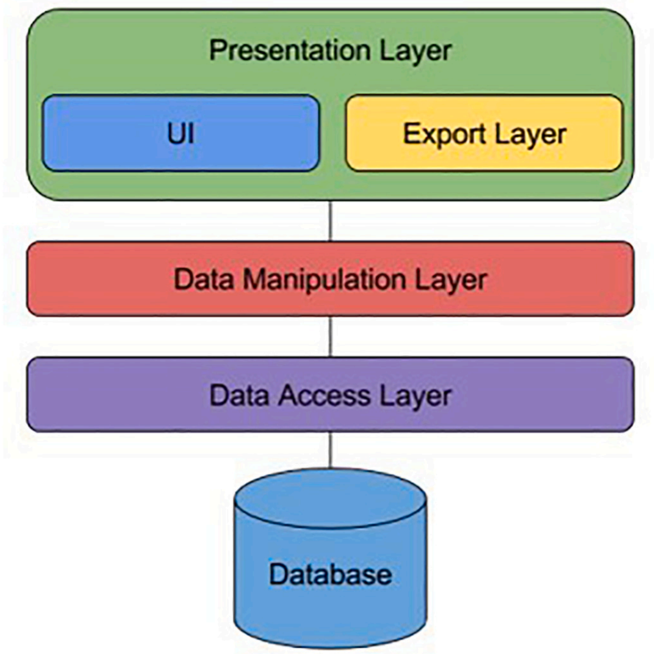

Fig. 6. App architecture.

classification performance was evaluated by calculating Pearson's correlations, both for conformation and for fat cover classes. Since the variables in analysis are of discrete type, the correlations of the Spearman correlation coefficients have also been calculated. The Correlation Procedure (CORR PROC) was used for data analysis (SAS Inst. Inc., Cary, NC, USA, release 9.4).

The assessment of the different evaluation distribution was carried out by calculating the concordance as follows: Diff. SEUROP = SEUROP Official (Off) - SEUROP App, and Diff. FC = FC Off - FC App. Negative values indicate an overestimation of the app classification compared to the official one; conversely, positive values represent an undervaluation, while the zero indicates concordance between the two methods. Then, frequencies for the differences detected were calculated.

Linear regression between official average classification (of a panel of 3 trained assessors) and classification obtained by VIA, was carried out to assess the accuracy and precision of the new tested method. The Regression Procedure (REG PROC) was used for data analysis (SAS Inst. Inc., Cary, NC, USA, release 9.4).

3. Results and discussion

3.1. Classification grid set up

Measurement obtained from the parameters related to conformation and fat cover classes, detected from the official reference photographs, were reported in Tables 1 and 2, respectively. Given that parameters differed were found to be variable from one image to another, they were all selected to be practically tested on carcasses in order to verify their actual reliability.

3.2. Concordance method

The Pearson and Spearman correlations were reported in Table 3, both for conformation and for fat cover classes.

The degree of concordance between the SEUROP classification, as calculated with the two alternative correlation methods was found to be close to 90%. As expected, Spearman correlation was lower, but still very near to the Pearson correlation. The correlation between the official

Table 3
Concordance among official (Off) evaluation and VIA (App) for classes conformation S (6) E (5) U (4) R (3) O (2) P (1) and classes fat cover (1, 2, 3, 4, 5), respectively.

Comparison	Correlation	*p*-value	Test
SEUROP_Off. vs. SEUROP_App	0.89563	<0.0001	Pearson
	0.86545	<0.0001	Spearman
FC_Off vs. FC_App	0.77356	<0.0001	Pearson
	0.76511	<0.0001	Spearman

degree of fat cover and the one determined by the App was found to be 0.77% for the Pearson coefficient and slightly lower for the Spearman coefficient. Both for the conformation and for fat cover classes the correspondence of the two methods was high and statistically significant. Similar results were reported by Wnęk, Gołębiewski, and Przysucha (2018) and Johansen, Aastveit, Egelandsdal, Kvaal, and Røe (2006). Although the repeatability of the method has not been tested in this study, several authors have found that modern VIA systems, when compared with measurements performed by trained operators, are able to guarantee better accuracy and higher repeatability (Moore, 2006).

The concordance frequencies of the compared methods in the conformation classification and fat cover are shown in Table 4.

For conformation, the methods were concordant in about 84% of the samples, while in 15.8% of the samples the measure was discordant, with over twice as many overestimations as underestimations. The difference in assessment was never greater than one class. The distribution of differences assessment by conformation classes are shown in Fig. 7. A clear distribution trend was evident, with higher over estimation in the O and R classes, and an underestimation in the U and E classes.

Regarding the frequencies of agreement of the methods compared in the fat cover classification (Table 4), the concordant measures were around 86% with a more homogeneous distribution of discordant classifications. Also, in this case difference in assessment was never greater than one class. The distribution of differences assessment by fat cover classes are shown in Fig. 8. The trend was less obvious, but also in this case the overestimation focused on the lower classes. There was a greater overestimation in low fat cover classes and more underestimation in classes with more fat cover. The average concordance reported by Craigie et al. (2012), was considerably lower when calculated on 15 point scale (subdivision of the existing 5 classes into high, medium, and low).

The results of the regressions for conformation and fat coverage showed that the slope coefficients were very high and for conformation the value is close to 1 (Table 5), indicating a high similarity of classification between the subjective and App method. The dispersion of data was higher for the fat cover in comparison to the conformation, with a lower value of r^2, but with a substantially equal average error.

The results obtained, in accordance with Stinga et al. (2020), showed how the statistical methodology used and the developed instrumentation (VIA System) successfully gave a highly performing SEUROP and FC classification. The values reported by Article 10 of the Commission Delegated Regulation (EU) No. 2017/1182 (EC, 2017b) for objective and automated classification systems were also respected and the validation process has begun at the national authorities.

Table 4
Total frequencies of concordance among official evaluation and VIA for conformation (Diff_SEUROP) and fat cover (Diff_FC).

Variable	Differences	Absolute frequencies (n)	Relative frequencies (%)
Diff_SEUROP	−1	24	4.8
	0	421	84.2
	1	55	11
Diff_FC	−1	44	8.8
	0	432	86.4
	1	24	4.8

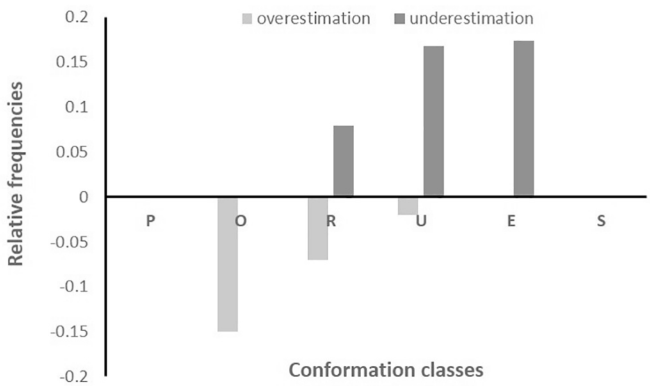

Fig. 7. Distribution of differences assessment by conformation classes.

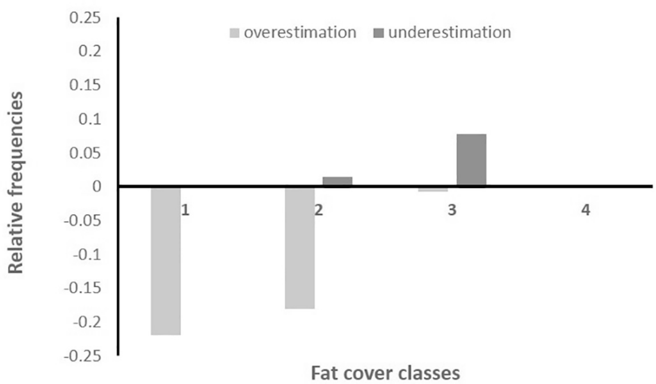

Fig. 8. Distribution of differences assessment by fat cover classes.

Table 5
Estimated parameters of regression on official evaluation and VIA system regarding conformation and fat cover, respectively.

Parameters[a]	SEUROP	FC
n	500	500
a	0.22 ± 0.07	0.59 ± 0.07
b	0.92 ± 0.02	0.78 ± 0.03
r^2	0.80	0.60
RMSE	0.39	0.35

a = intercept, b = slope, r^2 = coefficient of determination, RMSE = root mean square error.
[a] n = number of samples.

A possible limit of the App, as for almost all instrumental measurements, is that in particular environments, such as the slaughterhouses, there can be suboptimal lighting conditions and space constraints (e.g. at least 2 m between the operator and the carcass) hindering the acquisition of good quality images. Older or low-entry models of smartphones are equipped with low quality optical modules, not suitable for image acquisition in low-light settings with artificial light sources. Also, operators must be properly trained in the use of the smartphone and App to ensure valid carcass classification predictions.

4. Conclusions

The objectives of this research were to develop a measurement software for evaluation of carcasses in terms of muscle conformation and fat cover, in compliance with the requirements of current legislation. The App allowed overcoming the limits of subjective evaluation based on skills of operators. Also, the software-based SEUROP grading was more efficient in terms of uniformity of evaluation, preventing unwanted or fraudulent errors that can influence the prices of carcasses in European countries. This research has highlighted an important opportunity for meat industry to take advantage of the computational and optical hardware resources of next generation mobile phones, or of artificial intelligence algorithms, likely arriving at a completely automatic measurement system.

The software of App was developed pursuing the principles of versatility and simplicity, to offer a friendly interface to the slaughterhouse staff, even for less skilled operators, in the important task of evaluating carcasses. Slaughterhouses, research centres and private companies are currently validating the App, to speed up the validation steps required by the national authorities.

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Declaration of Competing Interest

The authors declare no conflict of interest.

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