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Information technology for culling poultry eggs before incubation based on gender

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Abstract. The necessity of rejection of poultry eggs by sex before their incubation is shown. The main methods for assessing the sexual dimorphism of bird eggs are considered, for the suitability of their use for evaluating bird eggs by sex before incubation. A hypothesis is presented about the presence of asymmetry of chicken eggs in spatial coordinates in bird eggs with male and female embryos A set of programs has been developed to confirm this hypothesis in studies to assess the sexual dimorphism of bird eggs before incubation. The results of testing the complex on a batch of eggs of hens of the breed Hisex white are given.

1 Introduction

An important demographic parameter characterizing the state of bird populations is the sex ratio at their birth [1].

In the poultry industry, during the incubation of poultry, male and female chickens hatch in almost equal proportions [2]. Previously, when, for example, hens at the same poultry farm were used to produce eggs, and cockerels served as a source of meat, this sex ratio suited poultry farmers quite well [3]. Currently, in connection with the separation of the production of poultry products of egg and broiler directions, there is an acute problem of selection for sexual dimorphism of poultry eggs before their incubation. This is due to the need to destroy a large number of one-day-old males in egg farms, which causes public concern about the unethical actions of bird egg producers [4]. In addition, manufacturers experience unreasonable economic losses due to the use of additional labor and energy resources [5]. Therefore, effective methods and technical means are needed to sort and reliably determine the sex of the embryo in eggs before incubation. At the same time, the batch of eggs rejected during sorting can be sold to consumers of this dietary product.

2 Problem definition

The following main technical requirements are imposed on the developed method for sorting a batch of poultry eggs before incubation.

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The method used should not violate the integrity of the external and internal structure of the egg, and also exclude a negative impact on the future embryonic development of the embryo in the incubated egg. In addition, the method of sorting by sexual dimorphism of eggs should be fast and suitable for its use with large batches of eggs placed in industrial incubators.

When determining the sexual dimorphism of bird eggs, the researchers used most of the methods of non-destructive control of the state of biological objects. For example, hyperspectral imaging (400-1000 nm) was used to image 94 hatching bird eggs. [6]. The reliability of determining the sex of egg embryos was 75% on the 10th day of incubation. Using infrared spectroscopy, the transparency of bird eggs was determined during incubation [7]. Significant differences between the sexes of the embryo were achieved on the 15th day of their development. When preparing hatching eggs with a laser and using fluorescence spectroscopy, it was possible to remove non-viable embryos at an early stage of the incubation process [4]. Magnetic resonance imaging [8], calorimetry [9], and other methods were used to determine the sexual dimorphism of embryos during the incubation of bird eggs. However, none of these methods is capable of culling eggs based on sex prior to incubation.

Researchers have been trying for many years to use the geometric dimensions, volume, surface area, mass, density of the egg to determine the sex of the embryo before incubation [5-9].

Many pin their hopes for a positive result on the calculation of the so-called shape index or shape coefficient$k$. The shape index is the ratio of the longitudinal l and transverse b of the geometric size of the egg multiplied by 100 [10]. The shape index of an ideal round bird egg is 100, and oblong eggs can range from 50 to 80 (for chickens, the shape index is at least 70) [10]. For the shape coefficient k, these intervals of values for future females are defined as

$$k = l/b = 1.2 - 1.3, \quad (1)$$

and for future males –

$$k = l/b = 1.4 - 1.5. \quad (2)$$

It should be noted that this indicator is different for the species, subspecies, chicken cross, and also depends on other factors [11-13]. In addition, in [14], a data set of various geometric parameters of 3313 eggs taken from 51 species of wild birds was subjected to statistical analysis and it was concluded that it was impossible to determine the sexual dimorphism of a bird egg by its geometric parameters. Despite similar studies of a batch of 289 Canadian goose eggs carried out in [13], where the possible influence of the shape index on the sex of embryos is assumed, it can be concluded from the literature that there is no correlation between sexual dimorphism and the geometric parameters of bird eggs.

3 Choice of research direction

In the development of the approach under consideration, it is proposed to focus on determining the asymmetry of the linear dimensions of the egg relative to spatial coordinates. It can be assumed that the nature of the asymmetry of chicken eggs in spatial coordinates with male and female embryos is different. The striving for symmetry of form in living organisms is a well-known fact and it is explained by a decrease in entropy in ordered systems, and the eggs of future females may be more symmetrical than those of future cockerels [14]. This will allow more even distribution of forces on the shell of an egg with a future hen under possible sharp mechanical loads and increase its resistance to shell damage, compared to an egg of the opposite sex. Indeed, complete symmetry characterizes inorganic objects [15]. The living egg of a bird is a dynamic developing system; the static balance is disturbed in it, which was maintained until the development of the embryo. At the same time, there is a restructuring of the organization of all structural parts of the whole, including the shell.

In addition, there is a hypothesis about the difference in the shape of eggs in oviparous animals and birds, depending on the sexual dimorphism of a particular egg [16]. Therefore, it can be assumed that the different nature of the asymmetry of the outer protective shell of the bird fetus can carry information about the sexual dimorphism of the egg with a live embryo.

Naturally, asymmetry parameters can be determined by various methods. We propose to determine the asymmetry of the shapes of images of eggs obtained using computer vision, according to the totality of the following features:

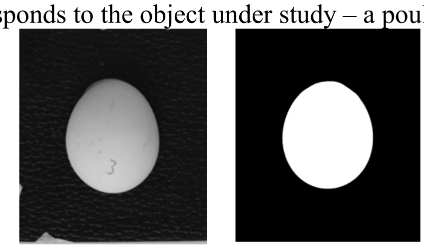
- the values of the distributed parameters of the shape indices of a single image;
- modulus values of radius vectors forming equal angular segments of a single image;
- values of asymmetry parameters when dividing a separate image into four equal sectors with their mirror image;
- the value of the asymmetry parameters outside the artificially inscribed reference circle in a separate image.

In this case, all features are generated by software, and a pixel is taken as a measure of their values. This will eliminate the procedure of precision measuring instruments and calculations of the proposed parameters, including the distribution of indices or form factors. It should be noted that with an increase in the resolution of the matrix of a digital camera, the reliability of determining the asymmetry of an object increases.

4 Materials, methods, results and discussion

Images of the object of study were obtained using a technical vision setup based on a digital camera Canon EOS 2000D EF-S 18-55 III Kit with a modern CMOS-matrix (22.3 × 14.9 mm) and a powerful processor [17].

A batch of eggs of the Hisex White breed in the amount of 80 pieces was chosen as the object of study. An HSV (hue, saturation, brightness) filter was applied to each received egg image frame, which made it possible to obtain a glare-free image with high image resolution (1660 × 1900 pixels) and black and white color (1-bit). Thus, after these transformations, a single white object was formed in the frame, in the form of a closed oval geometric figure, the shape of which corresponds to the object under study – a poultry egg (Figure1).



a) b)

Fig. 1. The procedure for the formation of a contrast image of an object: a) – the original image; b) – image after applying the HSV- filter.

Initially, the basic parameters were determined (Table 1)

In addition to mass, the basic parameters in the table were determined in pixels from a copy of the egg image. One pixel was chosen as the unit of measure. When determining the area and volume, the well-known expressions described in [18] were used. Weight determination was carried out on electronic scales OHAUS V31XH202 with a range from 0 to 200 g, resolution 0.01 g, serial number ARA530.

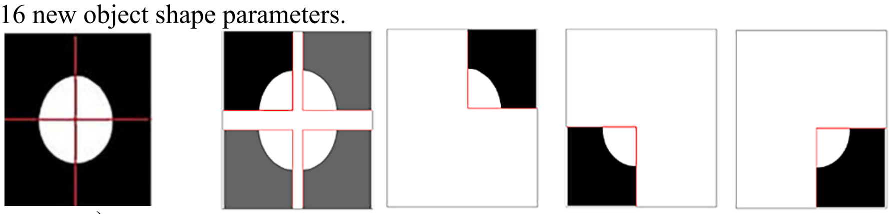
Further, on each of the images of the contour of the object of study, its longitudinal size was divided into 12 equal sections Δl and the obtained value of the section was used in the calculation of the shape indices k_i for each level of the longitudinal size (excluding the upper and lower points), i.e. k_i=Δl /b_i , i=1,2…12.

Table 1. Basic parameters.

Parameter designation	Feature description
x_gender	Gender of the chicken
x_id	Egg code mark
x_img	Name of original photo
x_hsv	Name parameters of HSV thresholds
x_mass	Massa, g.
x_height	Longitudinal size, pix.
x_width	Transverse size, pix.
x_area	Area, pix^2.
x_perim	Perimeter, pix.
x_shapeInd	Shape index

This slicing procedure, which was performed programmatically, made it possible to obtain 22 additional variables characterizing the shape parameters. The essence of the radius vector method is as follows: from the center of the egg image, radius vectors with a given slope angle (Ω = 10 degrees) are drawn programmatically, and for each of them its module is calculated to the border of the object contour. The method allows you to get 36 new object shape parameters.

The method of quarters is reduced to the following steps, carried out by software (Figure 2): the original image is divided into four sectors; four new images are formed from each sector by mirror addition; for each new image, the longitudinal and transverse dimensions of egg image sectors, area and perimeter are determined. The method of quarters allows you to get 16 new object shape parameters.



a) b)

Fig. 2. A fragment explaining the operation of the program for generating the parameters of the asymmetry of the egg image by the method of quarters: a) the original image; b) scheme for generating new images from copies of mirror fragments.

The method of circles is a logical continuation of the method of quarters. Each image obtained by the mirror complement method is the source of two parameters, which are calculated as follows: a circle with a diameter equal to the longitudinal size of the object is inscribed in the centre of the obtained image and the areas of the upper and lower figures of the egg images that are outside the inscribed circle are found. The method allows you to get 28 new object shape parameters (Figure 3).

The operation algorithms of the above programs for the formation of asymmetry parameters are given in [19]. The programming language of the complex is Python3. When processing images, the openCV library was used, and for working with machine learning algorithms and solving statistical problems, the scikit-learn and scipy libraries were used. All data on signs of asymmetry were entered into the created database.

Fig. 3. An example of the operation of the program for the formation and determination of the parameters of the asymmetry of the egg image, when inscribing a circle.

After the procedure for determining and saving the parameters of egg images in a personal computer, 8 eggs with low embryonic fertility were rejected from the entire batch of eggs under study.

Chicken eggs, in the amount of 72 pieces for 21 days were subjected to incubation. In the process of incubation, 69 live chicks hatched out of 72 eggs, of which 4 chicks died in the brooder and 7 hatched with signs of rickets.

Out of 58 healthy chicks, only 38 (24 males and 14 females) were reliably identified by sex. In order to increase the reliability of sex determination by organoleptic methods, the conclusion about their gender was taken only if the external signs of chicken feathers and their reflex reactions coincided.

Due to the fact that the distributions of almost all asymmetry parameters are different from normal, two criteria were used to test the hypothesis about the difference in the means: p1 – the Mann-Whitney U-test and p2 – the Kolmogorov-Smirnov test [20].

The use of two criteria will increase the reliability of confirming the hypothesis about the difference in the means (mathematical expectations). According to the results of statistical analysis, which did not give significant differences on the available data on asymmetry parameters, for the two groups under consideration, 26 of all indicators were selected.

This list includes data with the lowest p1 and p2 values (Table 2).

Table 2 shows that the indicators of the shape factor or shape index, taken as the main criterion for determining the sexual dimorphism of the egg in the prototype method, were not included in the list of essential features.

At the second stage of data analysis, to build a model that allows solving the problem, the following machine learning (ML) methods were used, which are used to solve binary classification problems for small samples with a large dimension of the original set of features [19-20]: logistic regression; single decision trees; random forests; random forests as part of the adaptive boosting method.

Due to the small number of samples for each of the listed methods, two trainings were carried out on a full set of features using the cross-validation method.

To do this, the original set with the same number of cockerels and hens was divided into two subsets, each of which was used at the first iteration as a training set and at the second iteration as a test set.

The evaluation of the results was carried out using well-known metrics: Accuracy, Precision, Recall, Specificity, F1-measure; functional [20].

Table 2. List of asymmetry parameters selected at the stage of statistical analysis.

No	Parameter code	Range, pel	Female, pel	Male, pel	p1	p2
Slice asymmetry parameters						
1	x_height	956.0 ÷1110.7	1052.9 ±38.7	1052.1 ±28.2	0.44	0.64
2	x_perim	2989.4÷ 3407.6	3234.7 ±97.5	3218.9 ±89.0	0.41	0.58
3	x_M1_shapeInd _01	2.2÷2.7	2.4±0.1	2.4± 0.1	0,75	0,44
4	x_M1_shapeInd _09	36.2÷40.7	37.9±1.2	37.8 ±0.7	0.89	0.32
5	x_M1_shapeInd _10	34.8÷39.2	36.5±1,2	36.3 ±0.8	0.82	0.49
6	x_M1_heightPer N	79.7÷92.6	87.7±3.2	87.7 ±2.4	0.44	0.64
Asymmetry parameters modulo radius vectors						
7	x_M3_a080	479.0÷558	527.0±19.8	527.5±14	0.42	0.70
8	x_M3_a090	479.0÷570	535.4±21.8	534.5±15	0.33	0.64
9	x_M3_a100	475.0÷557	527.0±19.8	526.1±15	0.41	0.64
10	x_M3_a140	423.0÷460	439.6±9.8	439.0 ±9	0.66	0.44
11	x_M3_a150	412.0÷446	425.4±9.2	425.2±8	0.86	0.44
12	x_M3_a250	470.0÷525	502.5±14.4	501.5±12	0.49	0.64
13	x_M3_a300	461.0÷510	489.4 ±13	488.6 ±9	0.59	0.49
Parameters obtained by the method of quarters and circles						
14	x_M4_UL_heig ht	958.0 ÷11388	1071.9 ±43.7	10701 ±30.3	0.34	0.49
15	x_M4_UL_peri mDown	2149.2 ÷2716.8	2404,2 ±135.6	2467,5 ±100.0	0.18	0.13
16	x_M4_UL_peri mUpper	2179.4 ÷2770.1	2418.4 ±142.1	2483.7 ±109.2	0.14	0.13
17	x_M4_UR_heig ht	958.1 ÷1140.2	1071.8 ±43.8	1070.1 ±30.6	0.34	0.49
18	x_M4_DL_peri mDown	2714.9 ÷3023.122	2914.2 ±78.6	2895.2 ±74.3	0.34	0.58
19	x_M4_DL_peri mUpper	2714.9 ÷3023.2	2916.1 ±80.8	2894.7 ±73.9	0.30	0.39
20	x_M4_DR_peri mDown	2710.6 ÷3064.6	2922.8 ±87.9	2888.3 ±84.4	0.31	0.64
21	x_M4_DR_peri mUpper	2711.4 ÷3062.6	292.4 ±82.2	2888.8 ±83.7	0.23	0.49
22	x_M4_UL_peri m_avg	2164.3 ÷2743.5	2411.3 ±138.6	2475.6 ±104.1	0.16	0.13
23	x_M4_DL_peri m_avg	2714.9 ÷3023.2	2915.1 ±79.6	2894.9 ±74.1	0.30	0.39
24	x_M4_DR_peri m_avg	2711.0 ÷3063.6	2924.1 ±84.8	2888.6 ±84.0	0.27	0.64
25	x_M4_UR_volu me	332384976÷4 2825441	387671169± 28014778	386×10^6 $\pm23.6\times10^6$	0.66	0.41

The results of computational experiments are given in the Table 3.

Table 3. Classification metrics values for each machine learning algorithm.

Method	Accuracy	Precision	Recall	Specificity	F1-measure	AUS ROC
Logic regression	0.81	0.81	0.81	0.80	0.81	0.71
Single decision trees	0.78	0.78	0.78	0.77	0.77	0.73
Random forests	0,78	0.78	0.78	0.76	0.78	0.76
Random forests in the adaptive boosting	**0.86**	**0.86**	**0.86**	**0.83**	**0.86**	**0.85**

Table 3 shows that the most effective machine learning method for solving binary classification problems for small samples with a large initial set of features is the use of the adaptive boosting method.

Truly adaptive boosting turns weak learning algorithms into strong learning algorithms for solving problems of classification, diagnosis and prediction [21].

5 Conclusions

Given that the proposed method uses a computer vision method that allows you to obtain precision two-dimensional (2-D) digital images and analyze and process them, it becomes possible to use all the advantages of this method in scientific and industrial applications in the poultry industry, in particular, when development of technological solutions and automated production systems, including sorting machines.

It is well known that the poultry industry needs accurate, efficient and reliable sorting systems that can be applied in an in-line production system to reduce sorting time and labor costs. Such systems can be applied anywhere in the production line. In addition, this proposed system, based on the techniques of this method, can be integrated with other quality determination systems, such as systems for detecting cracked eggs and other mechanical defects, systems for sorting chicken eggs, determining the fertility of the embryo and early detection of development. diseases in it, etc.

Experimental confirmation of the presence of asymmetry in the shape of an egg when determining its sexual dimorphism in the proposed method will make it possible to approach the solution of the world scientific problem - a reliable determination of the sex of an egg before incubation. And this is an important step towards the introduction of an industrial method of precise poultry sex determination in the near future. At the same time, the most important commercial problem of minimizing material (consumption of energy, heat, etc.) and time costs in the process of incubation is solved, and there is also a significant reduction in biological production waste.

Given the simplicity and accuracy of determining the significant parameters for evaluating sex in an egg in the proposed method, it can be used to reliably determine the sexual dimorphism of eggs of other bird species, the shape of which differs from the profile of a chicken egg. The method will make it possible to compare the shapes of different eggs, clutches and species, determined by simple mathematical indicators that can be computerized and easily processed within the framework of any analytical study.

The proposed geometrical description of the shape of the egg" based on its digital image-twin is of great importance in various studies and can be useful in predicting the quality indicators of table and hatching poultry eggs. Indeed, the proposed set of method techniques is practically flawless in the poultry and food industries for accurately representing the contour of any bird's egg, and can also be easily used to study such egg shape characteristics as volume, surface area, circumference, radius of curvature, area of a flat curve and etc.

And finally, the method will reduce social tension in society arising from the inhumane treatment of living organisms (cockerels) in the process of production of food poultry products.

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