Design and Performance of an Automatic Egg Sorting System Based on Computer Vision

Jakhfer Alikhanov [1], Stanislav M. Penchev [2], Tsvetelina D. Georgieva [2], Aidar Moldazhanov [1], Akmaral Kulmakhambetova [1], Zhandos Shynybay [1], Emil Stefanov [2], Plamen I. Daskalov [2]

[1] *Department of Energy Saving and Automation, Kazakh National Agrarian University, 8 Abay str. Almaty, Kazakhstan*
[2] *Department of Automatics and Mechatronics, University of Ruse, 8 Studentska str., Ruse, 7017, Bulgaria*

Abstract **– An automatic system for eggs sorting by indirect weight and shape assessment using computer vision is presented in the paper. Some basic geometric parameters of the eggs, namely: minor and major axis, area and perimeter, shape factor and shape index, are obtained using image processing algorithms. The weight is assessed from the geometric parameters using a regression model. The sorting accuracy of the proposed system is evaluated for two transport conveyors speeds, corresponding to 2 and 3 eggs per second. It is found that the overall sorting accuracy in each case is 94.6% and 90.3% respectively.**

Keywords **– Eggs sorting, computer vision, real – time inspection.**

1. Introduction

Poultry is the most intensive branch of agriculture and is aimed at ensuring food security of the country. In the face of competition, the improvement of technology and technological equipment for production, sorting and sale of products become relevant.

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Corresponding author: Plamen Daskalov,
University of Ruse, Bulgaria
Email: daskalov@uni-ruse.bg

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Huge amount of money and manpower are spent for sorting and packaging. The main disadvantages of manual sorting are inaccuracy and large labor costs. The productivity of manual sorting is less than 1000 eggs per hour. Human sorter is physically unable to detect many defects (eggs irregular shape, the notch of the shell, marbling, etc.) and do not accurately identify the eggs by weight. Therefore, most manufacturers widely use grading machines and complexes.

The main criteria according to the standards for classification of eggs is their weight. The weight of the eggs is specified according to regulation (EC) № 557/2007 by the European Commission [1]. The quality groups for standard eggs are as follows:

- S – small: from 43g to 53g;
- M – medium: from 53g to 63g;
- L – large: from 63g to 73g;
- XL – very large: above 73g.

Following the above-mentioned regulations, the operation of the existing machines is based on the weighting of each egg and separating it into proper category. However, in that case the productivity of the machine is limited by the speed of the weighting mechanism. The other disadvantage of the existing commercial systems is the use of specific equipment, which leads to maintenance complexity and high cost. The existing systems for egg sorting include different kind of parameters like colour, defects, size, etc., so separate sensors are used for determination of the individual quality indicators [2].

There are many researches published in the last 10 years that are related with the use of computer vision and artificial intelligence for the needs of food products quality control [3], [4], [5].

Computer vision is successfully tested in [6] as a potential tool to predict poultry meat colour, since the colour is an important quality attribute for the rapid detection of “pale poultry syndrome”. Colour measurements are compared to CIELab attributes of chicken breast obtained by analytical reference measurements. High correlation coefficients obtained between computer vision and colorimeter validate the approach for measuring L^* colour component.

A new on-line method based on combined machine vision techniques and linear and nonlinear classifiers to automatically categorise chicken portions is proposed in [7]. Geometrical aspects, colour, and textural features are extracted and different classification procedures are employed to classify the data. Experimental results indicated better performance level of artificial neural network (ANN) compared to linear models and the machine vision algorithm together with the ANN classifier were evaluated on a sorting machine to separate test samples using separating units in the on-line mode.

In [8] an artificial vision system for real time detection of defective eggs in a poultry farm is implemented. The image processing algorithm use shape detection techniques to obtain the region of interest, based on the egg shape. Colour processing on the eggshell and image segmentation are then performed to allow fast discrimination of defective eggs from clean ones. Such algorithm provides real time eggshell inspection with total processing time close to 100 milliseconds. The classification rates are in the range from 82 to 92% with the possibility to extract any type of defects, regardless of the aggregation, shape, location or colour of the eggs.

In [9], an expert system was developed to sort eggs into pre-defined categories based on the intended use of the eggs. The expert system uses the output values of the previously developed neural networks and its knowledge-base to make decisions on how to sort the eggs. The sorting decisions of the expert system were also influenced by several variable thresholds which could be set by the user. To demonstrate and test the expert system under varying threshold settings, a discrete computer simulation of the egg inspection process was performed. The simulation results indicated a reduction in the number of eggs requiring human inspection and demonstrated a potential for reducing the work load on human graders.

In [10] an expert egg grading system based on machine vision and artificial intelligence techniques was introduced. The main purpose of this research was design and development of an intelligent system based on combined fuzzy logic and machine vision techniques for eggs’ grading, using parameters such as eggs defects and size. The evaluation results of image processing algorithms showed that the use of image processing technique has good performance for defects and size detection. The Correct Classification rate (CCR) was 95% for size detection, 94.5% for crack detection and 98% for breakage detection.

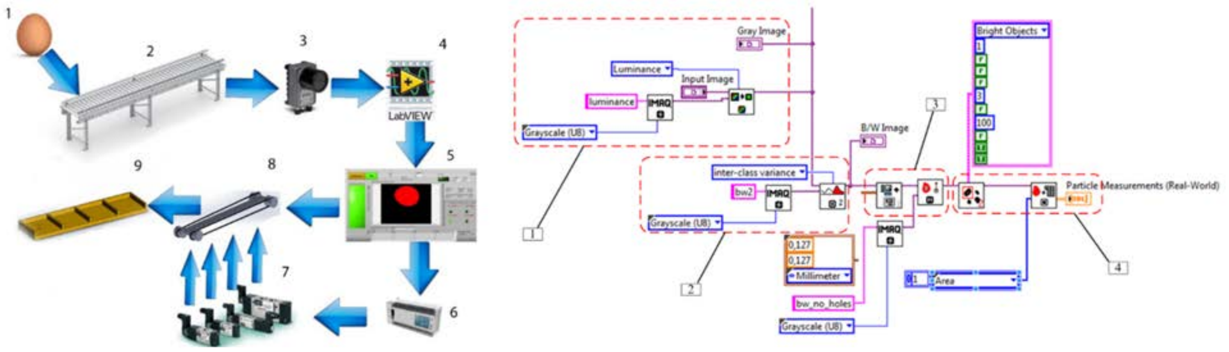
The most promising direction to solve the problem of separation of eggs is the creation of robotic technology conveyors with the use of machine vision and automatic recognition of indicators of eggs quality with subsequent distribution of the original flow on various quality parameters. The fundamental difference between such idea and the existing analogues, that separate the eggs into categories by weight, is the separation of the eggs into categories based on the size and irregular shapes and shell defects in a flow. All technological operations as: supply of eggs in the control zone, the receipt and processing of images, classification, separation of eggs into categories occur in motion (dynamic mode), which allows the improvement of sorting process performance at least twice in comparison with the existing method. The use of a technical vision system for quality determination and sorting eggs opens the possibility to raise the productivity and measurement accuracy with automatic recording, processing and transmission of information about parameters of eggs to separate them into categories in accordance with the requirements.

Some preliminary studies [11], [12], [13] discuss methods and approaches related to the use of computer vision in egg sorting in laboratory conditions. In these studies, procedures for determination of characteristics related to the size and shape of the eggs [12] and for creation of regression models for indirect assessment of the eggs weight from their geometric dimensions [11] are also presented. In addition, some principles for design and operation of the egg image acquisition system, together with the operation of the programmable logic controller for electrical drives control of an automatic egg sorting system [13] are considered. The work of such sorting systems, based on the abovementioned approaches, is of particular practical interest. However, there is a lack of information about performance and sorting accuracy for such systems.

This paper represents the performance and sorting accuracy of an automatic system for sorting eggs in a flow using computer vision, which measures the eggs visual and shape characteristics and uses a regression model for indirect calculation of the eggs weight, based on their visual parameters.

2. Materials and Methods

The general structure diagram of sorting machine operation is as follows (Figure 1): Chicken eggs (1) are fed to the roller conveyor (2), in which the eggs are laid and distributed to an equal distance between them. Next, the eggs pass one by one into the control area of the smart camera (3). The captured image is transferred to the embedded microprocessor with the installed software NI VISION BUILDER (4). A virtual instrument and an algorithm for analysis and classification of the egg parameters (5) are developed in LabView environment. After, the eggs are moved to the belt conveyor (8) and the data is sent to the controller (6). There, commands are formed to control the operation of pneumatic actuators (7), which send the eggs from the conveyor belt (8) to the relevant category accumulators (9) using an air flow.



a.) *b.)*

Figure 1. General structure diagram of the sorting machine operation

2.1. Image Processing Algorithm

The algorithm used for egg image processing includes the following main steps: RGB image acquisition, RGB to Gray image conversion, Gray to Black/White image conversion and calculation of egg geometric parameters [12].

The software implementation of image processing and analysis algorithm is performed in NI LabView environment, using NI Vision Development Module and Vision and Motion Toolkit. It consists of four main stages, as shown in Figure 1.

The stage 1 converts the input color image into grayscale by extracting the luminance plane from the input image. The grayscale image is then forwarded to stage 2, where IMAQ AutoBThreshold procedure and Otsu's method is used to compute the optimal threshold value for the image and to apply the computed threshold. Stage 3 consists of a calibration procedure, which sets the coefficients Kx and Ky. These coefficients determine how many millimeters correspond to one pixel from the egg image in horizontal (X) and vertical (Y) direction:

$$K_x = \frac{D_x}{P_x}, \; K_y = \frac{D_y}{P_y}, \qquad (1)$$

in which Dx and Dy are the dimensions of the standard object in millimeters;

Px, Py - the number of pixels in the directions X and Y, corresponding to these dimensions.

The two coefficients K_x and K_y are obtained using Image Calibration procedure, which is built in NI Vision Assistant. The coefficients K_x and K_y can be used to measure distances in a visual image, while the desired result should be in millimeters.

The binary image is then filtered with IMAQ FillHole function in order to fill the holes (if any) in the object particle. The function actually performs the morphological image operation "closing" (which is an image operation "dilation" followed by image operation "erosion"). This operation fills tiny holes and smooths boundaries. It does not significantly alter the area and shape of particles, because dilation and erosion are morphological complements, by which borders expanded by the dilation function are then reduced by the erosion function.

Finally, at stage 4, a binary image analysis is performed to obtain the values of the object's shape basic geometric parameters - minor and major axis, area and perimeter. At the later stage the other two parameters – Shape factor and Shape index are also calculated using the following equations:

$$Shape \;\; factor = \frac{P^2}{S} \qquad (2)$$

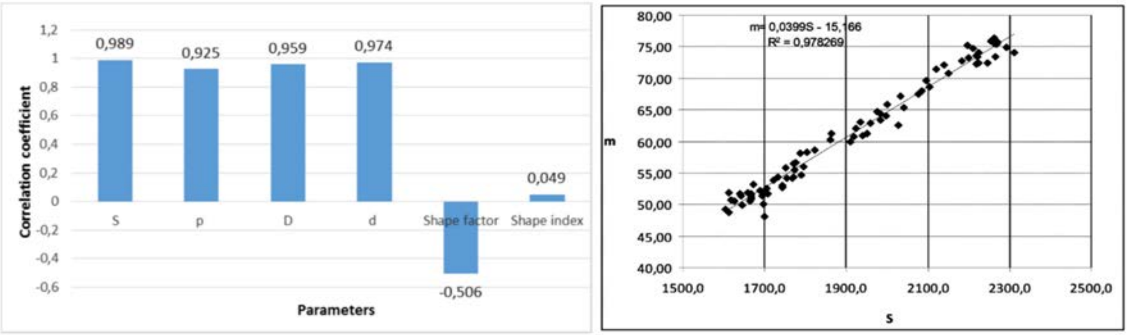
$$Shape \;\; index = \frac{d}{D} \qquad (3)$$

in which P is egg perimeter; S – egg area; d – minor axis; D – major axis.

2.2. Regression Analysis

To indirectly access the weight of the eggs from geometric egg parameters some preliminary experiments are carried out, in order to evaluate which egg geometric parameters has the strongest relationship with the weight [11, 12]. A set of egg samples was split into two subsets – train and test subsets. The train subset which includes 80 eggs from four classes – S, M, L and XL was used to obtain the egg weight mathematical model. The test subset (40 eggs from four classes) was used to test the accuracy of proposed approach. Each egg is manually weighted and its geometric characteristics are obtained using computer vision system.

The minimal and maximal values of every geometric parameter, shape index and shape factor of the four eggs classes are evaluated. When selecting an appropriate parameter from the computer vision system to indirectly determine weight, the correlation coefficient of each of the parameters, relative to the weight of the eggs is calculated. The results are represented graphically in Figure 2.



a.) *b.)*

Figure 2. Correlation coefficient of each of the parameters, relative to the weight of the eggs

The obtained results indicate that the strongest correlation is between the area relative to weight of the egg - 0.989, and the lowest between the two shape factors - K_1 and K_2.

To obtain the mathematical model for calculation of eggs weight based on their measured area, the data from the training sample is approximated. The results of the linear model show the greatest value of the correlation coefficient R2 (Figure 2).

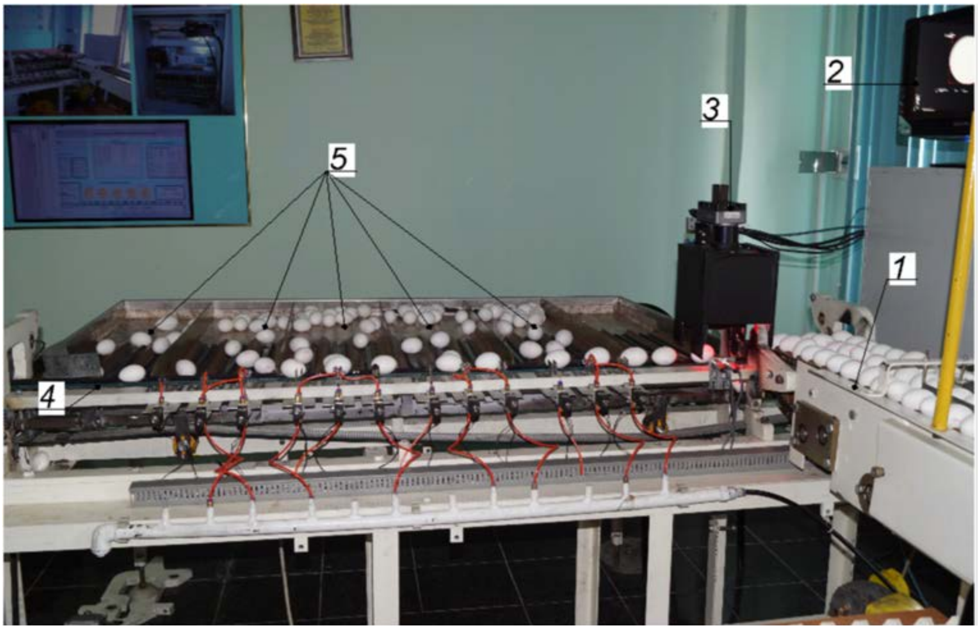
The correlation coefficient for the first and second order models differs only by sixth decimal place.

Therefore, a mathematical first-order model is selected because it involves less processing time:

$$m = 0{,}0399.S - 15{,}166 \quad (5)$$

2.3. Hardware and Software Performance of the Eggs Sorting Machine

An experimental sample of a machine for automatic sorting of eggs based on computer vision is made by reconstructing the commercial egg grading machine "Rhythm 3-8" (Figure 3).



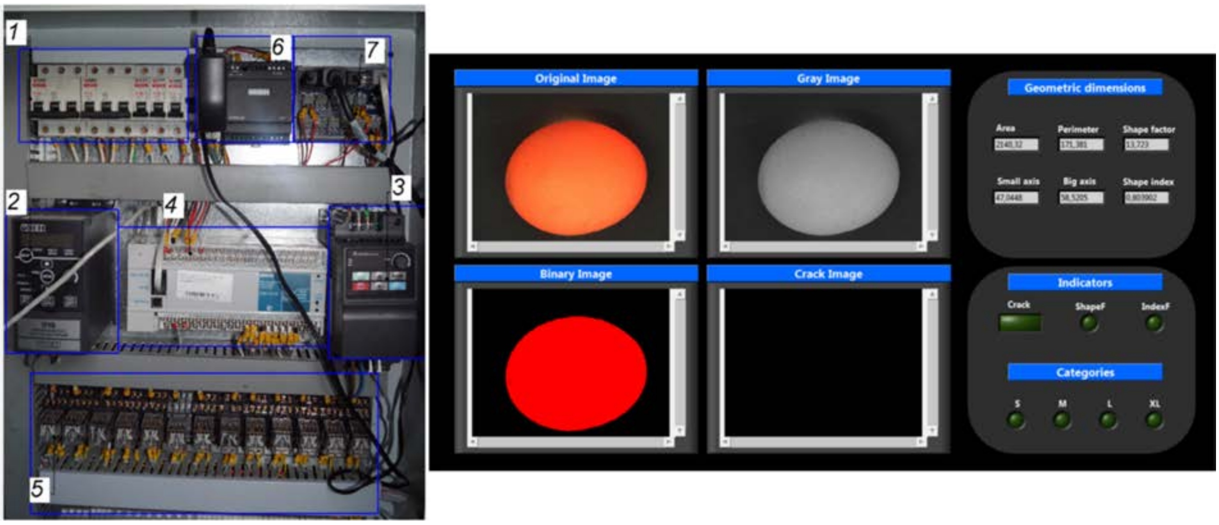
1 – roller-oriented conveyor, 2 – monitor with the analyzed egg, 3 – smart camera with red illumination, 4 – belt endless conveyor, 5 – section table

Figure 3 - General view of the experimental sample of the machine for automatic eggs sorting based on a vision system

Supply and orientation of eggs remains unchanged. The mechanism for weighing and division of eggs into weight categories is completely replaced. A new cable conveyor with independent frequency-controlled electric drive is manufactured and mounted into the egg grading machine "Rhythm 3-8". Additionally, smart camera, control cabinet, electro pneumatic valves, optical sensors and compressor are added.

The control cabinet is equipped with a programmable logic controller (4), frequency converters (2, 3), power supplies (6), relays (5), circuit breakers (1) and mounting elements (Figure 4).

division into categories using electro pneumatic valves. The division of eggs is carried out by air flows, controlled by the electro pneumatic valves.



a) *b)*

Figure 4. General view of the control cabinet and human – machine interface of the experimental eggs sorting machine

The operating principle of the new automatic egg sorting machine is based on digital processing of eggs video images in real time mode. Instead of a mechanism for weighing and sorting eggs by weight, a smart camera and electro pneumatic actuators are installed. A programmable logic controller is used for processing of information about eggs parameters and for formation commands for eggs separation into categories. To control the speed of conveyor movement, a frequency-controlled electric drive is used.

The vision system includes a smart camera NI-1772 (National Instruments®), with the following technical data: CPU Intel® Atom™ Z530 (1.60 GHz processor); DDR2 RAM 512 MB; 2 GB solid state storage; I/O includes digital lines (4 inputs, 4 outputs); an RS232 serial connection, and a Gigabit Ethernet connection; Resolution 640x480 pixels.

An algorithm and programs are designed to control the operation of the machine current model and the interaction of the technological line individual aggregates [13]. Additionally, a program for the programmable logic controller "OWEN PLC 110-160" with assisted human – machine interface is developed and executed in CodeSys 2.3 environment (Figure 4). The necessary dimension values for eggs sorting, namely: length (large diameter), width (small diameter), perimeter, area and the number of objects are transferred to the controller. The controller program defines the category to which the eggs belong. Simultaneously, the controller determines the location of each egg on the conveyor, by optical sensor signals and the encoder, and forms commands for eggs

3. Results and Discussion

The operation of the experimental model of the sorting machine was investigated at two conveyor speeds, which corresponds to production speed for two and three eggs per second respectively and with a total number of 760 eggs of various categories. Preliminarily, the eggs were weighed on a DX-1200 scale, with an accuracy of 0.1 gr. As a result, eggs were distributed into the following categories: 1st category (XL) weighing 70-80g – 170 eggs; 2nd category (L) weighing 65-70g – 136 eggs; 3rd category (M) weighing 55-65g – 276 eggs; 4th category (S) weighing 45-55g – 118 eggs; eggs of non-standard weight 35-45g – 60 eggs. In addition to machine sorting, eggs were evaluated by an expert too. The results of expert evaluation and machine sorting of eggs in the regime of 2 eggs per second are presented in Table 1.

At sorting machine speed corresponds to two eggs per second, it was found that the number of eggs in the XL category was 165; category L - 139 pieces; category M - 274 pieces; category S - 108 pieces. Eggs whose weight is less than 43 grams - 59 pieces. The number of non-standard eggs, from the entire set, was 12 pieces. Also, during the sorting process, due to the transfer of eggs to the conveyor, 3 eggs were broken and removed.

Similar studies were conducted in a mode with a capacity of three eggs per second. In this mode, 757 eggs were sorted and as in the mode of two eggs per second, 3 eggs were broken. Table 2 summarizes the results.

Table 1. Results of expert evaluation and machine sorting of eggs in the regime of 2 eggs per second.

Class	Expert evaluation			Machine sorting						Broken	Sorting accuracy %
	Standard	Rejected	Total	XL	L	M	S	RD	RF		
XL	168	2	170	158	9	0	0	0	3	0	94,71
L	134	2	136	7	122	3	0	0	2	2	92,65
M	273	3	276	0	8	261	3	0	3	1	96,01
S	114	4	118	0	0	10	104	0	4	0	91,53
RD	60	0	60	0	0	0	1	59	0	0	98,33
Total	749	11	760	165	139	274	108	59	12	3	94,64

RD – rejected by dimensions; RF – rejected by form

Table 2. Results of expert evaluation and machine sorting of eggs in the regime of 3 eggs per second.

Class	Expert evaluation			Machine sorting						Broken	Sorting accuracy %
	Standard	Rejected	Total	XL	L	M	S	RD	RF		
XL	168	2	170	155	10	0	0	2	3	0	92,94
L	132	2	134	8	118	3	0	0	3	1	90,30
M	272	3	275	0	13	254	5	0	2	1	93,45
S	114	4	118	0	0	16	99	0	3	0	86,44
RD	60	0	60	0	0	0	6	53	1	0	88,33
Total	746	11	757	163	141	273	110	55	12	2	90,29

RD – rejected by dimensions; RF – rejected by form

In the results of experimental studies in the regime of 3 eggs per second, which corresponds to a productivity of 10,000 eggs per hour, it was found that the number of eggs in the XL category was 163; category L - 141 pieces; category M - 273 pieces; category S - 110 pieces. Eggs whose weight is less than 43 grams - 55 pieces. The number of eggs with non-standard form was 12 pieces from the total set. Also, during the sorting process, due to the transfer of eggs to the conveyor, 2 eggs were broken and removed. The accuracy of sorting in the regime of 3 eggs per second was 90.29%.

4. Conclusions

In this study an automatic system for eggs sorting by indirect weight and shape assessment, using computer vision, is presented. The fundamental difference between the system and the existing analogues, that separate the eggs into categories by weight, is the separation of eggs into categories based on the size and irregular shapes. Instead of a mechanism for weighing and sorting eggs by weight, a smart camera, controller and electro pneumatic actuators are installed.

Image processing and analysis algorithms are developed to access some basic geometric characteristics of eggs: minor and major axis, area and perimeter, as well as shape factor and shape index. Smart camera NI-1772-EF00303A and LabVIEW programming environment are used for that purpose.

The system is equipped with a programmable controller and frequency-controlled electric drive which allows to control electro pneumatic actuators and the speed of transport conveyors. This fact makes the system more flexible and allows easy readjustment when changing production requirements.

The automatic system performance is experimentally tested in different production conditions. Different speeds of transport conveyors are used, which correspond to a speed of 2 and 3 eggs per second respectively. The sample used for the experiments consists of 760 eggs, which were preliminary selected and classified by an expert. It is found that the overall sorting accuracy of the automatic system in each case is 94.6% and 90.3% respectively. In addition, during the sorting process, as a result of the eggs transfer to the conveyor, no more than 3 eggs were broken and removed.

The use of a technical vision system for determination of the quality and sorting eggs opens the possibility to raise the productivity and measuring accuracy, with automatic recording, processing and information transmission regarding eggs parameters, and to separate them into categories in accordance with the requirements.

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