DEVELOPMENT OF AN AUTOMATIC EGG FERTILITY DETECTION SYSTEM APPLYING IMAGE PROCESSING TECHNIQUE

NGHIÊN CỨU CHẾ TẠO HỆ THỐNG PHÁT HIỆN TRỨNG CÓ PHÔI TỰ ĐỘNG ỨNG DỤNG XỬ LÝ ẢNH

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Abstract - Early detection of infertile and non-hatchable eggs benefits hatcheries by saving space, reducing costs, and preventing contamination from spoiled eggs. An automated system has been developed to detect and mark non-hatchable eggs efficiently. The system includes a conveyor that moves trays of 100 eggs through a high-power LED light assembly. Images of the illuminated eggs are captured by an industrial camera and processed using image processing technology. The eggs, analyzed 25 at a time, are filtered through an HSV filter and classified based on the blurred area. The classification results are then used to control stepper motors that mark spoiled eggs. Real-time experiments demonstrated an average accuracy rate of approximately 82.55% for eggs aged 4 days or more, with a processing speed of under 15 seconds per batch of 100 eggs.

Key words - Automation; image processing; egg detection; high power LED system.

Tóm tắt - Việc phát hiện sớm trứng không có phôi và không thể ấp nở đem lại lợi ích cho các trại ấp bằng cách tiết kiệm không gian, giảm chi phí và ngăn ngừa sự ô nhiễm từ trứng bị hỏng. Một hệ thống tự động đã được phát triển để phát hiện và đánh dấu trứng không thể ấp nở một cách hiệu quả. Hệ thống bao gồm một băng tải di chuyển khay chứa 100 quả trứng qua một cụm đèn LED công suất cao. Hình ảnh của các quả trứng được chiếu sáng được chụp bởi một camera công nghiệp và xử lý bằng công nghệ xử lý hình ảnh. Các quả trứng, được phân tích 25 quả một lần, được lọc qua bộ lọc HSV và phân loại dựa trên vùng bị mờ. Kết quả phân loại sau đó được sử dụng để điều khiển động cơ bước đánh dấu trứng bị hỏng. Các thí nghiệm thực tế cho thấy độ chính xác trung bình khoảng 82,55% đối với trứng từ 4 ngày tuổi trở lên, với tốc độ xử lý dưới 15 giây cho mỗi lô 100 quả trứng.

Từ khóa - Tự động hóa; xử lý ảnh; phát hiện trứng; đèn LED công suất cao.

1. Introduction

In a poultry egg incubation model, one crucial step that cannot be overlooked is the egg sorting process to determine whether the eggs are capable of hatching chicks or not. This is an extremely important step because if unchecked and left in the incubation process, infertile eggs will decay and give rise to harmful bacteria within the incubator, thereby affecting the eggs that are still developing. Additionally, infertile eggs, when sorted early, can be sold as food, providing additional income for businesses and family-run enterprises, thus preventing waste and environmental pollution.

The ability to automatically detect fresh eggs with no embryo during the incubation process allows timely removal of non-developing and dead-embryo eggs from the incubation process, contributing to the overall profitability of the livestock farm as eggs that cannot be incubated can be brought to market earlier.

Poultry egg incubation models have been used in Vietnam for quite some time, but most of these models involve manual operation with relatively low precision. Current manual methods include: Method 1. Determining how many days the egg has been incubated; Method 2. The transparency of the eggshell was observed; Method 3. Candling eggs; Method 4. Egg flotation test; Method 5. The eggs were placed on a listening device [1]. Most small and medium-sized enterprises in our country still operate this sorting process manually, using labor for visual inspection, which can be time-consuming and prone to errors, especially for large quantities of eggs. The egg incubators on the Vietnamese market [2] are mainly egg incubators; however, a crucial step in the poultry egg incubation model that cannot be ignored is the egg sorting process to determine whether the eggs can hatch chicks, and there is currently no automated machine.

Today, some companies worldwide, such as Sanovov [3] and Viscon [4], have successfully designed and manufactured automated egg sorting models with hatching potential, but they can only identify and classify older eggs (from 12 days old). Techniques such as machine vision and light spectrum analysis have been developed to address egg-related issues, including detecting blood spots, reproductive ability, and embryo development [5]-[7]. Imaging methods have also been used to detect external defects, such as dirt and cracks in eggs, although this detection is more challenging than detecting internal defects. In addition, some studies have used ultrasound to detect external defects such as dirt and cracks in eggs [8]-[10]. There are also some studies on classifying young eggs that have been proposed, but complete classification systems [11]-[14] have yet to be developed, mainly offering ideas and specific classification plans for each type of poultry egg. Recognizing these difficulties, we propose applying image processing techniques and automation technology to increase labor productivity and reduce costs in operations, thereby helping businesses save human resources, improve production efficiency, and contribute to business development.

Therefore, developing an automated egg sorting system with high speed, a compact size suitable for family business criteria, and the ability to sort poultry eggs younger than current proposals is suggested. An image of a cluster of eggs is automatically examined and captured using high-intensity LED lights to prepare for the sorting process. The images are processed with enhanced brightness and combined with image processing algorithms to differentiate between eggs capable of incubation and sterile eggs based on marked traces. The executive system will sort eggs that can hatch and those that cannot, based on the marked traces.

2. System configuration

Figure 1 shows a general diagram of the automated chicken egg scanning system. The main systems of the machine include a central control system with a computer used to process images captured from cameras and an Arduino board to control the LED light system and motors through specialized driver modules. The system is powered by 220 V of electricity which is then converted to the correct voltage and rated power for each device through switching circuits. This system interacts with users via a computer screen to communicate processing information and results after machine operations.

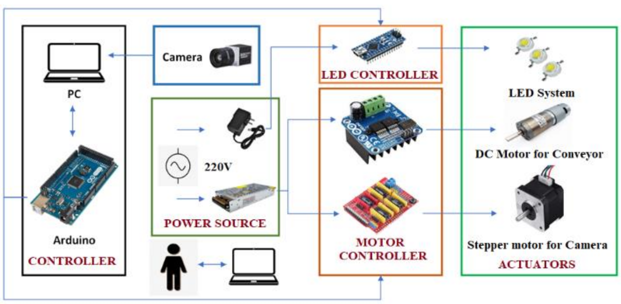

Figure 1. *System Configuration*

2.1. Mechanical construction

The overall mechanical structure of the chicken egg sorting system described in Figure 2 includes a dual conveyor belt system on both sides to move trays containing 100 chicken eggs. These conveyor belts are equipped with tensioning mechanisms to ensure belt tension during operation and are driven by DC motors with attached gearboxes for speed reduction. Below the conveyor belts is a high-power LED lighting system used for candling with 100 LED bulbs mounted in a 10x10 matrix configuration. Above the conveyor belt is a camera system mounted on a sliding mechanism controlled by a stepper motor capable of moving back and forth to capture different areas of the egg tray. At the end of the conveyor belt is a system consisting of marking pens to mark eggs identified as non-hatchable. This pen system consists of 10 ink pens controlled for vertical movement by a servo motor mechanism, with each pen equipped with a spring to reduce contact force on the eggshell to prevent breakage.

The frame of the machine is made of square section steel measuring 10×10 mm, with overall dimensions of 3850×1590×1450 mm. The camera and marking pen frames are made of shaped aluminum to ensure the aesthetic appearance and structural rigidity of the system. The motors for the conveyor belt system, cameras, and pens are selected and calculated to ensure sufficient power and the required speed. Specifically, the conveyor belts move eggs at a speed of 0.05 m/s with planetary GX43775 – 12 V reduction gear motors. The camera drive assembly is powered by two 17HS8401 stepper motors moving on shaped 20x40 aluminum. Ten marking pens are driven by ten MG995 servo motors at 60 rpm through a rack and pinion mechanism to ensure fast and stable pen movements up and down.

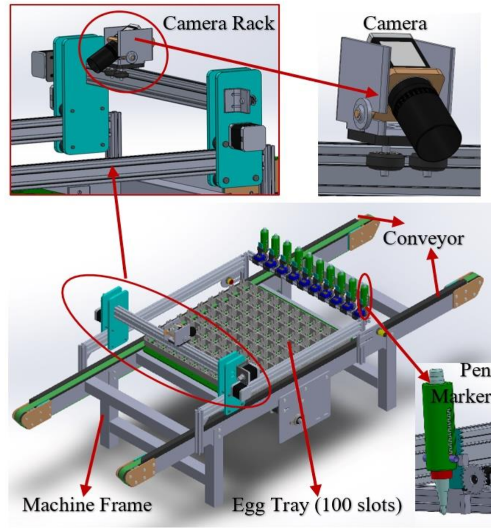

Figure 2. *Machine overview*

The Arduino board controls stepper motor for camera movement via electronic and programming interfaces. It sends pulse (step) and direction signals to stepper motor drivers, which convert these signals into the currents that drive the motors. Pulse signals determine the number of steps, controlling the motor's speed, while direction signals control the rotation direction. Micro stepping, configured by the Arduino, allows for finer control and smoother motion. Stepper motors require a separate power supply, managed by the motor driver as shown in Figure 1. The operational details of the motor drive for the entire system are described in Section 2.4.

2.2. High Power LED system

To illuminate a system of 100 eggs, we divided the process into four sessions, each involving the illumination of 25 eggs, equivalent to 5 rows and 5 columns of an egg tray per session. To calculate the wattage for a cluster of 25 LEDs, each rated at 1 watt and operating at 2 V, but powered by a 5 V source, we must determine the configuration of the LEDs and any necessary current-limiting resistors.

Since the LEDs are rated at 2 V and we have a 5 V power supply, each LED cannot be directly connected across 5 V. We need to use current-limiting resistors.

Each LED is rated at 1 W and 2 V. The current through each LED is:

$$I = \frac{P}{V} = \frac{1W}{2V} = 0.5A \quad (1)$$

Each LED requires 0.5 amps (500 mA) of current. The voltage drop needed across the resistor is 5 V-2 V= 3 V.

To decrease the voltage to 3 V at 0.5 A, the resistor can be calculated using Ohm's Law:

$$R = \frac{V}{I} = \frac{3V}{0.5A} = 0.6\,\Omega \quad (2)$$

The power dissipation in the resistor is:

$$P = V \times I = 3V \times 0.5A = 1.5\ W \quad (3)$$

The total power consumption includes the power used by the LEDs and the resistors. For each LED-resistor pair:

Total power per LED-resistor pair = 1 W + 1.5 W = 2.5 W

For 25 LEDs: $Power_{25LED} = 25 \times 2.5\ W = 62.5\ W$

Calculate the Total Wattage for 4 Clusters of 100 LEDs.

$$Total\ Power = 4 \times 62.5\ W = 250\ W \quad (4)$$

The total power (250 W) and the voltage (5 V) can be used to calculate the total current:

$$Total\ Current = \frac{Total\ Power}{Voltage} = \frac{250W}{5V} = 50\ A \quad (5)$$

The power supply required for a system that includes 4 clusters of 25 LEDs, with each cluster consuming 62.5 W, should be capable of providing 5 V at 50 A.

The measured value is lower than 50 A because we have not considered the factor of resistance in each LED and actual measurements show that the resistance in each LED significantly affects the total current needed. The resistance value of each LED is not fixed and tends to increase as the temperature of each LED becomes increases.

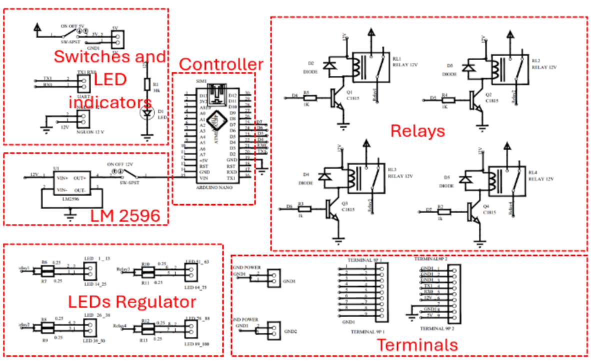

Figure 3. *Circuit design principles*

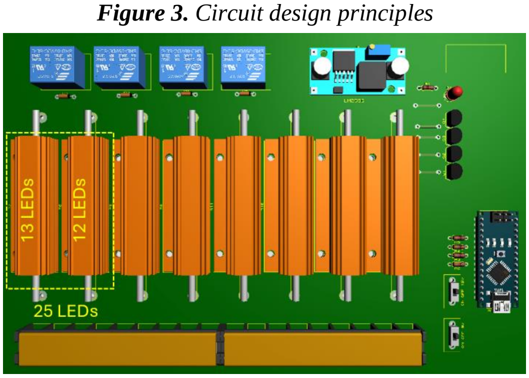

Figure 4. *3D LED circuit design*

In practice, supplying power to a cluster of 25 high-power LEDs can easily cause the driver circuit to overheat. Therefore, to reduce the heat generated, we divided the cluster of 25 LEDs to be powered by two driver circuits, with one circuit powering 13 LEDs and the other powering 12 LEDs. A schematic diagram, 3D design diagram, and actual circuit images are shown in Figures 3, 4, and 5, respectively.

Since this system has relatively high power for a common electronic circuit, we use four relays that can act as protective devices, automatically disconnecting when overload or short circuits are detected in the system. An Arduino Nano controller is used to control the LED lighting algorithm. Additionally, we use LM2596 an low-voltage regulator module, a voltage converter module that converts DC input voltage from 3 to 40 V into output voltage from 1.5 to 35 V, with a maximum output current of 3 A, to regulate the voltage signal for the LED driver system.

In this system, we manage heat and ensure the longevity of LEDs by implementing several strategies including attaching aluminum heat sinks as shown in Figure 4 and 5 and using thermal paste or pads for improved heat transfer, utilizing active cooling with increased airflow area, using current-limiting resistors and constant current drivers to prevent overheating, ensuring an appropriately rated power supply, designing an efficient PCB layout with thermal vias and larger copper areas, and employing Pulse Width Modulation (PWM) dimming to reduce average power dissipation without compromising light quality.

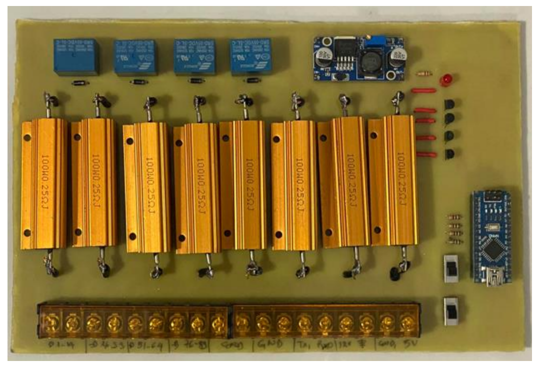

Figure 5. *Actual LED circuit board*

2.3. Egg scanning method

Based on the process of embryo development in chicken eggs as depicted in Figure 6 [15], we observed that fertilized eggs developed blood vessels after 4 to 8 days of incubation. If the egg shows dark rings around it, it has been invaded by bacteria and cannot hatch into a chick. In some cases, the appearance of porous spots when candling eggs is also considered damaged, with an 80% chance that they will not hatch. Figure 7 shows images of actual eggs captured by the research team for differentiation purposes.

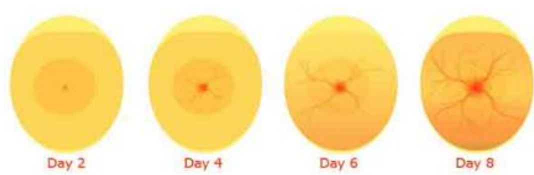

Figure 6. *Development process of a chicken egg [15]*

As shown in Figure 7, eggs older than 5 days that are not fertilized will allow light from the LED system to pass through an unobstructed system and will be marked "Not OK" as seen in the image. Other types of eggs that can hatch will allow light to pass through but will be obstructed, forming dark areas of varying sizes. The larger the area is the older the egg and the closer it is to hatching; smaller areas indicate younger eggs that need further observation to ensure normal development.

Image processing involves capturing images using a camera module and preprocessing them with noise reduction filters and brightness/contrast adjustments. The images are converted from

RGB to HSV color space for effective color-based segmentation [6]. Thresholding is applied to isolate objects based on specific Hue, Saturation, and Value (HSV) ranges. Morphological operations, such as erosion and dilation, are used to remove noise and fill gaps in the segmented objects. Contours are detected and extracted for further analysis, including object recognition and measurement, and features such as shape, size, and position are extracted.

The HSV color space is chosen for its ability to separate color (Hue) from intensity (Value), facilitating color-based segmentation. It is robust to lighting variations, as changes in brightness and shadows primarily affect the Value component, leaving Hue and Saturation relatively stable. This simplifies thresholding and improves segmentation accuracy, making it more effective for detecting and tracking specific colors.

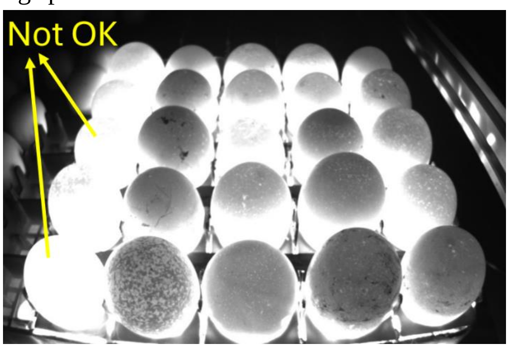

Figure 7. *Image of the sampled eggs*

With the requirement of identifying eggs with the least amount of dark areas for rejection, the author has employed the idea of calculating the dark area on the egg to determine whether it should be rejected. Once the dark area has been determined, it will be compared to a fixed threshold; if it is larger than the threshold, the egg will be rejected, and vice versa.

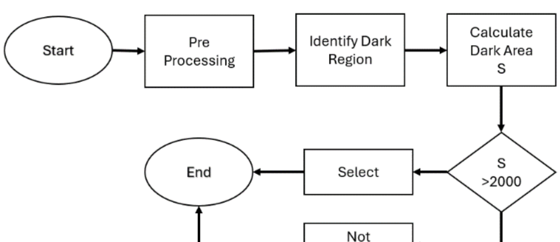

Figure 8. *Egg detection algorithm*

To calculate the area, we first need to preprocess the image by resizing it to 150 ×150 pixels and converting it to a binary image with only black and white color. By converting the image to the HSV color space and then adjusting the three parameters H (Hue), S (Saturation), and V (Value), we obtain the desired image.

After applying the HSV color filter, the dark areas on the egg appear white, and the light areas be black. At this point, we draw contours around the white regions on the egg to calculate the enclosed area. We then compared the calculated area to the minimum area (2000) that a fertilized egg could have, to determine whether the egg had been fertilized. Figure 8 shows the algorithm flowchart for this image processing procedure.

2.4. Main algorithm and user interface

Figure 9 shows the overall algorithm flowchart of the egg candling machine for detecting hatching chicken eggs. First, when the system is activated, all the modes are set up. When an egg tray is loaded, the conveyor motor moves the tray of 100 eggs to the correct position, as detected by sensor 1. Next, the conveyor motor stops, and the egg tray is positioned above the LED lighting system. The camera motor then sequentially moves to 4 positions corresponding to 4 egg candling zones (each zone containing 25 positions as mentioned in section 2.3). After each movement and capture, the faulty eggs are recorded and displayed on the interface (Figure 10). Finally, the egg tray is moved to the marking pen position, where the pens will move up and down to mark the faulty eggs that cannot hatch based on the detected positions.

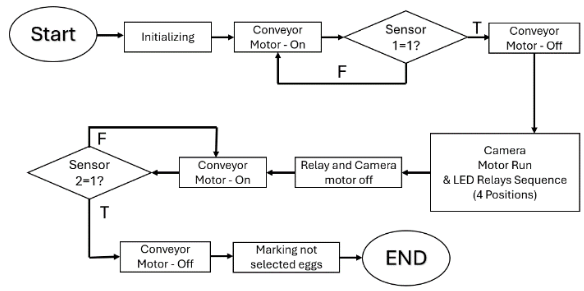

Figure 9. *Main algorithm*

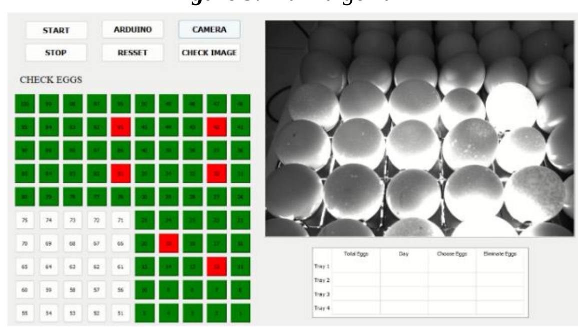

Figure 10. *Machine interface*

The system interface consists of the following functional buttons:

CAMERA: Connect the camera to display in interface

ARDUINO: Connect the microcontroller to the computer.

START: The system is started after the camera and microcontroller are successfully connected to the PC.

STOP: Emergency stop the system.

RESET: Restart system.

CHECK IMAGE: Open the folder containing all image files displaying the image processing progress.

3. Results and discussion

The team successfully built the machine as shown in Figure 11. The system was tested during the manufacturing process. The object under study here is 4 to 12 day-old chicken eggs, and Table 1 describes the results of 10 machine operations, with the eggs being classified on June 27, 2023.

Initially, the evaluation team found that the system runs stably with minimal vibrations during operation. The system is capable of classifying one tray of eggs (consisting of 100 eggs) in approximately 15 seconds, significantly reducing labor time and increasing productivity and economic efficiency for the business. The accuracy is calculated as 100% minus the absolute value of the difference between the actual and eliminated eggs (by the machine) divided by the actual number of eggs (percent error). The actual value represents the number of eggs identified as unhatchable by expert worker.

According to Table 1, the machine's accuracy is not stable; however, the average accuracy rate is within the desired range of 80%. This discrepancy is primarily due to variations in the color of the eggs. For eggs with dark brown shells or excessively thick shells, there is a higher rate of misclassification. Errors can also arise from the size and positional errors of the eggs, where overly large or small eggs can obstruct the visibility of smaller eggs behind them, causing positional deviations in image processing. Additionally, the lighting environment affects the accuracy of the images captured by the camera, leading to variations in the detection system's accuracy. Therefore, it is necessary to improve the accuracy of classification software for industrial egg sorting according to the specific types and sizes of eggs in future versions.

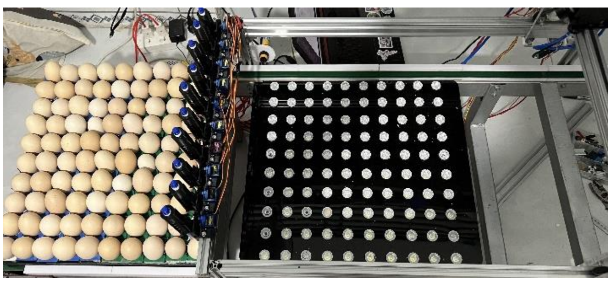

Figure 11. *Real Machine*

Table 1. *Statistics of the system accuracy rates*

Test #	Total	Chosen	Actual	Eliminated	Accuracy
1	100	88	15	12	80.00%
2	100	86	15	14	93.33%
3	100	90	10	10	100.00%
4	100	90	13	10	76.92%
5	100	88	12	12	100.00%
6	100	82	16	18	87.50%
7	100	85	12	15	75.00%
8	100	97	5	3	60.00%
9	100	93	9	7	77.78%
10	100	80	16	20	75.00%
Average accuracy					**82.55%**

4. Conclusion

The developed egg candling and sorting system demonstrates robust mechanical engineering, ensuring rigidity, durability, and aesthetic appeal, as proven by three months of continuous operation without malfunction. Its compact design facilitates easy transport without compromising component integrity, outperforming similar products [3], [4].

The software efficiently processes and consolidates data on classified eggs, exporting this information to an Excel file. This enables businesses to monitor classification accuracy and discard rates, allowing for strategic improvements. The software interface also allows operators to track the positions of discarded eggs and the total number of categorized eggs in real-time. As shown in the test in Table 1, the highest accuracy reached 100% while the lowest accuracy reached 60%. The lowest accuracy occurred when using eggs with many size and color differences.

The electrical system is designed by using commercially available modules and circuits. Thus, the system reduces processing costs and simplifies installation and maintenance, enhancing operational uptime. Overall, the effective performance of the egg candling and sorting system, provides significant benefits to poultry businesses.

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