Robotic egg candling system

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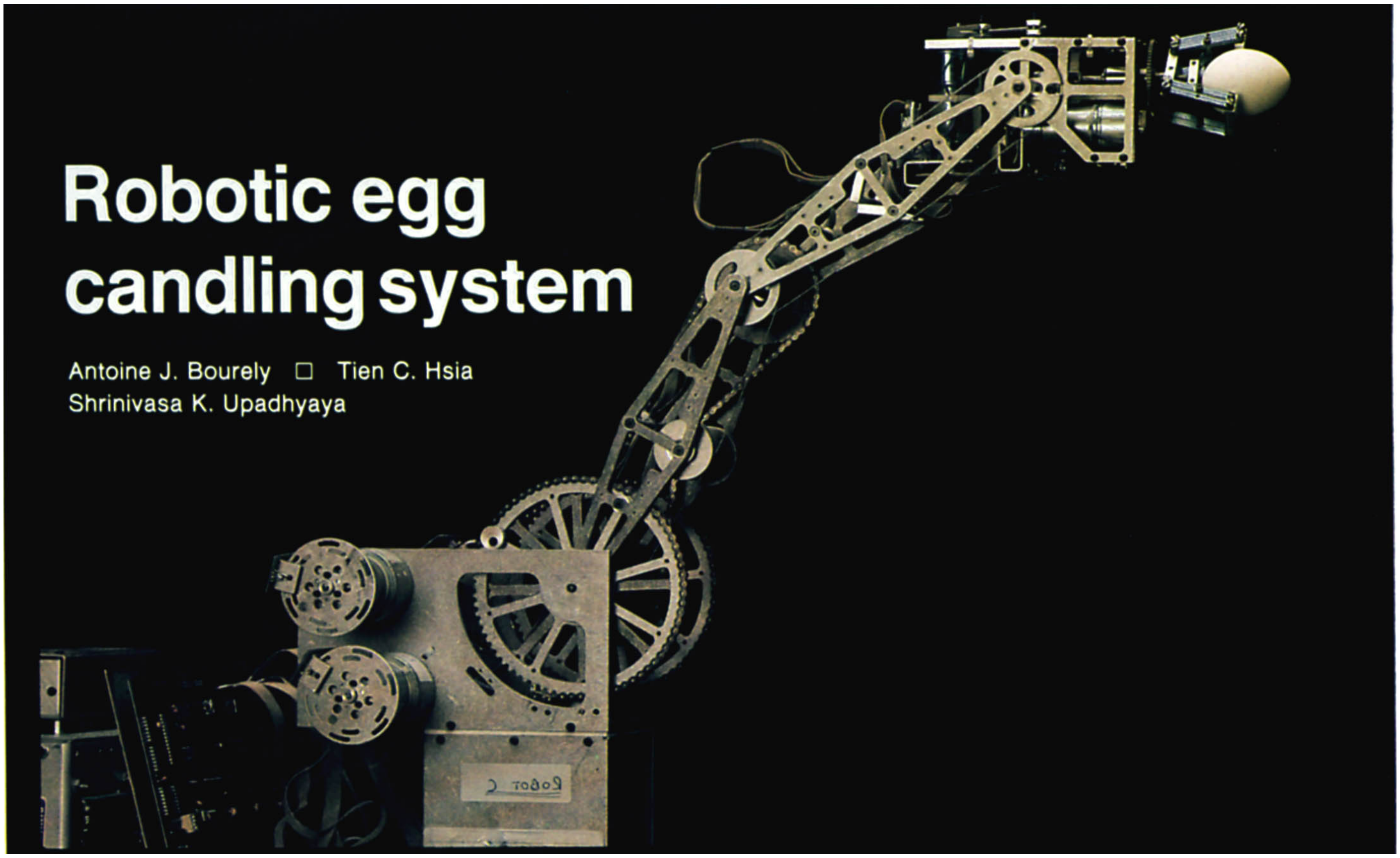

Jack Kelly Clark

Working with a Rhino XR-1 general-purpose "pick-and-place" robotic arm, in conjunction with a video camera and computer, UC agricultural engineers demonstrated that a robotic system for automatic egg candling is technically and economically feasible. The system detects a defective egg; the robot picks it gently from the conveyor belt and places it in an egg flat according to defect.

Candling is one of the major bottlenecks of the egg-processing industry. In most plants, it is still done manually. Eggs roll slowly on conveyor belts over bright lights that clearly show up defects, such as cracks, blood spots, dirt, and badly shaped yolks. Defective eggs are removed by hand and stored separately for various uses.

This paper reports on the automation of egg candling with an inexpensive robot and a digital camera.

Present system

The typical egg-production facility in the United States has 500,000 hens and is almost fully automated. After the eggs are laid, they are cleaned, sorted by quality and size, and packed into boxes for marketing, usually by a team of six people with specialized machinery. Loading the eggs onto the conveyor belt, candling, and removing defective eggs for secondary uses can be done at about 43,200 eggs per hour (120 cases, 360 eggs per case). Typically, each of two operators looks at six eggs per second and manipulates other eggs at the same time. The operator also activates pushbuttons to count each type of defect. The job is tedious, and usually 10 to 20 percent of the cracks — the most common defect — are missed.

There have been attempts at partial automation, in which operators pinpoint defective eggs with a pen connected mechanically to a computer. When contact with a defective egg is made, the pen position is recorded. Extra packing lines at the end of the chain handle the defective eggs, and a computer-controlled hand releases eggs into the correct weight or grade category. This procedure increases throughput, but at the expense of added hardware — one computer and two packing lines. These additional packing lines are underused, since together they handle less than 4 percent of the eggs.

In an attempt to improve automatic candling, we investigated the use of a video camera for detection of cracked eggs and robot arms for egg manipulation. Our study, which considered both real-time operation and cost effectiveness, suggested that a robotic system is both technically and economically feasible.

Robotic system

In an egg-processing facility, the automated candling process might use four fixed video cameras and two robotic arms. The fixed cameras would scan the first half of the candling booth and send digitized images to an image-processing computer to detect defective eggs. To achieve the throughput of 120 cases per hour, the computer must analyze 12 eggs per second.

The image is digitized into 256 gray levels; a threshold is set at a relatively high gray level. Then a binary (black and white) image is processed. The egg itself is dark and is not visible, and cracks appear as bright elongated objects. Since the eggs roll regularly on the conveyor belt, we assume it is possible to look at the whole egg by taking three pictures of each one.

The result of the image processing — the position and type of defect in a defective egg — is then sent to a microcomputer controlling the robot. The robot intercepts the moving egg, picks it gently from the conveyor belt, and places it standing in the appropriate egg flat according to defect. The procedure corresponds to two handling operations — mechanical sorting (picking) and packing (placing) — so that the robot would replace a complete packing line.

Since the robots operate in the second half of the candling booth, they would not interfere with the camera. They would handle as many as 15 rows of eggs. The buffer system resulting from this setup means that a temporarily high concentration of defective eggs in one row can be placed on a waiting list until the robot can handle them. The robot's speed is thus set for the average defect frequency.

The average time available to manipulate one defective egg is about 4 seconds, which is within the capabilities of a low-cost arm. The robot hand can be either a rubber-padded two-finger gripper or a vacuum finger.

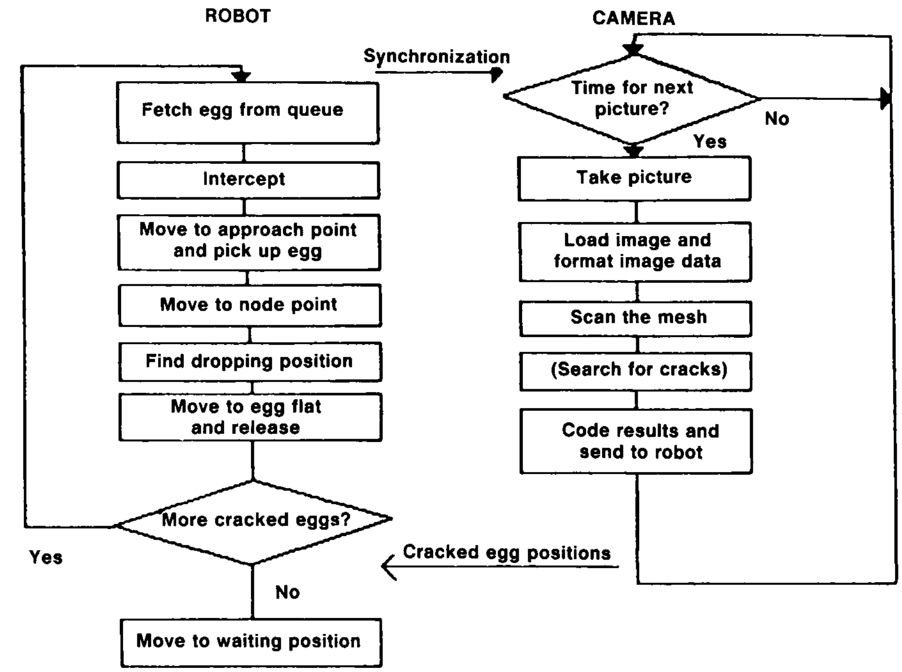

Fig. 1. Candling system block diagram.

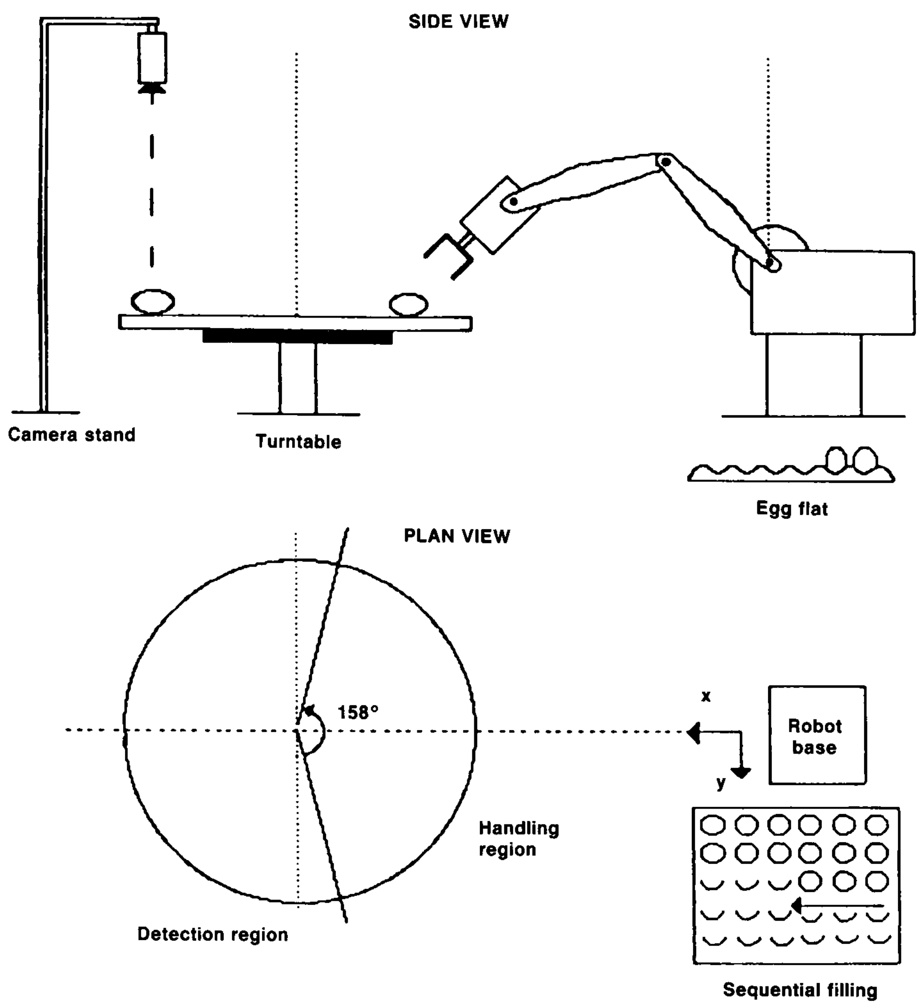

Fig. 2. Laboratory model physical layout.

Laboratory test model

To test the system, we used a laboratory model with only one camera, one robot, and a turntable to simulate the conveyor belt (fig. 1 and 2). The structure has two loosely connected loops: The master loop contains the robot (Rhino XR-1) and a computer (LSI 11/23) that performs both robot control and the high-level control of the system. The slave loop contains the camera (Microneye) and the image-processing computer (HP9836).

In operation, the robot computer sends a command to the slave loop to take a picture. When a cracked egg (or other defect) is detected, the slave loop interrupts the robot computer to record the position(s) of the defective egg(s) in the row. To this information, the robot computer adds the time at which the picture was taken and then puts the defective egg on a waiting list. The computer also controls the constant-speed movement of the turntable. The computer sends orders to take pictures at fixed time intervals. The camera thus operates in synchronous mode.

The robot computer processes each manipulation request as soon as it finishes the previous one. The information about the cracked egg is taken from the waiting list and fed into an interception routine, which finds where to pick up the egg, taking into account the time needed for the robot to get there. The robot goes to an approach point above the egg and starts the picking sequence — a vertical downward movement with simultaneous closure of the gripper — immediately after which the robot returns to the same approach point with the egg. Another routine is called to find where in the egg flat the egg must be placed. The robot goes to the flat, while bending its wrist, and releases the egg in standing position.

The robot is now ready for the next request. If the waiting list is empty, the robot goes to the entrance (waiting position) of its working area.

To simplify the experimental procedure, we lighted the eggs from above so that the background and eggs were white, and cracks appeared as the darkest areas. We compensated for the lack of resolution provided by our inexpensive test camera by using thin strips of black paper to simulate the cracks. This method resulted in a negative of the industrial picture but did not change the principle of the processing. The eggs were fixed on the table, not rolling as they would be on a conveyor belt, and so only one picture was taken instead of three.

Analysis and control

To handle 12 eggs per second, the computer must analyze the image in 0.08 second. A simple method of analysis is mesh

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screening, in which only some regularly spaced areas are scanned until an irregularity is located. As soon as a dark spot is detected, adjacent areas are searched systematically. If no continuous image in any direction is found, the object will be rejected as "noise." The minimum time to scan the mesh is 0.03 second in assembly language for a Motorola 68000-based machine, so the time for crack detection is realistic.

Industrial robots require basic software for motion control — for example, computing the necessary positions of the robot joints to achieve a given position and orientation of the robot hand. The software used in this project for the Rhino robot takes 0.05 second per solution, which is realistic for control since it is needed at only a few positions on the robot trajectory.

For the proposed industrial system, the robots should be fast and safe, need not necessarily be too precise, and should be low in cost. The repeatability in positioning of the Rhino robot is about ±2 mm, which is satisfactory.

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A more advanced state-of-the-art Puma 560 robotic arm markedly speeded up the egg candling process over the prototype model. The goal is to develop an intermediate model that is faster than the Rhino but less costly than the Puma.

Test results

Our laboratory model worked satisfactorily, although limitations of the equipment caused relatively high failure rates. About 10 percent of the cracked eggs were not detected, largely because uneven lighting created unexpected shadows. Around 25 percent of the eggs were not released in standing position in the egg flat, but this problem can probably be overcome by improvement of the gripper design and a slight vibration of the egg flat.

The laboratory robot took 10.4 seconds to handle one egg, which is close to twice as much as real-time requirements. Higher speed industrial robots can meet the requirements.

With our inexpensive camera, the image acquisition time via RS-232 serial link was a constant 8.6 seconds. The processing time was 0.4 second. Some high-speed acquisition systems can send images at TV rate — 30 images per second.

The estimated initial cost of a robotic egg candling system is about $42,000 (table 1), and the annual operating cost would be about $4,200. Assuming a five-year service life and 10 percent opportunity cost, the annual cost of this system (fixed and operating costs) works out to be approximately $15,000. If the system replaced two operators with an annual salary of $17,000, the annual savings would be about $19,000.

Conclusion

With present technology, it is possible to use robots to automate egg candling, one of the few functions not automated in today's large egg-processing plants. The entire system can be implemented using standard equipment with the exception of specialized hardware for image acquisition. Robotic egg candling can be expected to lead to considerable annual savings.

TABLE 1. Estimated initial cost of automated egg candling system

Item	Estimated cost
2 manipulators, $5,000 each	$10,000
2 controllers, $2,000 each	4,000
2 true 16-bit microprocessors, $5,000 each	10,000
4 high-quality CCD cameras	6,000
2 matrox fast digitizers, $3,000 each	6,000
Software packages for robot control and image processing	2,500
2 end effectors, $500 each	1,000
Design and installation	2,500
TOTAL	$42,000

A robot is also cost effective when compared with automated systems that add fixed machinery to detect defects and packing lines to handle the defective eggs. Robots can be inserted into an existing process and also offer flexibility in that they can be reprogrammed to perform other tasks, such as cleaning.

Our project was only a feasibility study. The crack detection model needs to be tested under the actual lighting conditions of an egg processing plant, using industrial robots for fast operation.

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