Design of an Automated Sorting System for Apples Based on Single Chip Microcomputer

Liqun WANG[1], Clarence W. DE SILVA[2], Bing LI[1], Yuan Cai[1]
(1. *Harbin Institute of Technology at Shenzhen*, *Shenzhen* 518000;
2. *The University of British Columbia*, *Vancouver*, *BC*, *Canada V6T* 1Z4)

Abstract: The grading judgment for apples is related to a variety of factors including, size, shape, color, texture, and scars. Traditional manual sorting methods are time consuming and labor intensive. In addition, the accuracy of the method is easily subjective, not repeatable, error-prone, and affected by the sorting environment. This paper presents a complete and automated grading system for apples. The system uses a single-chip microcomputer as the controller of the system, and a PC as the graphics processing unit. It also includes a conveyor, drive motor, frequency converter for motor control, photoelectric sensors, air compressor, and air jets for ejecting the graded apples. The classification algorithm is implemented by using a convolutional neural network (CNN). In order to eliminate contact damage of apples, the system specifically uses air jets as actuators to eject the graded apples into the corresponding bins. At the same time, in order to ensure that an apple triggers the correct ejecting actuator, this paper designs a jet controller with proper logic.

Key words: Automation, Single Chip Microcomputer, Apple Grading, Convolutional Neural Network, Air Jets.

1 Introduction

Apple sorting has been done by human resources for a long time. The reason is that the quality grade of an apple is not only related to its weight, a quantity that is easy to automatically measure, but also to other factors such as color, texture, size, and scars, which are difficult to automatically measure when the apples move with a sorting conveyor. Since the grading of apples is subjective, qualitative, non-repeatable, slow and prone to error, this approach recognized to be desirable. Furthermore, since the industry is seasonal, it is difficult and costly to retain a properly trained labor force throughout the year, for work in the subsequent seasons. With the rapid development of industrial automation, machine sorting technology tends to be desirable, and has begun to be applied to various types of processing and production. Currently in the industry of fruit sorting, the sorting lines generally only include a single indicator, and a large part of the sorting work is still done manually. Some researchers also use specific sensors to distinguish features such as fruit maturity [1]. Leekul proposed a non-destructive, non-invasive sensor system for classifying durian fruits according to their maturity stage [2]. The design of the sensor system had adopted the principle of wireless communications in which the Rician *k*-factors were utilized to determine the fruit maturity. The system could achieve an accuracy rate of as high as 92.7% with regard to the determination of durian maturity. Jhuria et al. proposed a method based on single element weight [3]. This method was achieved by counting the projected area of a mango from an image taken at a fixed distance of 22 cm. The area was measured by counting the pixels of the image of the mango. With the help of a mathematical formula, the weight of the mango was calculated, and mangos would be classified into five different grades based on the weight. In recent years, with the rapid development of machine learning, some researchers have begun to apply machine vision to fruit sorting. With regard to apple sorting, factors such as color, texture, size, shape, and scars are all important factors in determining the grade of an apple. Researchers have tried to extract these features in images through deep learning.

The related machine learning algorithms are mainly used in three stages grade determination: image preprocessing, image segmentation, and feature extraction. Image preprocessing includes grayscale processing, grayscale denoising, filtering, and other processes. It can also enhance the effect of contour extraction by enhancing the grayscale contrast between the apple and its background. The most common methods of image segmentation are the threshold segmentation methods, such as gray histogram peak-valley method and iterative selection threshold method. Sun used the top-hat transform algorithm to improve the global threshold OTSU method that is used to split the image [4]. Methods such as Fourier transform and the roundness value method, are used to extract the shape features of a generalized apple. Texture features are described by mathematical statistical methods such as mean, standard deviation, entropy [5]. Color features are generally extracted using color space models such as red-blue-green (RGB) and hue-intensity-saturation (HIS).

In recent years, the emergence of Support Vector Machines (SVM), fuzzy algorithms, convolutional neural networks (CNN) and other effective methods has made a new breakthrough in fruit grading algorithms. Especially for a convolutional neural network, one can directly input a two-dimensional image. It will enable automated extraction of useful features without having to design specialized algorithms. Nishi et al. presented a method of grading fruits and vegetables by means of using red-green-blue-depth (RGB-D) images and CNN [6]. The method remakes RGB images involving equidistant objects by using depth image, and then utilizes CNN for learning to classify RGB images for the grading of objects according to their size, where the CNN is structured for achieving both size sensitivity for grading and shift invariance for reducing error involved in RGB images. This undoubtedly improves greatly the efficiency of the algorithm. More desirably, the convolutional neural network has greatly improved the accuracy of fruit sorting. Thus, our developed grading system uses CNN to implement the sorting algorithm for apples.

In an automated fruit sorting process, the protection of apples from possible damage is very important. Conveyors are commonly used in the industry for moving the apples while being sensed and sorted. A key issue is how to get the graded apples ejected off the conveyor belt into the corresponding bins. The possible methods of carrying out this operation include robotic gripping and transfer, and pushing using a piston arm. A common feature of these methods is that apples must be touched and it can damage the fruit. Also, some ejecting devices can be quite complex. Although protective measures, such as adding rubber pads, can be taken to prevent damage to the apple during contact, there is still a possibility that the quality of an apple is "reduced" due to mechanical handling. In order to overcome these problems, we have proposed to use the contactless method of applying air jets to the apples to eject them, in the designed automated sorting system. This mechanism is simpler and has no contact with the apples, which can ensure that the apples are not damaged during ejection and maintain the original grade.

The overall grading process includes an algorithm part and an execution part. The complete process of the grading system has other parts including, power, transmission, control strategies, and electronic components. They are described in more detail next.

2 Sub-module Design

In order to make the design and construction of the system more convenient, the system is divided into several modules that are eventually combined into a complete automated grading system. According to their functions, the system is divided into the following units: the main control unit (MCU), the conveyor unit, the detection unit, the camera unit, the picture processing unit, and the action unit. The

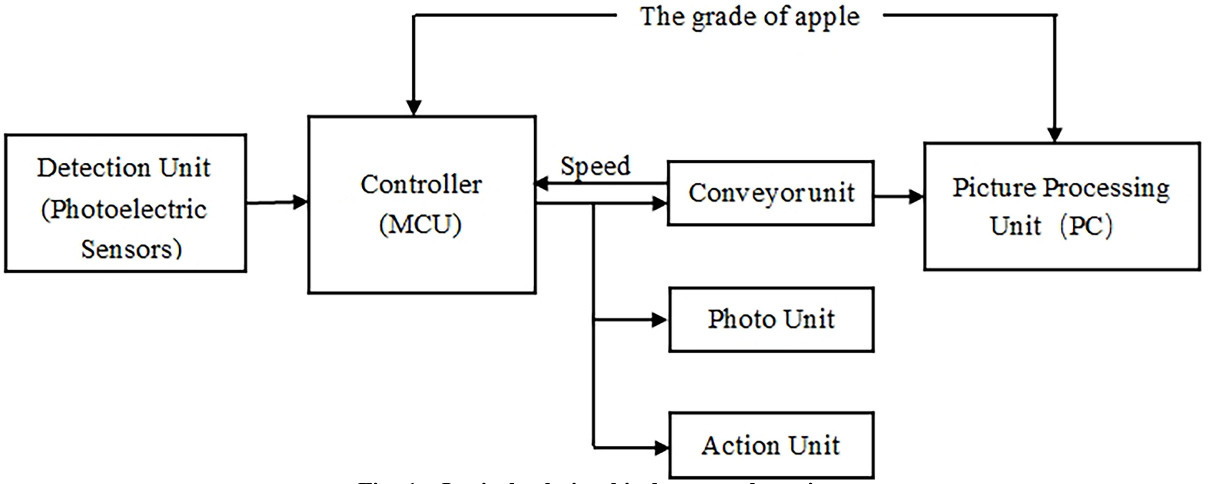

Fig. 1 Logical relationship between the units.

logical relationship between the units is shown in Figure 1. Apple classification process is shown in Figure 2.

The chip of the stm32F103 series is chosen as the controller of the system. Compared with the traditional 51 single-chip microcomputer, stm32 has more abundant resources and superior performance. The microcontroller can operate at a frequency of up to 72 MHz, on-chip integrated high-speed memory (256 KB of memory and 48KB of SRAM), rich enhanced awake I/O interface, which greatly simplifies the engineering design [7]. Therefore, the stm32 series microcontrollers are beginning become quite popular in industrial systems. In view of these advantages and in order to make it easier to upgrade the system in the future, we have chosen to use the stm32 series in the developed grading system. The main functions used in this system include I/O, PWM, and external interrupt.

2.1 Conveyor belt

The basic functions of the conveyor belt unit include the transportation of apples and the detection of conveyor speed. In this process, the apples pass under the color camera and the structured light camera in turn, from which information the apple quality is established. When an apple reaches the corresponding air jet, the air jet which is sourced by the air compressor, is activated to eject the apple to the corresponding box (bin). The conveyor belt system is equipped with two cameras, an LED light, a strip laser, six photoelectric sensors, three air jets (for three grades of apple), and a synchronous wheel encoder (to measure the conveyor speed).

The equipment required for other units needs to be installed on the conveyor unit of the automated sorting system, based on the single-chip microcomputer. The required flow of the system is determined according to the expected automatic classification function. The position of each unit and its device on the conveyor belt are then determined according to the grading process, which is shown in Figure 3.

Considering the space problem and the ease of installation, a chain drive is adopted as the motion transmission mechanism of the conveyor motor (shown in Figure 4). The chain drive has the following advantages. Compared with a gear transmission, it can transmit motion and power when the centers of the motor shaft and conveyor drive shaft are far apart. It can operate under low speed, heavy load and high temperature conditions and the bad environment of flying debris in the apple. Compared with a belt drive, a chain drive can ensure an accurate average transmission ratio, a large transmission power, and a small force acting on the shaft and the bearings. Its transmission efficiency is high, generally reaching 0.95 to 0.97.

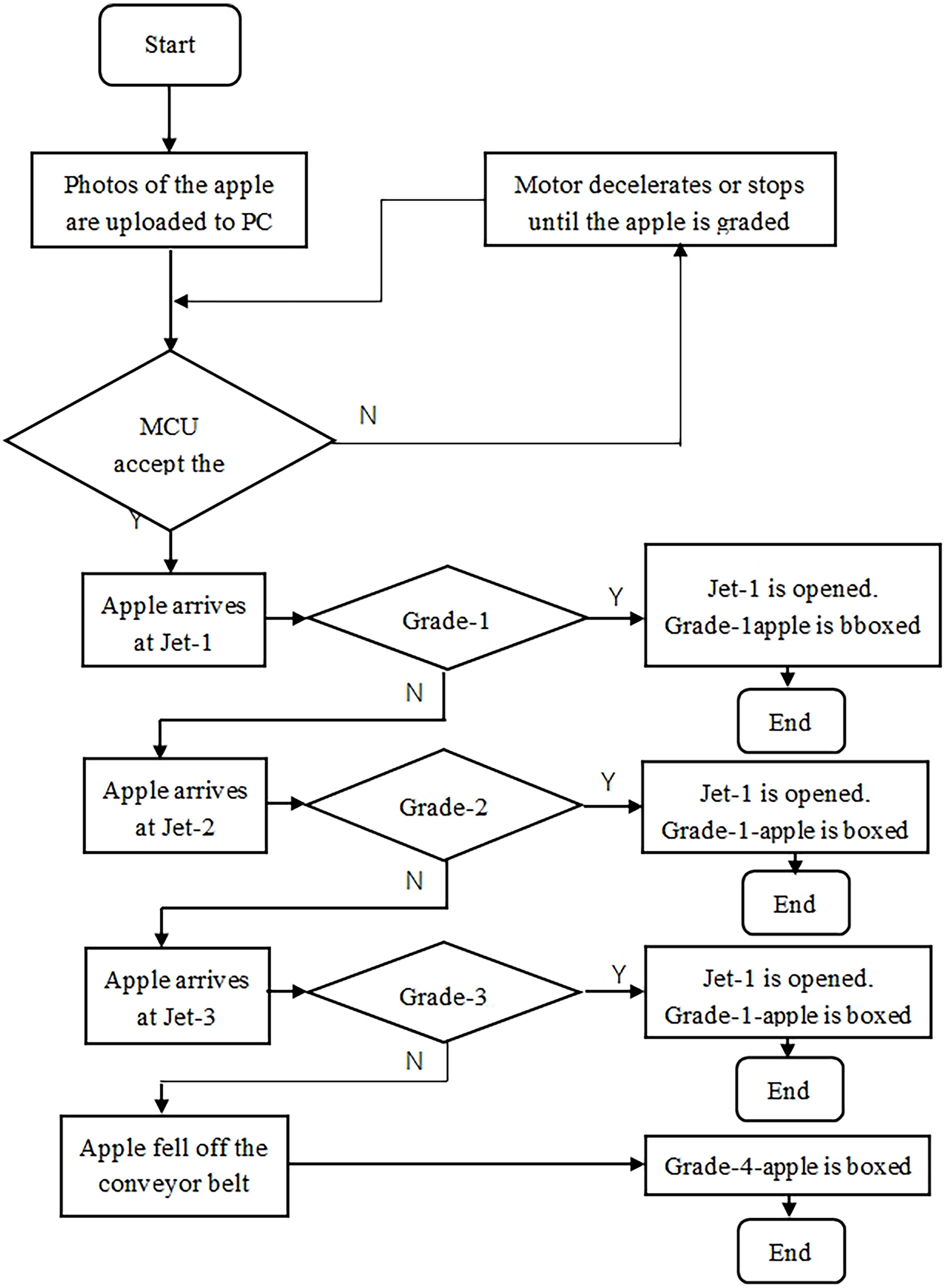

Fig. 2 Automated grading process of apples.

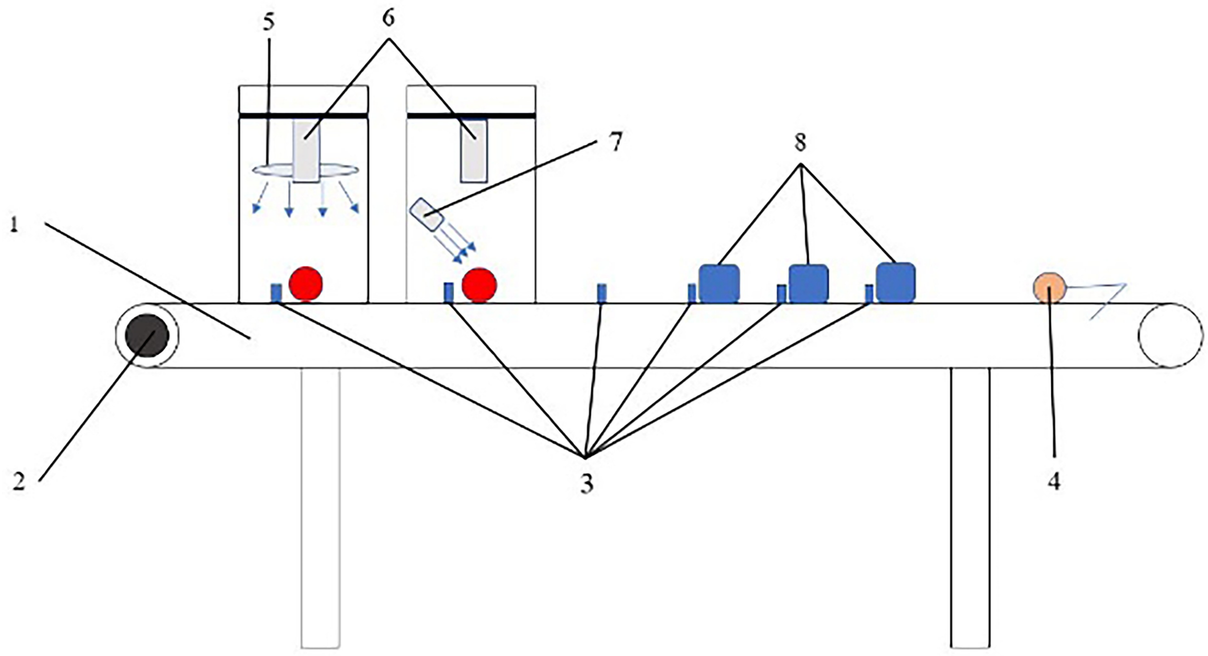

Fig. 3 Schematic diagram of the conveyor belt and other devices (1-conveyor belt, 2-speed motor, 3-photoelectric sensor, 4-synchronous wheel encoder, 5-LED lamp, 6-CCD camera, 7-laser stripe transmitter, 8-air jets).

Fig. 4 Chain drive.

To drive the conveyor, a combination of three-phase AC motor and a frequency converter that uses a 0-10V DC voltage signal to control the motor speed is used in the system. Since stm32 cannot directly output the DC voltage signal that meets the requirements, we have added a pulse width modulator (PWM) to the DC voltage module between the MCU and the inverter. The microcontroller outputs a constant-frequency and variable-duty PWM signal. Then this module linearly converts the PWM signal to the 0-10V DC voltage signal, depending on the duty cycle.

The interference problem that is common in frequency converters has been a difficult problem in the industry. The present system also encountered such problems during the experiments. We found that when the inverter started to work, the signal voltage of the photoelectric sensor was severely disturbed by interference and the system could not work normally. At the same time, due to the noisy sensor signal, the input pin of the MCU generated irregular pulses that affected the normal operation of the system. After repeated experiments, it was found that the cause of the problem was the electromagnetic interference generated by the inverter. In addition, since the entire experimental platform is similar to a metal frame cube, the interference on the sensor located on the surface of the platform is further exacerbated. To solve these problems, we first encased the inverter and the microcontroller with an aluminum metal box. Through this, the interference of the inverter was weakened but some interference remained, prevent the system from operating normally. Finally, the interference problems encountered by the system was solved by properly grounding the entire metal platform, as shown in Figure 5.

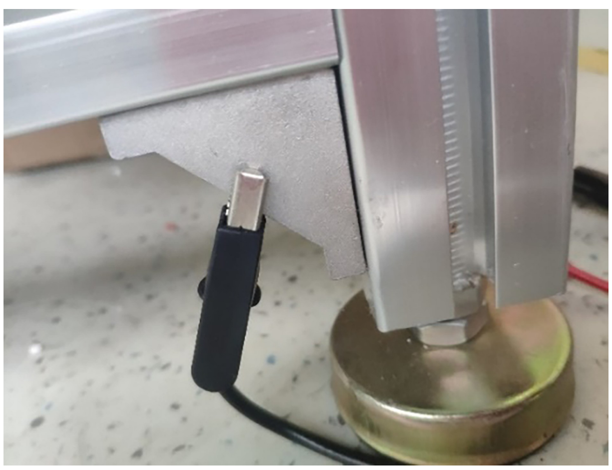

Fig. 5 Grounding the experimental platform.

2.2 Detection unit

Basic function of the unit is to monitor the conveyor speed and detect whether the apple has reached the two camera locations, a waiting position, and the proper air jet position. A total of six photoelectric sensors are used for enabling these different functions. Each sensor is connected to the microcontroller (MCU) via a level shifting module. On receiving a signal from a photoelectric sensor, the MCU performs the corresponding operation. Conveyor speed monitoring is done by a synchronous wheel encoder, which is shown in Figure 6. The signal voltage of a photoelectric sensor is 24V, and the pin voltage of the single chip microcontroller can withstand 3.3V (maximum 5V). At the same time, considering the interference problem of the sensors, we added a module with dual function (voltage conversion and opto-coupler isolation) to solve the problem. It converts the 24V signals to 3.3V and isolates them for transmission to the microcontroller.

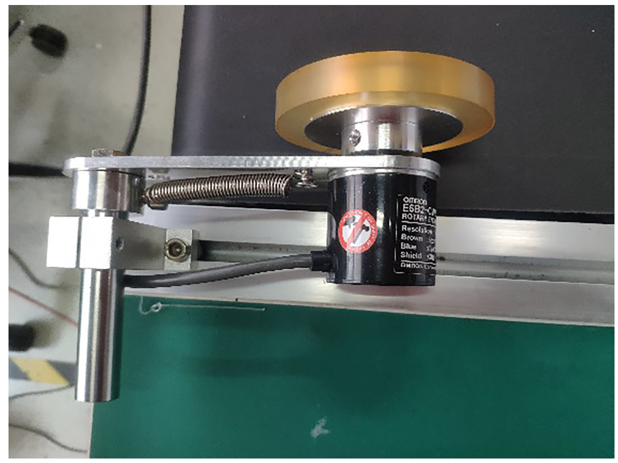

Fig. 6 Synchronous wheel encoder.

The detection unit contains a total of 6 photoelectric sensors and 1 synchronous wheel encoder. Among them, the first two sensors are responsible for detecting whether an apple has reached the specified imaging position. The third sensor is responsible for checking whether the process of grade determination has been completed when an apple reaches the pre-entry position of the bank of air jets. If the grading is not completed when the apple has been reaches this position, the motor decelerates or stops until the grading is completed. The 4th, 5th, and 6th sensors are responsible for activating the procedure for determining whether the apple has reached the air jet corresponding to its grade. If the grade of the apple corresponds to the air jet at this position, the jet is activated to eject the apple and complete the boxing. The apple that do not meet the specified grades reach the end of the conveyor where they are collected and rejected.

Synchronous wheel encoder is responsible for monitoring the speed of the belt. If the conveyor speed is out of control or the conveyor is stopped due to an accident, it will activate an alarm. The reason why a synchronous wheel encoder was selected in the present design, instead of a traditional optical encoder at the motor spindle is given next. We use a chain drive the conveyor belt using an AC motor. Due to the nature of the chain drive, the linear relationship between the speed of the belt and the speed of the motor is not critical. Compared to the motor speed, we are more concerned with the line speed of the conveyor belt. Hence, accurate sensing of the motor speed is not necessary, and besides the motor speed is determined directly by the drive frequency generated by the motor controller (inverter). The six photoelectric sensors are all NPN/diffuse type. The detection distance is selected to be 200 mm according to the width of the conveyor belt.

2.3 Imaging and image processing unit

After receiving the corresponding camera signal, two cameras will take images. Both cameras are in a black-box environment. One camera outputs a color image (shown in Figure 7) of an apple under white LED illumination, and the other camera outputs a structured light image (shown in Figure 8) of an apple, illuminated by red laser stripes.

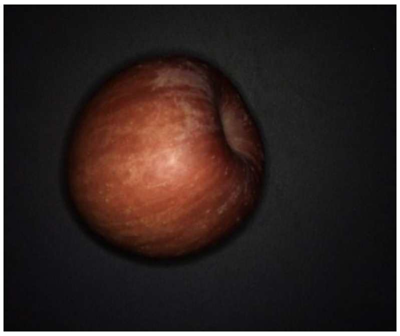

Fig. 7 Original color image.

Then this unit analyzes the images uploaded by the camera unit online and outputs the grade information of apples to the MCU. We first trained the apple grading model through convolutional neural networks in the Keras platform and python language environment. When the automated sorting system based on single-chip is operating, it will load the trained model online. Whenever an apple enters the corresponding area to trigger imaging, the camera automatically transmits the image to the PC. Then the program automatically loads the image for analysis, and finally the result is transmitted to the MCU. After obtaining the grade of an apple, the PC sends the grade information to the microcontroller control system via serial communication. The MCU then controls the jet accordingly.

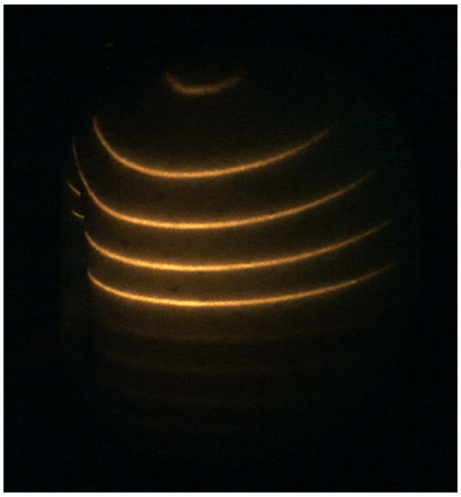

Fig. 8 Structured light image.

A general convolutional neural network is divided into four layers, which are an input layer, a convolution layer, a sampling layer, and an output layer. Its input is a two-dimensional image. The convolutional layer and the sampling layer appear alternately in the middle of the network, and these two layers are also two essential layers. The input layer directly accepts two-dimensional images (which can be a grayscale image, multiple grayscale images, color images, video multi-frame images, and so on), automatically extracts features from the original image data, and learns the corresponding class by means of the classifier, reducing the development complexity. The convolutional layer is in the middle layer, and carries out feature extraction. Multiple convolutional neurons are included in each convolutional layer. Compared to a general neural network, the local connection of the convolutional neural network greatly reduces the network parameters. The pooling layer also belongs to the middle layer, which is a feature mapping layer, and is generally used after re-convolution. This layer not only does not generate new training parameters, but also down-samples the features extracted from the previous layer of the network, further reducing the network scale. By down-sampling the local receptive region of the anterior layer network, it makes the network more robust to the distortions of the input image. By reducing the number of parameters, it prevents over-learning and speeds up training and detection.

In actual operation, a total of 3,200 images of apples are used. These apple images are divided into four grades: "1", "2", "3", and "4". There are 800 images of apples in each grade. For each grade, 480 images are used as the training set, 160 images are used as the testing set, to test the performance of the CNN model, and the remaining 160 images are used check whether there is over-training of the network (i.e., the validation set). Several methods of grade determination were implemented, such as *k*-nearest neighbor method, pure CNN, pure SVM, and their accuracy rates were found to be about 77%, 92%, and 95%, respectively. After continuous attempts, a neural network with 7 convolutional layers and a SVM layer was built. After the initial image is sent to these convolutional layers, output results is obtained. These results are sent to an SVM layer, and finally the classification result is obtained. After continuous trials, the accuracy of the final model can reach almost 98%.

After training the model off line, we place this model in the on-line system. A continuous save plugin is used in the program. The plugin is activated only when an apple arrives at the imaging location. Then an image is taken by the camera and it is transferred to the PC. In fact, the PC monitors the folder where the images are stored. Whenever a new image comes into the corresponding folder, the PC analyzes it. Then the result is transferred to the microcontroller.

2.4 Action unit

An apple is ejected from the conveyor when it reaches the packing position corresponding to its own grade. Three air jets (shown in Figure 9) are placed at apple packing boxes corresponding to the three grades of apples. The grade 4 apple is rejected, and they are directly dropped off at the end of the conveyor belt. The air jets are connected to the air source through solenoid valves. The solenoid valves are controlled by a signal from the MCU, turning them on or off. The air source of this system is an air compressor with a high-pressure compartment.

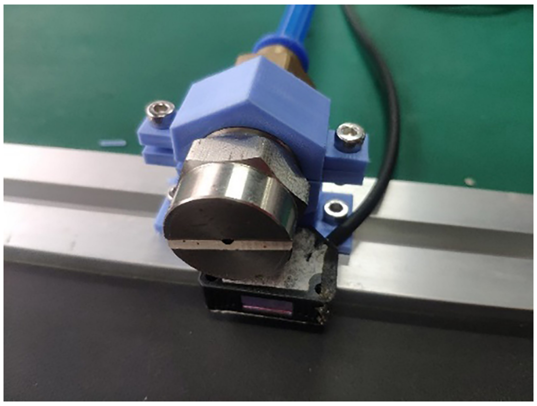

Fig. 9 Air jet and photoelectric sensor.

Three air jets are controlled by the corresponding three solenoid valves, which determine the connection between a jet and the air supply. Each solenoid valve is connected to a 24V power supply through a relay. The on-off switch of the relay is controlled by the 3.3V signal of the single chip microcomputer. Under normal circumstances, the relay keeps the solenoid valve in a de-energized state, and the air path is disconnected. When the graded apple reaches the corresponding jet, the single chip microcontroller sends a signal to the relay, the solenoid valve is powered on, and the gas path is connected. After the apple is ejected from the conveyor belt, the solenoid valve is de-energized and the air path is disconnected. The circuit diagram of photoelectric sensors, solenoid valves and relays is shown in Figure 10. The schematic diagram of the air jet system is shown in Figure 11.

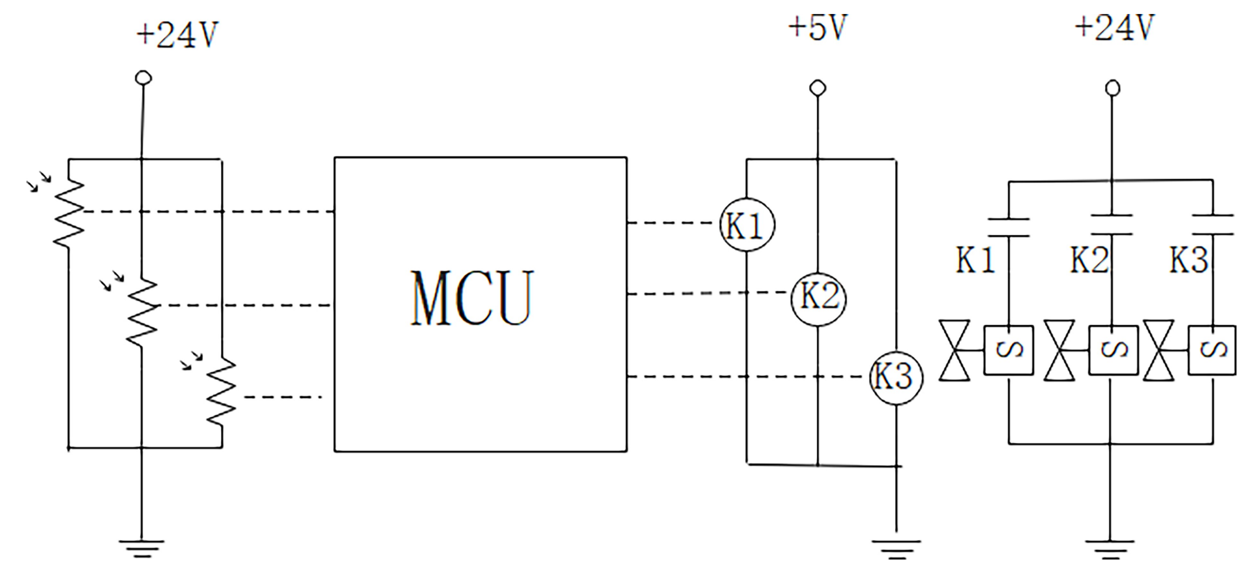

Fig. 10 Circuit diagram of photoelectric sensors, solenoid valves and relays.

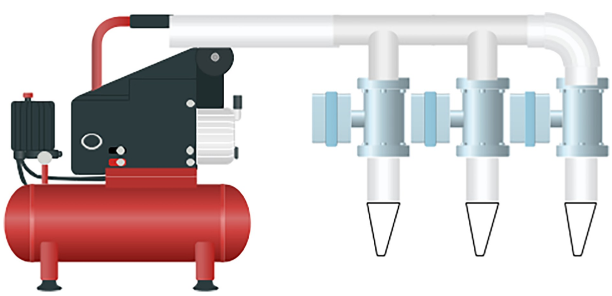

Fig. 11 Schematic diagram of the air jet system.

3 Design of Air Jet Control Logic

Since the apple is continuously transported on the conveyor belt, we need to ensure that an apple triggers an air jet when it reaches the jet that corresponds to its grade. This section proposes several options for the necessary logic for this purpose.

The first option is a time-based control scheme (shown in Figure 12). At the instant when the grade of an apple is determined, the time TN ($N=1, 2, 3$, representing the grade of apple) it takes for the apple to go from the current position to the corresponding jet is calculated. At the same time, the timer is started. From this moment on, the elapsed time T of the belt movement is recorded. When $T= TN$, it means that the apple has just reached the corresponding air jet position, and the jet is now activated. This solution can realize the packing operation of different grades of apples. But it also has the following disadvantages. Every graded but unboxed apple needs to start a timer. The timers of our microcontrollers are limited in number, and some timers are also needed for other control activities of the system, such as the encoder operation. This means, the number of apples on the conveyor belt has to be limited by the microcontroller constraint. Also, in order to accurately calculate the time TN, the speed of the conveyor belt needs to be kept constant or sensed accurately. Due to the nature of the chain drive, this is difficult to achieve in the present system.

In order to remove the shortcomings of the time-based control scheme, we have improved it into a location-based control scheme. At the instant when the grade of an apple is determined, the distance DN ($N=1, 2, 3$, representing the grade of apple) from the current position to the corresponding jet is calculated. At the same time, the corresponding process is started and the distance that the conveyor belt travels is recorded. When $D= DN$, it means that the apple has just reached the corresponding air jet position, and then the jet is activated. This program is based on recording the distance that the apple travels, which is a function of time and speed. Therefore, there is no specific requirement for conveyor speed. However, this program also has the following deficiencies. We need to accurately record the distance an apple moves, and there will be multiple computing processes that have to run corresponding to the multiple apples on the conveyor, which requires enhanced processor performance, and the program implementation is also difficult. Moreover, as mentioned before, precise control of the conveyor speed is also difficult.

In view of the deficiencies of the location-based scheme, a control scheme based on a photoelectric switch is proposed. At the instant when the grade of apple is determined, of the three jets, only the one corresponds to its grade is in placed in the active state, while the other two are placed in the inactive state. Once the apple is ejected from the conveyor at the corresponding air jet, the jet status is re-determined based on the grade of the next apple. The distance or time of the apple movement need not to be recorded in this method. But the plan relies on the photoelectric sensors to accurately determine whether an apple has reached its designated position. But this design has an obvious flaw: only one apple is allowed in the conveyor zone where the three air jets are located. That is to say, only after the first apple enters the jet area and is ejected from the conveyor belt, the second apple can enter the jet area for boxing. This will undoubtedly greatly reduce the efficiency of grading process.

While avoiding these problems, in order to enable an apple to continuously pass through the jet area and be correctly ejected by the corresponding air jet, to complete the boxing process, an improved scheme is proposed. One problem that needs to be solved is as follows. When an apple passes a jet, we need to confirm whether the apple's grade corresponds to that jet. If yes, the apple is ejected, if no, the apple is not ejected.

We set a flag array for each jet. For example, the flag array of the first jet is initially set to array1 = [0,0,0,0,0]. When the apple is classified and the MCU receives the grade information transmitted from the PC, the three flag arrays are operated. Here we specify the following: The first zero element of the jet's flag array corresponding to the apple's grade is set to 2, the first zero element of the flag array of the jet before this one is set to 1, and the flag array of the jet after this one is not operated. Here, "before" and "after" refer to the sequence of jets on the conveyor belt.

For example, the three flag array elements are all zeros in the beginning. array1 = [0,0,0,0,0], array2 = [0,0,0,0,0] and array3 = [0,0,0,0,0]. If the apple is determined to be grade 2, the three flag arrays change to be, array1 = [1,0,0,0,0], array2 = [2,0,0,0,0] and array3 = [0,0,0,0,0]. Suppose that the next apple is determined to be grade 3. Then the three flag arrays change to be, array1 = [1,1,0,0,0], array2 = [2,1,0,0,0], array3 = [2,0,0,0,0]. In this manner, the element values of a jet's flag array have actual meanings. The number of non-zero elements is equal to the number of graded apples that will pass. "1" means that the apple's grade does not correspond to this jet and "2" indicates that the apple's grade corresponds to that jet. The operation diagram of the flag array is shown in Figure 13. With the flag array of the 3 jets, we also need to design whether the ejection process has to be activated as an apple reaches a jet. Here we specify that each time an apple reaches an air jet, the first element of the jet's flag array is read and then removed from the array. If the element value is 1, the jet is not activated and the apple passes normally on the conveyor. If it is 2, the air jet is activated and the apple is ejected from the conveyor into the corresponding box. Note that there must be a delete action after reading the element in the array. In our design, the non-zero element of the flag array represents the apple and air jet the corresponding its grade. That element should be 0 in the array after the apple reaches the corresponding jet. This will ensure that the subsequent apples will be executed correctly. The operation diagram of the flag array when an apple reaches the jets is shown in Figure 14.

In order to make it easier to observe the sorting of the apples, the images of the apples that are being

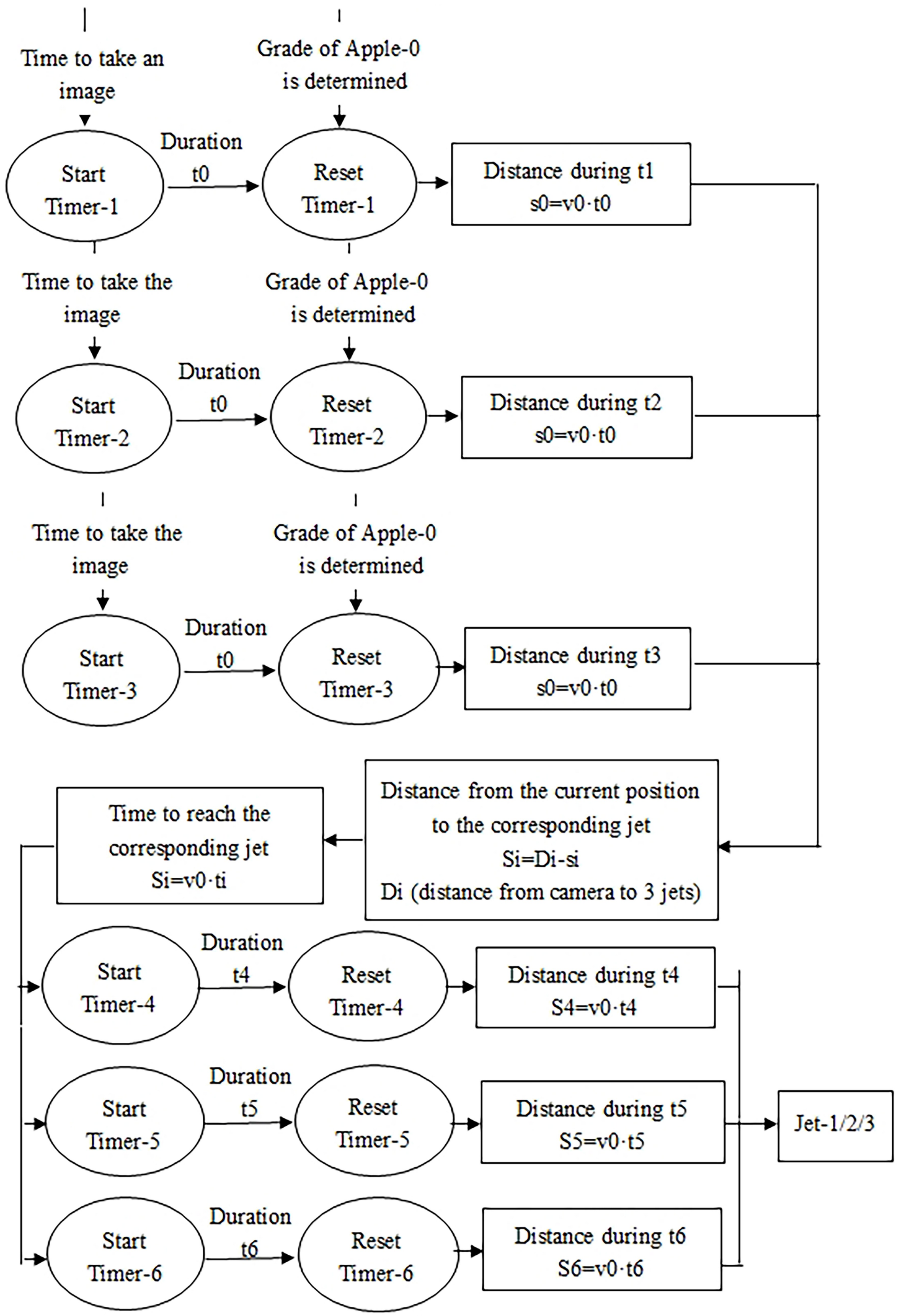

Fig. 12 Schematic diagram of time control scheme.

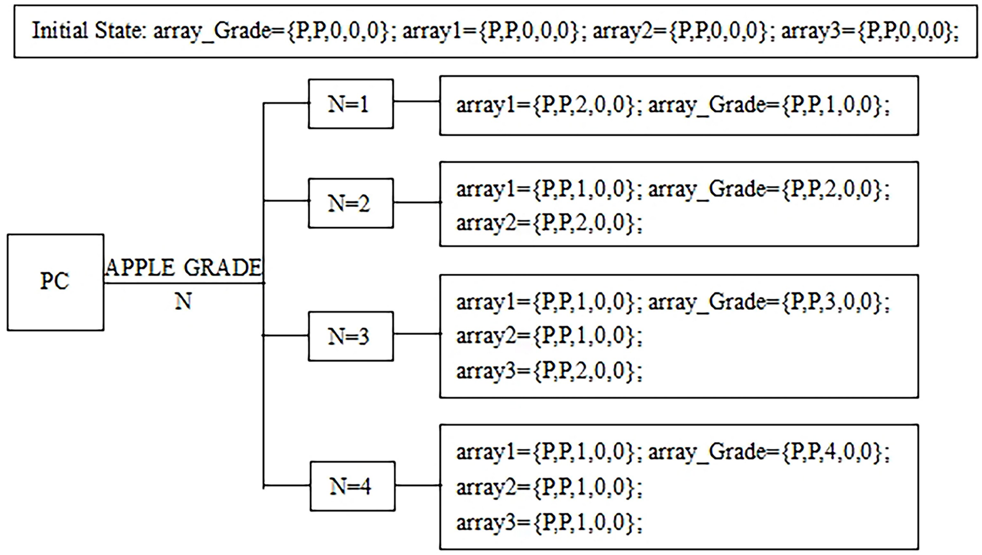

Fig. 13 The operation diagram of the flag array.

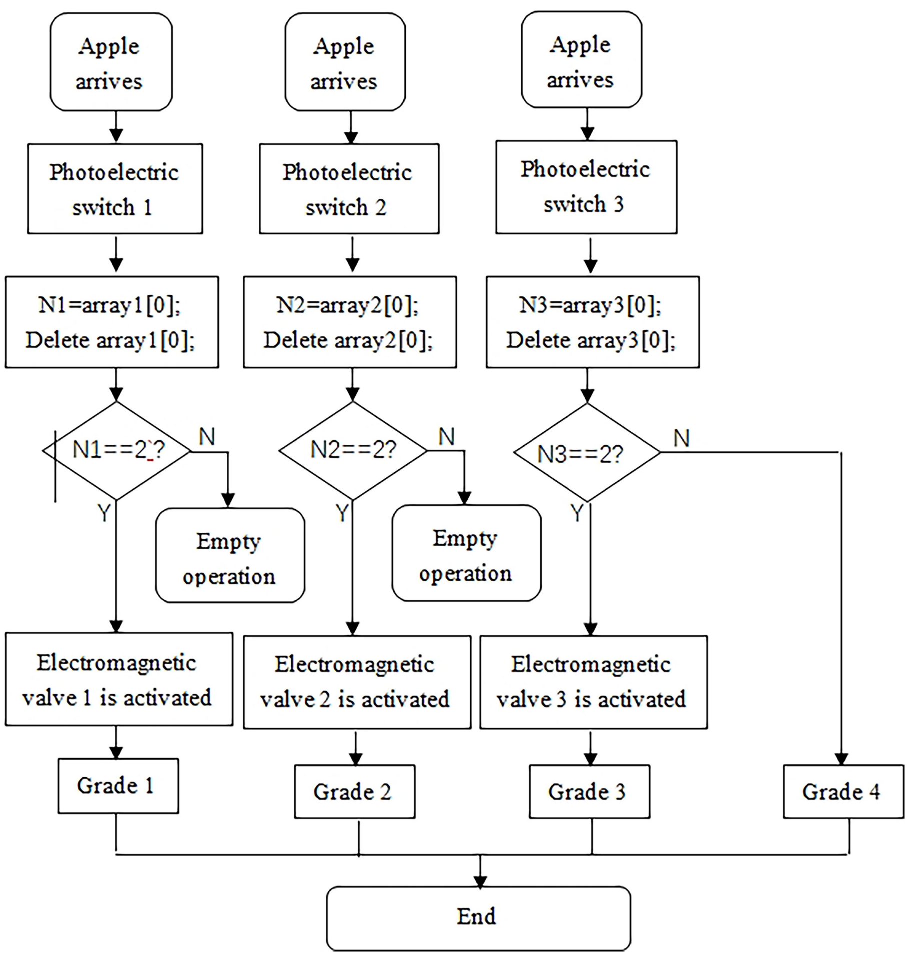

Fig. 14 The operation diagram of the flag arrays when an apple reaches the jet.

graded on the conveyor were taken out of an experimental video. As shown in Figure 15, the time interval between them is one second. The graph with 0s indicate the time before the jet releases air. The jet continues to blow air for about 1 second, which will be slightly affected by factors such as the size and weight of the apple. With the photoelectric sensor undisturbed, sorting errors rarely occur. The error here means that the grade of the apple does not match the grade information given by the PC.

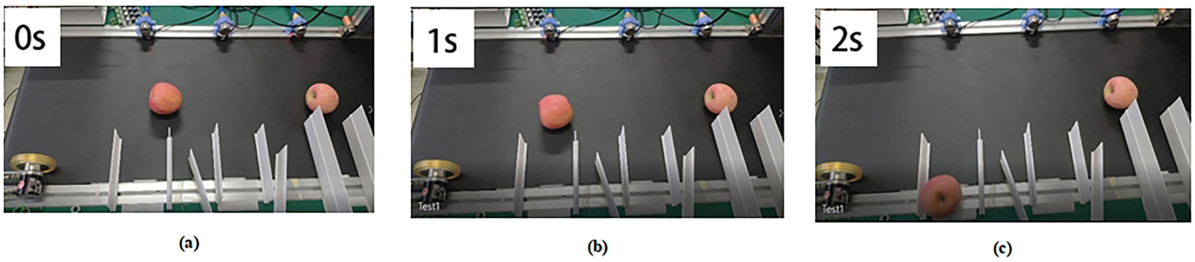

Fig. 15 (a), (b), (c): The process of an apple being ejected from the conveyor by an air jet.

4 Conclusion

This paper designed a complete and automated system for grading apples. The system controlled the whole hardware platform through mutual communication between the MCU and the PC, utilized the sensory information, and used an apple grading algorithm based on CNN. The problem of the inverter interference encountered during the experiments was solved, and the jets were innovatively integrated into the apple sorting line. Jet control logic that works in accordance with the system´s working mode was designed, which ensured that an apple would trigger an air jet only when it reached the correct jet. It is very important to apply sensory information to apple sorting. Subsequent research will incorporate other sensory information such as olfactory hearing into the system, to improve the comprehensiveness and the accuracy of the system.

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Authors' Biographies

Liqun WANG, received the B.S. degree from the Harbin Institute of Technology, China, in 2018, where he is currently pursuing the M.S. degree. His research interests include robot control and mechatronic engineering.
Email: 317310167@qq.com

Clarence W. de Silva, received Ph.D. degrees from Massachusetts Institute of Technology, Cambridge, MA, in 1978, and the University of Cambridge, Cambridge, U. K., in 1998, the Honorary D. Eng. degree from the University of Waterloo, Waterloo, ON, Canada, in 2008, and the higher doctorate, Sc. D., from the University of Cambridge, in 2020. He is a Professor of Mechanical Engineering at the University of British Columbia, Vancouver, BC, Canada, since 1988. His appointments include the Tier 1 Canada Research Chair in Mechatronics and Industrial Automation, Professorial Fellow, Peter Wall Scholar, Mobil Endowed Chair Professor, and NSERCBC Packers Chair in Industrial Automation. He has authored 25 books and about 560 papers, approximately half of which are in journals. His recent books, published by Taylor & Francis/CRC Press, include *Modeling of Dynamic Systems – With Engineering Applications* (2018), *Sensor Systems* (2017), *Sensors and Actuators – Engineering System Instrumentation*, 2nd Edition (2016), *Mechanics of Materials* (2014), *Mechatronics – A Foundation Course* (2010), *Modeling and Control of Engineering Systems* (2009), and *VIBRATION – Fundamentals and Practice*, 2nd Edition (2007); and by Addison Wesley, *Soft Computing and Intelligent Systems Design – Theory, Tools, and Applications* (with F. Karray, 2004). Dr. de Silva is a Fellow of the American Society of Mechanical Engineers (ASME), the Institution of Electrical and Electronics Engineers (IEEE), the Canadian Academy of Engineering, and the Royal Society of Canada.
Email: desilva@mech.ubc.ca

Bing Li, received PhD from Hong Kong Polytechnic University (HKPU) in 2001. He is currently a Professor and PhD Supervisor, at Harbin Institute of Technology, Shenzhen (HITSZ). His main research interests include Robotics, bionic robot, and mechatronic engineering.
Email: libing.sgs@hit.edu.cn

Yuan CAI, is a Master degree candidate of Harbin Institute of Technology at Shenzhen (HITSZ). Her main research interest is mechatronic engineering.
Email: caiyuanhitsz@163.com