Design, Development and Evaluation of an Online Potato Sorting System Using Machine Vision

Abdollah Golmohammadi¹, Farid Bejaei², and Hossein Behfar³

1. Deptment of Agricultural Machinery, Faculty of Agricultural Technology and Natural Resources, University of Mohaghegh Ardabili, Ardabil, Iran
2. Department of Agricultural Machinery, University of Mohaghegh Ardabili, Ardabil, Iran
3. Deptment of Agricultural Machinery, Faculty of Agriculture, University of Tabriz, Tabriz, Iran

Corresponding author email: agolmohammadi42@yahoo.com

ABSTRACT: The focus of this research is to design and develop a potato sorting machine by means of image processing in the framework of a machine vision project. Following steps were considered: design of a feeder system, selection of a proper camera, optimization of the connection between the camera and computer, selection of a proper lighting system, design of input and output boards with least errors, selection of an accurate synchronizer, online commands and selection of accelerators based on their proper capacity. The system is consisted of three major parts: the feeder, the processing and the accelerators. Each part was designed and made separately and then put together as a sorting system. In the design of the feeder system, based on the stabilization angle of different potatoes, an adjustable inclined belt conveyor was used. After testing a variety of light sources, 6400k fluorescent lamp was selected as the lighting system. The images were processed using MATLAB software. To separate potatoes, an accelerator system based on Pneumatic control valves and air pressure was used. As the system is online, all of timings related to image processing, product transferring and accelerators operation were calculated and applied based on the speed of the potatoes being fed to processing and sorting system. For the primary evaluation of the system, 100 kg of potatoes were manually sorted into three categories. Then the same potatoes were fed to the system, which sorted them out with an accuracy of 97.4% with the speed of two potatoes per second.

Key words: Design, Machine vision, Manufacture, Online, Potato, Sorting

INTRODUCTION

Potato (Solanum tuberosum) is considered as a strategic and staple food product in Iran (after wheat and rice) because of its high nutritional value and being a source of starch and different proteins. According to the statistics published by FAO (2013), the area of potato cultivation in Iran was estimated at 150,317 thousand acres, and the potato production was around 4.822 million tons in 2011. A part of this product finds its way in processing plants like chips factories, fries factories, and half baked frozen potato factories; however, the majority of potato production in Iran finds its way in the market and it is used at homes and restaurants for the purposes of supplying consumers’ nutritional requirements. Each one of these types of consumption requires a certain type of potato in terms of quality, shape and size. Manual sorting, in addition to being subjective, is costly and time consuming, and mechanical methods are not economically sound because of the possibility of inflicting damage to the product. As a result, in most developed countries attention has been given to potato sorting based on machine vision systems because of their high accuracy and also because they do not inflict damage to the product. In most of those countries, because of the strategic importance and also because of the production volume of this product, machines are responsible for the potato grading and sorting. In Iran, most of the activities in this area have been offline. In this research project a potato sorting system based on online machine vision was designed, developed and primarily evaluated.

Barnes et al. (2009) introduced new methods to recognize and find the potato blemishes using the machine vision. After segregating potato from background, they used a pixel-wise classifier which was trained to detect blemishes using features extracted from the image. They first extracted a large set of specific features which were based on the statistical information related to colour and texture of the region enclosing a specific pixel. Then, they used an adaptive boosting algorithm (i.e. AdaBoost) to automatically choose the best features to discern
between blemishes and non-blemishes. This approach enabled them to choose different features for a variety of potatoes and they achieved accuracy rates of 89.6% and 89.5% for white and red potato varieties, respectively.

Heinemann et al. (1996) developed a prototype inspection station to grade potatoes according to the United States Department of Agriculture inspection standards. Their station was consisted of an imaging chamber, a belt conveyor, a camera, a sorting unit and a computer for image acquisition and its analysis and also for equipment control. Their system managed to accurately classify 80%, 77%, and 88% of the moving potatoes in three runs at the speed of three potatoes per minute in online mode, and correctly classified 98%, 97%, and 97%, of offline stationary potatoes in another three runs.

Noordam et al. (2000) designed a high speed machine vision system for the inspection of quality and grading of potatoes. By using a CCD camera their vision system graded potatoes based on size, shape, and in addition to that they also classified potatoes based on their outside defects like rhizoctonia, greenness, mechanical damages, silver scab, common scab, cracks and growth cracks. They used mirrors to get a 360 degree view of the potato.

![Figure 1. Schematic design of the developed online potato sorting system based on size](image-url)
Rios-Cabrera et al. (2008) managed to extract potato properties by the means of image processing. Their goal was to find out the quality and to evaluate the physical properties of potatoes by using Artificial Neural Networks i.e. ANN's. A method which was named FuzzyARTMAP, because of its stability and convergence speed, outperformed the other models. They suggested a few algorithms to determine potato defects like greening, scab and cracks which could be efficiently used to grade potatoes of different qualities.

In a research, Hassankhani and Navid (2012) used machine vision as a fast, proper, less damaging and modern method to sort potatoes in an offline system. Their method was based on taking images of samples, analysing these images and comparing them based on a pre-defined standard. They prepared 110 samples of a specific potato variety which were manually sorted based on quantitative, qualitative and total factors. By improving image quality and extracting the best thresholds, they managed to gain 96.8% accuracy in the sorting process.

The main objective of this research project was to design, develop and evaluate an online potato sorting system based on size using the machine vision technology.

**MATERIALS AND METHODS**

The built online system is consisted of the following parts (Figure 1):
- Storage, feeder system and separation of potatoes from product bulk
- Product transfer belt conveyor and electromotor drive accompanied by the inverter
- Light box
- Synchronizer
- The computer, MATLAB 2011 software and a Panasonic CCD camera
- RS232 port expansion card
- Accelerators and Pneumatic system

**Storage, feeder system and separation of potatoes from product bulk**

The potato storage was made using 30x50x50 cm metal sheets with 30% of slope on the bottom. The storage slope was a little more than the potato static stabilization angle which let the potatoes exit easily from the storage. For the sizing purposes the potatoes have to be separated from each other and one by one enter the processing and separating stage. To achieve this, an inclined belt conveyor with 150 cm length and 50 cm width was designed and made. To transport the potatoes, ten attached "V" shape parts were made on the belt of the conveyor which could transfer ten equally-distanced-from-each- other potatoes to the second belt conveyor with a full circle rotation of the first belt conveyor (Figure 2).

![Figure 2. a) storage and the adjustable feeder system; b) conveyor accompanied by attached "V" shape parts](image)

**Product transfer belt conveyor and electromotor drive accompanied by the inverter**

In addition to the feeder system, a belt conveyor with 300 cm length and 50 cm width was designed and made to transport the product to the lighting box to take the images, also to transport the product to the accelerators and to sort them. Considering the fact that among the potatoes that were used, the largest potato dimension was 18 cm, in order to get 50% to 60% of the receiving images in each frame, there was a need for a photography space that was approximately 36 cm to 40 cm. Because of the low-light bands with the width of 5 cm.
that were formed on the sides of the lighting box, the width of the belt conveyor and the lighting box were both designed to be 50 cm. For the power source of the belt conveyor and the feeder system, a 0.5 kilowatt AC three-phase electromotor was used. An inverter with LG S6 digital control capability was used to adjust the electromotor speed. Considering the fact that feeder speed and linear speed of the belt conveyor affect the distance between the potatoes, electromotor speed selection depends on image processing time and accelerators actuation time which will be discussed in the accelerators design section.

**Lighting box**

To capture clear and noise-free images, the product has to pass through the lighting box which works with artificial light. To achieve this, a box with 50 cm in both length and width and 30 cm height was designed and made (Figure 3). Because of the fact that parallel rays of light could cause unwanted brightness in the images which could -to some degree- disrupt the image processing operation, also to give the system the ability to process both washed and unwashed potatoes, it is necessary to avoid using a light source that emits parallel rays of light. Therefore, to create a divergent and scattered light, a dome shape fixture with 47 cm of diameter was placed inside the main light box. Three light sources which were LED, fluorescent lamp and halogen lamp were tested and finally the 6400k high frequency fluorescent lamp was selected.

![Figure 3. Lighting box and the belt conveyor](image)

**Synchronizer**

In those research projects that deal with sorting based on machine vision, it is often the case that a good coordination between the timing that the product enters the lighting box on one hand, and taking photos on the other hand, does not exist and the assumption is usually this that the products enter the box in equal time intervals; consequently in those instances in which there is a change in the sequence of the products entering the light box, or in other instances in which there is a stoppage in the product-flow, the system still continues to take pictures and process them, and this decreases the accuracy of the system and its operational functionality to a great degree. An Autonics photoelectric sensor was used to deal with this issue. The light transmitter and the light receiver in this sensor are LED type and the whole thing has been placed in one set and the way it works is like this: if the product does not pass through, the light beam that was emitted by the transmitter is not going to be received by the receiver sensor and consequently the sensor will not send a signal whereas when the product passes through, a light beam will be reflected by the product toward the receiver and this will send a signal to the RS232 port expansion card and because of this signal being sent to the computer by the expansion card, the photo taking operation is being commanded by the MATLAB software.

**The computer, MATLAB 2011 software and a Panasonic CCD camera**

For image processing purposes, the MATLAB software was used which was installed on a five core Pentium four computer with an RS232 serial port. To lower the costs, a close circuit PROLINE analog camera was used which had a CCD sensor. CCD cameras have a good performance in visible wavelength range of 400 - 700 nanometers and they can measure all three blue, green and red colors equally with a medium resolution. As these cameras are being used in industries, contrary to the consumer cameras they do not change the natural conditions of the colors in the pictures. The CCD camera was plugged in into a Sony analog to digital video converter card and MATLAB software supports this card.
MATLAB software was used to acquire the pictures, and to process and control the accelerators. The procedure was this: the algorithm was on standby to receive the signal from the synchronized system; the very second that the product entered and the signal from the synchronized system was sent, a picture was taken from the product that was located in the light box; this picture was given to the image processing tool box and the image processing software received the image data from RAM and changed it into a numerical matrix. This numerical matrix contains the color data related to the potato image and its background (the belt conveyor). Most of the commands on this tool box accept one-dimensional variables as input and this means that a monochrome picture is what we are looking for and so by using the RGB to GRAY command, the color picture is being inverted to a black and white picture. Equation 1 is used in this command:

\[ I = 33\%R + 33\%G + 33\%B \]

where R is the value of color red, G is the value of color green, B is the value of color blue and I is the value of color gray.

Consequently, a number between 0 and 225 is found for each pixel and this causes the image data to be downsized to one third of the original, and this also increases the processing speed.

In the next stage, the product pixels had to be separated from background pixels. To achieve this, a threshold was utilized which is actually the differentiation border between the potato and the background which means that the gray values in each pixel is being compared with this threshold. The smaller values are related to the potato and the bigger than the threshold values indicate the background. To find the desired threshold a number of potatoes were placed in the imaging box and their images were taken in an offline mode to test different thresholds and eventually number 120 was chosen, but for this system to have the ability to deal with a variety of potatoes and a variety of conditions of potato colors, the possibility to change and to modify this threshold was also included in the computer program. The program algorithm considers numbers greater than this threshold as zero and numbers less than this threshold as one. Equation number 2 is used to calculate the geometric area of the product which has 'one' as its value.

\[ X(i,j) \]

where 'n' is the number of picture columns and 'm' is the number of picture lines and X(i,j) is the same as I(i,j) considering the point that the threshold-making process is being applied to I(i,j) and as the logical consequent of that, we get the X(i,j) values which have either the value of 'one', or the value of 'zero'. Then the decision making algorithm is being applied to this number. An expert graded 100 kg of potatoes (based on their size) and put them into three categories as grade one, grade two and grade three potatoes, and then each set was processed offline and thus three ranges of the area size of the potatoes were calculated based on the pixels. These numbers were used as the threshold values between varieties of grading. The resulted final decision about the grade of the potato that is currently inside the light box - which was taken based on the threshold values - is then being given to the output expansion board of RS232 port; however, because the separation accelerator system is outside the box, consequently there is a need to generate a necessary time delay for the product to pass from the middle point to the front of the accelerator. It is for this reason that the necessary time for taking the photo and finishing up the processing of this image i.e. the decision making stage for each product would be measured using the MATLAB software and the difference between the necessary delay time on one hand, and the processing time on the other hand would be applied to the expansion board by the software as a delay before the conveyance of the degree of quality which will be discussed in the section related to accelerators (Figure 4).
RS232 port expansion card

The operating systems of new computers are in a way that these computers can only recognize the serial ports. To be able to receive the computer output data and to be able to control the relays and if necessary to be able to change their timing when applying them, the expansion board of port RS232 was used. On the other hand and in addition to that, for safety reasons and for the ability to fully separate the power section from the processing section and so preventing damage to the computer, it is necessary to use this card. Atmega8 microcontroller was used to control the port RS232 expansion card and its program was written in the Code Vision software environment and was loaded into the microcontroller. The expansion card converts the received data from the synchronizing sensor into serial data and transfers them into the computer and from the other hand sends the quality degree of the made decision -by applying some changes related to the time that the accelerators remain open - to the relays that control the accelerators.

Accelerators and Pneumatic system

In the final stage, the operations of sizing the potatoes based on their processed images, and identifying the different sizes from each other, were done by a separating accelerator. To do this, there are many methods like stepper motor, Pneumatic jack and fluid flow. In this project, with the consideration of the response diagram and also the ease of installation, the fluid flow method was used for that section of the project that deals with accelerators. To achieve this, a 100 liter compressor was used to provide compressed air to separate the potatoes. Then to control the compressed air, two Pneumatic valves were used which were installed opposite to each other at the end of the belt conveyor (Figure 5).
In online machine vision the timing between the speed of the product movement and the timing of the accelerators operation, and the distance between the light box and the accelerators, are all very important. The following five parameters play a vital role in the accurate operation of the system: the speed of the movement, the exact photo taking timing, the time it takes to process an image, the length of the time delay before the actuation of the accelerators, and the time it takes to actuate the accelerators. So at the first stage, it is necessary to have the inverter adjust the movement speed of the belt conveyor in a way that during the time delay, the product could be able to travel from the light box to the accelerators. The next determinative principle is to assess the time it takes for the product to enter into the light box as the calculation of all of the next timings is based on this one. After the product enters and its photo is taken, the time necessary for the image processing is taken into consideration and based on the distance between the light box and the accelerators a certain amount of delay is being added to the processing time and the actuation of the accelerator has to happen after the overall of these timings. The last point is the duration of time in which the Pneumatic valves are open (the times it takes to actuate the accelerators) and this timing would be experimentally calculated and applied based on the discharged air from the nozzles and the aerodynamic shape of the potatoes.

RESULTS AND DISCUSSION

For the primary evaluation of the online potato sizing system using the computer vision method, 100 kg of potatoes were given to a sizing expert who divided the potatoes into three separate sets and then each set was processed offline and thus three ranges of the area size of the potatoes were calculated based on the pixels. Then all the potatoes were mixed again and were given to the feeder section of the system and this time the online sizing was applied to them. A comparison between the results of the manual sizing on one hand and the results from this system on the other hand showed that the system has the ability to sort the potatoes based on size with an accuracy of 97.4%.

After conducting several tests in various parts of the system, the following results were found for optimal system performance. For two potatoes to enter the processing and sorting stage per second, the linear speed was calculated as 0.7 m per second. The linear speed of the belt conveyor which transfers the potatoes was adjusted as one meter per second. After testing different light sources, the 6400k high frequency fluorescent lamp was selected as the best light to be used with this system. For the input and output purposes, considering the required speed, RS232 port with the RS232 port expansion card was used. Considering the high speed of the Pneumatic accelerator and as there was no need for this system to return to the primary conditions to continue the sorting process, compressed air system was used and at the end of the track, two Pneumatic valves were installed which had a 60 degree angle with the movement path of the belt conveyor. As the end result, the system could sort the potatoes online based on size with the speed of two potatoes per second with an accuracy of 97.4%.

REFERENCES