Rapid Sensing and Classification of Blueberry Maturity

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Abstract

More than 200 million pounds of blueberries are sorted annually based upon visual observation by men and women on inspection lines or with equipment that observes blueberry color. As domestic hand labor becomes more expensive, the industry continues to move towards mechanized sorting processes using less than adequate sorting technologies. We discuss a novel, commercially viable, low-cost classification method based upon analysis of the blueberry optical density spectrograph that will meet the needs of the growers and the industry, increasing their profits, and creating new marketing opportunities for growers with product that might have otherwise been discarded.

Motivation for Maturity Sorting

After a berry reaches the ripe state and has a bluish surface color, it continues to undergo significant internal chemical changes for many days. Presently no commercially available system is able to detect these changes. Therefore a typical fresh market box of ripe berries will have a significant variation in the maturity of its berries. Presently frequent re-harvesting of the field controls the ripeness variation.

In fresh market product, overripe berries result in premature spoilage as their ability to defend against pathogens (fungus) is reduced. Elimination of overripe berries should result in a safer product with a longer shelf-life and thus should obtain a higher price at the market.

It has been reported that the Japanese culture is willing to pay a premium for blueberries sorted such that all berries in the package have similar taste. To achieve this, each berry needs to have a similar ratio of sugars and acids. Berry maturity is closely related to this ratio.

Research by R.L. Prior has shown that of 43 fruits and vegetables tested, blueberries had the highest antioxidant activity. Antioxidants are associated with reduced head disease, cancer, arthritis, memory loss and eye problems. Apparent aging of rats has been shown to be reversed when blueberries were included in their diets. These benefits have been associated with total antioxidants anthocyanin and phenolics - which are known to more than double in vine ripened Rabbit-Eye berries as they change from “just-ripe” to overripe. Over-ripe berries that have little or no fresh market value are now expected to be in demand as raw materials for health and pharmaceutical products.

State of the Art for Maturity Sorting

The state of the art for blueberry maturity sorting is based on surface color analysis. This sorting method is traditionally and still frequently done by several people visually analyzing berries as they pass on a conveyer belt as shown in figure 1. Typically, people will pick out the green and/or red berries, leaving the ripe berries to pass. The work is clearly tedious and labor intensive – and it is unclear how the job can be performed accurately for the required duration.

Recently, advances in computer processing and machine vision have enabled the commercial introduction of equipment (figure 2) that can perform an equivalent maturity sorting function. In this form surface color analysis is rapid and efficient and able to sort upwards of 10,000 pounds per hour of both fresh and frozen product with significant accuracy.

In figure 7 we have photographs of four blueberries in various degrees of ripeness. It is possible to distinguish the red berry from the others, however the ripe, riper, and overripe berries look to be nearly the same. Casual visual inspection would result in the ripe berries being sorted into the same category

In 1999 dIDEAS, in cooperation with others, began research and development of a prototype surface-color blueberry maturity sorting system. Results of our experiments indicate that such as system is able to sort into three output categories, which we refer to as green, red, and ripe.

It is easy to distinguish between the green and red berries, but more difficult to separate red and ripe berries (see figure 7). In our system this is due to the inability of cameras to see the low intensity blue colors in the presence of the relatively strong red component captured by the camera when viewing a ripe berry. We developed a learning algorithm that would permit the user to teach the sorting system the three sorting categories by running samples of each category though the machine. You might use the similar method to teach people that do not know how to sort blueberries and do not speak a common language.

We also tested the ability to adjust the selection boundary between the red and ripe berries in real time. If the machine was rejecting too many berries, a knob could be adjusted to increase or decrease the number of red berries with immediate results in the output berry stream.

In figure 3 we have a photograph of the machine's view of green berries just before they are ejected. The left portion of this image is the actual video camera output, and the right portion of the image is the color-segmented image, which after automatic computer filtering of the image, only contains the (green) berries that will be rejected. A computer analyzes this image locating and tracking each berry that does not have the proper color or size – for later rejection by a solenoid.

Figure 4 contains an image of the output of the computer (during our research). As each green berry enters the computer camera's field of view, the object is segmented from the background and the size and location is determined. For purposes of visualization, we have instructed the computer to surround each object with a red box. As the object moves from frame to frame the computer remembers the list of objects from the previous frame - and associates them with same object in the current frame. This refines the computer's knowledge of the berry's position and eliminates miss fires of the rejection solenoid. After the object leaves the camera's field, its existence must be remembered so that a solenoid can be closed at the precise interval to eject only the bad berry. Figure 4 (right) shows the computer's prediction of the berries' position as they leave the camera's field (white dots). For testing and visitation purpose, the white dots change to blue in the frame immediately before the solenoids are fired and red after. The vertical line in the image represents the location of the solenoids.

Limitations of Surface Color Analysis

Surface color analysis when implemented by a modern machine vision based sorting system, is rapid and efficient. It appears to be a highly cost effective means to sort blueberries by apparent maturity. However it also suffers from significant limitations, which may become more important as new markets for blueberries develop and increased quality and safety standards for fresh produce are required.

Surface color analysis measures the apparent ripeness of the berry - in that it measures the amount of chlorophyll in the berry’s surface. When the berry becomes ripe, the surface chlorophyll is depleted and the berry color remains constant. However the berry becomes “ripe” – the berry continues to ripen.

As it is the chlorophyll that enables our surface color sorting system and all other chlorophyll based sorters to function – it be comes difficult to distinguish red and ripe berries. Moreover, as the chlorophyll is depleted in ripe berries, the surface color becomes constant, and it is not possible for color based sorting system to disambiguate just-ripe, ripe, and overripe berries.

Optical Density Sorting

The limitations with surface color sorting were recognized long ago when the first published experiments with optical density sorting where made by Birth and Norris in 1965. In 1977 Dr. Rohrbach and Dr. Mainland of the NC State University developed the M-Belt sorter which used optical density sorting to accurately sort blueberries into a large number of categories including the ability to distinguish various ripe berries.

The commercial success of the M-Belt sorting was limited due to the complexity and environmental sensitivity of the technology available to implement the system. M-Belt used what is essentially an analog computer to compute the mathematical results used to decide into which output category a berry would fall. These analog circuits had a tendency to drift and required frequent re-tuning and calibration.

Our goal is to implement a commercially viable optical density sorting system using modern digital image processing techniques, digital signal processors, and commonly available computer systems

In figure 5 we have a cartoon sketch of the main components of an optical density sorting system.

As in the surface color-sorting system, blueberries traverse the machine on a singulated belt conveyance system with belt speeds from 50 to 200 FPM. The berry passes over a bright white (incandescent) light source. White light enters the berry from below and a portion of the light exits the berry in all directions from above. Some of the light from the berry is observed by an optical system consisting of lenses and a prismatic element. The prism will split the light into its component colors, which are observed by a video camera. [Note : The light source is off the optical axis – so that in the absence of a berry, the light source is not visible to the camera.] A computer analyzes the berry’s spectrum as seen in the video camera images and makes a ripeness determination. This ripeness determination is based on the computer's knowledge of the relationship between a berry's spectrum and its ripeness. Finally if the berry is to be rejected, the computer will send – just as the berry passes by - a precisely timed ~5mS pulse to a solenoid that removes the berry from the line.

We envision a sorting system that has several solenoids on each line (alternatively, product could be run multiple times with different settings). Each solenoid would be activated only when a berry with a very specific range of ripeness is present. Thus, an N-way sorting system could be implemented. Conceivably a system could be built that allows separation of berries into the following categories: Green, green-red, red, 1 day before just ripe, just-ripe, 1 day ripe, 2 days ripe, 3 days ripe, greater than 3 days ripe (over ripe), etc.

Technical Details of Optical Density Sorting

Optical density sorting is based upon analysis of the optical spectrum of the light that is transmitted through the berry. When white light (energy in all colors) enters the berry, some colors of light are transmitted, others are absorbed. Whereas the size of the berry affects all colors of light equally, the pattern of color dependent transmission and absorption is solely a function of the internal and surface chemical composition of the berry. This enables us to make essentially direct measurements of the berry's chemistry.

In figure 6 we show a photograph from the optical density experimental apparatus, which was shown in a video at the growers conference. We use this setup to simulate the temporal conditions of the berries moving by just as they will final sorting system. The figure 6 photograph consists of two video camera images side by side.

The right image is that of a rotating disk with small holes punched out near the edge. Each hole contains a blueberry with ripeness anywhere from green to overripe. A light source beneath the disk (not directly visible) illuminates the berries as the disk rotates.

The left portion of the image is the output from a special camera with an integrated prismatic element. When a berry in the right image passes over the illumination source, the camera observes the berry's spectrum. Otherwise this image is dark.

In figure 7 we show the maturity spectrum. The surface color photographs show the berries with normal frontal lighting (coming from the direction of the camera). The transmitted light row shows photographs of berries with all of the light coming through the berry. In the bottom of figure 7 we show the optical density area spectrograph of each of the four berries. Each white vertical stripe is the optical density spectrum of the transmitted light berry above, in the same column.

As already mentioned, though observation of the surface color we are unable to disambiguate the ripe berries. However observing the ripe berries using the transmitted light we can immediately see differences. These differences are due to internal chemical differences between berries with different degrees of ripeness.

The optical density area spectrograph is labeled with the light wavelength (color) on the vertical axis. Moving from top to bottom we have the visible colors violet (400nM), purple, blue, green, yellow, orange and red (650nM). Further down, we then enter the near infrared region of invisible light from ~650 to 900 nM. The brightness of the berry spectrum at a particular wavelength in the area spectrograph represents the level of light transmission at that wavelength through the berry. Thus dark areas in the spectrum indicate that the berry is absorbing all of the light energy at that wavelength.

From the area spectrograph it appears, we can summarize that as a berry ripens the transition from opaque to transparent moves towards the infrared. Thus, ripe berries preferentially absorb visible light, while underripe berry pass the infrared and some of the red and yellow components of the light. This is more apparent in figure 8, which graphs the normalized transmitted light intensity versus wavelength for five berries with maturity ranging from green to overripe.

The graphs of the red-green and of the red berries show an interesting dip in the region of 700 nM. We believe this is due to the presence of chlorophyll in these underripe berries. Also notice that the dip is not present on any of the riper berries – which is the primary sorting criteria use for all surface color and chlorophyll sorters.

Advantages of Optical Density Sorting

Optical density sorting has some obvious advantages over surface color sorting, primarily that it is able to sort blueberries on a fine scale of true berry maturity over the complete blueberry ripeness spectrum.

There are also some not so obvious advantages – namely that optical density sorting is able to resolve import chemical criteria of the berry, which are related to the shelf life of the berry and its potential for pharmaceutical use. Research has shown that the percentage soluble solids, percentage acid, and pH can all be determined – through analysis of the light that passes through the berry.

In figure 8 we observed that other chemicals such as chlorophyll could be detected. From this we hypothesize the ability to detect many chemicals that are in large enough concentrations. Thus it may also be possible to make direct measurements of the levels of antioxidants or detect the presence of fungus or other forms of rotting that might be the result of improper handling or damage from the weather.

Conclusion

Maturity sorting is important for increasing fresh product safety and shelf-life; and enables opportunities to enter emerging markets and is ultimately necessary for the competitiveness of farms. Surface color analysis is a valuable but limited method for maturity sorting as it is limited to three sorting criteria, green, red and ripe. Optical density sorting is a promising approach to fine grained maturity determination across the entire ripeness spectrum.

Postscript

Digital Designs and Systems, Inc. has applied for a USDA SBIR grant where we propose to develop a machine vision and computer system that will be able to make accurate berry ripeness determinations as descried in this paper. Following completion of the phase I SBIR, we will apply for a phase II grant where we will propose to develop an actual prototype optical density sorting system and machine that can be run at a growers or production facility. We plan to work with Dr. Rohrbach and Dr. Mainland of the NC

State University in Raleigh, NC, both of whom have performed the majority of the research related to blueberry maturity sorting using analysis of the optical density spectrum.

Company Background

Digital Designs and Systems, Inc. (dIDEAS) was formed in 1994 to commercialize a machine vision system called the CVM (Color Vision Machine) developed in conjunction with the MIT Artificial Intelligence Lab. It was the world's first miniature computer system able to process color images from a color video camera in real-time. The CVM is 4x6 inches and can be powered by 4-D batteries for nearly an hour. The CVM's computation performance was anywhere from two to six times faster than even large desktop computer systems available at the time. In computer vision, higher performance is always important. The unique combination of performance, low power, and size enabled ground breaking research into self contained, visually guided color mobile robotics at the MIT AI Lab throughout the mid 90s.

The CVM held its unique position as one of the only miniature general purpose color vision systems up until the late 90s, although it is still more power efficient that competing product. Throughout the mid to late 90s dIDEAS provided a number of computer solutions and onsite integration assistance to the MIT Leg Laboratory (which investigates bipedal walking in robotics). These computers form the brains of the various mechanical robots they researched and built. In September 2000, the leg lab robot called "M2" was featured in a cover story in the international publication "Wired Magazine". M2 is a real robot that stands about 4 feet in height and is currently able to take "baby steps" – with similar results. The CVM is the brain that with the help of the Dr. Pratt and his students of the leg lab, enables M2 to learn to walk and navigate.

In 1999 dIDEAS began research with another group in the process of developing a surface color sorting blueberry-sorting system. We used the CVM to develop a prototype blueberry sorting brain that was added to their existing conveyance and solenoid blueberry rejection system. The results were encouraging and within a few months we were sorting berries. We have since decided to focus our efforts on developing a better sorting system based on the transmitted light spectrum. Our experience with real-time mobile robotics, machine vision, and artificial intelligence gives us a unique perspective from which to approach the problem.

Web Sites With Additional Resources	
dIDEAS	http://www.dideas.com
CVM project at MIT	http://www.ai.mit.edu/projects/frankie/frankie-project.html
M2 project at the Leglab	http://www.ai.mit.edu/projects/leglab/robots/robots.html
MIT Leglab home page	http://www.ai.mit.edu/projects/leglab/people/people-main.html
Wired Magazine	http://www.wired.com/wired/archive/8.09/