FINAL PROJECT REPORT

Project Title: An automated device for rapid and accurate rating of fruit size and color

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Total Project Funding: 48,396

Budget History:

Item	**Year 1:**
Salaries	19,000
Benefits	5,396
Wages	
Benefits	
Equipment	10,000
Supplies	6,000
Travel (Zhang)	3,000
Travel (Whiting)	2,000
Travel (Wang)	1,000
Publications	2,000
Miscellaneous	
Total	48,396

Footnotes: [1] **50% time of one post-doctoral research associate.**
[2] **An imaging system, an artificial lighting system, programming software and a computer.**

OBJECTIVES

The primary goal of this research was to develop and prove a concept of automated fruit rating in terms of color and size. On this concept development stage, we used cherry fruit as an example in performing this possibility study in a laboratory environment. Four specific research objectives were conducted to achieve this goal.

(1) Search and review previous attempts on developing similar technologies for fruit quality assessment, as well as for other applications. Analyze the reasons for unsuccessful attempts and determine the key attributers to successful systems.

(2) Based on the outcomes obtained from objective (1), develop a research prototype of fruit size and color rating device to prove the proposed concept.

(3) Verify the color and size rating capability using the research device and improve its detecting sensitivity, rating accuracy and reliability via laboratory tests. Demonstrate the developed prototype to growers/users in a laboratory setup.

(4) Prepare technical document, develop a research plan for moving the conceptual research into a practical technology for developing a device usable in orchard and/or in packing house environments.

SIGNIFICANT FINDINGS

This preliminary study has accomplished all proposed research objectives. The following list summarizes the significant findings from this project:

- Identified the major obstacles in realizing outdoor color rating of cherries using computer vision. The top three attributors are as follows:
  - Varying lighting conditions;
  - Strong surface reflections caused by smooth skin of cherry fruit; and
  - Complicated tree structures and background.
- Designed and built an image acquisition system to support image analysis algorithms development:
  - The system could promptly acquire cherry images in both indoor and outdoor environments; and
  - The system has adjustable lighting equipment for compensating varying lighting conditions when used in an indoor environment.
- Investigated methods for removing identified major obstacles as follows:
  - A method using a color chart as a dynamic calibration tool was developed and tested to reduce the effect of varying lighting conditions on rating consistence;
  - A method using camera flash was developed and tested to override the ambient light in attempt to reduce large area surface reflection on the skin of fruits; and
  - A computer algorithm was developed to detect and remove small area reflection on the skin of fruits.
- Developed an automated algorithm to rate cherry size and color based on image analysis; and this algorithm could perform the following functions:
  - Interactive cherry detection;
  - Automated reflection detection and removal; and
  - Automated rating of fruit color and size.
- Tested the developed software on the developed prototype in an outdoor environment with varying lighting conditions. The research prototype achieved the following performances:
  - Average fruit rating speed: 10 samples/min (including color and size);

- Color rating accuracy: 94.4%; and
- Size rating error: ± 0.6 mm (comparable in accuracy to a commercial cherry sizer which provides a 1.2 mm accuracy).

RESULTS AND DISCUSSION

Literature Review and Preliminary Experiments

A portable research prototype for rapid and accurate cherry fruit color and size rating is valuable to growers, because its capability to provide more efficient and objective measurement when compared to current manual measurements. Although the computer-aided measurement of color and size has been successfully used on fruit packing lines, its applications in more complicated environments, such as in orchards, are still a challenging task. Literature review and preliminary experiments disclosed that the major obstacles to outdoor applications include:

(1) Varying lighting conditions
Outdoor lighting conditions are subject to weather, sun angle, clouds and many other factors. The light variation will affect the visual appearance of cherry fruits in images, which brings difficulties to define the rules for color rating. Figure 1 shows images of a cherry fruit in two different lighting conditions, and indicates that the skin color of the same fruit appears lighter in bright light condition than in a shadow.

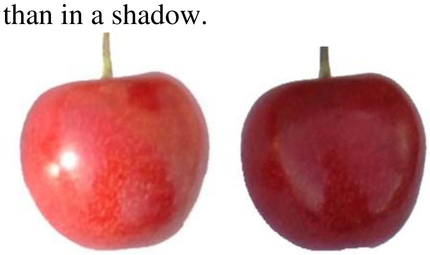

Figure 1. Images of a cherry fruit taken in two different lighting conditions of direct sunshine (left) and in a shadow (right)

(2) Reflection caused by smooth skin of fruits
Reflection is usually very bright and saturates the color of a fruit (Figure 2). Depends on the relevant light and camera angles, skin reflectance may occupy a large area on a fruit.

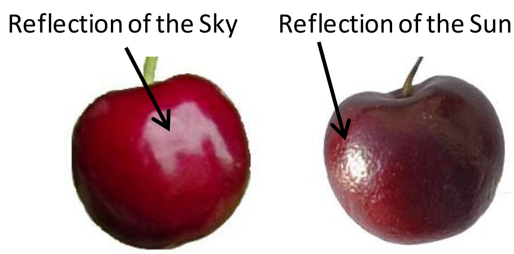

Figure 2. Reflection on fruit skin under different conditions

(3) Complicated tree structures and background
This obstacle makes it difficult to detect and segment a single fruit using computer vision in an orchard environment.

Within the limit of one-year preliminary project, we could focus our research efforts on investigating solutions for removing obstacles (1) and (2). As the third obstacle (complicated tree structures and background) was identified in this preliminary study, we have to leave this problem to be addressed in the continuing project. This arrangement agreed with the proposed scope of this project: conducting a laboratory scale preliminary research to validate the possibility and the feasibility of using computer vision to rate fruit color and size.

Prototype of Image Acquisition and Processing System

The functions of this prototype included to shoot, store and process cherry fruit images in a laboratory setup (both indoor and outdoor environments). As shown in Figure 3, this prototype system consists of three major parts:

1. Artificial lighting equipment: Two sets of daylight bulbs were used to create a variable lighting condition in laboratory. One set had a color temperature of 5,400 K (9,260 F), and the other had 6,500 K (11,240 F). The reason for selecting those color temperatures was that 5,400 K is approximately the color temperature of the sun at noon, and 6,500 K is about the color temperature of an overcast sky. Those light sources were used to rate fruit color in different lighting conditions.
2. Camera: A Nikon D5000 digital color camera was used in this study to take fruit images in both indoor and outdoor environments.
3. Computer: A laptop computer was used to store images and run processing software.

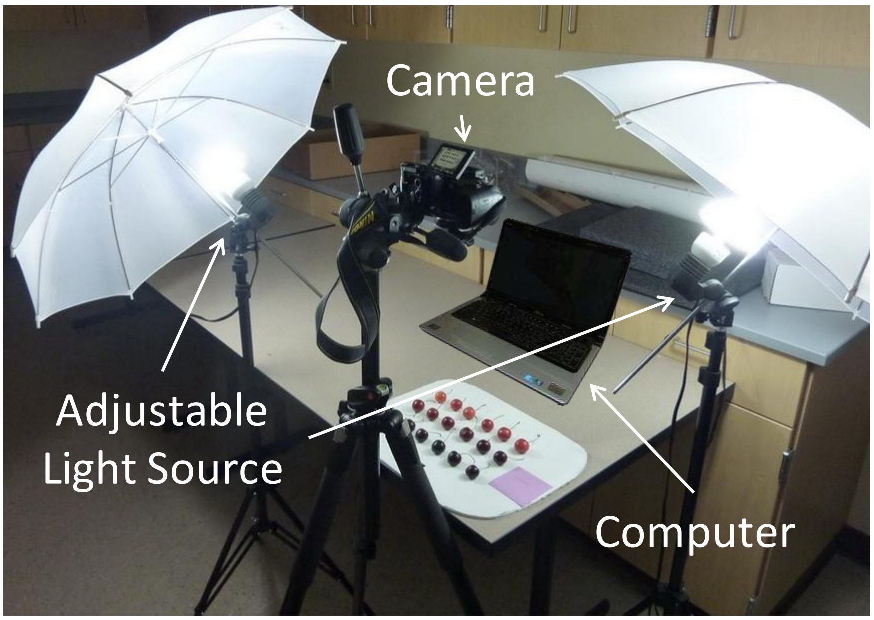

Figure 3. The Image acquisition and processing system for rating cherry color and size

Methods for Removing Major Obstacles

Three methods were investigated in attempt to remove major obstacles (1) and (2) in this project. The details of those methods are described as follows.

Method 1: Using a Color Chart to Compensate for Light Changes

In this approach, we have designed a dynamic calibration card based on the cherry color chart currently used by growers. As shown in Figure 4, the calibration card has exactly the same seven levels of redness as in a cherry color chart. The card is compact, and is convenient to be placed in front of the camera when sampling cherry fruit color. Since the cherry fruit and the card are exposed to the same environmental condition, any change of visual appearance caused by lighting variation is the same on both objects. In such a way the computer software is comparing their colors, and determines the accurate level of redness for the sampling cherry fruit.

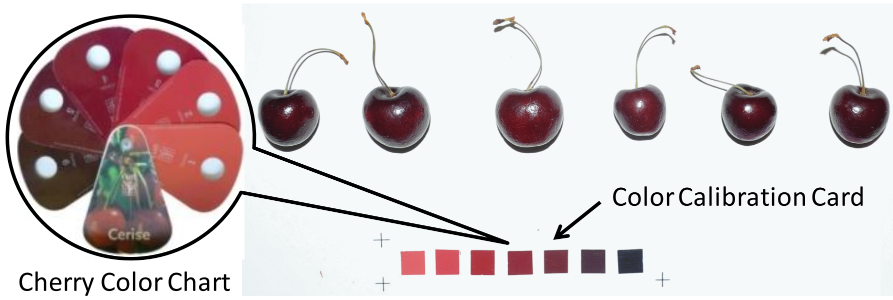

Figure 4. A color calibration card, derived from a cherry color chart, is used to rate cherry fruit color. The card serves as a dynamic benchmark in response to light changes.

Method 2: Using Camera Flash to Reduce Reflection

We have also used the camera flash to investigate its capability of overriding the ambient light to reduce the reflection on fruit skin. This experiment provided a satisfactory performance in reducing reflection. As shown in Figure 5, three pairs of cherry fruit images were taken in three lighting conditions on a sunny day under: (1) direct sunshine; (2) a bright shadow; and (3) a dark shadow. The first row of images was taken without camera flash, and those images showed a strong reflection covered almost the entire surface on the fruit in all the three conditions. In comparison, after using the camera flash, the areas of reflection were noticeably reduced on fruit surface and resulted in the original cherry fruit colors more observable.

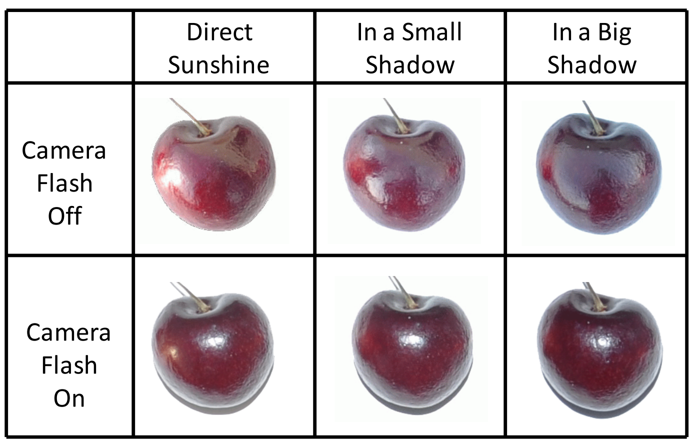

Figure 5. Reflection comparison on a fruit in different lighting conditions

Method 3: Automated Reflection Detection and Removal

While the camera flash method could reduce the area of reflection; it still left a small area of reflection not removable (see Figure 5), and prevented the system from obtaining a more accurate color rating. In this research we have also developed a computer algorithm for automated detecting and removing reflection on selected skin areas. As shown in Figure 6, this automated reflection removal algorithm first determines the existence of reflection by checking the skin color distribution. If there is a reflection, the histograms of the skin color, which is decomposed into red, green and blue, will skew to the right. The algorithm will then detect and cut off the right tails, which will effectively remove the reflection from the original image.

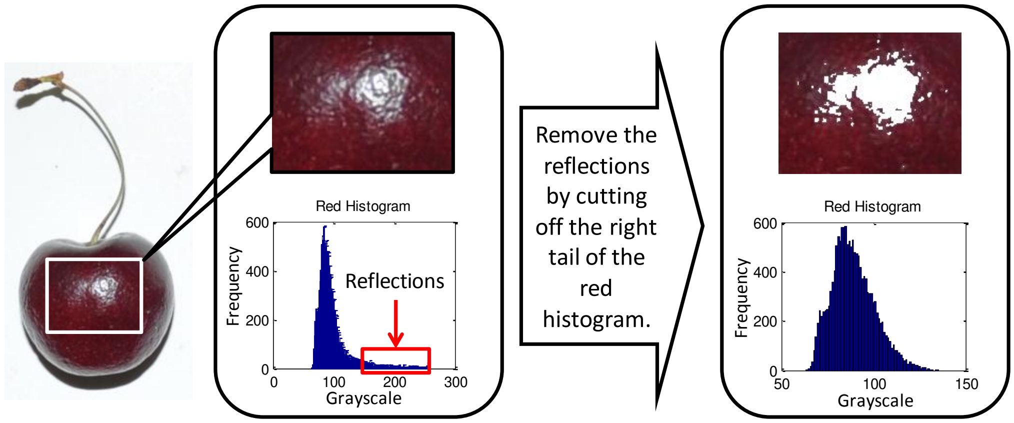

Figure 6. The illustration of automated reflection detection and removal

<u>Algorithm for Automated Color Rating</u>

Another major task of this project was to develop an automated color algorithm implementable in real time. This auto-rating algorithm carries three major functions of (1) interactive cherry detection; (2) automated reflection detection and removal; (3) automated color and size rating. As function (2) has been described in the previous section, this section will briefly introduce functions (1) and (3).

Interactive Cherry Fruit Detection

To detect a cherry fruit accurately is an essential step to realize automated fruit color and size rating. As mention earlier about major obstacle (3), an automated fruit detection method was not within the scope of this preliminary research. Therefore, we developed an interactive method to identify a cherry fruit from acquired image manually. As shown in Figure 7, the interactive method requires manually marking the location of a cherry fruit and the color calibration card on computer screen. Each cherry fruit is marked to include two points: A (in the upper-left part of the cherry) and B (in the lower-right part of the cherry) to form a rectangle area for color rating. To locate the color calibration card, this interactive method also requires marking control points 1, 2 and 3. The algorithm then could perform the automated color rating.

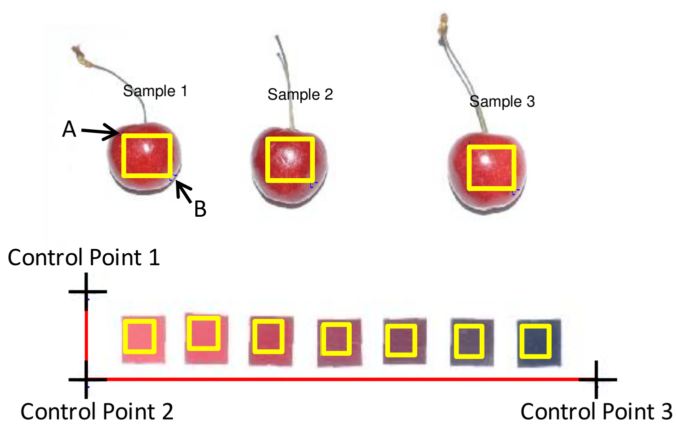

Figure 7. An illustration of screen shot of the interactive software for cherry detection

Automated Color Rating

After interactively locating a cherry fruit and the color calibration card, the software would first digitize the color chart to obtain the color rating scale in the specific lighting condition under which the image was taken. Figure 8 illustrates the basic method of the digitization process, after which the average redness of each rating level could be calculated. The developed software would calculate the average redness of a cherry fruit, R, using the procedure. After the average redness is calculated, a set of rules listed in Table 1 would be applied to determine the color rating of the fruit sample (L_{EST}).

Level of Redness	1	2	3	4	5	6	7
Ave. Redness (in Gray Scale)	224.4	213.8	174.7	147.4	119.4	80.9	48.6

Figure 8. An illustration color digitization process of color chart

Table 1. Rules used to determine the color rating of cherry fruits

Conditions	**Rules of Calculation**
R > Level 1	$L_{EST} = 1.0$
R < Level 7	$L_{EST} = 7.0$
Level (N+1) < R < Level N (N = 1, 2, 3, 4, 5, 6), the value of each level is L_N.	$L_{EST} = N + (L_N - R) / (L_N - L_{N+1})$

Automated Sizing

The sizing algorithm follows the process shown in Figure 9 to perform the automated fruit sizing. This algorithm uses a redness threshold and some de-noising techniques to obtain the contour of a cherry fruit; then, searches an ellipse best fitting the contour; and uses the length of the short axis of the ellipse as cherry size (in pixel). The algorithm also uses three control points shown in Figure 7 to calculate the actual size a pixel represents; then convert a fruit size from pixel to millimeters.

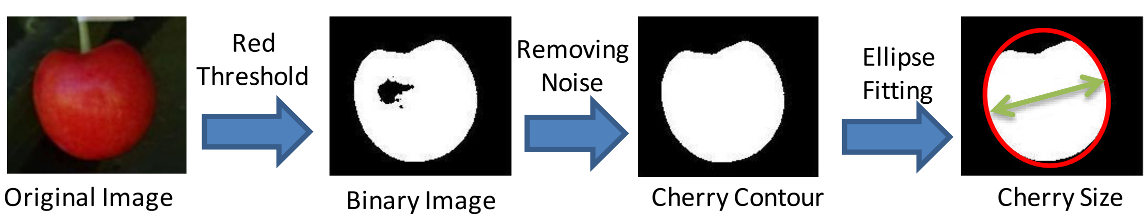

Figure 9. An illustration of automated cherry fruit sizing process

<u>Performance Tests</u>

Color Measurement

The developed algorithms were evaluated in three natural lighting conditions on a sunny day under: (1) direct sunshine; (2) a bright shadow; (3) a dark shadow. A total of 18 samples were automatically color rated and sized under each condition. An experienced horticulturist has rated all samples against the color chart to provide a baseline in evaluating the measurement accuracy. The human rating could reach the precision of 0.5 color level.

Data analysis on the automated color rating evaluation study presented the following results:

- The average color measurement error was 0.
- The standard deviation of color measurement error was 0.2 color level.

- Out of all samples, 94.4% measurements were in the error range of ±0.3 color level.

The results verified that the developed color rating method could provide an accurate and consistent fruit color rating.

Size Measurement

In this study, we have measured the sizes (widths, in mm) of 100 cherry fruits using both a caliper and the developed automated sizing software. The caliper data were used as baseline for the automated measurements. The measurement error using the developed software was ± 0.6 mm. This accuracy is higher than using a commercial cherry sizer making a manual measurement (±1.2 mm).

Speed of Auto-measurement

The developed prototype, supported using developed software, has achieved an average rating speed of 10 samples/min (including color and size). It was much faster than manual rating performed by a human worker. Considering that current software was programmed for feasibility study purpose, the rating speed could be noticeably increased through optimizing the software.

<u>Significance to the Industry</u>

The significance of this novel technology to the industry includes, but not limited to:

- Realize rapid and accurate cherry fruit color rating and sizing in either orchards or packing houses;
- Provide more objective fruit maturity information based on color rating to help growers determining optimal harvest time; and
- The core technology could be transferrable to sample other fruits.

<u>Potential Economic Benefits</u>

The potential economic benefits of the technology include, but not limited to:

- Saves labor for pre-harvest fruit sampling; and
- Realize fast sampling on a large scale to support growers making better marketing decisions.

<u>Suggestions to Future Work</u>

Automated Cherry Detection

Based on the outcomes obtained from this preliminary study, we would like to suggest developing an automated capability of detecting cherry fruits from complex background as a high priority for next stage of research. This capability would boost sampling efficiency to a much higher level.

Portable Design

To make the investigated technologies practically usable to growers, we would like to suggest continuing the development work to invent a portable fruit sampling device for in-field use. To do so, there are a few technical challenges need to be solved:

- Define the minimum requirements of a camera flash to obtain consistent sampling in varying lighting conditions; and
- Develop image processing technologies which do not require a dynamic color calibration.

Sampling of Other Fruits

The promising results obtained from the preliminary study have inspired us to expand the technology to be applied to different fruits. We would like to suggest testing apples and pears in the next phase. We believe that the evaluated technology showed sufficient potential to support the design of a portable fruit color rating and sizing device for multiple fruits.

EXECUTIVE SUMMARY

An automated device for rapid and accurate rating of fruit size and color could provide a useful tool to more effective orchard management. This preliminary research investigated the possibility and feasibility of using an image analysis based technology to develop an automated fruit color rating and sizing device. A computer vision-based prototype was developed and tested both at indoor and outdoor environments. A total of 54 cherry fruits were colored rated in three natural lighting conditions, and a total of 100 fruits were sized using the prototype. Obtained results verified that this conceptual device could achieve a satisfying color rating and sizing accuracy under a sampling speed acceptable for in-field use. The color rating accuracy has achieved 94.4%, and the size measurement error was less than ± 0.6 mm, which is comparable to, if not better, manual measurement by an experienced worker using a commercial cherry sizer. The average rating speed was 10 samples/min (including color and size) with a high potential to be increased. To make the innovative conceptual system usable in actual orchard production, we would like to suggest continuing the development of a portable device by addressing a few more technical challenges, such as the capability of automated cherry fruit detection from complicated backgrounds. The promising results obtained from this preliminary study have inspired us to expand the technology to be applied to different fruits.