Detection of Red Tomato on Plants using Image Processing Techniques

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ABSTRACT

Tomatoes are the best-known grown fruit in greenhouses that have been recently attempted to be picked up automatically. Tomato is a plant which its fruit does not ripe simultaneously, therefore it is necessary to develop an algorithm to distinguish red tomatoes. In the current study, a new segmentation algorithm based on region growing was proposed for guiding a robot to pick up red tomatoes. For this purpose, several colour images of tomato plants were acquired in a greenhouse. The colour images of tomato were captured under natural light, without any artificial lighting equipment. To recognize red tomatoes form non-red ones, at first background of images were removed. For removing the background, subtraction of red and green components (R-G) was applied. Usually tomatoes touch together, so separating touching tomatoes was next step. In this step, the watershed algorithm was used that was followed by improving process. Afterwards, red tomato was detected by the region growing approach. Results obtained from testing the developed algorithm showed an encouraging accuracy (82.38%) to develop an expert system for online recognition of red tomatoes.

Keywords: Colour-based algorithm, greenhouse, robotic harvesting, segmentation algorithm, vision-based system, watershed algorithm.

INTRODUCTION

Tomato belongs to Solanaceae family, native to central, South and Southern North America from Mexico to Argentina that was rapidly spread to other parts of the world due to its importance and popularity (Rick and Butler, 1956). Tomato is daily consumed by millions of people for its valuable nutrients. In addition to the high amount of vitamin C and A, tomato contains several nutrients such as Calcium, Phosphorus, Potassium, Iron and Copper (Beecher, 1998). As a result, cultivation of tomato has greatly increased in recent years. According to the FAO statistics, world production of tomato in 2011 was about 159 million tons. In 2011, Iran with 6.82 million tons of harvested tomato has been ranked 6th in the world that shows increasing trend compared to past years (FAO, 2011). Recently, greenhouses are considered as a place for growing agricultural crops during the year. Nowadays, the main obstacles at expanding greenhouses are high labour costs and consuming time. Automatic robotic harvesting can effectively be in concert with the growing greenhouse, because automation of fruit harvesting operations decrease labour costs and improve the efficiency.

Several studies have been carried out to design harvesting robots to pick up fruits on trees. In most cases; leading robot was carried out using a vision-based system. The first step in developing a robotic system is recognition of a fruit. The RGB model was used for recognition of cotton, and R-B relation was defined for this purpose (Wang et al., 2008). In another effort, a colour-based algorithm was developed for the automatic recognition of Fuji apples on tree (Bulanon et al., 2002).

During ripening procedure, the colour of tomatoes varies from mature green, yellow and orange to intense red colour. Then a robot should pick up only red tomatoes and leave others. Many studies have been conducted to develop an expert system for picking red tomatoes. Most of them were based on colour feature because the colour is as an effective factor of the tomato quality. The ripeness of a tomato can be estimated through its surface colour (Arias et al., 2000), and traditionally consumers prefer a quite-red tomato rather than others (Jahns et al., 2001). Arias et al. (2000)
reported that the surface colour of a tomato is a major factor in determining its ripeness. On this basis, Hayashi and Sakaue (1996) proposed a colour-based algorithm for recognizing tomatoes. The defined algorithm was not able to recognize tomatoes one by one and considered several tomatoes as a big tomato. To overcome this problem, a stereoscopic vision system was developed to recognize tomato individually (Hayashi et al., 2005). Recognizing tomatoes from the background was successfully done in Hayashi’s study; however, they did not recognize red tomatoes from non-red ones. Hahn (2002) reported the application of a multi-colour system to select physiologically immature tomatoes, claiming an approximation of 85%. Polder et al. (2004) developed a method for measuring the spatial distribution of these compounds in tomatoes using hyperspectral imaging. Spectral image yielded satisfactory result; however the involved equipments were relatively expensive.

In this paper, ability of an image processing techniques based on region growing was evaluated for recognizing red tomatoes. Additionally the improved watershed algorithm was introduced to separate touching tomatoes.

**MATERIAL AND METHODS**

Under common lighting condition of greenhouse, images of tomatoes were acquired in RGB colour model using a CCD camera (Sony Cyber Shot w200, resolution 1944×2592 pixels). Tomatoes were classified into red and non-red tomatoes based on American standards for grades of fresh tomatoes (Code of Federal Regulations, 1991). According to this standard, red tomatoes were those ones with more than 90% red colour on their surface and other colour tomatoes such as light red, pink and yellow were considered non-red tomatoes. Recognition of Red Tomatoes:

A process including four steps was implemented in this study for recognition of red tomatoes from non-red tomatoes as follows:

1. **Removing Image Background**

At the first step, it is useful to detect ripe tomatoes from their background which consist of green tomatoes, branches, leaves, soil, etc. After extracting the colour data of different objects, subtraction of red component from green and blue ones \((D_{rb}=R-G)\) and \((D_{rg}=R-B)\) were defined for removing the background. The result of the R-G and its threshold as a binary image with black coloured background are shown in Fig.1-b and Fig.1-c, respectively. Fig.1-a presents the original colour image. Multiplying each value in zero value is equal to zero; on this basis, the binary image with zero pixels at the background was separately multiplied by R, G, and B channels in order to remove the background. The final image after the processing was a colour image of tomatoes without background (Fig. 1-d).

2. **Removing Noise**

In the greenhouses, tomatoes are cultivated at parallel rows, so in the captured images the tomatoes belonging to behind rows extracted with the interested ones. Removing those noisy tomatoes is necessary; otherwise the robot will pick the back row tomatoes by mistake. Because noisy tomatoes have more distance from the robot’s camera rather the others, their size looks smaller. On this basis, an algorithm was developed to remove the noisy tomatoes which their size was smaller than a certain value. To reach this aim, opening algorithm by reconstruction operation was used (Gonzalez and Woods, 2004).

3. **Separating Touching Tomatoes**

Separation of touching fruits is a key factor in recognizing red tomatoes from non-red ones. Common algorithms in image processing have considered several touched tomatoes as one big tomato and they are not able to extract features of touching tomatoes one by one. The similar problem was reported in sorting operations of some products such as rice, wheat and citrus (Chinchuluun et al., 2009; Courtois et al., 2010; Wang and Chou, 2004). To overcome this problem, numerous algorithms were developed. Watershed transform is one of the best-known proposed algorithms (Gonzalez and Woods, 2004). This method is especially suitable for circular objects (Faessel and Courois, 2009). On this basis, the watershed algorithm was used for separating touching tomatoes in the current study. Although the watershed algorithm could successfully separate touching tomatoes, it may generate incorrect results. For example, the watershed algorithm split an individual object into the several pieces (Fig. 1-e). To overcome this problem, watershed improvement process (WIP) was performed as follow:

1. Two-dimensional Euclidean distance transform of the binary images was calculated (Fig. 1-f).
2. To determine number of objects in an image, the resulting image from previous step was converted to a binary image and the number of objects was counted.
3. The erosion operation was started with an M-sized disk. This operation would be
continued until all touching objects were separated. On the other hand, if the number of objects was one, the erosion operation would not require (Fig. 1-g).

4. The result of erosion operation (step 3) was used to join over-segmented components (Fig. 1-h). Flowchart of watershed improvement process is shown in Fig. 2.

Fig. 1. Image preparing operations before recognition of red tomato from non-red tomato. a) original color image, b) gray scale image, c) binary image, d) image after removing background, e) separated objects by watershed algorithm, f) The two-dimensional Euclidean distance transforms, g) erosion operation and h) jointing of over-segmented objects.

4. Red Tomato Detection

Red tomato detection was carried out based on the region growing approach. Region growing is one of the conceptually simplest approaches for image segmentation; neighbouring pixels with similar characteristics are grouped together to form a segmented region until no more pixels can be merged. The basic approach is to start with a set of “seed” points. Selecting a set of one or more starting points often can be based on the nature of problem. Selection of criteria is another important factor for ensuring success of segmentation. Definition of criteria depends not only on the problem under consideration, but also on the type of available image data. When images are monochrome, region analysis must be carried out with a set of descriptors based on grey levels or spatial properties such as moment and texture. Since success of region growing approach depends on colour models, selection of the most usefulness colour models is important. Colour images are saved in the three-dimensional RGB (red, green and blue) colour space. Colour space transformation is a powerful tool for colour feature extraction. HSI (hue, saturation and intensity) space is known as one of the most powerful colour spaces. HSI space are developed based on the concept of visual perception in human eyes; therefore their colour measurements have a better relationship to the visual significance of food surfaces. HSI is calculated by a non-linear relation from RGB using the following equations:
In the HSI colour model, colour information (hue and saturation components) has been separated from intensity (Cheng et al., 2001). On this basis, after removing the background, the images in RGB space were converted to HSI colour space.

Since hue (H) represents the basic colour and red tomatoes were redder in colour rather than others, hue component could be an effective selection. On this basis, region analysis was carried out by hue information.

To do basic the region growing, the following syntax developed by Gonzales and Woods (2004) was used in MATLAB software:

\[
H = \arctan \left( \frac{\sqrt{3}(G-B)}{(R-G)+(R-B)} \right) \tag{1}
\]

\[
S = 1 - \frac{3}{(R+G+B)} \left( \min(R,G,B) \right) \tag{2}
\]

\[
I = \frac{1}{3}(R+G+B) \tag{3}
\]

RESULTS AND DISCUSSION

The results showed that the non-uniform lighting condition in greenhouse may influence on the extraction process of red tomato. In the parts of the greenhouse that light was sufficient; the images had a good quality. In these images, it was easier to distinguish the red tomato from the non-red tomatoes. However where light was insufficient, images were of lower quality and the colour of non-red tomato was darker which hampered the detection of the red tomato from non-red one.

Since the lighting conditions were not controlled in this study, using the HSI colour model was more suitable.

Removing Background:

Thresholding is a convenient way for object segmentation. Good segmentation is obtained when high contrast exists between object and background (Zheng and Sun, 2008). In the current study, segmentation was performed based on thresholding by definition of two relations R-G and R-B. After applying R-G and R-B relations, Weber
contrast was defined as $\frac{l_t - l_b}{l_b}$ to measure the contrast value between tomatoes and the background. Where $l_t$ and $l_b$ presented the tomato and background intensity values, respectively. Statistical analysis showed that there was a significant difference ($p<0.01$) between Weber contrast values. Results of Fig. 3, show that application of R-G has caused a darker background than R-B model. On this basis, R-G relation was used for removing the background. In the cases that the colour of strings was red, they would be recognized as tomato fruits. To solve this problem, it is suggested that strings with red colour should not be used.

**Separation of Touching Tomatoes:**

Separation of touching tomatoes allows robot to measure location of each individual tomato and to picks up red tomatoes one by one. The watershed algorithm, developed by Gonzalez and Woods (2004) could successfully separate touching tomatoes. Although, over-segmented was the main drawback of algorithm. In these cases, the watershed improvement operations could merge over-segmented parts and produce acceptable results. Counting tomatoes in an image was a key step in the WIP. If the algorithm was not able to count objects correctly, the algorithm would confront with serious problem in the erosion step because controlling the erosion process was done by the number of tomatoes. In some cases, the developed algorithm was not able to determine number of tomatoes correctly. It usually occurred when tomatoes had high overlap with each other. The lack of any defined border between tomatoes could be the main reason. The proposed algorithm in this study showed that is suitable for the tomato end-effectors developed by Monta et al. (1998).

![Fig. 3.](image_url) (a) original grey image, (b) corresponding grey image to R-G, (c) grey image resulted from R-B.

![Fig. 4.](image_url) Test of developed algorithm: a) determining the seed points, b) reference image, c) result of algorithm: region growing started from seed points and merged all pixels satisfying the defined criteria.

**Red Tomato Detection Accuracy:**

Hue is considered as an angle between a reference line and the colour point in RGB space. The range of the hue value is from $0^\circ$ to $360^\circ$ (Gonzalez and Woods, 2004). Usually, zero angle shows red colour. On this basis, it was decided to pixels with zero value be selected as seed points. As before mentioned, correct selection of seeds is a criteria factor at success of the region growing approach. After testing the algorithm, it was observed that the algorithm could not obtain acceptable results because there were a few numbers of zero pixels in a red tomato or not. Comparison of extracted colour data from red and
non-red tomato showed this fact that the red pixels with value close to zero could ensure better results when were selected as seed points. The location of these pixels usually was in the bottom part of red tomato, because tomato fruit started to grow from the bottom to the top parts (Fig. 4-a). Although selection of seed points was successfully carried out, yet there was a serious problem. The parts of tomato exposed to light had a different colour (close to white colour) rather than red parts. It caused to those parts were not extracted by the algorithm. Since recognition of red tomato was based on a comparison between extracted area and the total area of a tomato, it was necessary to extract parts exposed to light separately. For this aim, first colour data of those parts were extracted. After analysing colour data, it was concluded that Eq. 5 could suitably extract light parts.

$$P_{light\ parts} = G - S \quad (5)$$

For testing of the proposed algorithm, the extracted area by algorithm was compared with the main area of the same tomato that was obtained after removing the background. If extracted area by the algorithm was more than 90 percent of the main area of tomato, the tomato was considered as red tomato otherwise it was known as non-red tomato, one example is shown in Fig. 4. (If tomato in Fig. 4-b is compared with Fig. 4-c, it is easily observable that area of tomato in Fig. 4-c is more than 90 percent of total area). Confusion matrix and classification accuracy obtained for red and non-red tomato is presented in Table 1. The classification accuracy for detecting red tomato and non-red tomato were 80.95% and 83.80% respectively. The total classification accuracy was 82.38%. Although, the detection accuracy of tomato was acceptable but the proposed algorithm may have better performance at recognizing red tomato when an artificial light system is used.

<table>
<thead>
<tr>
<th>Output/Desired</th>
<th>Red tomato</th>
<th>Non-red tomato</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red Tomato</td>
<td>85</td>
<td>17</td>
</tr>
<tr>
<td>Non-red Tomato</td>
<td>20</td>
<td>88</td>
</tr>
<tr>
<td>Accuracy (%)</td>
<td>80.95</td>
<td>83.80</td>
</tr>
</tbody>
</table>

**CONCLUSION**

1. Two relations R-G and R-B were defined to remove the image background. Results showed that removing the image background was successfully done by R-G relation because it could make a high contrast between tomatoes and the background.

2. If the overlapped tomatoes were not separated, watershed algorithm was effectively improved and could separate touching tomatoes correctly. After separating touching tomatoes, it would be possible to determine location of each individual tomato.

3. Results showed that region growing algorithm could consider as a useful method at recognizing red tomatoes at harvest operations. Overall classification accuracy was 82.38%.

**REFERENCES**


