Vision Based Fruit Sorting System Using Measures of Fuzziness and Degree of Matching

Wen-Hung Chang , Suming Chen
Sinn-Cheng Lin* , Pai-Yi Huang * , and Yung-Yaw Chen*

Department of Agricultural Machinery Engineering
Department of Electrical Engineering*,
National Taiwan University,
Taipei, Taiwan, R.O.C.

Abstract--Fuzzy approaches were used to determine optimal thresholding values of fruit's images, and fuzzy degree of matching was applied to classify the color and size of fruit. Results showed that fuzzy method was superior to the traditional statistical methods, and a better accuracy of 93.3 % for combined sorting was reported. The errors due to miscategorization could thus be reduced if the fuzzy methods were used. The developed fuzzy algorithms were integrated with machine vision guiding robotic sorting system for fruits.

Keywords: Sorting, Fuzzy, Vision, Fruits

1.Introduction

An image X of M × N dimensions and L levels can be considered as an array of fuzzy singletons, each with a value of membership function denoting the degree of brightness which is related to some brightness levels l,l=0, 1, ... L-1, i.e. $X = \bigcup_{m=1}^{M} \bigcup_{n=1}^{N} p_{mn} / x_{mn} = \bigcup_{m=1}^{M} \bigcup_{n=1}^{N} \mu_{mn} / x_{mn}$ where p_{mn} / x_{mn} represents the grade possessing some property p_{mn} by the (m,n)th pixel x_{mn}. This fuzzy property may be 'bright image', 'dark image' . And the threshold is one of the most important process during image segementation, using the membership function of shape property to find the optical threshold value for every image. In traditional fruit sorting by image processing, the criteria should be set first. The degree of matching by measure of fuzziness was used for size sorting and color sorting.

2. Method

The gray level of original fruit image captured by CCD camera was distributed between 0 (dark) and 255 (white), the image was then transferred into an equivalent fuzzy set. By minimizing the fuzziness of the fuzzified image, an optimal threshold value was obtained. The threshold value was adopted to segment the fruit from background image. In order to get an equivalent fuzzy set "Color", the gray level of segmented histogram was normalized into the interval [0,1] to represent the corresponding membership function. Three fuzzy sets for color sorting were defined as {Green, Turning, Yellow}. The values for degree of matching in the fuzzy pairs (Color, Green), (Color, Turning) and (Color, Yellow) were calculated. The maximum matching degree represents the color of fruit.

2.1 Measure of fuzziness

The index of fuzziness responds to the average amount of ambiguity (fuzziness) which presents in A by measuring its distance(linear and quadratic corresponding to the linear index of fuzziness and the quadratic index of fuzziness, as Eq.2.1 and Eq.2.2) from its nearest ordinary set

A_c. And the concept of compactness was applied to fuzzy image subset, to generalize some standard geometric properties of the relationships among regions to fuzzy subset. Then the compactness of μ can be defined as Eq.2.3

$$v_l(A) = \frac{2}{n}\sum_{i=1}^{n}\left|\mu_A(x_i) - \mu_{A_c}(x_i)\right| = \frac{2}{n}\sum_{i}\min[\mu_A(x_i), 1-\mu_A(x_i)] \quad (Eq2.1)$$

$$v_q(A) = \frac{2}{\sqrt{n}}\left[\sum_{i=1}^{n}(\mu_A(x_i) - \mu_{A_c}(x_i))^2\right]^{\frac{1}{2}} \quad (Eq2.2)$$

$$comp(\mu) = \frac{a(\mu)}{p^2(\mu)} \quad (Eq2.3)$$

$$\text{where}\begin{cases} a(\mu) = \int \mu \\ p(\mu) = \sum_{\substack{i,\\ i<j}}^{r}\sum_{j=1}^{r}\sum_{k=1}^{r_{ij}}\left|\mu_i - \mu_j\right|\left|A_{ijk}\right| \end{cases}$$

2.2 Image Thresholding

In order to find the optical threshold value through whole image, the algorithms based on minimization of fuzziness and compactness were established as below:

Algorithm I :(minimization of fuzziness)

The image of the object (fruit) is belong to the group of 'bright pixel', at the beginning, the membership function(μ_x) of 'bright pixel' was constructed as Eq.2.4, where L denotes the gray level values, $b = l_i$ is the crossover point, and bandwidth $\Delta b = c - l_i = l_i - a$ Secondly, The amount of fuzziness was computed as Eq.2.5 through all the pixels, where $T_i(l)$= min(S,1-S) and $h(l)$ denotes the number of pixels of the gray level l. Thirdly, calculate the minimum of V(x) by varying l_i from $l_{\min}$ to $l_{\max}$ to select the optical threshold value l_c.

$$\mu_x(l) = S(l;\ a,\ l_i, c),\ l_{\min} \le l,\ l_i \le l_{\max} \quad (Eq2.4)$$

$$v(X)|_{l_i} = \frac{2}{MN}\sum T_i(l)h(l) \quad (Eq2.5)$$

Algorithm II:(minimization of fuzziness)

The first step is the same as the algorithm to constructed the membership function. And according to Eq.2.3 the area and perimeter of μ_x corresponding to b=l_i were calculated at Eq.2.6 . Secondly, the compactness can be computed according to area and perimeter . Thirdly, varying l_i from $l_{\min}$ to $l_{\max}$ to select $l_i = l_c$ for which compactness is a minimization.

$$a(\mu)|_{l_i} = \sum_m\sum_n \mu_{mn} = \sum_l S(l;a,l_i,c)h(l)$$

$$p(\mu)|_{l_i} = \sum_{m=1}^{M}\sum_{n=1}^{N-1}\left|\mu_{mn} - \mu_{m,n+1}\right| + \sum_{n=1}^{N}\sum_{m=1}^{M-1}\left|\mu_{mn} - \mu_{m+1,n}\right| \quad (Eq2.6)$$

2.3 Degree of Matching

After measuring the fuzziness for image thresholding, we used the degree of matching for both size sorting and color sorting. In this study, two different approaches will be discussed to determinate the degree of matching for two fuzzy quantities.

Method I :

This method is based on distance measured by Eq.2.7, and the measure of matching of two class A and B is taken by complementing $d_n(A,B)$, $1-d_n(A,B)$ d_r where $0 \le d_n(A,B) \le 1$ is the normalization of d_r .

$$d_r(A,B) = \left(\int\left|\mu_A(x) - \mu_B(x)\right|^r dx\right)^{1/r},\ r \ge 1 \quad (Eq2.7)$$

Method II:

This method just simply gets the highest degree of two membership function overlapping, as Eq2.8 shows.

$$DM(A,B) = \sup_{x\in X}[\min(\mu_A(x), \mu_B(x))] \quad (Eq2.8)$$

3. Results and Discussion

The fuzzy algorithms were finally integrated with a machine vision guiding fruit sorting system which consisted of a SCORBOT-ER V robot with its controller, conveyor with photo sensors for position control, adjustable camera stand, an illumination chamber, CCD camera, VISIONETIC VFG-512 frame grabber and an 80486 IBM compatible personal computer. The configuration was shown as Fig 1 .

After establishing the algorithm for image thresholding ,we implement this algorithm to vision based fruit sorting system for finding the optical threshold value of the image. A 300×300 with 256 gray level image was evaluated at every sorting cycle. Although both algorithms perform well for thresholding with high accuracy during sorting, it takes about 2 minutes execution time at personal computer 486-DX33 while using algorithm II for thresholding . And the algorithm I needs only 2-3 seconds for the same image. It needs $300 \times 300 \times (l_{min} \sim l_{max})$ time for evaluation at one image while using algorithm II . After optical threshold value is found, the image fruit can be segmented from the whole image and then the area and average gray level of the fruit can be calculated correctly .

The membership function of criteria was established by statistical data before sorting processing . For color sorting , for instance, we selected 5 samples for each grade(green, turning ,and yellow) and established the criteria membership function for each grade for a constant crossover point . A measuring fruit was grabbed for its image by CCD camera on the conveyer when the photo sensor detected. After measuring minimization of fuzziness for optical threshold (Fig2) ,the membership function of gray level distribution was matching to those of three grades. The highest degree of matching of these membership function was corresponding to its sorting result as shown in Fig3 and Fig4 .

For size sorting, there were 3 grades {Large, Middle, Small} in this study and 3 grades {Green, Turning, and Yellow} for color sorting . For the combination of size and color, there were totally 9 grades for combined sorting . And the sorting result by degree of matching was compared to the traditional statistical sorting and sorting by Lab meter value as Table 1 showed.

The measurement of fuzziness will enhance the sorting accuracy when the image were segmented by optical threshold value. And using degree of matching for fruit sorting will reduce the miscategorization ,because the sorting criteria established by membership function will be more flexible than the traditional statistical one .

4.Conclusion

The vision-based system using measures of fuzziness and degree of matching for fruit sorting was established. Lemons were used in experiments and the results shown in Table 2 indicated that fuzzy method gave better sorting accuracy in all cases when compared with traditional statistical method. The sorting criterion of the traditional method uses crisp sets, and usually causes the events miscategorized in color or size occurred around the boundary values of adjacent grades. Especially when the color on fruit peel is not uniformly distributed, the matching degree by fuzzy rules will improve sorting accuracy. As the result shown in Table 2 , we compare the result of traditional statistical method and fuzziness measurement. For size sorting and color sorting ,the accuracy of sorting have improved obviously. And the sorting speed was also evaluated to 3 sec/cycle.

5.Reference

1. A. Rosenfeld and S. Haber. 1985. The perimeter of a Fuzzy set. Patt. Recog., vol. 18(2):125-130.
2. C. A. Murthy and S. K. Pal. 1992. Histogram thresholding by minimizing graylevel fuzziness. Inform. Sci. 60:107-135.
3. Chen, S., D. S. Fon, S. T. Hong, C. J. Wu, K. C. Leu, B. T. Tien and W. H. Chang. 1992.

Electro-optical citrus sorter. ASAE Paper No.923520. St. Joseph, MI: ASAE.

4. Chen, S., D. S. Fon and C. C. Chang. 1990. Universal color indices for maturity evaluations of fruits. ASAE Paper No.90-7054. St. Joseph, MI: ASAE.
5. Chang, W. H. , S.Chen. 1993. Robotic sorting of fruits using machine vision. Journal of Agricultural Machinery, Taiwan Vol(2):11-24.
6. K. Hirota and W. Pedrycz. 1991 .Matching Fuzzy Quantities. IEEE Trans. on SMC, Vol 21(6):1580-1586.
7. Pal, S. K. 1991. Fuzzy tools for the management of uncertainty in pattern recognition, Image Analysis, Vision and Expert Systems, Int. J. Sys. Sci. Vol 22(3):511-549
8. Rehkugler, G. E. and J. A. Throop. 1989. Image processing algorithm for apple defect detection. Transactions of the ASAE 32(1)267-272.
9. S. Cho, O. K. Ersoy and M. Lehto. 1992. An algorithm to compute the degree of match in Fuzzy Systems, Fuzzy Sets and Systems 49, 285-299.
10. Slaughter, D. C. and R. C. Harrell. 1989. Discriminating fruit for robotic harvest using color in natural outdoor scenes. Transactions of the ASAE 32(2):757-763.
11. S. K. Pal and A. Ghosh. 1992. Fuzzy geometry in image analysis. Fuzzy Sets and Systems 48 : 23-40.
12. Wolfe, R. R. and W. R. Sandler. 1985. An algorithm for stem detection using digital image analysis. Transactions of the ASAE 28(2):641-644.

Table 1 Color Sorting Result

No	Grade by Lab	Lab value	Grade by S.M.	Statistic Method	D.M Method	Grade by D.M.
1	1	39.8	1	122.2	121.45	1
2	1	38.1	1	122.7	121.23	1
3	1	37.9	1	116.1	115.56	1
4	1	37.3	1	116.5	115.3	1
5	1	40.1	1	124.5	124.24	1
6	1	41.3	2	131	130.88	1
7	2	50.4	2	160.4	158.67	2
8	2	49.8	2	157.2	156.5	2
9	2	50.7	2	162.5	161.01	2
10	3	57.6	3	174.7	172.52	3
11	2	51.3	2	147.3	146.34	2
12	3	59.4	3	177.4	177.03	3
13	3	60.3	3	181.1	158.78	3
14	3	58.4	3	174.1	173	3
15	1	41.4	1	124.4	123.18	1
16	1	38.3	1	115.3	114.51	1
17	1	36.3	1	111.6	110.54	1
18	2	42.9	1	125.9	124.46	1
19	1	41.4	1	123	121.9	1
20	1	36.8	1	109.3	108.74	1
21	1	38.6	1	118.5	118.1	1
22	1	37.8	1	116.8	116.03	1
23	2	49.1	2	148.7	147.63	2
24	3	54.2	3	163	162.18	2
25	2	48.1	2	144.3	142.63	2
26	2	48	2	143.6	142.45	2
27	2	50	2	143.4	142.92	2
28	3	57.3	2	166.7	165.05	2
29	3	58.3	3	174.2	173.64	3
30	3	63	3	181.1	180.75	3
31	2	45.3	1	121.3	119.77	1
32	1	37.7	1	118.5	118.02	1
33	1	38.3	1	119.3	117.71	1
34	1	39.9	1	110	109.36	1
35	1	38.6	1	119.9	118.56	1
36	1	36.1	1	108.9	108.72	1
37	1	39.4	1	118.8	117.46	1
38	2	45	2	149.2	148.51	2
39	3	54.7	2	131.3	130.48	1
40	2	46.5	2	147.5	145.99	2
41	3	54	2	161.7	159.84	2
42	2	51.1	2	151	151.11	2
43	2	51.5	2	159.3	158.77	2
44	3	59.6	3	171.6	168.9	3
45	3	63.8	3	180.7	179.68	3

Table 2 Sorting Result

Size Sorting	Traditional Method	Fuzzy Method
Samples	45	45
Correct (%)	42 (93.3%)	44 (97.8%)

Color Sorting	Traditional Method	Fuzzy Method
Samples	45	45
Correct (%)	39 (86.73%)	40 (88.9%)

Combine Sorting	Traditional Method	Fuzzy Method
Samples	45	45
Correct (%)	41 (91.1%)	42 (93.3%)

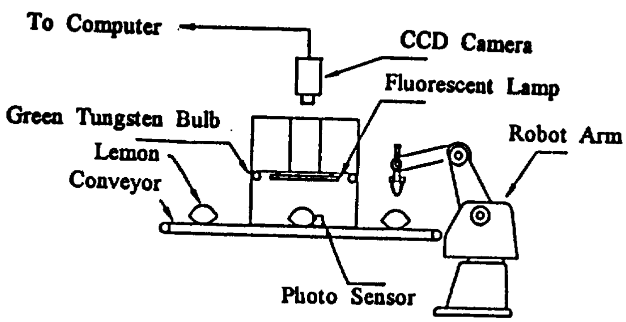

Fig 1 Configuration of sorting system

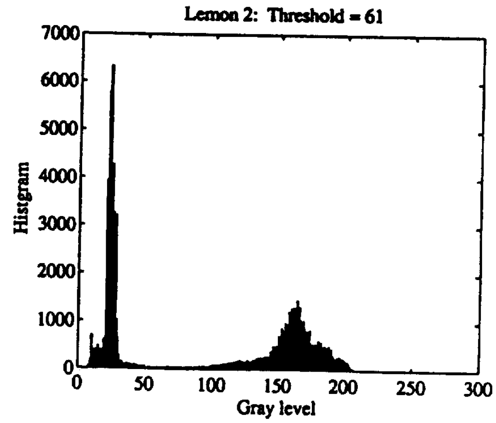

Fig 2 The thresholding result of histogram

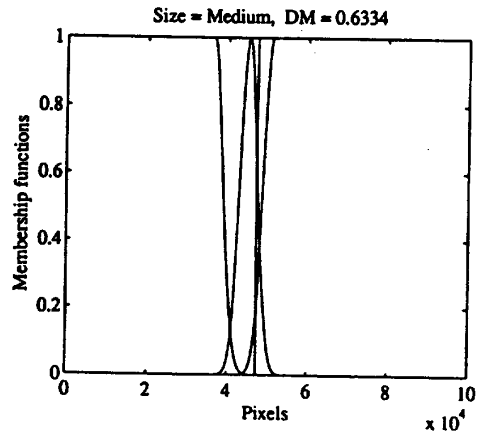

Fig 3 Size sorting result

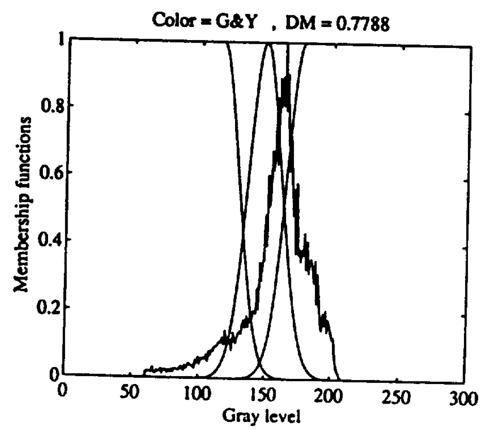

Fig 4 Color sorting result