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Development of ON-Line Three Dimensional Contour Extraction System for Poultry Carcass Using Laser Structured Lighting

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Abstract

As an initial step to develop the on-line quality evaluation system for poultry processing, a prototype laboratory scaled on-line three dimensional contour extraction of a poultry carcass was developed using a set of computer vision system and a laser structured lighting device. A multi-parallel line pattern of a structured laser was used. The proposed algorithm was composed of three stages. At the first stage, the camera calibration, which determines the coordinate transformation between the image plane and the real three dimensional world, was performed using known six pairs of points. At the second stage, utilizing the shifting phenomena of the projected laser beam on the surface of a poultry carcass, the contour(height) information of the carcass was computed. Finally, using the height information of the two dimensional image point, the corresponding three dimensional coordinate information was computed using results of the camera calibration. The maximum error of the extracted three dimensional feature using the proposed algorithm was less then 0.7 mm. Results showed that the proposed system and algorithm was accurate enough for on-line three dimensional geometric feature detection of a poultry carcass. Three dimensional contour combined with two dimensional projection image of a poultry carcass will be possible substitute of the conventional load cell based weight measurement for size grading of a poultry carcass.

Key words: Three Dimensional Contour, Poultry Carcass, Structured Lighting, Computer Vision, On-line System

Introduction

Measuring feature information of agricultural products using computer vision is mostly limited to two?dimensional geometric information including color and texture. However, three dimensional contour of an object or distance information are useful for many applications such as automating tasks of handling and on-line processing of livestock and marine products.

Since three dimensional feature extraction using computer vision depends on the accuracy of the camera calibration, many researches have been done to develop the efficient algorithms for camera calibration proper to the required application environment. Hwang (1998) carried out three dimensional feature extraction of steady objects using a structured laser lighting device that has 19 multi-line patterns. Roger (1986) developed an efficient two stage method of calibration. They were effective to characterize not only internal parameters of a camera but also external parameters like camera position and orientation.

The objective of this study was to develop the contour extraction system which can be utilized for on-line quality inspection of poultry carcass at the processing line. Three dimensional contour extraction can be utilized for inspecting an amount of flesh of poultry and as a substitute method for the size measurement. Laboratory scaled prototype on-line three dimensional contour extraction system was built. Algorithm to extract three dimensional contour of a breast of a poultry carcass was developed using a set of color computer vision system with a 19 multi-line laser structured lighting device.

The proposed algorithm was composed of three

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stages. The camera calibration, which determined a coordinate transformation between the image plane and the real three dimensional world, was performed using known 6 pairs of points at the first stage. Then utilizing the shifting phenomena of the projected laser beam on a poultry carcass, the height information of the carcass was computed at the second stage. And using the height information of the two dimensional image point, the corresponding three dimensional information was computed using results of the camera calibration.

Materials and Methods

Experimental System

The experimental system was composed of image acquisition and processing parts, multi-line laser generator (SNF19L 670S3045, Stockeryale, Canada), and variable speed poultry carcass feeding system. Progressive scan color CCD camera (TM7CN, Pulnix, USA) was used. 19 line laser having 670 nm wavelength and 0.77 degree of line interval angle was mounted with 45 degree of the projected center line from the vertical.

Camera Calibration

Camera calibration was carried out through two stages. The first stage was calibration related to transformation of two dimensional image coordinates to three dimensional world coordinates. The second was extracting height information from the shifting phenomena of the selected projected laser lines.

Relation between three dimensional world coordinates and two dimensional image coordinates is expressed as following.

$$C=PW \tag{1}$$

, where C is image coordinate (u, v), is transformation matrix, and is the reference or world coordinate $(x, y, z)^T$.

Three dimensional world and two dimensional image coordinates of six points, which are not coplanar, were used for the calibration. Image coordinate (u, v) is expressed as following using 4 by 4 linear transformation matrix $P=[P_{ij}]$.

$$ku = P_{11}x + P_{12}y + P_{13}z + P_{14} \tag{2}$$

$$kv = P_{21}x + P_{22}y + P_{23}z + P_{24} \tag{3}$$

$$k = P_{41}x + P_{42}y + P_{43}z + P_{44} \tag{4}$$

Substituting Eq. (4) into Eq. (2) and (3) yield

$$\begin{aligned} &P_{11}x+P_{12}y+P_{13}z - P_{41}ux-P_{42}uy \\ &- P_{43}uz - P_{44}u + P_{14} = 0 \end{aligned} \tag{5}$$

$$\begin{aligned} &P_{21}x+P_{22}y+P_{23}z - P_{41}vx-P_{42}vy \\ &- P_{43}vz - P_{44}v + P_{24} = 0 \end{aligned} \tag{6}$$

Eq. (5) and (6) are obtained from world coordinate and corresponding image coordinate of a point. Now, from known 6 points, 12 Eq.s are obtained and P_{44} can be set as 1. In matrix representation, Eq. (7) is obtained.

$$\begin{bmatrix} x_1 & y_1 & z_1 & 1 & 0 & 0 & 0 & 0 & -u_1x_1 & -u_1y_1 & -u_1z_1 \\ 0 & 0 & 0 & 0 & x_1 & y_1 & z_1 & 1 & -v_1x_1 & -v_1y_1 & -v_1z_1 \\ & & & & & \vdots & & & & & \\ x_6 & y_6 & z_6 & 1 & 0 & 0 & 0 & 0 & -u_6x_6 & -u_6y_6 & -u_6z_6 \\ 0 & 0 & 0 & 0 & x_6 & y_6 & z_6 & 1 & -v_6x_6 & -v_6y_6 & -v_6z_6 \end{bmatrix} \begin{bmatrix} P_{11} \\ P_{12} \\ \vdots \\ P_{42} \\ P_{43} \end{bmatrix} = \begin{bmatrix} u_1 \\ v_1 \\ \vdots \\ u_6 \\ v_6 \end{bmatrix} \tag{7}$$

If we set Eq. (7) as $AP=B$, transformation matrix P is obtained from pseudo inversion.

$$P = [A^TA]^{-1}A^TB \tag{8}$$

Then, x and y coordinates are obtained from substituting values of P_{ij}, which were obtained from Eq. (8), into Eq.(5) and (6).

$$\begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} R_{11} & R_{12} \\ R_{21} & R_{22} \end{bmatrix}^{-1} \begin{bmatrix} K_1 \\ K_2 \end{bmatrix} \tag{9}$$

Where,

$R_{11} = P_{11} - P_{41} \times u,\ R_{12} = P_{12} - P_{42} \times u$

$R_{21} = P_{21} - P_{41} \times v,\ R_{22} = P_{22} - P_{42} \times v$

$K_1 = -P_{13} \times z + P_{43} \times u \times z + u - P_{14}$

$K_2 = -P_{22} \times z + P_{43} \times v \times z + v - P_{24}$

Extracting Height Information

From Figure 1, a laser line is projected onto the y-axis line of the reference bottom surface when there is no object to interfere transmission of laser. When there exists an object on the line of laser transmission, the projected laser line is shifted by Δx resulting into the image shift Δv depending on the height change of the object Δz. Considering non linear characteristic of laser beam and camera projection, the second order regression equation was used for six set of pre-specified known points (image coordinates and real coordinates).

$$\Delta z = \alpha(\Delta v)^2 + \beta(\Delta v)^2 + \gamma$$

From the set of known Δz, i=[1,6] and corresponding image shift Δv_i, coefficients of the above equation can be obtained.

$$[\Delta z_i] = \left[\Delta v_i^2\ \Delta v_i\ 1\right]\begin{pmatrix}\alpha \\ \beta \\ \gamma\end{pmatrix}$$

And let $Z=VM$

Coefficient matrix can be obtained using pseudo inverse

$$M = [V^T V]^{-1} V^T Z \qquad (10)$$

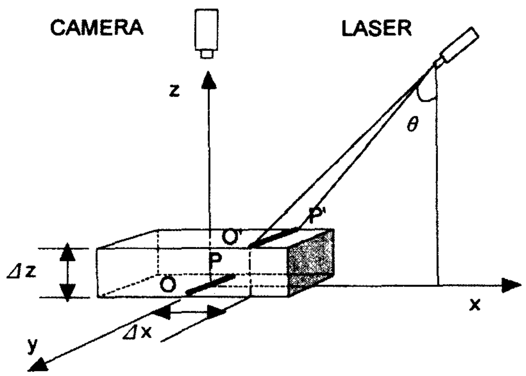

Fig. 1. Shift of the projected line caused by the laser interference.

This process was applied to each laser line resulting 19 correlation coefficients. In determining breast flesh contour of poultry carcass five laser lines were selected.

3D Feature Extraction

Image of the poultry carcass was captured via trigger signal from the optic sensor. To reduce the noise of the captured image low pass filter was applied first. Then it was converted to binary image using pre-specified threshold value. The thickness of projected image of the structured laser line was about 4~8 pixels and was thinned using mid-pixel.

Height information was obtained from Eq. (10). From height information and two dimensional image information , three dimensional world coordinates was obtained using Eq.(9).

Results and Discussion

Transformation of Three Dimensional Reference Coordinates

From the relation of two dimensional image coordinates and three dimensional reference coordinates, transformation matrix P was obtained as following.

$$\begin{pmatrix} 1.0030 & 0.0023 & -0.3128 & 314.7270 \\ -0.0081 & -0.9789 & -0.2333 & 236.4386 \\ 0.0000 & 0.0000 & -0.0000 & 1.0000 \end{pmatrix}$$

Table 1 showed reference values (x,y,z) of 6 sample points, corresponding image pixel values (u,v), computed coordinates (x',y') and errors.

Extracting Height Information

Table 2 shows results of the 2nd order correlation between height and shift amount of the image for six set of sample points for the five selected laser lines.

As shown in Table 2, The maximum computed error of the extracted three dimensional feature using the proposed algorithm was less then 0.66 mm in the range

Table 1. Calibration errors of sample points(*x,y,z* unit: mm) Computed and original coordinates of sample points for camera calibration sample at 243 mm(*x,y,z* unit: mm).

Node	Original coord.			Image coord.		Computed coord.		Error		
	x	y	z	u	v	x'	y'	ǀΔxǀ	ǀΔyǀ	ǀΔEǀ
1	50	50	243	384	173	50.27	50.09	0.27	0.09	0.02
2	100	50	262	454	305	99.78	50.09	0.22	0.09	0.02
3	100	100	283	177	103	99.94	99.91	0.06	0.09	0.00
4	50	50	303	245	311	50.27	49.93	0.27	0.07	0.02
5	0	100	323	318	94	0.14	100	0.14	0.02	0.00
6	0	100	343	319	391	0.29	100	0.29	0.00	0.00

The maximum error of the camera calibration for sample point was less then 0.02 mm within the range of 243 mm height. Figure 2 shows resulting image after noise removal using low pass filter and thinning.

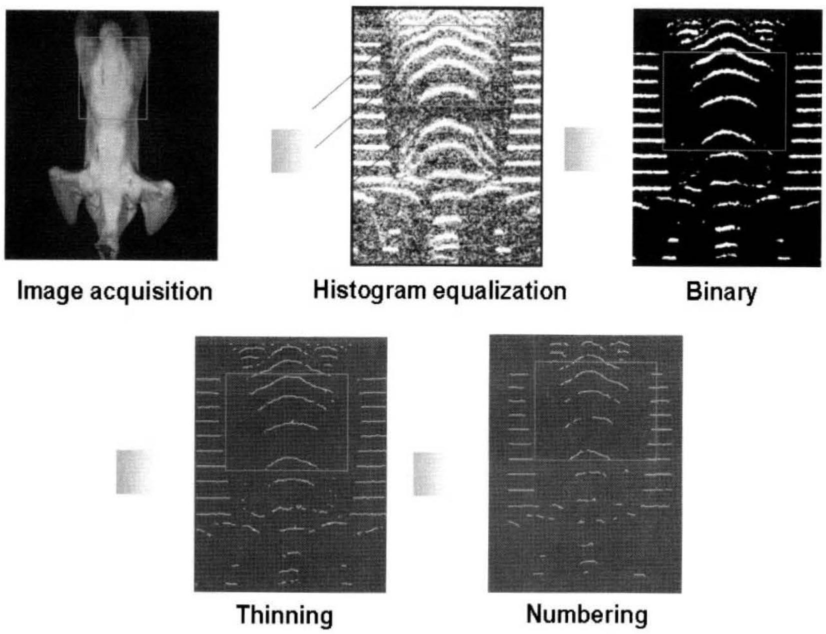

Fig. 2. Resulting image after low?pass filter and thinning.

of height from 243 mm to 343 mm.

Three Dimensional Contour of Extraction of Poultry Carcass

Using the height information of the two dimensional image point, the corresponding three dimensional coordinate information was computed using results of the camera calibration. Three dimensional contour of the poultry carcass were displayed using MATLAB as shown in Figure 3. Since laser line was mounted at the fixed position and orientation and poultry carcass hung on the shackle varied its size and shape, the contour information should be combined with two dimensional projection image to obtain more precise size estimation. Figure 4 showed the experimental system built in the laboratory.

Conclusions

As an initial step to develop the on?line quality evaluation system for poultry processing line, an algorithm to extract three dimensional geometric shape feature of a poultry carcass was developed using a set of two dimensional computer vision system and a laser

Table. 2. Computed heights from laser structured laser line from the shift using the correlation equation (z_{i-2}, z_{i-1}, z_i, z_{i+1}, z_{i+2} unit : mm).

No	z_{i-2} (mm)	v (pixel)	Δv (pixel)	z (mm)	ΙΔΕΙ (mm)
1	243	246	0	243	0.00
2	263	218	28	263.37	0.37
3	283	188	57	282.45	0.55
4	303	156	89	302.88	0.18
5	323	121	126	323.66	0.66
6	343	84	163	342.72	0.28

No	z_{i-1} (mm)	v (pixel)	Δv (pixel)	z (mm)	ΙΔΕΙ (mm)
1	243	272	0.00	243.00	0.00
2	263	243	29	263.13	0.13
3	283	214	58	282.69	0.31
4	303	182	90	302.86	0.14
5	323	146	126	324.49	0.49
6	343	110	162	342.78	0.22

No	z_i (mm)	v (pixel)	Δv (pixel)	z (mm)	ΙΔΕΙ (mm)
1	243	298	0.00	243.00	0.00
2	263	263	29	263.18	0.18
3	283	240	58	282.70	0.30
4	303	208	90	302.91	0.09
5	323	172	126	323.37	0.37
6	343	136	162	342.84	0.16

No	z_{i+1} (mm)	v (pixel)	Δv (pixel)	z (mm)	ΙΔΕΙ (mm)
1	243	325	0.00	243	0.00
2	263	294	29	263.17	0.17
3	283	267	58	282.71	0.29
4	303	235	90	302.91	0.09
5	323	200	126	323.37	0.37
6	343	163	162	342.83	0.17

No	z_{i+2} (mm)	v (pixel)	Δv (pixel)	z (mm)	ΙΔΕΙ (mm)
1	243	353	0.00	243	0.00
2	263	324	28	263.37	0.37
3	283	293	57	282.45	0.55
4	303	264	89	302.82	0.18
5	323	227	126	323.66	0.66
6	343	190	163	342.72	0.28

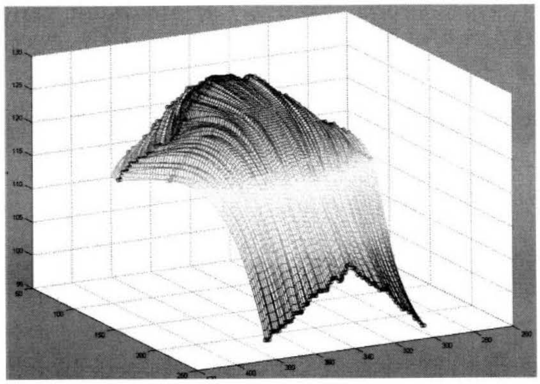

Fig. 3. Breast image of poultry carcass generated using MATLAB.

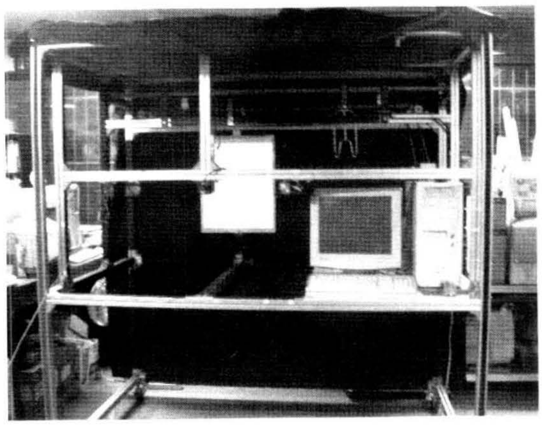

Fig. 4. The experimental system built in the laboratory.

structured lighting device. A multi-parallel line structured light pattern was used. The proposed algorithm was composed of three stages. The camera calibration, which determined a coordinate transformation between the image plane and the real three dimensional world, was performed using known 6 pairs of points at the first stage. Utilizing the shifting phenomena of the projected laser beam on a poultry carcass, the height information of the carcass was computed at the second stage. Finally, using the height information of the two dimensional image point, the corresponding three dimensional information was computed using results of the camera calibration.

The maximum error of the camera calibration for sample point was less then 0.02 mm within the range of 243 mm height. The maximum error of the extracted 3

D feature using the proposed algorithm was less then 0.66mm in the range of height from 243 mm to 343 mm. From the results, the proposed algorithm and system which extract 3 D geometric contour was accurate enough for measuring the degree of the poultry body flesh. Combined information of the height contour and the projected 2 D contour can be used to substitute the size (weight) grading of poultry carcass and some of disease.

Acknowledgments

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