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Research on nondestructive measuring method of tree growth state based on vision technology

Jie Xu[1,2], Dawei Qi[3]

[1]College of Engineering and Technology, Northeast Forestry University, Harbin, 150040, (CHINA)

[2]College of Information Technology, Heilongjiang Bayi Agricultural University, Daqing 163319, (CHINA)

[3]College of Science, Northeast Forestry University, Harbin, 150040, (CHINA)

ABSTRACT

This paper aims to improve the accuracy in measurement of tree growth status and to overcome the disadvantages in traditional measurement methods. In this paper, the author starts with parallax processing and combines organically the imaging technologies and vision theories, in order to determine the changes in tree growth status in a period of time on basis of the tree image information acquired at various time points. During the tests, the author calibrates rectangular information points on trees in the image acquired and then acquires tree growth information at such character points by using two cameras, and then carries out comparison studies on the two tree images, in order to calculate and determine the space information of such information points on the trees during a certain time period and to determine the position changes at the information point during such time period. It is found in the tests that for purposes of the calibrated information points, the height and thickness increased respective by 5.63 and 5.75mm by using traditional measurement methods and that the two values are close but do not agree with the actual growth status of trees. However, the heights and thickness increase respectively by 2.4 and 1.5mm by using the visual technology based measurement, of which the height change is 1.6 times larger than thickness change and agrees with actual growth process of trees. Therefore, the measurement methods on basis of visual technology can effectively realize nondestructive measurement of trees, so as to determine the changes of growth status of trees.

KEYWORDS

Binocular vision; Image processing; Object matching; Corresponding point.

INTRODUCTIONS

Tree growth is largely affected by natural environment. It is very hard to find a universally applicable method for effective measurement of tree's space information, because the traditional measurement method is affected by a number of factors including tree outline[1]. However, machine vision may be used, instead of human eyes, to determine and identify objects, so as to meet people's needs for acquisition of tree space information[2]. A series of achievements have been made in researches on application of vision technology to forest growth status in and outside China: Hu Tianxiang et al.[3] placed two cameras in vertical positions to acquire tree images. However, the attempt was limited to simulation of trees. Zhang Chao et al[4] applied the 3D vision technologies in researches on forest distribution measurement, in order to increase the measurement accuracy of forest distribution but no description of tree growth status was made. Cai Jianrong et al[5] realized acquisition and restructuring of 3D information of fruit trees but did not carry out specific analysis on their growth characteristics. Xiang Rong et al[6] carried out positioning researches by using binocular 3D vision but did not provide comparison analysis on basis of various time points.

On basic of thee researches as mentioned above, the authors of the paper calculate the changes of space information at the calibration points on trees during various time periods by using traditional measurement methods and vision measurement methods respectively. Comparison analysis is made on basis of the measurement results by using such two methods, in order to demonstrate the scientificity and accuracy of the vision technology based measurement method.

THEORY BASIS

Vision imaging principles

Figure. 1 shows a schematic diagram of binocular 3D imaging principle at eye level[3,7], and the distance of line connecting the centers of two projection, knwon as Baseline distance, is *B*.

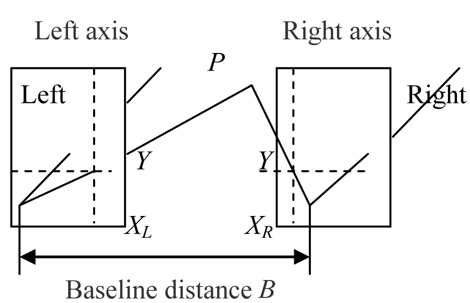


Figure 1 : Binocular 3D imaging principle

Two cameras are used to image a same character point $P (x_c,y_c,z_c)$ on a same object at a same time and acquire the image coordinates of *P* respectively in the left and right image, namely coordinates (X_L,Y) and (X_R,Y). If the focal lengths of both cameras are *f*, then the following can be concluded from their triangular geometry relationship:

$$\begin{cases} x_c = \dfrac{B \cdot X_L}{D} \\ y_c = \dfrac{B \cdot Y}{D} \\ z_c = \dfrac{B \cdot f}{D} \end{cases} \quad (1)$$

Wherein, D indicates the parallax, $D=X_L-X_R$, therefore if any point in the image of the left camera can be found on the image of the right camera, then the 3D coordinates of such point can be determined[7-8].

Coordinate transformation

The image size is indicated by ($M\times N$), then take the upper left corner of the images as origin of coordinates O_0, if (u,v) is the coordinate in unit of pixel and (X,Y) is the coordinate in unit of mm, then in the XY coordinate system, the origin of coordinates O_1 is defined as the crossover point of camera optical axis and the image, if the coordinates of O_1 in uv coordinate system are (u_0,v_0), abd the physical size of each pixel respectively on the XY axis is dX *and* dY, the coordinate transformation is as shown in Figure. 2[2], then

$$\begin{cases} u = \dfrac{X}{dX} + u_0 \\ v = \dfrac{Y}{dY} + v_0 \end{cases} \quad (2)$$

Wherein, dX is the physical unit of each pixel in X axis direction; and dY is the physical unit of each pixel in Y axis direction.

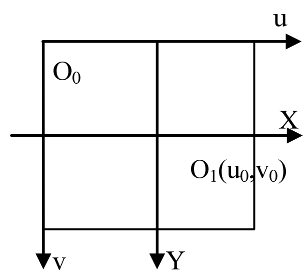


Figure 2 : Coordinate transformation

Calculation of parallax D

Place the camera horizontally and keep optical axis parallel and the image is formed at a same plane, then parallax D is only related to pixel coordinate u_1 and u_2. According to Formula (2), the relations between pixel coordinates u_1 and u_2 and physical coordinate X_1 and X_2 is expressed as[2,9-10]:

$$X_1 = (u_1 - u_0)dX \quad (3)$$

$$X_2 = (u_2 - u_0)dX \quad (4)$$

Then:

$$D = X_2 - X_1 = (u_2 - u_1)dX \quad (5)$$

By combining formula (5) and formula (1), the space information of the calibration point of the tree at pixel center can be calculated, namely

$$x_c = \frac{B \cdot X_L}{(u_2 - u_1)dX} \quad (6)$$

$$y_c = \frac{B \cdot Y}{(u_2 - u_1)dX} \quad (7)$$

$$z_c = \frac{B \cdot f}{(u_2 - u_1)dX} \quad (8)$$

TEST DESIGN

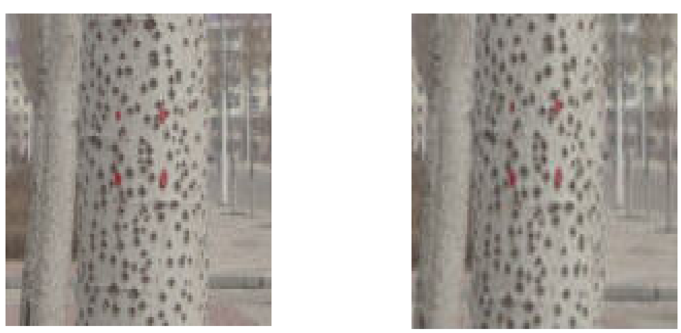
The test is carried out on basis of MV-VS220 type binocular 3D vision measurement system platform and DS3 level gage and a J2 theodolite are used to ensure the same position in two measurements. A Microvision MV-VS078FC high definition industrial camera is used to collect images and AFT-0814MP is used as camera lens which is fixed by a stiff tripod provided by the platform and the camera is connected to a MV-1394 image capture card. Camera parameter settings: imaging plane 3.225mm×3.225mm, defin， resolution: 1024×768. Thethe following result is obtained: dX=3.225/1024 = 0.00315mm, dY=3.225/768 =0.0042mm. In this test, the focal lengths of both cameras are adjusted to f=20mm, with initial baseline distance B=60mm.

During the test, 4 rectangular information points are calibrated on the trees to be imaged and the measurement position is precisely located by using a DS3 level gage and a J2 theodolite. For purpose of traditional measurement method, a 50 scale division vernier caliper and a meter ruler are used to measure the distance; for the other measurement method, the binocular vision measurement platform is used to collect information at the calibration point on the tree. The test aims to carry out tree image information collection and measurement from a fixed position but at various time points. (The test is done once every six months)

IMAGE PROCESSING

Image collection

The image collection is mainly done by using a MV-VS220 binocular 3D vision measurement system and image collection is made at the red points from a fixed position at various time points. During the image collection, the camera is maintained horizontally and the optical axis is parallel to produce images at a same plane. The images collected at the first attempt is as shown in Figure. 3 below.



a. Left camera image b. Right camera image

Figure 3 : Collected images

Color extraction

The image collected at the calibrated tree position by camera includes color information. But for purposes of image processing, since the tree is marked by red color, only data in red channel should be extracted and all post-processing are made on basis of the image data extracted. This paper uses the color extraction algorithm and commands of Matlab language[11-12], to realize information extraction for the red calibration point on the tree.

Separation of calibration point

Since the 4 red calibration points differ from other image information points, the coordinates extracted by color is relatively stable and it is very easy to obtain the precise information of the calibration point, so as to realize separation. For sake of convenience in image processing, the grayscale images are converted to binary images with threshold value of 2. Besides, where necessary, reversal processing is made on the binary images, to obtain the calibration point image, as shown in Figure. 4:

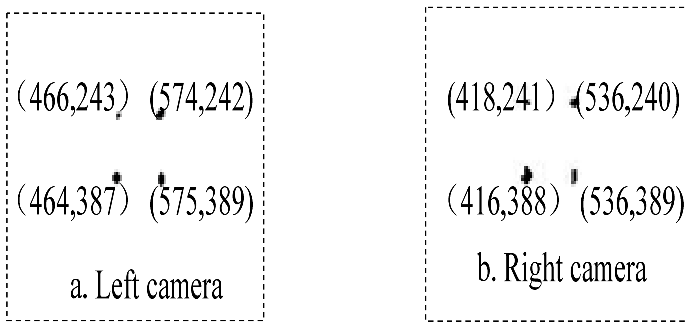


Figure 4 : Camera calibration point and center coordinate

Determination of center of calibration point

Since each calibration point on the image collected is made of many pixels, it is very hard to accurately calculate the information of each calibration point. This paper adopts the pixel center coordinate of each calibration point to calculate the position relationship between calibration points. In this test, the the pixel center of each calibration point area is calculated to determine the center coordinates of such calibration point, as shown below[7,13]:

$$i_m = \frac{1}{N_S} \sum_{(i,j)\in S} i, \qquad j_m = \frac{1}{N_S} \sum_{(i,j)\in S} j \tag{9}$$

Wherein, S indicates connected domain, namely the position of each calibration point; N_S indicates the number of pixels in thee connected domain; and (i_m, j_m) is used as the coordinate of pixel center of the calibration point. According to the camera settings, the coordinates of pixel centers of each calibration point are as shown in Figure. 4 below.

DATA PROCESSING

Space information of initial calibration point

On basis of the pixel center coordinates of the calibration point, calculation can be made to work out the space coordinate information of the pixel center of each calibration point. Take the upper left corner of the image as origin of coordinates, the world coordinate system and camera coordinate system coincide[7,14-15]. Take the pixel center at upper corner as an example, the calculation result in accordance with formula (6)~ formula (8) are as follows:

$$x_{1Upper\ left} = 582.50mm, \ y_{1Upper\ left} = 405.00mm, \ z_{1\text{Upper left}} = 7936.51\text{mm}$$

Similarly, other pixel center coordinate may be calculated: Upper right (717.5,403.33,7936.51), LL (580.0,645.0,7936.51), and LR (718.75,648.33,7936.51). Change the baseline distance by 2 mm each time and take 10 measures. The measured data are as follows:

TABLE 1 : Statistical graph of 10 times measurement result

N	B	Upper left coordinates/mm			Upper right coordinates/mm			Lower left coordinates/mm			Lower right coordinates/mm		
		X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
1	60	582.50	405.0	7936.51	717.5	402.38	7936.51	580.0	645.0	7936.51	718.75	648.33	7936.51
2	62	582.63	409.96	8033.69	714.76	400.11	7873.02	587.1	652.9	8033.69	727.55	656.27	8033.69
3	64	582.78	406.59	7967.63	720.31	401.92	7967.63	582.27	647.53	7967.63	721.57	650.88	7967.63
4	66	580.30	403.47	7906.56	728.54	403.54	8058.61	577.81	642.57	7906.56	729.81	658.31	8058.61
5	68	581.81	408.00	7995.30	722.81	402.32	7995.30	584.3	649.78	7995.30	737.74	665.46	8146.15
6	70	582.50	405.00	7936.51	717.50	403.33	7936.51	580.00	645.00	7936.51	731.82	660.12	8080.81
7	72	581.36	409.26	8020.05	713.55	400.55	7881.77	586.11	651.79	8020.05	739.29	666.86	8163.27
8	74	582.27	406.37	7963.41	719.86	402.71	7963.41	581.97	647.19	7963.41	721.19	650.53	7963.41
9	76	580.59	403.67	7910.49	715.15	402.01	7910.49	578.1	642.89	7910.49	728.33	656.98	8042.33
10	78	582.26	407.61	7987.71	716.74	399.49	7860.92	583.74	649.16	7987.71	723.39	652.52	7987.71

According to the aforesaid test data, after 10 measurements, the average physical coordinates of each calibration point pixel centers can be worked out: Upper left (581.82,406.49,7965.79), Upper right (718.67,401.83,7938.42), Lower left (582.14,650.38,7967.79), and Lower right (724.94,653.63, 7958.01).

Space information measured 6 months later

On conditions that the imaging positions of two cameras remain unchanged, the influences by natural factors on the cameras are neglected. Camera focal lengths are both f=20mm, with initial baseline B=60 mm. The physical coordinates of pixel center of the upper left calibration point measured 6 months later are as follows:

$$x_{2\text{upper left}} = 577.50\text{mm},\ y_{2\text{upper left}} = 401.67\text{mm},\ z_{2\text{upper left}} = 7936.51\text{mm}$$

Similarly, other pixel center coordinate may be calculated: Upper right (720.0,400.0,7936.51), LL (578.75,646.67,7936.51), and LR (721.25,650.0,7936.51). Change the baseline distance by 2 mm each time and take 10 measures. The measured data are as follows:

TABLE 2 : Statistical graph of 10 times measurement result after six months

N	B	Upper left coordinates/mm			Upper right coordinates/mm			Lower left coordinates/mm			Lower right coordinates/mm		
		X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
1	60	577.50	401.67	7936.51	720.00	400.00	7936.51	578.75	646.67	7936.51	721.25	650.00	7936.51
2	62	572.88	398.45	7873.02	714.24	396.8	7873.02	585.84	649.55	8023.69	730.08	657.96	8011.32
3	64	579.76	403.24	7967.63	708.92	393.85	7814.41	581.02	649.2	7967.63	724.08	652.55	7967.63
4	66	586.38	407.85	8058.61	709.11	391.11	7760.14	576.57	644.23	7906.56	718.53	647.55	7936.86
5	68	581.78	404.64	7995.30	712.15	395.64	7849.93	572.44	639.61	7849.93	713.38	642.91	7958.23
6	70	577.50	401.67	7936.51	720.0	400.00	7936.51	578.75	646.67	7936.51	721.25	650.00	7898.37
7	72	583.58	405.89	8020.05	715.03	397.24	7881.77	584.84	650.47	8020.05	716.28	645.52	7963.56
8	74	579.46	403.03	7963.41	722.44	401.36	7963.41	580.71	648.86	7963.41	723.69	652.2	7964.62
9	76	575.61	400.35	7910.49	724.50	405.33	8042.33	586.47	647.29	8042.33	730.87	658.67	7972.65
10	78	581.23	404.26	7987.71	726.52	409.18	8118.66	592.03	648.51	8018.66	725.9	654.19	7957.70

After 10 measurements, the average physical coordinates of each calibration point pixel centers are: Upper left (579.57,403.1,7964.92), Upper right (717.29,399.05,7937.67), Lower left (581.74,647.11,7966.53), and Lower right (722.53,651.15, 7956.7).

Numeric calculation and analysis

Vision measurement based data calculation

(1) Distance change of coordinates of pixel center of the calibration point

From TABLE 1, it can be found that the space distance from coordinate at upper left pixel center to 3 other pixel centers are respectively $L_{1\text{upper left upper right}} = 139.6\text{mm}$; $L_{1\text{upper left upper right}} = 243.9\text{mm}$; $L_{1\text{upper left upper right}} = 285.7\text{mm}$;

Similarly, from TABLE 2, the distance from the upper left pixel center to other pixel centers is respectively: $L_{2\text{upper left upper right}} = 141.1\text{mm}$; $L_{2\text{upper lef lower left}} = 246.3\text{mm}$; $L_{2\text{upper left lower right}} = 288.0\text{mm}$;

6 months later, $\Delta L_{\text{upper left upper right}} = 1.5\text{mm}$; $\Delta L_{\text{upper lef lower left}} = 2.4\text{mm}$; $\Delta L_{\text{upper lef lower left}} = 2.3\text{ mm}$;

$\Delta L_{\text{upper left upper right}}$ indicates changes in X axis direction, while $\Delta L_{\text{upper left lower left}}$ indicates changes in Y axis direction. Although the increments in X axis direction and Y axis directions are relative quantity, they indicate the increment changes of the rectangular information point is horizontal and vertical directions, which means that growth status changes have occurred to the rectangular information point in the 4 months. The changes in vertical direction is 1.6 times the same in horizontal direction, which means that the tree grows faster in height while grows relatively slow in thickness. The finding agrees with actual growth status of the tree[4,10];

(2) Position change of coordinates of pixel center of the calibration point

From the pixel center coordinates measured in TABLE 1 and TABLE 2, $\Delta_{\text{upper left}} = (2.25, 3.39, 0.87)$; $\Delta_{\text{upper right}} = (1.38, 2.78, 0.75)$; $\Delta_{\text{lower left}} = (0.39, 3.27, 1.26)$; $\Delta_{\text{lower right}} = (1.41, 2.52, 1.31)$. From the results as shown above, changes have occurred after the 6 months to the space information of the calibration points. Increase of all 4 pixel center distances is found, indicating the size of the rectangular point also changed in comparison with the same before such six month period. However, the changes in XZ direction is relatively smaller, while data changes in Y axis direction is large. The findings agree with facts that trees grow faster in heights than in thickness[4,10].

Traditional measurement based data calculation

In actual measurement, a meter ruler with minimum scale of 1mm is used to measure the tree depth; a 50 scale division vernier caliper is used to measure in horizontal and vertical directions. In the test, only the distance between information points is measured and recalculated by 10 times average value. The measurement results at initial and after six months are as shown in TABLE 3 below:

TABLE 3 : Statistical graph of 10 times measurement result between initial and after six months

Corresponding points	Initial measurement (10 times mean)/mm			Measured after six months (10 times mean)/mm		
	Z	XY	L	Z	XY	L
(ULUR)	26.3	135.52	137.42	26.2	139.74	143.17
(ULLL)	25.9	242.12	243.50	26.8	247.68	249.13
(ULLR)	25.6	280.26	281.43	26.5	288.32	289.54

From TABLE 3, the measurement of tree growth parameters can also be measured by using the traditional methods. Six month later, $\Delta L_{\text{upper left upper right}} = 5.75\text{mm}$; $\Delta L_{\text{upper lef lower left}} = 5.63\text{mm}$; $\Delta L_{\text{upper left lower right}} = 8.11\text{mm}$, which means growth status changes have occurred to the tree. $\Delta L_{\text{upper left upper right}}$ indicates growth in horizontal direction, while $\Delta L_{\text{upper lef lower left}}$ indicates growth in vertical direction. Six months later, the rectangular area also increased. However, the increments in horizontal and vertical directions are very close, which do not agree with the fact that trees grow faster in height and slower in thickness.

Comparison analysis on traditional measurement and vision based measurement

According to the results measured six month later, changes have occurred to the distance between information points, whether measured by traditional method or by vision based measurement method. The results show that the tree growth status has changed. However, in comparison with vision based measurement, the traditional measurement method has many disadvantages, specifically including:

1) In terms of measurement accuracy, the minimum scale is 1 mm on the meter ruler used in traditional measurement and 0.02 mm on the vernier caliper used in vision based measurement. In consideration of data accuracy, the traditional measurement is inferior to vision based measurement.

2) In terms of measurement results, in traditional measurement, the increment is 5.75(mm) in horizontal direction and 5.63(mm) in vertical direction. The two increments are very close, which does not agree with facts that trees grow faster in height and slower in thickness[4,10]; but in vision based measurement, the increment in vertical direction is 1.6 times the same in horizontal direction, which agrees with the fact that trees grow faster in height and slower in thickness.

3) In terms of errors, traditional measurement is based on information center point selected by man, which means that the data source and handling method is not scientific. However in vision based measurement, measurement is done on basis of the data of images collected and the pixel center coordinates are determined by computer calculation, which means that the measurement results so obtained are accurate and scientific.

4) In terms of data collection environment, in traditional measurement, field recording and measurement by man are required, which is to a large extent affected by natural environment. But in vision based measurement, the measurement has relatively lower requirements on environment[12,28], and the distance between four rectangular information points is relatively stable, even the tree has changed its position due to wind and rain.

CONCLUSIONS

Tree image information is collected and processed respectively by using a binocular vision measurement system platform and by using the traditional measurement method, on basis of which comparison analysis is made on the measurement results obtained in an interval of 6 months. Form the measurement results, the growth of tree in height (2.4mm) is 1.6 times the growth in thickness (1.5mm) when vision measurement is used; the growths in height and thickness are close to each other when traditional measurement is used which does not with facts. It can be therefore concluded that the vision technology based measurement is more accurate and scientific in comparison with traditional measurement methods and the measurement results agree with principles of tree growth. In follow up stages, the measurement parameters will be studied and multi-view cameras will be used to study the tree growth and changes, in order to provide technological supports for researches on remote monitoring of tree growth.

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