Journal of Applied Sciences

ISSN 1812-5654

Journal of Applied Sciences 13 (7): 1013-1020, 2013
ISSN 1812-5654 / DOI: 10.3923/jas.2013.1013.1020

Automobile Longitudinal Axis Extraction Based on Symmetric Points Detection

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Abstract: The longitudinal axis was an important feature of automobile which extraction had special significance in vehicle testing field. In order to meet the increased demand for automobile detection, the method of automobile longitudinal axis extraction using vision image processing technologies was studied. The basic two methods of automobile longitudinal axis technologies were introduced, including the method based on image processing and the way based on machine vision. The system total structure of automobile longitudinal axis extraction was designed which consisted of single camera, computer and tested automobile. After being preprocessed, the sub-pixel level corners of overhead automobile image were detected by Harris method and fitting interpolation for corner sub-domain. The symmetric corners were found by making use of modified normalized cross correlation based on pixel by pixel symmetry method and finally the automobile longitudinal axis was extracted. The system running showed that this method effectively realized the task of automobile axis extraction, which laid good foundation for later automobile detection.

Key words: Automobile detection, longitudinal axis, symmetric point, harris corner, normalized cross correlation

INTRODUCTION

In recent years, with the rapid development of automobile industry, the production quantity and ownership number have been greatly increased, the functions is more powerful, people's travel is more convenient and the life styles have been changed dramatically. At the same time, the automobile structure is more sophisticated than before. Then, in the usage process of automobile, the performance and technical conditions of automobile must be understood, as early as possible to find the faults and potential failures, or to predict the occurrence of failures, thereby protecting the safety of personals and vehicles. As a result, the automobile performance testing is so essential and important that every country provides some mandatory testing projects for vehicle performance. To meet this requirement, the vehicle detection technology is growing rapidly. There have been a variety of new equipment and methods, detection projects and contents are richer and the detection precision and accuracy reach new levels.

Automobile longitudinal axis, longitudinal centerline or symmetrical line, is one of the main features of automobile. The detection and extraction of automobile longitudinal axis has special significance in vehicle testing. For example, the Chinese national standard demands that the performance testing for headlamp is an important project. During testing a headlight, it is required to align with the headlight tester. If the vehicle is not perpendicular to the rail of headlight tester, the measurement error would be happen. In general, it is difficult to avoid misalignment, but this error can be corrected by detecting the deviation of actual longitudinal axis of automobile to amend the measurement data measured by the headlight tester and the more accurate detection data can be gotten (Wang, 2008). There is another example in the detection of vehicle type, some premise data are necessary, mainly the height and width of the automobile, then the longitudinal axis extraction is the prerequisite.

For the past few years, the technologies of image processing and machine vision have developed very rapidly and had very extensive applications (Szeliski, 2010). In the fields of automobile detection and recognition, these technologies can comprehensively analyze and manage the information of automobile and traffic, including the detection and recognition of vehicles and license plates, testing of traffic operation state, control and treatment of intelligent traffic and so on (Guo *et al*., 2007).

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This study designs an automobile longitudinal axis extraction system based on vision image processing technologies, which is realized with computer as the center. The overhead image of automobile is captured by a camera just above the vehicle. The corners are detected by Harris method and the sub-pixel level feature points are obtained by curve fitting interpolation method for corner sub domain. The symmetrical points are determined by using normalized cross-correlation theory and the automobile longitudinal axis is finally gotten. The research result can establish foundation for the next vehicle detection and it has good practical value and application prospect.

EXTRACTION METHODS OF AUTOMOBILE LONGITUDINAL AXIS

In order to implement some projects of vehicle detection, the automobile longitudinal axis should be extracted firstly. In the process of longitudinal axis extraction, there are two important methods, they are based on digital image processing and based on machine vision.

Technology based on image processing: The image is an important source and access to acquire and exchange information in people's daily life. Image processing is to make use of computer to extract information, process, recognize, store and display for optical image. The digital image processing technologies mainly include image enhancement, image compression, image segmentation, image recognition and so on. In recent years, with the development of optical technology and image processing technology, it is widely used in industrial field. The technology is also used for non-contact measurement methods in automotive industry, such as in the automobile headlamp testing, automatic recognition of vehicle license plate, intelligent identification of vehicle type and other applications. It can provide more advanced ways for further automatic testing, high accuracy and number increasing of testing projects for vehicle detection. Accordingly, the methods of automobile longitudinal axis based on image processing technology have also gotten some progresses.

In the processing of studying the detection system of automobile bodywork deviation, Wang (2005) used the digital image processing technology to detect the centerline of automobile. Two cameras are set up, respectively in the head and rear of automobile, the head and rear images are captured and input to the computer for processing. The computer adds the scales to the two images. The images of head and rear of automobile are placed in the middle of scales. Then, the original points of scales are in the midpoints of the head and rear images. Connecting the two midpoints can build the centerline of automobile. The disadvantage of this approach is that the additional scales must be added to the images, then it is inconvenient to achieve and not easy to guarantee the measurement accuracy.

When studying the headlight detecting technologies based on digital image processing, in order to eliminate the errors caused by misalignment between vehicle and headlight tester, Zhu (2005) proposed a measurement data correction method by finding vehicle parking declination angle. The overhead image is collected firstly, the automobile outline is analyzed and gotten and the automobile longitudinal axis is extracted based on approximation method according to the symmetric characteristics of automobile outline. Zhu (2007) further researched the image segmentation techniques and gives an algorithm of automobile contour image segmentation of two-dimensional maximum entropy threshold based on image blocking, just choosing two locations and their vicinity of the automobile overhead contour image to detect the longitudinal axis and the method can improve the detection speed of automobile longitudinal axis. Min *et al.* (2010) extracted the automobile outline and then gets the central axis based on OTSU adaptive threshold segmentation algorithm. The extraction method of automobile longitudinal axis based on image segmentation and approximation method requires less hardware and it has good real time. But its drawback is that the detection result largely depends on the contour accuracy. If the color of automobile is not much different from the background, it becomes very difficult to detect the automobile contour and the approximation method only considers few points of automobile contour, the extraction accuracy will deteriorate if the automobile changes in shape.

Technology based on machine vision: Vision is an important function and means of human observing and understanding the world. Machine vision system is generally computer-centric, mainly consists of vision sensor, image acquisition system and special image processing system. The system has high intelligent and universal adaptability. Along with the technology development, it has increasingly wide range of applications, especially in industrial field. In the application of automobile detection and test, it has gotten more and more attention and can be used to improve the detection accuracy and automation degree, but it is used seldom in the extraction of automobile longitudinal axis.

Peng (2008) detected the central axis of automobile based on machine vision technology when studying measurement of vehicle size. At first, the obtained automobile image information is preprocessed, including smoothing, filtering, edge detection and so on. Several key points, mainly the highest point, lowest point and two points in the diagonal line, are detected by feature points extraction and matching methods. According to their coordinates, the central axis is extracted. Lastly, the height, length and width of automobile can be calculated.

In studying the testing system of the position deviation of vehicle body and axle, Lin (2008) extracted the automobile longitudinal axis based on the symmetrical features of vehicle contour. The left and right two images of vehicle body are obtained by stereo cameras. The two images are, respectively processed, including edge detection, tracking and getting contour. The lines within certain slope and length are extracted from the image outline, the center lines can be detected with the simplified lines on the left and right sides. The line equation under the world coordinate system is lastly gotten after three-dimensional reconstruction of the two center lines which is the automobile longitudinal axis.

Bevilacqua *et al*. (2009a, b) proposed a method of aligning automobile longitudinal axis with the headlight measuring instrument based on machine vision. Labeling the baselines and reference points on the testing site, the feature points of automobile license plate are extracted and the corresponding points are matched. The automobile longitudinal axis are extracted by license plate recognition and tracking. But, to be exact, the so called longitudinal axis in that project is just the center line of automobile traveling.

The detection method of automobile longitudinal axis based on machine vision requires two cameras and has better accuracy in general, but the test results also depend on the vision image processing technology, especially corner detection technology and feature matching technology. The disadvantage is that it needs two cameras, then the cost is high, but with the progress of electronic technology, the cost has been greatly reduced.

By the previous analysis, the research on automobile longitudinal axis extraction method has achieved certain results which have been put into practical use, but they have their own flaws in the detection accuracy, cost, system complexity and other aspects.

SYSTEM DESIGN OF AUTOMOBILE LONGITUDINAL AXIS EXTRACTION

System design principle: Aiming at the features of automobile longitudinal axis detection, combined with the advantages of image processing and machine vision inspection technologies, a method of automobile longitudinal axis detection based on image feature points detection and symmetrical points matching is proposed.

As described above, the longitudinal axis of automobile is the intersecting line of bilateral symmetry plane and ground. In the simplest case, as long as two symmetric points in the automobile body are found, they can be connected to form a line, which perpendicular bisector is the so called automobile longitudinal axis. Or, if several pairs of symmetric points are gotten, each pair are connected to find the center points, the line connecting them is longitudinal axis. Therefore, in order to realize the longitudinal axis detection, the obtained automobile overhead image can be firstly preprocessed, the important feature points are gotten by corner detection method, the pairs of symmetric points through querying the detected corners are found and then the longitudinal axis can be extracted finally.

System total design: On the basis of measurement principle of automobile longitudinal axis extraction, the system structure is designed as shown in Fig. 1. The automobile longitudinal axis extraction system based on symmetric corner detection consists of the tested automobile, camera and computer. The automobile is parked in the detection site, the camera is set just above the automobile, about three meters far from the ground, the camera captures images and sends them to the computer via USB interface, the latter processes and analyzes them to get the longitudinal axis of automobile.

Progress of system realization: The concrete system realizing process is as follows:

- **Image acquisition:** An automobile longitudinal axis detection system is constructed which makes the computer as the center and captures the automobile overhead image through a single camera

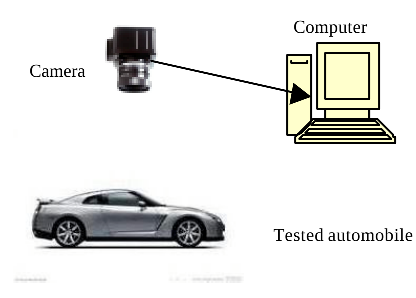

Fig. 1: Hardware structure of automobile longitudinal axis extraction system

- **Image preprocessing:** The automobile image is transferred to computer through USB interface and gray scale image is gotten after image preprocessing
- **Feature point detection:** The corners of gray scale image of automobile are detected on the basis of Harris corner detection principle. According to the fitting interpolation, the two-dimensional sub pixel coordinates of feature points are obtained
- **Symmetric points querying:** Using the gray scale information, based on the normalized cross correlation theory and the symmetry characteristic of the detected Harris corners of automobile image, the symmetrical points are matched
- **Longitudinal axis extraction:** According to the pairs of symmetric feature points, the longitudinal axis of automobile can be extracted

FEATURE POINTS DETECTION OF AUTOMOBILE IMAGE

Corner is one of the most important characteristics of image. It is generally defined as the point with dramatic change in brightness or maximum curvature in the edge of two-dimensional image (Niu, 2011). The corner retains most of the image feature information. In the image operation, it can effectively reduce the information amount and improve the operation speed and matching reliability. Corner extraction plays an important role in image processing and computer vision, especially in image registration and matching, object recognition, motion analysis and other application fields.

Corner detection method: With decades of research and exploration, there are a lot of methods for corner detection, mainly the following three categories: corner detection algorithm based on gray scale image, method based on binary image and technology based on contour curve.

Corner detection algorithm based on gray scale image: There are two important realization methods based on gray scale image.

Template-based method: This method primarily considers the gray scale change of neighborhood of each pixel, that is, the change of image brightness is main factor. If the luminance contrast between a point and its neighboring points is large enough, then this point can be seen as a corner. Before the corner detection, a template with different angles is firstly created and the approximation degree between the standard template and the detected image in the defined window are compared. Since the template cannot cover all directions of the corner points, then, not all corners can be detected by this method. In addition, the calculation quantity of this detection method is large and the computing process is complex (Ren, 2009).

Gradient-based method: The method determines whether the corner exists or not by calculating the curvature of image edges. The calculating amount of corners is determined not only by the edge strength, but also on the change rate of edge direction (Deriche and Giraudon, 1993). In general, this algorithm is more sensitive to noise.

Corner detection algorithm based on binary image: Liu and Zhu (2000) brought forward a mathematical morphological skeleton method to detect corners based on binary image. The method makes the original binary image as a polygon which corner points are located in the extension line of skeleton. The maximum disk of skeleton points corresponding to the corners should tend to zero. Meanwhile, in order to obtain the concave corners, the original image need be complemented and in order to overcome the problem of inconsistency boundary between original image and complemented image, an expansion operation should be performed. The corner detection method based on binary image is more efficient, easily be implemented in hardware and has strong anti-interference ability. However, the binary image is in the intermediate level between gray scale image and edge contour image, then, it is seldom used in practice.

Corner detection algorithm based on outline curve: The edge of an image contains abundant information which is important for image analysis. The method takes curvature of image contour curve as the primary measurement basis to detect corners. It can be achieved by calculating the intensity of corner points (Asada and Brady, 1986) or computing the extreme value of curve curvature. Xiao and Lu (2003) proposed an adaptive corner detection algorithm based on Gaussian smoothing which smooths the detected object boundary curve in the curve scale space to avoid the problem of selecting smoothing factor which uses adaptive curvature method to estimate the curvature of curve and this method has great flexibility. Qian and Lin (2008) put forward a calculation method based on contour sharpness which realizes Gaussian smoothing contour curve in multi-scale space, it calculates the sharpness of each point of the contour in the local supporting area and determines the corners combining certain corner screening rules.

Harris corner detection algorithm: Harris corner detection algorithm uses gray scale information of image to detect corners (Harris and Stephens, 1988) which is used widely.

For an image, the corner has relation with the curvature characteristics of autocorrelation function. The basic principle of this algorithm is to take a small window making the target pixel as the center, calculate the gray scale change of window after moving in any direction. It can be expressed by an analytic function as Eq. 1:

$$E_{x,y} = \sum_{u,v} w_{u,v} |I_{x+u,y+v} - I_{x,y}|^2 \quad (1)$$

where, I is a gray scale image; $w_{u,v}$ is window function, usually Gaussian smoothing filter function which is given in Eq. 2:

$$w_{u,v} = e^{-\frac{(u^2+v^2)}{2\sigma^2}} \quad (2)$$

The change amount of gray scale can be expressed in the form of Taylor polynomials as Eq. 3:

$$E_{x,y} = Ax^2 + 2Cxy + By^2 \quad (3)$$

Where:

$$A = X^2 \otimes w, B = Y^2 \otimes w, C = (XY) \otimes w \quad (4)$$

$$X = I \otimes [1 \;\; 0 \;\; -1] \approx \frac{\partial I}{\partial x} \quad (5)$$

$$Y = I \otimes [1 \;\; 0 \;\; -1]^T \approx \frac{\partial I}{\partial y} \quad (6)$$

Then, $E_{x,y}$ can be translated to a quadratic form as Eq. 7:

$$E_{x,y} = [x\ y]M[x\ y]^T \quad (7)$$

where, M is a real symmetric matrix as shown in Eq. 8:

$$M = \begin{bmatrix} A & C \\ C & B \end{bmatrix} \quad (8)$$

The extreme curvature of autocorrelation function of image gray scale in certain point can be expressed approximately by the characteristic values of M which reflects the image surface curvature in the two main axis directions. When the two characteristic values are both small, the adjacent region of the target point is flat. But if the one value is large and the other is large, it indicates that the feature point is in the image edge. Only when the both values are relatively large and moving in any direction results in dramatic changes in gray scale, the point can be considered as a corner.

The function of Harris corner detector is expressed as Eq. 9:

$$R(x,y) = \det(M) - k.(\mathrm{tr}(M))^2 \quad (9)$$

where, det means the determinant of a matrix; tr is the trace of a matrix; k is a coefficient which recommended value is 0.04.

When R(x, y) of the target pixel value is greater than a given threshold, the pixel is regarded as a corner.

Corner extraction in sub-pixel level: The detected Harris corners are in the pixel level with the above method. In order to improve the accuracy of extracted corners, the corners in sub-pixel level are need, which can be realized by fitting interpolation in the corner point field (Zhang, 2005). This method of corner extraction in sub-pixel level is shown in Fig. 2, where X is the actual location of a corner.

The common used fitting surface is Gaussian surface as Eq. 10:

$$f(x,y) = ce^{-\frac{(x-x_0)^2+(y-y_0)^2}{2\sigma^2}} \quad (10)$$

where, the fitted point (x_0, y_0) is the interpolation position of a corner. Since Gaussian function is separable, the relation can be obtained as Eq. 11:

$$\begin{aligned} f(x,y) &= f(x)f(y) \\ f(x) &= \sqrt{c}e^{-\frac{(x-x_0)^2}{2\sigma^2}} \\ f(y) &= \sqrt{c}e^{-\frac{(y-y_0)^2}{2\sigma^2}} \end{aligned} \quad (11)$$

That is to say, the fitting method based two-dimensional Gaussian surface can be implemented by two

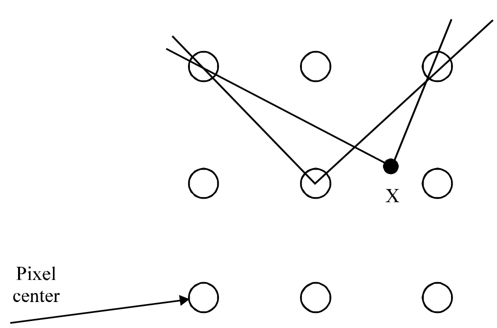

Fig. 2: Schematic diagram of interpolation for pixel gray in sub-domain of detected Harris corners (X is the actual location of a corner)

one-dimensional Gaussian surface fittings. Then, the fitting process can be greatly simplified and the corner detection accuracy after such fitting interpolation is in the sub-pixel grade.

The first 120 detected corners of the captured automobile overhead image by Harris detector and gray scale interpolation are shown in Fig. 3a.

SYMMETRIC POINTS SELECTION AND AUTOMOBILE LONGITUDINAL AXIS EXTRACTION

Symmetric points detection method: According to the detected corners, in order to obtain the automobile longitudinal axis, the symmetric points of automobile should be queried.

Currently, the research on image symmetry has gotten some results, such as method based on pattern matching, means based on statistical method (Wu *et al.*, 2001), technology based on phase information (Yang, 2002; Yu *et al.*, 2004) and so on. However, the searching algorithm for symmetric points is fairly lack.

In fact, the symmetric point detection studied in this project is very similar with feature points matching in vision image. Then, the common corners matching algorithm can be referred to get symmetric points.

Symmetric points detection based on normalized cross correlation: In this project, a common method, normalized cross correlation or NCC, is used to search for the symmetric pairs from the detected Harris corners. The normalization algorithm is achieved based on gray scale information of an image, which can effectively remove the interference caused by luminance information of the low frequency background (Zhao, 2006). Moreover, it is easy to set up testing threshold because the calculating result has fixed range [-1, 1] (Xie *et al.*, 2011). The method makes the gray scale value of neighboring pixels of the detected corners as the basis and the corners can be matched according to their similarity.

Since the automobile is a typical axially symmetric object, the detected feature points are divided into two parts according to the symmetric axis. In the ideal case, the feature points are generally distributed symmetrically relative to the longitudinal axis of the image.

Suppose that the two windows W_1 and W_2 have the same size. They, respectively make the corner P_1 in the top half of the image and corner P_2 in the bottom half of the image. The size of window is M×N, the gray scale means of relevant windows are, respectively u_1 and u_2 which can be expressed as Eq. 12 and 13:

$$u_1 = \frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N} W_1(x_i, y_j) \qquad (12)$$

$$u_2 = \frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N} W_2(x_i, y_j) \qquad (13)$$

Then, the NCC can be described as Eq. 14:

$$NCC = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N}[W_1(x_i,y_j)-u_1][W_2(x_i,y_j)-u_2]}{\sqrt{\sum_{i=1}^{M}\sum_{j=1}^{N}[W_1(x_i,y_j)-u_1]^2\sum_{i=1}^{M}\sum_{j=1}^{N}[W_2(x_i,y_j)-u_2]^2}} \qquad (14)$$

As can be seen from the above equation, the cross correlation of two-dimensional image is based on the gray scale value of corresponding point pixel. But in the detection of symmetric points of automobile, the value of cross correlation should be determined by the symmetric pixels.

Assuming that the size of window is 3×3, the central pixel position of a certain template in the bottom half of the image is (i, j) and that of a corner in the bottom half of the image is (s, t). Then the pixel correspondence relation of pixel by pixel is shown in Table 1.

Then, according to the pixel correspondence relation, the normalized cross correlation can be modified as Eq. 15:

$$NCC = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N}[W_1(x_i,y_j)-u_1][W_2(x_{M+1-i},y_j)-u_2]}{\sqrt{\sum_{i=1}^{M}\sum_{j=1}^{N}[W_1(x_i,y_j)-u_1]^2\sum_{i=1}^{M}\sum_{j=1}^{N}[W_2(x_i,y_j)-u_2]^2}} \qquad (15)$$

When matching corners, firstly, any one corner in the top half image is selected as a template to find the corner with highest correlation in the bottom half image. Then, in the same way, any one corner in the bottom half image is selected as a template to find the corner with highest correlation in the top half image. If the corners with highest correlation searched by the bidirectional method are correspond to each other and the value of cross correlation is greater than a certain threshold, it is said to find a pair candidate symmetric corners and so on, several pairs of symmetric points can be gotten.

As a matter of convenience, the corners near the center line of automobile are not queried. Setting a certain threshold, the detected five pairs of symmetric corners are

Table 1: The corresponding relation between corner's pixels of top half image and bottom half image in symmetric points analyzing

Top half	i-1, j-1	i-1, j	i-1, j+1	i, j-1	i, j,	i, j+1	i+1, j-1	i+1, j,	i+1, j+1
Bottom half	s+1, t-1	s+1, t	s+1, t+1	s, t-1	s, t	s, t+1	s-1, t-1	s-1, t	s-1, t+1

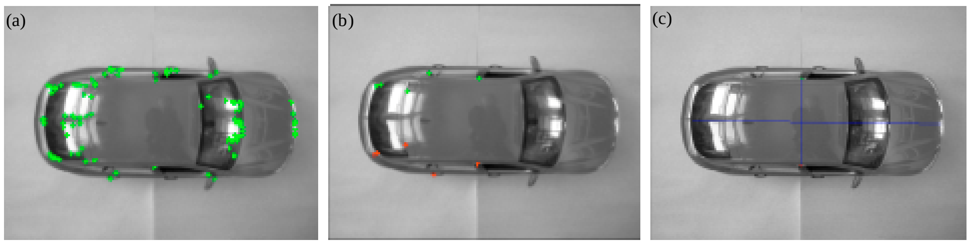

Fig. 3(a-c): The process of automobile longitudinal axis detection, (a) The first 120 detected corners in sub-pixel level of automobile image, (b) The detected five pairs of symmetric points of automobile image and (c) The extracted automobile longitudinal axis according to a pair of detected symmetric corners

shown in Fig. 3b. It is can be seen that there are two pairs having obvious deviation because of lighting problem.

Automobile longitudinal axis extraction: In order to extract the longitudinal axis of automobile, several pairs of symmetric points can be taken.

Since there is obvious mismatching in querying symmetric points, the corner pairs with large errors must be discarded. For convenience, a pair of corners is taken to generate the longitudinal axis of automobile.

The two symmetric corners are connected to produce a straight line, which perpendicular bisector is the longitudinal axis of automobile. The extracted automobile longitudinal axis is shown in Fig. 3c.

CONCLUSION

On the basis of analyzing and comparing several common used methods of automobile longitudinal axis extraction, a system of longitudinal axis extraction based on feature points detection and symmetric point query approach is designed and implemented.

The experimental result shows that the operation of fitting and interpolation for sub domain of Harris corner point can obtain sub-pixel level corner which improves the detection accuracy. Symmetric corners can be detected based on modified normalized cross-correlation algorithm, and then the automobile longitudinal axis can be extracted. This project lays good foundation for the follow-up image analysis and vehicle detection. It has certain theoretical and practical value.

Whereas the accuracy of longitudinal axis extraction mainly depends on the corner detection algorithm and symmetric point matching algorithm, at the same time, it is also affected by the color, texture and shape of automobile. For these reason, the following studies should focus on the development of new corner detection method and symmetric query algorithm to minimize the impact of environmental factors.

ACKNOWLEDGMENT

This study is supported by the Graduate Student Research and Innovation Program of Jiangsu Province, P. R. China (No. CXLX13_513). The authors acknowledge the support of Education Department of Jiangsu Province and Nanjing Forestry University for the study.

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