Image acquisition system for agricultural context-aware computing

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Abstract: Context-aware computing is a new mode originated from ubiquitous computing. Its emergence brings a substantial change to traditional computing and related service. Image is a pervasive tool for context awareness. A large number of applications are developed based on images analysis. In this paper, an image acquisition system is presented for agricultural context-aware computing. The potential use of the system includes production evaluation, precise management and assistant control. The system includes four modules: the camera system, the control system, mechanism, and communication. The system can be easily installed in target crop fields. The camera system is composed of a binocular stereo camera and a color camera. Two cubic images and a corresponding texture image are collected for each plant in the process of data acquisition. An accessorial software system is developed to control and manage the capture system. Experiments show that the presented system is effective for image acquisition of agricultural context-aware computing.

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1 Introduction

Data-based decision making and management is of critical importance to modern agriculture. Information technologies are widely used in agricultural data acquisition for crops information and environment data[1-3]. Related researches have been broadly carried out on both the computer and the botanical ends.

1.1 Agricultural data acquisition

The decision making and management of modern agriculture heavily depends on sensor-collected data of plants and environments. Precision agriculture as well as intelligent agriculture is a heated research issue promoted by development of agricultural Internet of Things[4-6]. One target of data acquisition is crop growth measuring and monitoring which is closely associated with crop yields. To monitor nitrogen content in plant, a crop growth measuring system was developed by Cui and colleagues based on optical principle[7]. Photoelectric technology was used in plant growth status analysis, and Cheng et al.[8] proposed a method and developed an analyzer by analyzing variation of chlorophyll content in crop leaves. Patel and coworkers[9] studied crop growth parameters using airborne imaging spectrometer data. Another important aspect of agricultural data acquisition is environment information collection for plant growth, including weather, soil, water and sunlight. Measured data provide precise reference for agricultural evaluations and decision making.

1.2 Context-aware computing

Context-aware computing is a novel processing and service mode originated from ubiquitous computing,

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where the center of computing shifts from machine to human[10,11]. Based on the definition of context, all properties relevant to computing objects including parameters, things, connections and descriptions are expressed context. Awaring is a basic and directly information acquisition way for "context" and this computing mode has been widely used in human and social applications[12]. Context-aware computing is a rising issue associated with Internet of Things, which is expanded in agriculture in past decades[13,14]. Zhang et al.[15] implemented an information system platform for quality and security of agricultural products based on Internet of Things. Fruitful researches showed that context-aware computing based on Internet of Things is a clear direction of future agriculture.

1.3 Image-based methods in agriculture

Image-based methods have particular advantages including being non-destructive and non-contact, and the image capture process is fast enough for many synchronous data acquisition applications. Image-based methods are widely used in computer vision, analysis, feature extraction and reconstructions[16,17]. Yang and Tang[18] proposed a method for target visibility and measurement precision analysis of stereo vision systems. Xiong et al.[19] presented a framework of design on the system of farm land image acquisition and wireless transmission, of which the communication system was based on Zigbee and GPRS. Li[20] proposed a method of acquiring geometrical shape data of vegetal leaves based on image processing. Images contain large amounts of useful information for applications in agriculture.

Although various approaches have been developed for data acquisition and analysis, traditional image-based technologies cannot satisfy current agriculture applications such as canopy analysis, three-dimensional reconstruction, feature extractions, etc. Context- aware computing is a new challenge and opportunity for modern agriculture. The lack of effective image acquisition systems for context-aware computing is a prominent problem. This paper presents an image acquisition system for agricultural context-aware computing, as shown in Figure 1.

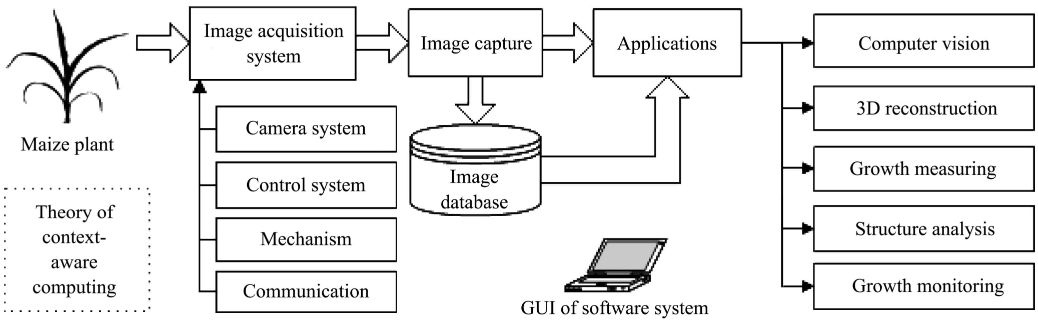

Figure 1 Framework of the system

2 Framework of the system

The presented image acquisition system includes four modules: the camera system, the control system, mechanism, and communication, as shown in Figure 1. Due to obstruction of crop canopy, the best shooting perspective was the top-down direction over the object plant, where most details can be differentiated in images from this angle. The framework was designed following this principle. A horizontal motion platform was set with adjustable height from the field ground. The distance between the camera and the top of crops was around 1 to 2 m. In order to obtain most complete plants' images, the platform was designed to move on a fixed level alone both X and Y directions. Figure 2 presents the main structure and components of the image acquisition system, including a support frame, a horizontal motion unit, a binocular stereo camera and an industrial computer. The motion range of the horizontal motion unit covered the objective canopy. A high resolution color camera was fixed nearby the stereo camera for color image capture which was necessary for creating the texture for structure analysis applications.

For motion of the horizontal platform on the XOY plane, a two-direction driving structure was designed, in which the motion unit could go freely in both ways. A cross slider structure was installed to the platform. One of motion statuses of the system on the Y-direction is shown in Figure 3, which included two supported slider-orbit systems and two chain-wheel driving systems. The wheels were supported by shafts fixed by bearings, and a common shaft insured the synchronous rotation of wheels. The motion beam was driven to move alone a fixed direction. At one end of the shaft, a transmission mechanism connected a step motor which powered the whole system.

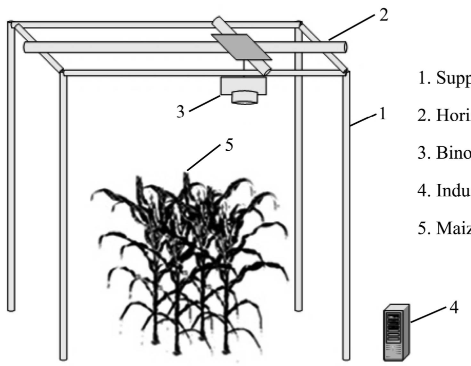

Figure 2 Main structure and components of the image acquisition system

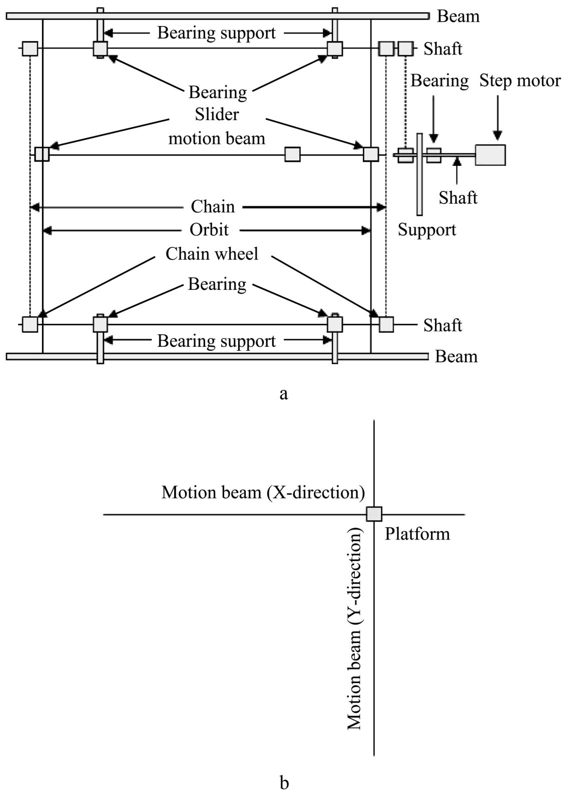

Figure 3 Sketch map of Y-direction motion system

3 Materials and methods

3.1 Implementation of the system

The system for experimenting on maize image capture was implemented in the experimental farm of Beijing Academy of Agriculture and Forest Science. The main framework was founded by a set of steel girder with 4 m length, forming a cubit frame with 4 m on each side. Sliders and motion beams were fixed to the framework. A cross platform linked two motion beams and the image capture system with a rainproof shell is appended under the platform, as shown in Figure 4. Chains and wheels were supported on appropriate positions and driven by two step motors in X and Y directions. In the experimental system, the distance between the camera plane and the ground was about 3.5 m, which was a proper height for maize image capture.

a

b

Figure 4 Results of constructed system in the maize field

3.2 Image acquisition

The growing density of maize crops in the experiment was 4000 plants /Chinese acre. The distance between two neighboring lines was 0.6 m, and the distance between two neighboring plants in a line was about 0.3 m. Due to the obstruction in maize canopy, we could get most information when the camera was placed closely above crop canopy. From this angle we collected images of maize canopy one plant at a time. The camera was driven by the motion beams which were driven by step motor. Synchronous images including binocular stereo images and color image were acquired at the same time controlled by software system. Figure 5 shows an example of a stereo image couple and the corresponding color image. All collected images were stored on the computer by capture time and plant order.

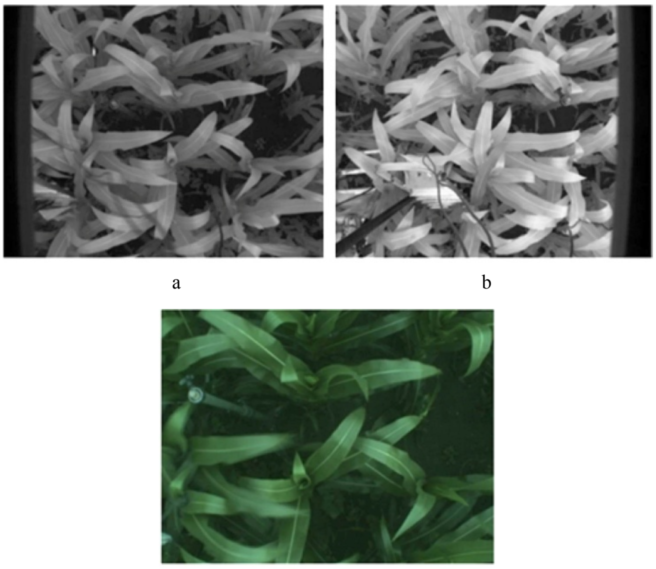

Figure 5 Example of captured stereo image couple and corresponding color image

3.3 3D Reconstruction by binocular stereo vision

Following the experiment design explained above and using technology binocular stereo vision, we computed the three-dimensional values in XYZ space by use of a couple of synchronous images. After calibration of visual space, we could define the projection matrixes P_i for the left and the right cameras, respectively when $i = 1$ or 2. A point was defined as $M[x, y, z]$ in 3D coordinate, and as $m1(x1, y1)$ and $m2(x2, y2)$ on the left and the right images, respectively. The value of M can be calculated by Equation (2).

$$P_i = \begin{bmatrix} a_{11}^i & a_{12}^i & a_{13}^i & a_{14}^i \\ a_{21}^i & a_{22}^i & a_{23}^i & a_{24}^i \\ a_{31}^i & a_{32}^i & a_{33}^i & a_{34}^i \end{bmatrix} \quad i = 1,2 \qquad (1)$$

$$\begin{bmatrix} (a_{11}^i - a_{31}^i x_i) & (a_{12}^i - a_{32}^i x_i) & (a_{13}^i - a_{33}^i x_i) \\ (a_{21}^i - a_{31}^i x_i) & (a_{22}^i - a_{32}^i x_i) & (a_{23}^i - a_{33}^i x_i) \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} x_i a_{14}^i \\ y_i a_{24}^i \end{bmatrix} \qquad (2)$$

4 Experimental results

4.1 Software development

To manage the device of image capture, we developed a software system named “Image Acquisition System for Agricultural Context-Aware Computing”. The system is running on an industrial computer in field environment with a 3.0GHz CPU and 2.0G memory. The system interface is shown in Figure 6 including menus, tool bar, control pane and image display view. At the beginning of a task, the software links the device and cameras. During system’s running, it captures the camera images and stores them in computer disk. Some additional functions such as image zoom, network management, data management are installed, too.

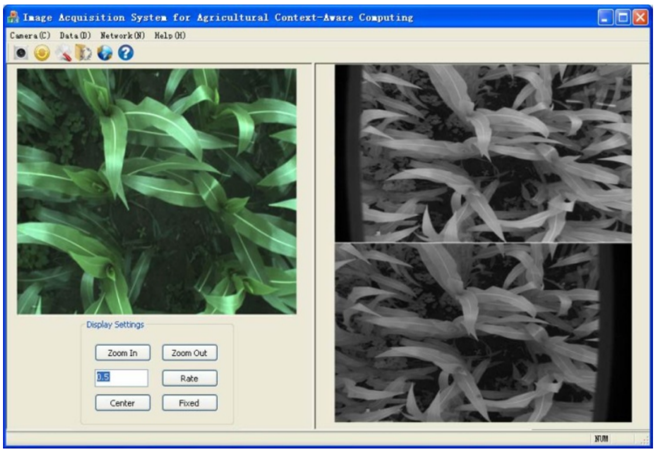

Figure 6 The interface of image collection software system

4.2 3D Reconstruction and computing

By use of 3D reconstruction approach based on binocular stereo vision introduced in Section 3.3, we reconstructed maize canopy point cloud model for typical scenes and images, as shown in Figure 7. Initial data of 3D model included lots of noise points. An important work for data analysis and computing is data processing for noise filtering. The next step was to compute agricultural parameters for maize production such as plant height. In the point cloud model of maize canopy, the density of points in different area was obviously distinct. The ground has the highest density, and plant is second highest. Noise points have the least density. So we used the density of point cloud models, and fitted a plane to approximate ground, as shown in Figure 7. In the post computing stage, by means of a set of processing algorithm including filtering, clustering, we calculated the value of plant height and distances between lines and plants. Plant height was defined as the vertical distance from the top point of a plant to fitted land in the processed model without noise data. The key point of this work is the image capture approach and system. The processing algorithm is not the emphases of this paper, thus it is not extended here.

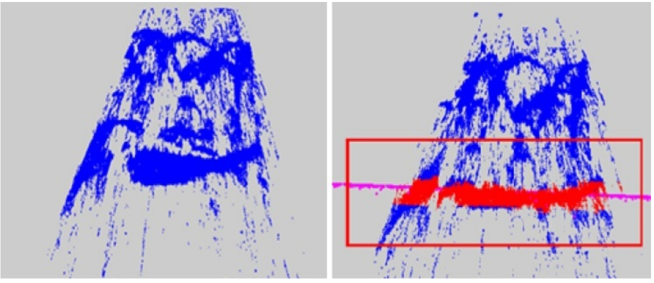

Figure 7 3D Plant models reconstructed by aware images

4.3 Discussion

Experimental results show that the system was an effective tool for agricultural image acquisition. Images retrieved can be used in various applications such as computer vision system for crops, three-dimensional reconstruction of crop canopy, crop growth measuring and monitoring, and canopy structure analysis.

Using context-aware computing, we can obtain maize plant parameters such as plant height, number of leaves, line distance, plant distance, canopy density, etc., which suggests potential applications of the presented methods and the constructed image capture system.

5 Conclusions

An image acquisition system including mechanism and software system was designed and implemented in this study. The system includes four modules: the camera system, the control system, mechanism and communication. Driven by cross motion beams, the camera system captures binocular stereo images and color images of crops. To achieve the image acquisition aim for crops, we designed and installed the system in an experimental farm. Experiments results proved the feasibility and effectiveness of the system. The system has the potential of becoming a widely applicable data capture tool for agricultural context-aware computing applications in outdoor field conditions. It is applicable for a variety of plants such as maize, rice, wheat, etc. However, due to volume and structure limitations, it is not suitable for large-size crop canopy. In future research, we expect to focus on automatic and robotic acquisition technology to improve the system for expanded crop applications.

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