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Research of Key Technology for Microscopic Image Processing Platform in Sugar Cane Crystallization Process

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Realization of automatic sugar cane crystallization process depends on the development of advanced detective technology. At present, most factories still rely on manual operation to extract sucrose. And workers deduce the extent of further absorption and sucrose brix level by watching the seed size in mother liquor. Detective method based on visual observation of artificial morphology brings some disadvantages, such as strong subjectivity, observation error of each index, time-consuming, hard sledding and inefficient. Lack of detective method seriously hinders the development of automatic sugar crystallization process. As an on-line detection technology, image process has been widely used in industry. The use of image process helps computer to make real-time decision, thus raising automatic level. In order to meet the requirement of sucrose on-line real time testing during sugar crystallization process, this paper researches some key technology for microscopic image processing platform. Modular design approach is adopted in this platform, which includes hardware architecture and software architecture. Hardware architecture, which realizes the function of sucrose automatic sampling, image acquiring and transmission, consists of automatic sampling and imaging device, lighting source system and image acquisition system. Software architecture consists of the self-developed sugar particle image process software (SPIPS) based on VC++ 6.0, which realizes the function of image displaying and storage, image preprocess, image feature extraction and crystallization state prediction. Improved watershed algorithm is used to achieve the segmentation of the adhesive particles. The attribute reduction and state classification of the crystals is realized by combining rough set and Gaussian process classification method. Experimental result shows that this platform is able to meet the requirement of actual production. What's more, this platform is faster and more precise than other detection methods.

1. Introduction

Crystallization process is the most important step in sugar boiling process. However, it is also the only process that doesn't realize automatic control. At present, most factories still rely on manual operation to extract sucrose. And workers deduce the extent of further absorption and sucrose brix level by watching the seed size in mother liquor, which is depending on their experience. The detective method based on artificial visual observation brings strong subjectivity, observation error, time-consuming, hard sledding and other disadvantages, which is confirmed by Huang (2004). Realization of automatic sugar cane crystallization process depends on the development of advanced detective technology. Patricio, Maravall (2007) and Wang (2005) reported that using image recognition technology to realize visualized operation in sugar crystallization process, will help to judge the sucrose quality and make control decision in real time, on line and directly. There are some similar researches in recent years. Zhang (2010) uses color space transformation and improved Otsu threshold method to process sucrose image. Some characteristic values, such as the number, area, perimeter, and shape index, are extracted after image preprocess. Wang, Zhu and Fan (2009) design the detective system for crystals in sugar cane crystallization. Million pixel CCD camera and machine vision algorithms are adopted to obtain crystal image and process the image relatively. This system is proved to have some feasibility, but the computation time of it is too long, which is meant to low efficiency. Pan, Zhu and Zhang (2010) design the image acquisition and control system for sugar cane crystallization. Some characteristic values are obtained by image process algorithm. These values are sent to the host computer to combine with the original controlling parameters, and the control commands are sent by wireless sensor. Pan, Zhu and Zhang (2010) also design a sucrose image information acquisition system based on S3C2440 embedded hardware processing platform and WinCE 5.0 operating system. This system has friendly interface, which can realize function of real-time monitoring, photographing and storing. This system reduces system complexity effectively, and saves storage space greatly. Faria et al (2003) designs the automatic image analysis system for sucrose crystals based on discriminant factor analysis (DFA) method. Crystals are identified by calculating the classification output degree, and is furtherly divided into two types according to the projection profile. Liao, Yu and Tarng (2010) develop an on-line detective system for particle size analysis. Particle images are obtained by optical linear scanning technology, and are analyzed by digital image processing. This system consists of four modules, such as particle separation module, image acquisition module, image processing module and an electric control module. The particle size distribution and roundness can be obtained by using this image analysis system. From the research status of sucrose image process detection, there are not any related researches on microscopic image processing platform for sugar cane crystallization process, especially the research of automatic sampling mechanism and crystallization state technology.

According to the actual requirement of sucrose detection in sugar boiling process, some key technology for microscopic image process platform is researched in this paper. Modular design approach is adopted in this platform, which includes hardware architecture and software architecture. Hardware architecture, which realizes the function of sucrose automatic sampling, image acquiring and transmission, consists of automatic sampling and imaging device, lighting source system and image acquisition system. Software architecture consists of the self-developed sugar particle image process software (SPIPS) based on VC++ 6.0, which realizes the function of image displaying and storage, image preprocess, image feature extraction and crystallization state prediction. Improved watershed algorithm is used to achieve the segmentation of the adhesive particles. Experimental result shows that this platform is able to meet the requirement of actual production. What’s more, this platform is faster and more precise than other detection methods. By getting information of sucrose crystal’s shape and size, as well as predicted crystallization state, this platform provides important date support for realization of automatic control in sugar crystallization process.

2. Overall structure of sugar cane crystallization microscopic image process platform

As is shown in Fig. 1, overall architecture of sugar crystallization microscopic image process platform includes hardware architecture and software architecture. Hardware architecture consists of automatic sampling and imaging device, lighting source system and image acquisition system, which will obtain sucrose crystallization image data automatically and transmit them to the host computer for image process via Ethernet. Software architecture is composed of sugar particle image process software (SPIPS), including four modules which are image display and storage, image preprocess, image feature extraction and image crystallization state prediction. Processing result will be sent to the open intelligent monitoring experiment platform during sugar boiling process by OPC server. Host computer makes real-time decision based on the processing result, and controls valve opening of sugar syrup and hot water, thus controlling the flow of material to realize automatic production of sugar boiling process.

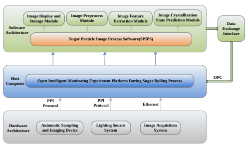


Figure 1: Overall structure of sugar cane crystallization microscopic image process platform

3. Hardware design of sugar crystalli-zation microscopic image process platform

By using symmetrical double eccentric structure and crank-rocker mechanism to realize reciprocating motion, this device can extract sugar crystal from sugar tank body, and also clean the imaging platform automatically after imaging. As is shown in Fig. 2, this device consists of nine parts, such as sampling rod, guide rail, slider, and other components. Experiment results showed that this device can prevent overlapping and adhesive situation effectively, which lays a good foundation for the image data acquisition.

4. Software design of sugar crystallization microscopic image process platform

4.1 Software Function

The main function of sugar particle image process software (SPIPS) is processing digital image which is converted by computer from the CMOS camera. Using relevant algorithm to analyze crystal image, SPIPS can obtain some key features, such as shape, size and crystallization state level of each sucrose. The main feature of SPIPS includes four parts, such as image display and storage, image preprocess, image feature extraction and image crystallization state prediction.

4.2 Modular Design

This paper designs four functional modules. Image preprocess module uses some effective preprocess methods to preprocess the real-time image. After image preprocess, the image feature extraction module obtains sugar crystal's seven characteristic values. There are only four characteristic values left after attribute reduction. Considering these four characteristic values, image attribute reduction and crystallization state prediction can obtain crystal state level, which is taken by operator to determine current process in sugar boiling process.

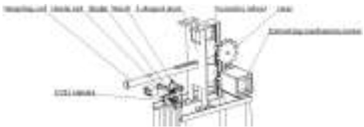
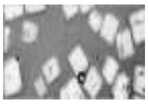


Figure 2: Internal mechanical structure diagram of automatic sampling and imaging device

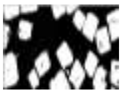
4.2.1 Image Preprocess Module

This paper uses piecewise linear gray level transformation to enhance image and expand contrast of the sugar crystal and its background, which was confirmed by CASTLEMANKR (1998). Using adaptive median filtering algorithm based on PCNN, this platform can eliminate pepper and pulse noise from image acquisition and transmission. Using Otsu thresholding, this platform can separate the sugar crystal from its background, which was confirmed by Ferreira, et al (2005)]. Using morphology denoising method, this platform can take opening operation, hole searching and filling for the image after thresholding. Because the image still remains crystal adhesion phenomenon after above process, this paper adopts an improved watershed segmentation based on distance transform to segment adhesive crystal.

The process and result of image preprocess is shown in the following Fig. 3(a)~(h). Fig. 3(e) shows that the hole in particle is searched precisely. According to the final image shown in Fig. 3(h), image preprocess module achieves good result, which eliminates background noise basically and segments the adhesive crystal completely.

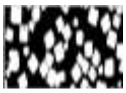



(a) Piecewise linear gray level transformation (b) Piecewise linear gray level transformation




(c) Otsu thresholding (d) Morphology opening operation denoising


(e) Hole searching (f) Hole searching




(g) Crystal image which exists adhesive situation (h) Improved watershed segmentation

Figure 3: Result of image preprocess

4.2.2 Image Feature Extraction Module

Extracting features of sugar crystal is the most important part of the software architecture, which was confirmed by Zhou, Srinivasan and Lakshminarayanan (2009). Usually crystal features include two aspects, one is the parameter which measures crystal size, including perimeter, area and so on. The others are parameters which measure crystal shape, including shape factor and so on. This paper selects seven parameters as characteristic values, which are shown in Table 1.

Table 1: Characteristic parameters and expressions of sugar crystal

Characteristic parameters	Expression
Mean area: $\bar{S}$	$\bar{S}=\sum_{i=1}^{n} S_i / n$, where $S_i=\sum_{j=1}^{n}(X_{jR}-X_{jL}+1),\ 1\le j<n$
Area variance: $\sigma_S{}^2$	$\sigma_S{}^2=\frac{\left[\left(S_1-\bar{S}\right)^2+\left(S_2-\bar{S}\right)^2+\cdots+\left(S_n-\bar{S}\right)^2\right]}{n}$
Area difference between two continuous detection: E	$E=\bar{S}-\bar{S}_b$, where $\bar{S}_b$ is the mean crystal area for the first time
Mean perimeter: $\bar{L}$	$\bar{L}=\sum_{i=1}^{n} L_i / n$, where $L_i=N_{i1}+N_{i2}+\sqrt{2}N_{i3},\ \ 1\le i<n$
Perimeter variance: $\sigma_L{}^2$	$\sigma_L{}^2=\frac{\left[\left(L_1-\bar{L}\right)^2+\left(L_2-\bar{L}\right)^2+\cdots+\left(L_n-\bar{L}\right)^2\right]}{n}$
Mean shape factor: $\bar{P}$	$\bar{P}=\sum_{i=1}^{n} P_i / n$, where $P_i=L_i^2/4\pi S_i,\ \ 1\le i<n$
Mean value of minimum bounding rectangle area: $\bar{S}'$	$\bar{S}'=\sum_{i=1}^{n} S_i'/n,\ \ 1\le i<n$

4.2.3 Attribute Reduction and Crystallization State Prediction Module

The main idea of this module is shown as Fig. 4.

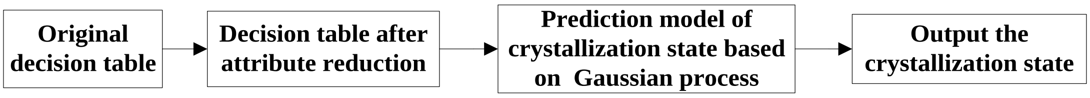


Figure 4: Main idea of attribute reduction and crystallization state prediction module

In order to increase the speed of image process and ensure the accuracy of process result, this paper uses rough set theory to do attribute reduction for above feature values, which was confirmed by Meng (2013). This paper builds initial decision-making table by taking the above seven feature values as input and crystallization state as output. The number of sample feature values is turned into four after attribute reduction, respectively, which are the mean area, area variance, area difference between two continuous detection and perimeter variance. This result is helpful to reduce the time of image process, thereby increasing process speed. What's more, Gaussian classification model is established, and the original image data is divided into five categories. Namely, this paper uses 1 to 5 to represent the crystallization state, which is the best, the better, good, fair, and poor.

4.3 Analysis of Experimental Results

This paper selects an image sample which has a capacity of 50 to make experimental analysis. We obtain sugar crystal image from state 1-5 by sugar crystallization microscopic image process platform, and arrange the set of image randomly, so as to ensure this sample set having excellent representation. Then the image is input into SPIPS for real time image analysis, and we get the process time and crystallization state prediction result before and after attribute reduction. The result is shown in Fig. 5 and Fig. 6. In order to prove the efficiency of Gaussian algorithm, we input the same sample into expert system and get process time, which is shown in Fig. 7.

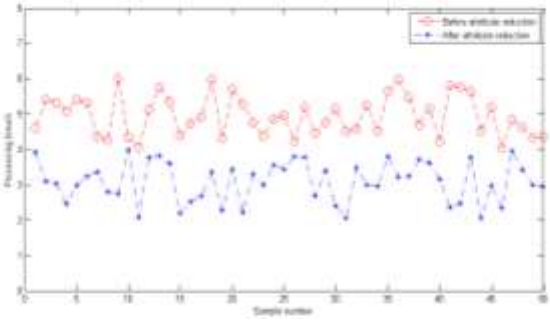


Figure 5: The contrast of processing time before and after attribute reduction

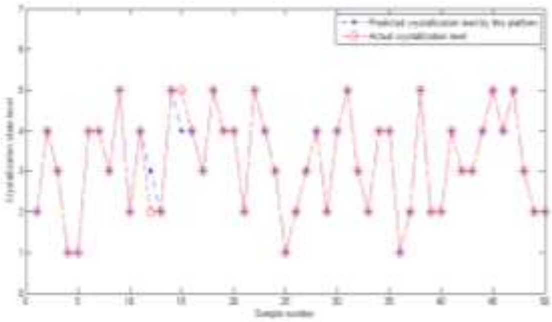


Figure 6: The contrast between actual level and prediction level

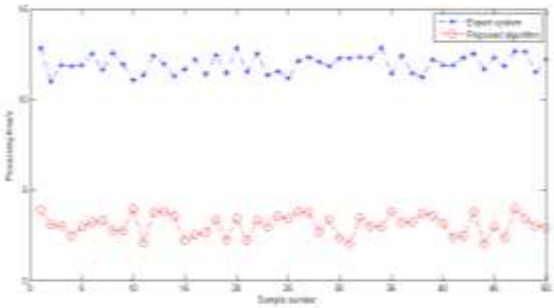


Figure 7: The contrast of processing time between expert system and proposed algorithm

Experimental results show that the proposed SPIPS based on rough set attribute reduction and Gaussian process classification has good prediction accuracy and process speed, and the error between prediction and actual result is small, the prediction accuracy rate of which is 96%. What's more, the calculation time of proposed algorithm is 3~5 s approximately, which is half of the expert system, proving that the operation speed is greatly improved. The prediction result is returned to the sugar boiling process intelligent monitoring comprehensive experimental platform, which can determine the next step according to the crystallization state. The purpose of automatic sugar boiling process is achieved by controlling the valve opening degree.

5. Conclusions

In order to solve the problem that there isn't any visualized real-time detection way in sugar boiling process, this paper researches the key technology of sugar crystallization microscopic image process platform. This platform adopts modular design approach to design and develop hardware architecture and software architecture. This platform uses symmetrical double eccentric structure and crank-rocker mechanism to realize the design of automatic sampling and imaging device, combined with lighting source system and image acquisition system to finish the design of hardware architecture. And VC++6.0 is applied to design sugar particle image process software (SPIPS), using morphology optimization, watershed segmentation algorithm based on distance transform and classification algorithm based on Gaussian process to complete the design of four modules, such as image display and storage module, image preprocess module, image feature extraction module and image crystallization state prediction module. Experimental result shows that this platform has a fast process speed than expert system, and the prediction accuracy is 96% with stable performance and high feasibility.

Acknowledgments

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