Sensor Review

Crystalline object evaluation by image processing

Kuniaki Kawabata
RIKEN, Hirosawa, Wako, Japan
Mutsunori Takahashi
Saitama University, Sakura, Saitama, Japan
Kanako Saitoh
Saitama University, Sakura, Saitama, Japan
Mitsuaki Sugahara
RIKEN, Spring-8 Center, Sayo-cho, Sayo, Japan
Hajime Asama
The University of Tokyo, Kashiwanoha, Kashiwa, Japan
Taketoshi Mishima
Saitama University, Sakura, Saitama, Japan
Masashi Miyano
RIKEN, Spring-8 Center, Sayo-cho, Sayo, Japan

Sensor Review, Vol. 28 No. 2, 2008,

Sensor Review

ISSN 0260-2288

Awarded in recognition of Emerald's production department's adherence to quality systems and processes when preparing scholarly journals for print

Indexed and abstracted in:
CAD-CAM Abstracts
Cambridge Scientific Abstracts
CSA Aerospace and High Technology Database
CSA Civil Engineering Abstracts
CSA Computer and Information Systems Abstracts
CSA Earthquake Engineering Abstracts
CSA Electronic and Communications Abstracts
CSA Mechanical & Transport Engineering Abstracts (Selective)
CSA Solid State and Superconductivity Abstracts
Engineered Materials Abstracts
Engineering Information
INSPEC Database
Metals Abstracts
PNA Research
Scopus
Zetoc Electronic Table of Contents

Sensor Review provides up-to-date coverage of international activities that relate to the design and application of sensors and sensor systems. Coverage is essentially of a practical nature and designed to be of material benefit to those working in the field. Proven applications are covered together with company news and new product information. *Sensor Review* now also includes research articles that reflect the most interesting and strategically important research and development activities from around the world. A double-blind review process ensures the validity and relevance of all academic articles.

This journal is also available online at:
Journal information
www.emeraldinsight.com/sr.htm
Table of contents
www.emeraldinsight.com/0260-2288.htm

Emerald Group Publishing Limited
Howard House, Wagon Lane,
Bingley BD16 1WA, United Kingdom
Tel +44 (0) 1274 777700
Fax +44 (0) 1274 785201
E-mail **emerald@emeraldinsight.com**

INVESTOR IN PEOPLE

Regional offices:

For North America
Emerald, 875 Massachusetts Avenue, 7th Floor,
Cambridge, MA 02139, USA
Tel Toll free +1 866 901 1923; Fax +1 617 354 6875
E-mail **america@emeraldinsight.com**

For Japan
Emerald, 3-22-7 Ohwada, Ichikawa-shi, Chiba, 272-0025, Japan
Tel +81 47 393 7322; Fax +81 47 393 7323
E-mail **japan@emeraldinsight.com**

For India
Emerald, 301, Vikas Surya Shopping Mall, Mangalam Place, Sector -3,
Rohini, New Delhi -110085, India
Tel +91 11-27948437/8; Fax +91 11-27948437/8
E-mail **india@emeraldinsight.com**

For Asia Pacific
Emerald, 7-2, 7th Floor, Menara KLH, Bandar Puchong Jaya,
47100 Puchong, Selangor, Malaysia
Tel +60 3 8076 6009; Fax +60 3 8076 6007
E-mail **asiapacific@emeraldinsight.com**

For China
Emerald, 7th Xueyuan Road, Haidian District,
Room 508, Hongyu Building 100083, Beijing, China
Tel +86 10 8230 6438
E-mail **china@emeraldinsight.com.cn**

Customer helpdesk:
Tel +44 (0) 1274 785278; Fax +44 (0) 1274 785201;
E-mail **support@emeraldinsight.com**
Web **www.emeraldinsight.com/customercharter**

Orders, subscription and missing claims enquiries:
E-mail **subscriptions@emeraldinsight.com**
Tel +44 (0) 1274 777700; Fax +44 (0) 1274 785201

Missing issue claims will be fulfilled if claimed within six months of date of despatch. Maximum of one claim per issue.

Hard copy print backsets, back volumes and back issues of volumes prior to the current and previous year can be ordered from Periodical Service Company. Tel +1 518 537 4700;
E-mail **psc@periodicals.com** For further information go to
www.periodicals.com/emerald.html

Reprints and permission service
For reprint and permission options please see the abstract page of the specific article in question on the Emerald web site (**www.emeraldinsight.com**), and then click on the "Reprints and permissions" link. Or contact:
Copyright Clearance Center- Rightslink
Tel +1 877/622-5543 (toll free) or 978/777-9929
E-mail **customercare@copyright.com**
Web **www.copyright.com**

Emerald is a trading name of Emerald Group Publishing Limited

Printed by Printhaus Group Ltd, Scirocco Close,
Moulton Park, Northampton NN3 6HE

Research article

Crystalline object evaluation by image processing

Kuniaki Kawabata
RIKEN, Hirosawa, Wako, Japan

Mutsunori Takahashi and Kanako Saitoh
Saitama University, Sakura, Saitama, Japan

Mitsuaki Sugahara
RIKEN, Spring-8 Center, Sayo-cho, Sayo, Japan

Hajime Asama
The University of Tokyo, Kashiwanoha, Kashiwa, Japan

Taketoshi Mishima
Saitama University, Sakura, Saitama, Japan, and

Masashi Miyano
RIKEN, Spring-8 Center, Sayo-cho, Sayo, Japan

Abstract
Purpose – The purpose of this paper is to propose a state discrimination for crystallization samples (droplets), the purpose of which is to discriminate between diffractable extracts (crystal) and other objects.
Design/methodology/approach – The line feature from the image of the protein droplet was extracted and the state discriminated using a classifier based on line features. A support vector machine is used as the classifier.
Findings – In order to verify the performance of the proposed method, the growth state was discriminated experimentally using the images taken by TERA, an automated crystallization system. The correction ratio was determined to exceed 80 percent.
Originality/value – Contribution to automated evaluation process of the growth state of protein crystallization samples.

Keywords Crystallization, Image processing

Paper type Research paper

Introduction

Recently, the clarification of protein structures and functions for the purposes drug discovery and clarifying vital activity has been studied extensively in structural genome science, and higher-throughput protein structure analysis (in terms of both quantity and speed) is required. High-throughput X-ray structure analysis is a commonly used method of protein structure analysis. In the crystallization process using X-ray structure analysis, it is necessary to obtain fine-quality protein crystals by crystallization with protein solutions. However, specific crystallization conditions (factors that facilitate the crystallization of protein solution, such as temperature, types of chemicals to be added) of protein solution are generally unknown. In order to examine the numerous possible combinations of crystallization conditions, numerous experiments under various crystallization conditions must be conducted, and this limitation has prevented the realization of high-throughput X-ray structure analysis. Thus, research and development of a robotic crystallization system is important for the realization of a high-throughput crystallization process.

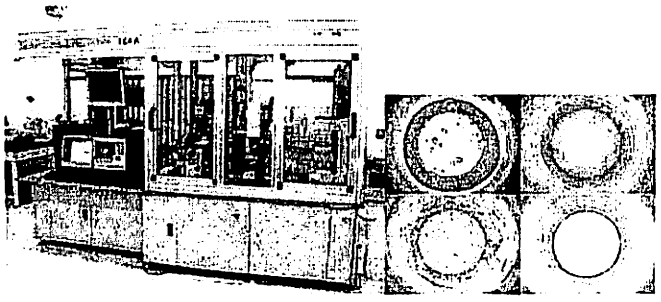
Currently, the TERA automatic crystallization system is under development at the RIKEN Harima Institute (Sugahara and Miyano, 2002). In this crystallization system, a protein solution-blending unit and a handling unit for administrating the droplets have been already realized. This system is also equipped with a camera unit and can automatically capture images of crystallization droplets. Figure 1 shows the TERA system and a number of sample images captured using the TERA system. The acquisition image size is 1,392 × 1,040 pixels, and the pixel size is 4.65 × 4.65 μm.

However, at present, the task of identifying samples that contain subjects for X-ray diffraction experiments is

The current issue and full text archive of this journal is available at
www.emeraldinsight.com/0260-2288.htm

Sensor Review
28/2 (2008) 143–149
 [ISSN 0260-2288]
[DOI 10.1108/02602280810856714]

Figure 1 Automatic crystallization system – TERA – and examples of autographed images



performed manually. Thus, the images have been evaluated through observation by human experts (observers). The score decision is also conducted in order to evaluate and record the growth condition of each crystallization droplet by matching crystals with the score decision criteria. TERA can take 500,000 images per month, and it is difficult to process all of the images by observers. Therefore, an efficient protein structure analysis experiment to realize automation of the score decision work is needed.

Previous studies on automated growth evaluation of crystallization solutions employed various methods, including the utilization of polarized filters(Bodenstaff *et al.*, 2002), a rotating-polarizing filter (Echalier *et al.*, 2004), and image processing (Cumbaa *et al.*, 2003, Zuk and Ward, 1991). Rupp (2003) used phase congruency to detect a large number of small crystals and Gester *et al.* (2003) automated the counting of the number of crystals to generate three-dimensional surface plots of the crystals and to determine crystal size based on the length of the perimeter of the crystals. Miyatake *et al.*(2005) developed an automated crystallization/observation robotic system: HTS-80, which was reported to be able to categorize the crystallization droplet status into four stages based on extracted contour information. Most of these previous studies focused on the existence or absence of a crystal. No detailed study to determine whether detected crystals are suitable for X-ray diffraction experiments has yet been conducted. Nonetheless, for efficient high-throughput protein structure analysis, it is important to determine whether a specific crystal from among a large number of crystallization droplets is suitable for X-ray diffraction analysis.

Thus, in previous studies, the determination of whether a detected crystal is actually a subject for the X-ray diffraction experiment was not discussed in any detail, despite its importance to efficient protein structure analysis. In order to realize a high-throughput crystallization process, a large number of crystallization samples should be treated, and it is important to judge whether there is sufficient subject crystal for the X-ray diffraction experiment.

The reason why it is not easy to automate such observation processes is thought to be that there is no definition of detailed criteria for evaluation. In the present paper, we attempt to evaluate the incipient growth states of protein crystallization droplets by image processing and statistical analysis in order to achieve a categorization accuracy of more than 80 percent in individual classes, whereas the evaluation accuracies in each class for the above-mentioned methods are not stabilized.

Categorization of crystallization droplets

The purpose of the present study is to determine whether the crystallization droplet contains the subject for the X-ray diffraction experiment. In the score decision criteria (Figure 2), scores between 6 and 9 indicate the condition in which the sample contains the subject, and scores between 0 and 5 indicate the condition in which the sample does not contain the subject. We realized a highly accurate determination of the scores 0, 1, 2, 3, and 4-9 in a previous study Saitoh *et al.* (2004, 2005). Thus, in the present study, we discuss only scores between 4 and 9, and images of crystallization droplets evaluated scores between 4 and 9 are classified into either category A, in which a sample containing the subject for the X-ray diffraction experiment is indicated by scores between 6 and 9, or category B, in which a sample that does not contain the subject for the X-ray diffraction experiment is indicated by scores between 4 and 5 (Figure 3).

Scores between 5 and 9 indicate that the sample contains protein crystals. A score of 5 (microcrystal) is not considered to be an experimental subject for the X-ray diffusion experiment due to its insufficient size. The relationship between score and crystal size is shown in Table I. A score of 4 (amorphous grain) denotes that the sample is not crystal and is not an experimental subject for the X-ray diffusion experiment.

Figure 4 shows some typical examples of images captured by the TERA system. The proposed method was evaluated using such images, which depict several crystalline objects in

Figure 2 Score decision criteria

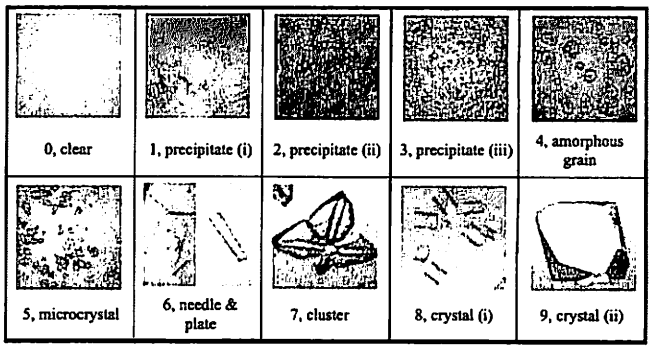


Figure 3 Decision category

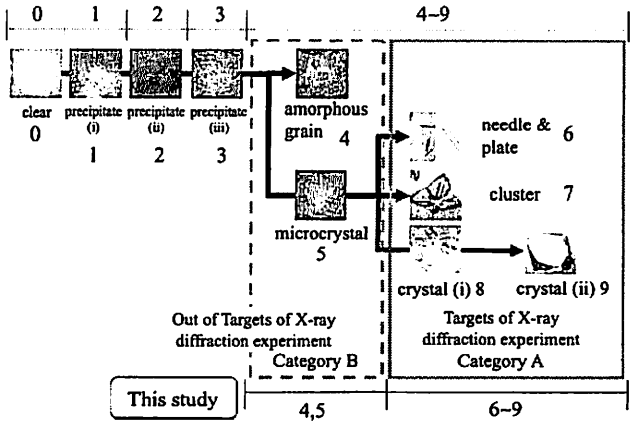
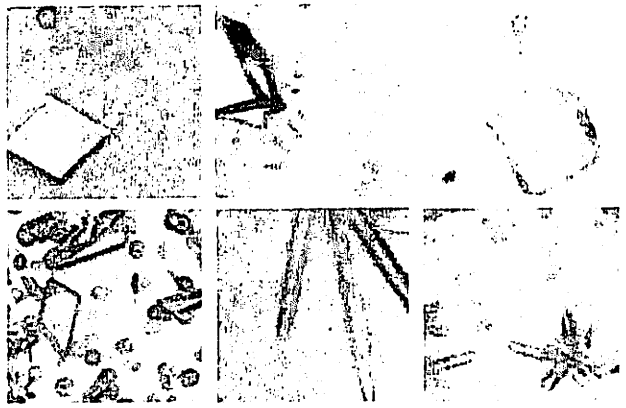


Table I Categorization criteria

	Score 5 (Category B)	Scores 6 ~ 9 (Category A)
Size		
Length (long side)	Less than 0.05 mm	0.05 mm or more
Thickness	Less than 0.01 mm	0.01 mm or more
Width	Less than 0.01 mm	0.01 mm or more

Figure 4 Examples of images obtained by TERA. Several growth states are present in the same droplet



various stages of growth (amorphous grain, microcrystal, and crystal) in the same droplet. For example, some of the droplets contain amorphous grains and microcrystals, and others contain microcrystals and crystals.

In the present paper, we discuss a method by which to determine whether a detected crystal is actually a subject for the X-ray diffraction experiment based on image processing.

Proposed method

The determination process, in which it is determined whether the crystallization droplet contains an object for the X-ray diffraction experiment, is a sort of pattern recognition process. The determination process is used to categorize images of crystallization droplets as images that contain the subject for the X-ray diffraction experiment or images that do not contain the subject for the X-ray diffraction experiment. The pattern recognition process consists of a sequence of preprocessing, feature extraction, and determination. For accurate determination, it is important that proper features are selected for the problem. In order to evaluate the second half of the growth period (scores between 4 and 9), the experts observe objects in the crystallization droplet (such as crystal amorphous grain). The experts commented that they determined whether the subjects were appropriate for the X-ray diffraction experiment based on shape or size. Thus, the characteristic shapes of objects are regarded as characteristic contours, and these contours are employed as feature values. Figure 5 shows the workflow of the proposed method.

Preprocessing

For the extraction of feature values, images are preprocessed, and the contours of the objects are extracted as binary edge images (Figure 6). For this purpose, original color images are

Figure 5 Workflow of the proposed method

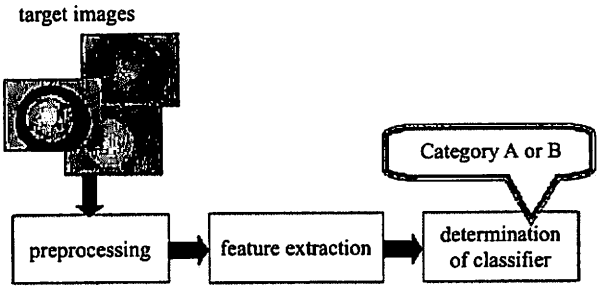
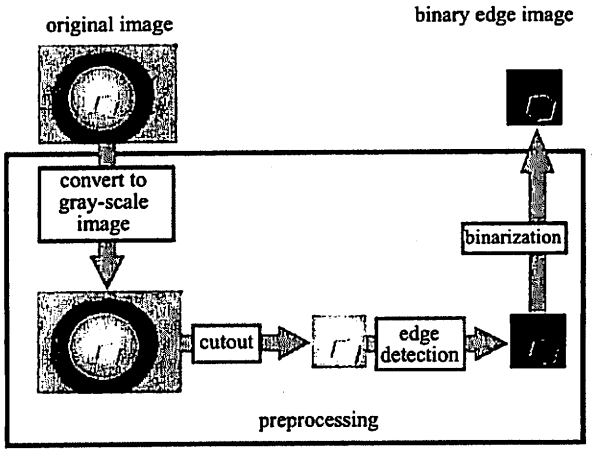


Figure 6 Workflow of preprocessing



converted into 256-level grayscale images. Since, the original images depict not only the crystallization droplet but also the lateral side of the droplet plate and near the base of the plate, only part of the image containing the crystallization droplet need be cut from the grayscale images. The size of the cut-out images was set at 450 × 450 (pixel) such that most of the droplet at the base could be included. In the present paper, we focus on crystal growth evaluation. Therefore, in this stage, the images are cut out manually and an automated system is a subject of future research.

Next, the edge detection process is applied to the cut-out images in order to emphasize the contours of objects in the crystallization droplet. Among the various edge detection methods, the Sobel transformation, which is a general method, was employed in the present study. Following the Sobel transformation, binarization processing is conducted on the edge-detected images to extract the contours of objects as the binary edge images. In the usual binarization, a certain threshold value is fixed, and only the pixels with grayscales that are equal or greater than the threshold value are considered as objects (edge pixels). However, the threshold configuration remains a key problem. When crystallization droplet images of the objects were binarized using the threshold value that was configured by the discriminant analysis, several problems were encountered. For example, a subtle concentration difference in the crystallization droplet was extracted as a contour line, and the contours of the objects could not be completely extracted.

More concretely, the edge magnitude distribution of 100 images that did not contain any objects from among the

images with a score of 0 (clear) was investigated (Figure 7). A threshold value of 29 that binarized 99.9 percent pixels of this distribution was employed as a background to extract the contour lines. As a result, TERA maintained its illumination condition for capturing the image, and so the threshold value can be used as a fixed value in this experiment.

Here, we discuss the determination of the threshold value for the images captured by TERA. The determination sequence can be applied to the images of another system when such a system can maintain the same condition for capturing the image of the droplet.

Feature extraction

Using the binary edge images of the contours of the extracted object that were obtained by preprocessing, the effective feature values for the determination were extracted based on the relationship between the size of the crystals and the scores, as shown in Table I. Comparison of the contour lines belonging to category A and category B shows that most of the contour lines of crystals belonging to category A are longer than the contour lines of microcrystal (score 5) belonging to category B (Figure 8).

In addition, if the curved contours lines of non-crystalline grain (score 4) consist of a collection of short line segments, the contour lines of objects in category B have short line segments. In other words, in categories A and B, the lengths of the line segments that comprise the contour lines of the objects differ from each other (Figure 9).

Consequently, the longest line segments within the images (maximum length, L_{max}) were utilized as the feature value. Furthermore, the number of objects in images belonging category B tends to be greater than that in the images belonging category A. As a result, the number of line segments is also proportionally greater (Figure 10). Therefore, the number of line segments within the object images (N_{all}) was employed as a feature value.

In order to extract the maximum length, L_{max}, a number of line segments, N_{all}, from among the feature values, linear features are scanned within the binary edge images. The edge pixels that exist sequentially in-line are considered to be the line segments, and their lengths and numbers are determined. However, since it is impossible to predict either the location at which objects will be formed in the crystallization droplet or the location of contour lines that will be obtained by preprocessing,

Figure 7 Edge magnitude distribution of clear images

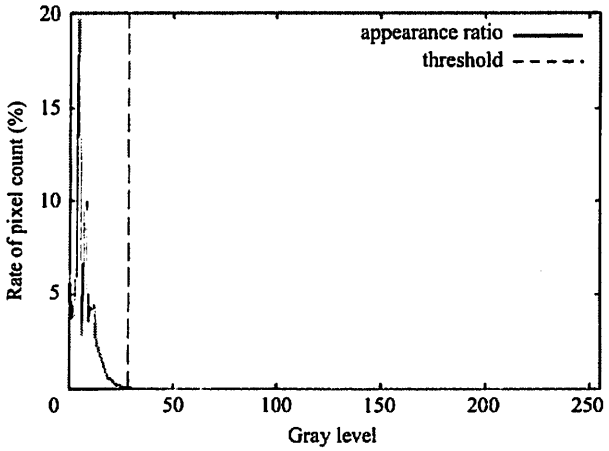


Figure 8 Examples of categories A and B

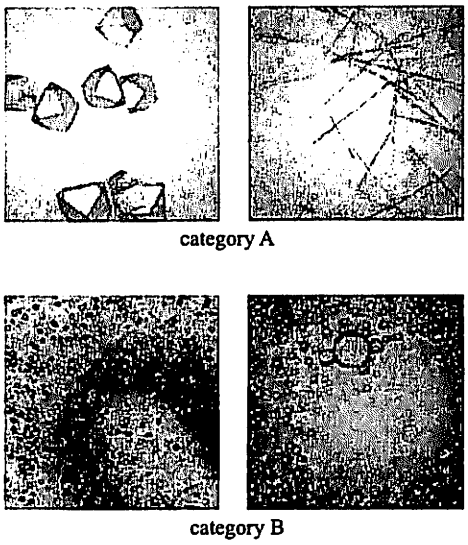


Figure 9 Contour lines comprising the objects

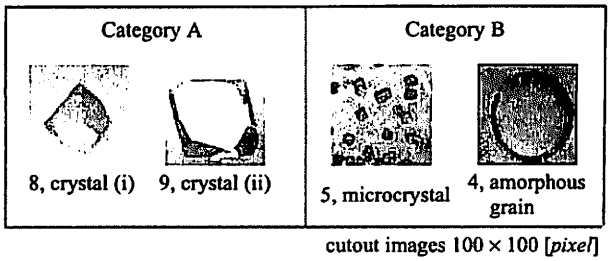
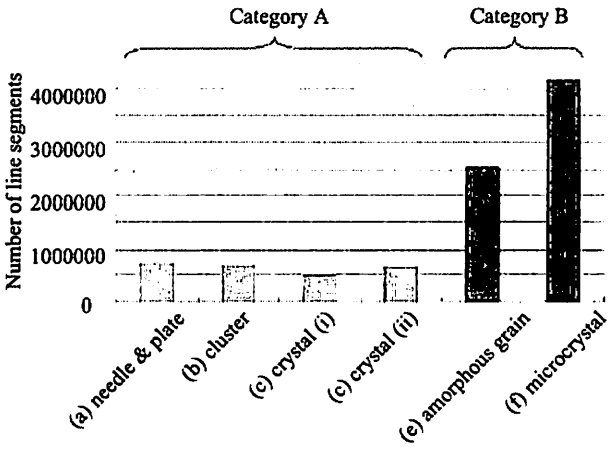


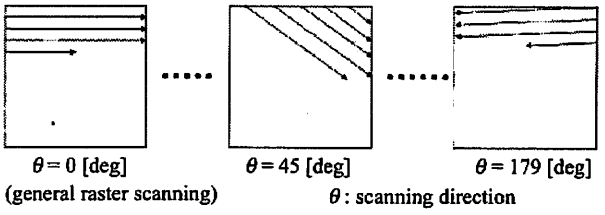
Figure 10 Number of line segments in categories A and B



the object images must be scanned from every possible direction. Thus, raster scanning was applied by altering the scanning direction, θ, ($0 \leq \theta < 180$ (deg), resolution: 1 (deg)) (Figure 11).

An edge pixel that was detected on a scanning line, when n-1 line segments had already been detected, was counted as the nth line segment, and the pixel was considered to be the origin of the nth line segment $S_n(x_{sn}y_{sn})$, and the scanning

Figure 11 Raster scanning in the θ direction



process was continued. Next, when the edge pixel was discontinued on the scanning line or a scanning point was reached at the margin of an image, the last edge pixel was considered to be the terminal $E(x_{en}y_{en})$. In this case, the length of the nth line segment (L_n) was defined as:

$$L_n = \sqrt{(x_{en} - x_{sn})^2 + (y_{en} - y_{sn})^2} \quad (1)$$

and is added to the total number of line segments. If a total of m line segments were detected at the completion of scanning, then the maximum length $L_{\max}$ and the number of line segments N_{all} can be evaluated as:

$$L_{\max} = \max(L_n) \quad (1 \le n \le m) \quad (2)$$

$$N_{all} = m, \quad (3)$$

respectively.

Classifier for categorization

The maximum length of the extracted feature values, $L_{\max}$, and the number of line segments, N_{all}, are input to the classifier to determine whether the object images belong to either category A or B. Various classifiers, for example, self-organizing neural nets (Spraggon *et al.*, 2002), C5.0 (Bern *et al.*, 2004), and Bayes theorem (Wilson, 2002), have been used in previous studies for crystal image analysis. Although various identifiers are available, the proposed method employs the support vector machine (SVM) (Vapnik, 1995),(Duda *et al.*, 2001), which provide efficient for two-class identification.

The SVM performs pattern recognition for two-class problems by determining the separating hyper-plane with the maximum distance to the closest points of the training set. These points are called support vectors. If the data is not linearly separable in the input space, a nonlinear transformation $\Phi(\cdot)$, which maps the data points $\mathbf{x} \in \mathbf{R}^n$ into a high-dimensional space H called a feature space, can be applied. The data in the feature space is then separated by the optimal hyper-plane, as described above.

The mapping $\Phi(\cdot)$ is represented in the SVM classifier by a kernel function $K(\cdot,\cdot)$ that defines an inner product in H, i.e. $K(\mathbf{x},\mathbf{x}') = \Phi(\mathbf{x})^T\Phi(\mathbf{x}')$. The decision function of the SVM has the form:

$$f(\Phi(\mathbf{x})) = \sum_{i=1}^{r} \alpha_i y_i K(\mathbf{x},\mathbf{x}_i) \quad (4)$$

where r is the number of data points, and $y_i \in \{-1,1\}$ is the class label of training points $\mathbf{x}_i$. Coefficients α_i in (5) can be determined by solving a quadratic programming problem with linear constrains. The support vectors are the nearest points to the separating boundary and are the only points for which α_i in (5) can be nonzero.

Examples of admissible kernel functions are the polynomial kernels:

$$K(\mathbf{x},\mathbf{x}') = (\mathbf{x}^T\mathbf{x}' + 1)^d \quad (5)$$

where d is the degree of the polynomial, and the Gaussian kernels:

$$K(\mathbf{x},\mathbf{x}') = \exp(-\|\mathbf{x} - \mathbf{x}'\|/2\sigma^2 \quad (6)$$

where σ is the variance of the Gaussian.

The SVM is used for classifying categories A and B based on line features extracted from the droplet image.

Experiment and results

In order to verify the effectiveness of the proposed method, the experiment is conducted using the SVM as classifiers. In this experiment, 866 images (600 images of category A and 266 images of category B), the correct categorization of which was performed ahead of time by experts, were prepared. Then, 300 of these images (200 images of category A and 100 images of category B) were used as training data to construct the classifier, and the remaining 566 images (400 images of category A and 166 images of category B) were used as test data to estimate the identification ability of the classifier. These images were autographed by several TERA systems at different times, and the possibility exists that these images may by slightly different based on the illumination condition. Figure 12 shows some of the actual images used in the experiment.

The images of training data were preprocessed, and the line features were extracted. Next, using the extracted features, the classifier was constructed using each classifier to decide the discrimination function. The classification performance was then evaluated using test data. Using the extracted features, the discrimination function is constructed using the SVM algorithm ($\sigma = 0.01$). The classification performance of the SVM was then evaluated using the test data.

As a result, using the SVM, the correct answer ratio for the learning data were 86.3 percent (Table II (a)) and the correct

Figure 12 Examples of experimental images

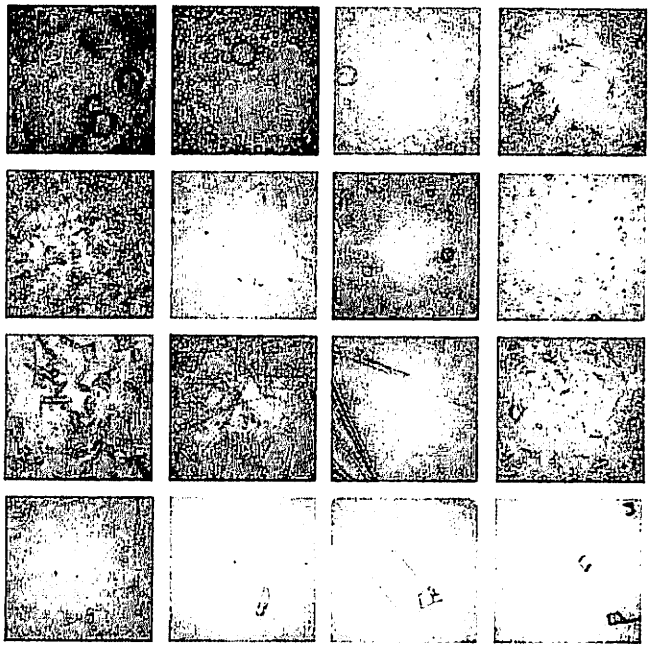


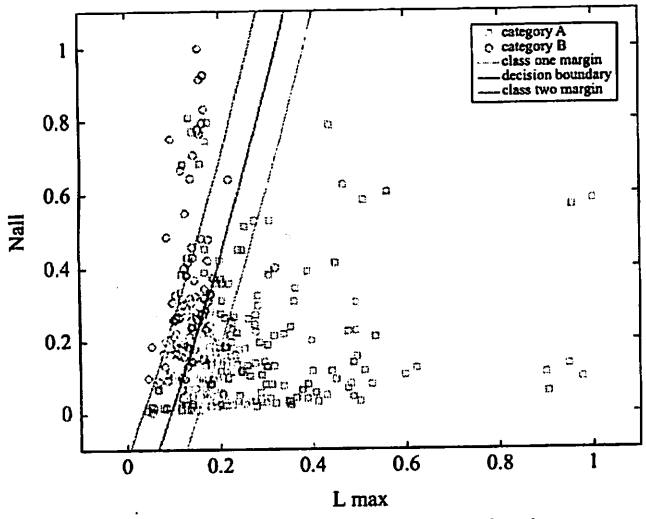
Table II Classification results of SVM

		Classification result	
		A	B
(a) Results using training data			
Human evaluation	A	180	20
	B	21	79
(b) Results using test data			
Human evaluation	A	334	66
	B	14	152

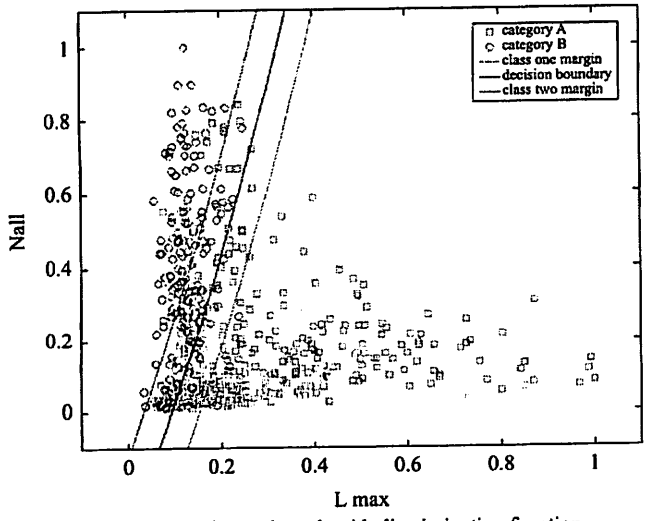
answer ratio for the test data were 85.9 percent (Table II (b)). The correct answer ratios for both the training data and the test data exceeded 80 percent.

Figure 13(a), (b) show the results by using derived discrimination function with training data and experimental data.

Figure 13 Discrimination by SVM: (a) training data with discrimination function (b) experimental result with discrimination function



(a) training data with discrimination function



(b) experimental result with discrimination function

Discussion

As mentioned above, TERA maintains the illumination condition for taking pictures. Therefore, in this experiment, the threshold for binarization was a fixed value (gray level: 29). Such a threshold value can be determined for each machine. However, this would require the introduction of an automated threshold decision method for such problems.

In the feature space, the distribution of data sets belonging to categories A and B used at this time had a distributed complex shape in the region of the boundary.

In addition, since the feature values, the maximum length, and the number of line segments were selected by investigating the entire image, in the case of the images containing both categories A and B, it is ascertained that these features caused erroneous decisions by extracting the features of both categories A and B. For example, the images in Figure 14 belong to category A. However, the effect of extracting feature values from the objects belonging category B, which occupy most of the image, caused an error. Thus, if only the feature of a crystal belonging category A can be extracted from the images, the error for images that include both category A and category B objects may decrease. Consequently, extraction from partial images, i.e. the extraction of feature values from an object as a unit, will be considered in the future.

Conclusion

In the present paper, we discussed the improvement of the efficiency of the crystallization experiment for protein X-ray structural analysis and proposed a classification method to decide whether a protein crystallization droplet contains the experimental subject for X-ray diffraction. The processing flow of the proposed method is as follows. First, the contour lines of objects in the images were extracted as binary edge images by preprocessing. Next, the feature values, i.e. the maximum length and the number of line segments, are considered for classification based on the expert's comments.

Figure 14 Erroneous decision images

Furthermore, these extracted feature values are utilized for discriminant analysis via SVM. Using the classifier, the correct answer ratio with respect to the test data were over 80.0 percent, verifying the applicability of the proposed method.

References

Bern, M., Goldberg, D., Stevens, R.C. and Kuhn, P. (2004), *J. Appl. Cryst.*, Vol. 37, pp. 279-87.

Bodenstaff, E.Rene, Hoedemaeker, Flip J., Kuil, Maxim E., de Vrind, Hans P.M. and Abrahams, Jan Pieter (2002), "The prospects of protein nanocrystallography", *Acta Crst.*, Vol. D58, pp. 1901-6.

Cumbaa, C.A., Lauricella, A., Fehrman, N., Veatch, C., Collins, R., Luft, J., DeTitta, C. and Jurisca, I. (2003), "Automatic classification of sub-microlitr protein-crystallization trials in 1536-well plates", *Acta Crst.*, Vol. D59, pp. 1619-27.

Duda, R.O., Hart, P.E. and Stork, D.G. (2001), *Pattern Classification*, Wiley-Interscience, New York, NY.

Echalier, A., Glazer, R.L., Fulop, V. and Geday, M.A. (2004), *Acta Cryst.*, Vol. D60, pp. 696-702.

Gester, T.E., Rosenblum, W.M., Christopher, G.K., Hamrick, D.T., DeLucas, L.J. and Tillotson, B. (2003), *United States Patent*, Vol. 6, pp. 529-612.

Miyatake, H., Kim, S-H., Motegi, I., Matsuzaki, H., Kitahara, H., Higuchi, A. and Miki, K. (2005), *Acta Cryst.*, Vol. D61, pp. 658-63.

Rupp, B. (2003), *Acc. Chem. Res.*, Vol. 36, pp. 173-81.

Saitoh, K., Kawabata, K., Kunimitsu, S., Asama, H. and Mishima, T. (2004), "Evaluation of protein crystallization states based on texture information", *Proc. of 2004 IEEE/RSJ International Conference on Intelligent Robots and Systems*, pp. 2725-30.

Saitoh, K., Kawabata, K., Kunimitsu, S., Asama, H. and Mishima, T. (2005), "Evaluation of protein crystallization states based on texture information derived from Greyscale images", *Acta Cryst*, Vol. D61, pp. 873-80.

Spraggon, G., Lesley, S.A., Kreusch, A. and Priestle, J.P. (2002), *Acta Cryst.*, Vol. D58, pp. 1915-23.

Sugahara, M. and Miyano, M. (2002), "Development of high-throughput automatic protein crystallization and observation system", *Tanpakushitsu Kakusan Koso*, Vol. 47 No. 8, pp. 1026-32 (in Japanese).

Vapnik, V.N. (1995), "The Nature of Statistical Learning Theory", Springer-Verlag, Berlin.

Wilson, J. (2002), *Acta Cryst.*, Vol. D58, pp. 1907-14.

Zuk, W.M. and Ward, K.B. (1991), "Methods of analysis of protein crystal images", *Journal of Crystal Growth*, Vol. 110, pp. 148-55.

Corresponding author

Kuniaki Kawabata can be contacted at: kuniakik@riken.jp

Author guidelines

Sensor Review

Copyright
Articles submitted to the journal should be original contributions (see www. emeraldinsight.com/info/copyright/plagiarism_full.jsp for the journal plagiarism policy) and should not be under consideration for any other publication at the same time. Authors submitting articles for publication warrant that the work is not an infringement of any existing copyright and will indemnify the publisher against any breach of such warranty. For ease of dissemination and to ensure proper policing of use, papers and contributions become the legal copyright of the publisher unless otherwise agreed. Copyright is assigned through the use of a digital signature as part of the submission process in Manuscript Central.

The Editor
Dr Clive Loughlin,
17 Old Lane, Low Mill Village, Addingham, Ilkley,
West Yorkshire LS29 0SA, UK.
Tel: +44 (0) 1943 830 399; Fax: +44 (0) 1943 831 876;
E-mail: CliveLoughlin@engineeringfirst.com

Editorial objectives
Sensor Review provides up-to-date coverage of international activities that relate to the design and application of sensors and sensor systems. Coverage is essentially of a practical nature and designed to be of material benefit to those working in the field. Proven applications are covered together with company news and new product information.

The journal also includes a substantial section reserved for "research articles". These will be selected by the Guest Specialist who is an international authority on the theme for that issue and he/she will commission typically four research articles from academia and commercial research centres. These articles will reflect the most interesting and strategically important research and development activities from around the world.

Although typically more academic in content than other articles in the journal, emphasis will be placed as much on fundamental concepts and application potential as rigorous academic analysis. This will ensure that the research articles remain accessible to all subscribers regardless of their particular areas of expertise.

The reviewing process
Each paper is reviewed by the Editors and, if it is judged suitable for this publication, it is then sent to two referees for double blind peer review. Based on their recommendations, the Editor then decides whether the paper should be accepted as is, revised or rejected.

Emerald Literati Editing Service
The Literati Network can recommend the services of a number of freelance copy editors, all themselves experienced authors, to contributors who wish to improve the standard of English in their paper before submission. This is particularly useful for those whose first language is not English. Please see www.emeraldinsight.com/editingservice for further details.

Submission process
Submissions to *Sensor Review* are made using Manuscript Central, Emerald's online submission and peer review system. Registration and access is available at http://mc.manuscriptcentral.com/sr
Full information and guidance on using Manuscript Central is available at the Emerald Manuscript Central Support Centre:
http://msc.emeraldinsight.com

Registering on Manuscript Central
If you have not yet registered on Manuscript Central, please follow the instructions below:

- Please log on to http://mc.manuscriptcentral.com/sr
- Click on "Create Account"
- Follow the on-screen instructions, filling in the requested details before proceeding
- Your username will be your e-mail address and you have to input a password of at least eight characters in length and containing two or more numbers
- Click "Finish" and your account has been created.

Submitting an article to *Sensor Review* on Manuscript Central

- Please log on to *Sensor Review* at http://mc.manuscriptcentral.com/sr with your username and password. This will take you through to the Welcome page
- (To consult the Author Guidelines for this journal, click on the **Home Page** link in the **Resources** column)
- Click on the **Author Centre** button
- Click on the **submit a manuscript** link which will take you through to the Manuscript Submission page
- Complete all fields and browse to upload your article
- When all required sections are completed, preview your .pdf proof
- Submit your manuscript.

Manuscript requirements
The manuscript will be considered to be the definitive version of the article and should be in **MS WORD** format, in 1.5 line spacing and 12 point font size. Good electronic copies of all figures and tables should also be provided. All manuscripts should be run through a UK English spell check prior to submission.

As a guide, articles should be approximately 2,000 and 4,000 words in **length**. A **title** of not more than eight words should be provided. A brief **autobiographical note** should be supplied including full name, affiliation, e-mail address and full international contact details. Authors must supply a **structured abstract** set out under 4-6 sub-headings: Purpose; Design/methodology/approach; Findings; Research limitations/implications (if applicable); Practical implications (if applicable); and Originality/value of the paper. Maximum is 250 words in total. In addition provide up to six **keywords** which encapsulate the principal topics of the paper and categorize your paper under one of these **classifications**: Research paper, Viewpoint, Technical paper, Conceptual paper, Case study, Literature review or General review. For more information and guidance on structured abstracts visit: www.emeraldinsight.com/structuredabstracts

Notes or **Endnotes** should be used only if absolutely necessary and must be identified in the text by consecutive numbers, enclosed in square brackets and listed at the end of the article.

Figures should be supplied within the article itself.

All **Figures** (charts, diagrams, line drawings and photographic images) should be submitted in electronic form. Figures should be of clear quality and numbered consecutively with arabic numerals. Graphics may be supplied in colour to facilitate their appearance in colour on the online database.

Figures created in MS Word, MS PowerPoint, MS Excel, Illustrator and Freehand should be saved in their native formats.

Electronic figures created in other applications should be copied from the origination software and pasted into a blank MS Word document or saved and imported into a MS Word document by choosing "Insert" from the menu bar, "Picture" from the drop-down menu and selecting "From File ..." to select the graphic to be imported.

For figures which cannot be supplied in MS Word, acceptable standard image formats are: .pdf, .ai, .wmf and .eps. If you are unable to supply graphics in these formats then please ensure they are .tif, .jpeg, or .bmp at a resolution of at least 300dpi and at least 10cm wide.

To prepare screenshots, simultaneously press the "Alt" and "Print screen" keys on the keyboard, open a blank Microsoft Word document and simultaneously press "Ctrl" and "V" to paste the image. (Capture all the contents/windows on the computer screen to paste into MS Word, by simultaneously pressing "Ctrl" and "Print screen".)

For photographic images good quality original photographs should be submitted. If supplied electronically they should be saved as .tif or .jpeg files at a resolution of at least 300dpi and at least 10cm wide. Digital camera settings should be set at the highest resolution/quality as possible.

In the text of the paper the preferred position of all tables and figures should be indicated by typing on a separate line the words "Take in Figure (No.)". Tables should be typed and included as part of the manuscript. They should not be submitted as graphic elements. Supply succinct and clear captions for all tables, figures and plates. Ensure that tables and figures are complete with necessary superscripts shown, both next to the relevant items and with the corresponding explanations or levels of significance shown as footnotes in the tables and figures.

References to other publications must be in Harvard style and carefully checked for completeness, accuracy and consistency. This is very important in an electronic environment because it enables your readers to exploit the Reference Linking facility on the database and link back to the works you have cited through CrossRef. You should include all author names and initials and give any journal title in full.

You should cite publications in the text: (Adams, 2006) using the first named author's name or (Adams and Brown, 2006) citing both names of two, or (Adams *et al.*, 2006), when there are three or more authors. At the end of the paper a reference list in alphabetical order should be supplied:

For books: surname, initials, (year), *title of book*, publisher, place of publication, e.g. Harrow, R. (2005), *No Place to Hide*, Simon & Schuster, New York, NY.

For book chapters: surname, initials, (year), "chapter title", editor's surname, initials, *title of book*, publisher, place of publication, pages, e.g. Calabrese, F.A. (2005), "The early pathways: theory to practice – a continuum", in Stankosky, M. (Ed.), *Creating the Discipline of Knowledge Management*, Elsevier, New York, NY, pp. 15-20.

For journals: surname, initials, (year), "title of article", *journal name*, volume, number, pages, e.g. Capizzi, M.T. and Ferguson, R. (2005), "Loyalty trends for the twenty-first century", *Journal of Consumer Marketing*, Vol. 22 No. 2, pp. 72-80.

For electronic sources: if available online the full URL should be supplied at the end of the reference.

Authors' Charter

This highlights some of the main points of our Authors' Charter. For the full version visit: **www.emeraldinsight.com/charter**

Your rights as an author

Emerald believes that as an author you have the right to expect your publisher to deliver:

- An efficient and courteous publishing service at all times
- Prompt acknowledgement of correspondence and manuscripts received at Emerald
- Prompt notification of publication details
- A high professional standard of accuracy and clarity of presentation
- A complimentary journal issue in which your article appeared
- Article reprints
- A premium service for permission and reprint requests
- Your moral rights as an author.

Emerald represents and protects moral rights as follows:

- To be acknowledged as the author of your work and receive due respect and credit for it
- To be able to object to derogatory treatment of your work
- Not to have your work plagiarized by others.

The Emerald Literati Network

The Emerald Literati Network is a unique service for authors which provides an international network of scholars and practitioners who write for our publications. Membership is a free and unique service for authors. It provides:

- A dedicated area of the Emerald web site for authors
- Resources and support in publishing your research
- Free registration of yourself and your work, and access to the details of potential research partners in Emerald Research Connections
- The opportunity to post and receive relevant Calls for Papers
- Information on publishing developments
- Awards for outstanding scholarship
- Usage information on authors, themes, titles and regions
- Access to tips and tools on how to further promote your work
- Awards for Excellence.

To discuss any aspect of this Charter please contact:

Emerald Literati Network, Emerald Group Publishing Limited, Howard House, Wagon Lane,
Bingley BD16 1WA, United Kingdom
Telephone +44 (0)1274 777700
E-mail: **literatinetwork@emeraldinsight.com**

Emerald

The world's leading publisher of management journals and databases