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The Third International Workshop of Advanced Manufacturing and Automation

27 November 2013 Trondheim, Norway

Kesheng Wang, Jan Ola Strandhagen
and Dawei Tu (editors)

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Preface

IWAMA – International Workshop of Advanced Manufacturing and Automation – began in 2010 as a joint seminar between SFI Norman (SINTEF and NTNU) and Shanghai Key Laboratory of Manufacturing Automation and Robotics (Shanghai University). In 2013 IWAMA expanded to include academic and industrial experts in the fields of advanced manufacturing and automation worldwide when the University of Manchester and Tongji University joined as co-organizers. As IWAMA becomes an annual event, we expect more universities and industry sponsors will join the international workshop as co-organizers.

Manufacturing and automation have assumed paramount importance and are vital factors for the economy of a nation and the quality of life. The field of manufacturing and automation is advancing at a rapid pace and new technologies are also emerging in the field. The challenges faced by today's engineers are forcing them to keep on top of the emerging trends through continuous research and development.

IWAMA aims at providing a common platform for academics, researchers, practicing professionals and experts from industries to interact, discuss trends and advances, and share ideas and perspectives in the areas of manufacturing and automation.

IWAMA 2013 takes place in Trondheim, Norway, 27 November 2013, organized by Norwegian University of Science and Technology, SFI Norman/SINTEF, Shanghai University, University of Manchester and Tongji University. The program is designed to improve manufacturing and automation technologies for the next generation through discussion of the most recent advances and future perspectives, and to engage the worldwide community in a collective effort to solve problems in manufacturing and automation. Participants from different countries, such as Norway, China, UK, Germany, Italy and India attend the workshop.

Manufacturing research includes a focus on the transformation of present factories, towards reusable, flexible, modular, intelligent, digital, virtual, affordable, easy-to-adapt, easy-to-operate, easy-to-maintain and highly reliable "smart factories". Therefore, IWAMA 2013 has mainly covered 3 sessions in manufacturing engineering:

1. Intelligent Manufacturing Technology
2. Intelligent Logistics and Supply Chains
3. Intelligent Diagnosis and Prognosis of Wind Turbines

The proceedings of IWAMA2013 provide up-to-date, comprehensive and worldwide state-of-the-art knowledge of the manufacturing and automation science and engineering. All papers submitted to the workshop have been subjected to strict peer-review by at least 2 expert referees. Finally, 28 papers have been selected to be included in the proceedings after a revision process. We hope that the proceedings will not only give the readers a broad overview of the latest advances, and a summary of the event, but also provide researchers with a valuable reference in this field.

On behalf of the organization committee and the international scientific committee of IWAMA 2013, I would like to take this opportunity to express my appreciation for all the kind support, from the contributors of high-quality keynotes and papers, and all the participants. My thanks are extended to all the workshop organizers and paper reviewers, NTNU and SFI Norman for the financial support, and co-sponsors for their generous contribution. Thanks are also given to Quan Yu, Yi Wang, Cecilia Haskins, Tonje Berg Hamnes, Line Holien, Jorurnn Auth, and Lilan Liu for

their hard editorial work of the proceedings and arrangement of the workshop. Thank also goes to Lasse Postmyr from Tapir Academic Press for producing the proceedings.

Kesheng Wang, Ph.D. Professor of NTNU
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About Editors

Prof. Kesheng Wang holds a Ph.D. in production engineering from the Norwegian University of Science and Technology (NTNU), Norway. In 1993 he was appointed Professor at the Department of Production and Quality Engineering, NTNU. He is a director of the Knowledge Discovery Laboratory (KDL) at IPK, NTNU at present. He is also an active researcher and serves as a technical adviser in SINTEF. He was elected member of the Norwegian Academy of Technological Sciences in 2006. He has published 17 books, 10 book chapters and over 214 technical peer-reviewed papers in international journals and conferences. Prof. Wang's current areas of interest are intelligent manufacturing systems, applied computational intelligence, data mining and knowledge discovery, swarm intelligence, condition-based maintenance and structured light systems for 3D measurements and RFID.

Prof. Jan Ola Strandhagen is a research director of the research center SFI NORMAN at SINTEF. He is also Professor at Department of Production and Quality Engineering, the Norwegian University of Science and Technology (NTNU). He holds a PhD in Production Engineering from NTNU (1994). His research has focused on production management and control, logistics, manufacturing economics and strategies. He has managed and performed R&D projects in close collaboration with a wide variety of Norwegian companies and participated as researcher and project manager in several European projects.

Prof. Dawei Tu received his bachelor's degree, master's degree and PhD from Zhejiang University in 1987, 1989 and 1993 respectively. Since 1993 he joined Shanghai University, and became a professor in 2000. Now he is the Executive Dean of the School of Mechatronics Engineering and Automation, Shanghai University. His research interests include optoelectronic detecting, precision mechanics and instrumentation, 3D vision and vision-based robot servo-control.

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Toward Intelligent Manufacturing: a Label Characters Marking and Recognition Method for Steel Products with Machine Vision

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Abstract Correctly coding materials and identifying characters marked on materials is very important for steel manufacturing industry to realize informatization management and intelligent manufacturing. However, the steel products manufacturing is often in a high temperature environment, and there are a lot of material storage and retrieval processes, workers are not easily close to the environment and complete tasks, so it is a great challenge to automatically mark and identify characters on the steel products. This paper presents a framework of label characters marking and management for steel materials, furthermore, a kind of marked characters online detection and tracking method has been provided based on machine vision. In addition, some experiments have been done in BaoSteel to mark characters on hot billets and recognize them in multi situations, and the results show that the proposed method is practical, and has provided a helpful exploration in obtaining accurate fundamental data for the intelligent manufacturing system in steelworks.

Keywords Intelligent manufacturing**,** Enterprises informatization, Label character marking, Machine vision, Marked character recognition

1 Introduction

Informatization and automation technology can rise up the competitiveness of a company, especially, for large manufacturing enterprises. Using intelligent manufacturing management method can not only improve the quality of products, but be effective and efficiency in organizing production, reducing product costs, strengthening market shares. By integrating informatization and automation technology, the production process is increasingly moving toward intelligent manufacturing [Wang, 2013]. The steel industry is the typical capital-intensive and large manufacturing industry, and the production process in steelworks usually consists of mining, beneficiation, coking, ironmaking, steelmaking, rolling, etc. Therefore, it is of great value for steelworks to enhance the comprehensive capacity by intelligent manufacturing.

With development of computers and artificial intelligence, the application of AI in the steelworks had been concerned as far back as 30 years. During this period, AI was mainly used in equipment fault diagnosis, production planning, expert systems, etc, and gradually from theoretical research into practical applications[Iida, & Urakami, 1993; Huang, 1994]. In the past decade, the steel enterprises have paid more attention on

informatization and automation, and many large-scale steelworks applied ERP, MES, and other information management and control system[Wang, et al., 2006]. However, the effect of information and automation management system, to much more extent, depends on the accuracy and timeliness of fundamental data acquired online, in which coding and identifying the marked information of materials is the key work to achieve information and automation management[Brewer, Sloan, &Landers, 1999].In order to facilitate in tracking and identifying the marked information, the label characters are generally printed on the surface of the steel materials. Because of the long production cycle and many material delivery processes, it is necessary to identify marked information in each process or different production stages for inventory management and logistics. However, it is not easy to manually identify and mark the label characters on the hot steel products in high temperature environment. Therefore, the non-contact measurement method in tracing and detecting the label characters of steel material has great value. Among the various non-contact methods of detecting and tracking, Machine vision is more suitable for long-distance detection and tracking in steelworks, so many steelworks have shown great interests in the application of machine vision to solve this kind of problem [Agarwal, 2013; Kang, 2008; Choi, et al, 2010].

The application of machine vision in steel enterprises generally includes the following two aspects: 1) Surface defect detection to achieve quality control. For example, in order to prevent the unqualified product entering the next manufacturing process. Periodical surface defect detection methods [Bulnes, Usamentiaga, & Garcia, 2011]and the strip steel surface scratches detection methods [Jia, et al, 2004; Zhu, et al, 2007], etc, have been proposed. 2) Marking characters and recognition to track the manufacturing of steel products. Some recognition methods that combined image segmentation with KLT, SVM, ANN or optical flow [Park, 2006; Yanagita, 1995; Park, 2007; Shim, 2010] have been proposed. However, most of the current methods focus on the information detection or recognition of natural temperature steel materials, and there are still no solutions to detect and recognize the marked information of high temperature steel materials. In practice, many hot manufacturing processes(e.g., continuous casting, hot rolling) in steelworks are needed to automatically identify the steel material information in online states. Additionally, the weak contrast of hot steel surface and the marked information makes it difficult to identify the marked characters. Therefore, there are more challenges and values in identifying the marking information of hot steel materials.

The main object of this paper is to study the acquiring, recognition and management method of the marked information on steel products, and we will pay more attention on the label characters capturing and identifying process on hot steel materials with machine vision. The rest of the paper is arranged as follows. In section 2, the framework of label character marking and management is put forward. In section 3, the machine vision recognition methods of steel material marked information is illustrated. The experimental research and analysis are presented in section 4, and this work is summarized in section 5.

2 Framework of Label Characters Marking and Management

Due to the long production cycle and complex logistics transportation, the management information system of steel enterprise is often constructed by multi-layers. Figure 1

presents a steel material label information marking, identifying and management framework in intelligent manufacturing system, it is mainly composed of the CRM / ERP (Customer Relationship Management / Enterprise Resource Planning) system, MES (Manufacturing Execution System) , WMS (Warehouse Management System) and SCM / LMS (Supply Chain Management / Logistics Management System), etc.

According to customer orders from CRM or the main production plan, the manufacturing tasks will be assigned by the ERP system through manufacturing forms, and the property of a manufacturing product will be defined by the BOM (bill of materiel) and manufacturing process, therefore, the marking information of a steel product is defined in ERP system and will be stored in a shared database. In the production process, MES system obtains information or manufacturing commands from the ERP system, and the label characters of a product will be marked by the marking machine. In practice, there are often three kinds of situations for marking the characters on steel materials, the first is marking the characters on billets in steelmaking factory, and the marking operation is instantly completed after the billets sheared; The second is marking the characters on a semi-product which is manufactured by the continuous casting and continuous rolling plant, and the marking operation usually can be done online; the third is marking characters on final steel products in rolling plants, and the marking operation will be executed after the product has passed the quality check. Finally, the marked information will be checked before the storage and then the checked information will be stored in the WMS. In addition, the marked information also need to be checked or identified in stock out process or in some manufacturing processes(e.g., the marked information identifying for reheat materials in hot rolling). By this way, every material can be tracked in manufacturing process with the marked information. Finally, after the product is sold, or in logistics delivery process, the tracing or tracking operation can be achieved in the SCM with the recorded and marked label information.

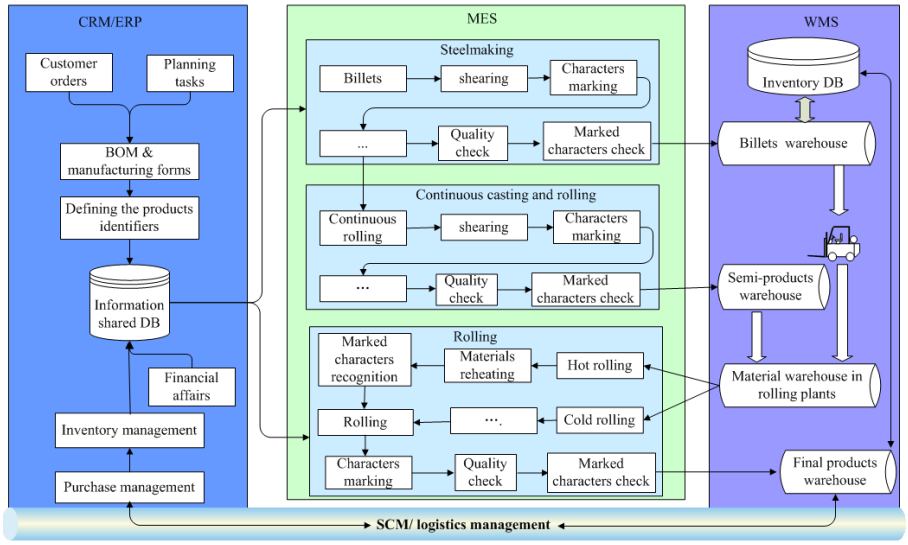


Fig.1 Management framework of label characters in intelligent manufacturing system

The methods of label marking on the surface of steel products usually include templates marking, hand writing, printing by marking machine [Park, 2006; Yoshikatsu, et al, 1986]. Owing to high temperature and inaccessible to the environment in steelworks, the automatically marking and identifying methods are welcomed. However, the contrast of label information and steel background is very weak, especially for the hot steel materials. In order to decrease the difficulty in recognition, we proposed an image capturing system to enhance the contrast effect between marked characters and the steel surface, shown in Figure 2. A kind of lighting is used to illuminate the area of marked characters, and a filter which permits certain wavelength light passing, is mounted before the camera lens, with the match of lighting and filters, the contrast of the marked characters and background can be increased. The captured images are pre-processed and segmented as recognition sample images, and then the marked characters can be identified by the recognition algorithm. Following this process, the identified characters will be compared or stored in the corresponding EPR/MES/WMS system.

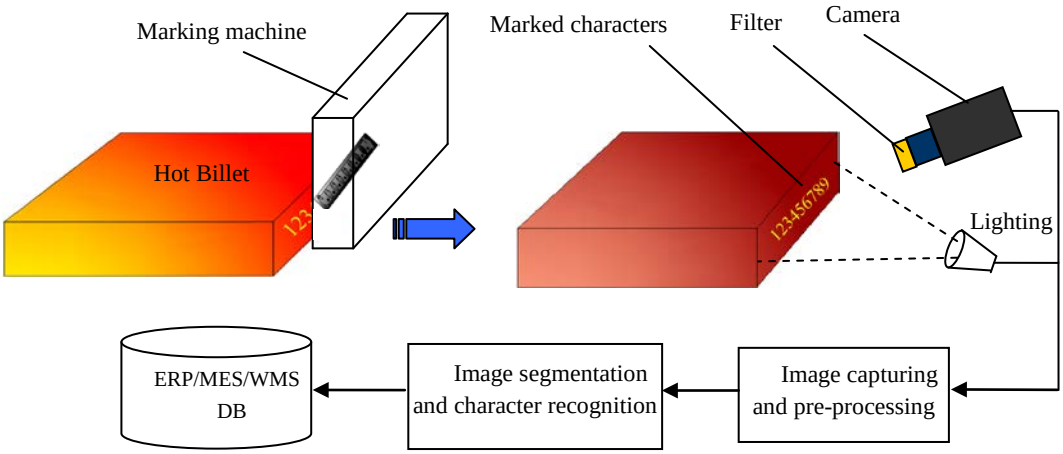


Fig.2 Process of label characters marking and machine vision recognition

3 Method of Marked Characters Recognition

The label characters often marked on the rough interface of steel materials, and the captured images need to be further processed before segmentation and recognition. The characters recognition algorithm proposed in this paper mainly consists of three parts, image pre-processing, image segmentation, and characters recognition, shown in figure 3.

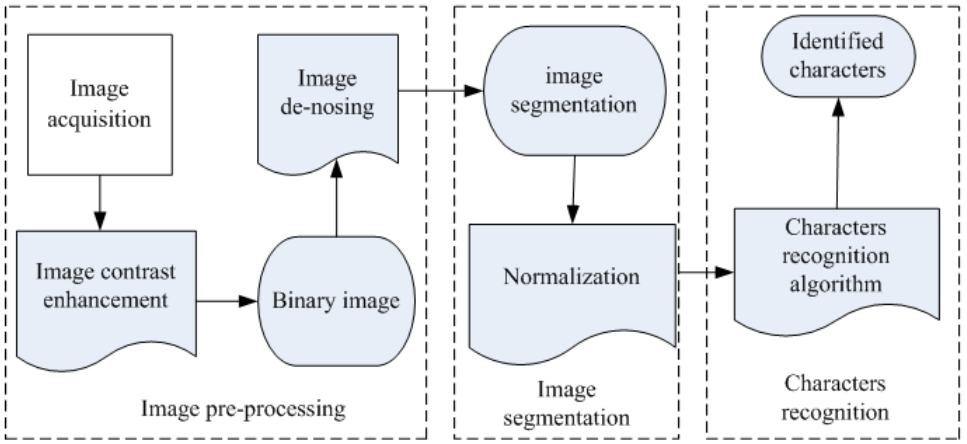


Fig. 3 Process of marked characters recognition

3.1 Image Pre-processing

The proposed image pre-processing method mainly includes image contrast enhancement, image binarization, and de-nosing operation. After images enhanced, the binarization processing and median filter operation are helpful to image segmentation. Among the pre-processes, image contrast enhancement is the key operation, and the grey histogram and grey linear transformation enhancement are the common methods[Panetta, Agaian, &Zhou, 2011]. However, the grey value in characters marking area non-linearly changes, it is caused by the uneven cooling and rough surface of steel materials. So we construct a non-linear operation model with top-hat transformation and gamma transform. The constructed Top-hat transformation is presented in formula (1).

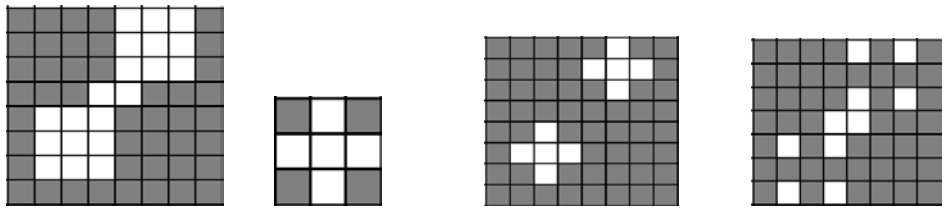
$$h = f - (f \circ s) \tag{1}$$

Where, f represents the image grey level and $f \circ s$ means the open operation to the image with the structure element s.

The expression of gamma transformation is shown as follow

$$y = (x + esp)^{\gamma} \tag{2}$$

Where, esp represents the compensation coefficient, γ means gamma coefficient, and the variation range of x and y are [0, 1].



(a) Original image (b) Structure element (c) Open operation (d) Hat-top operation

Fig .4 The process of top-hat transformation operation

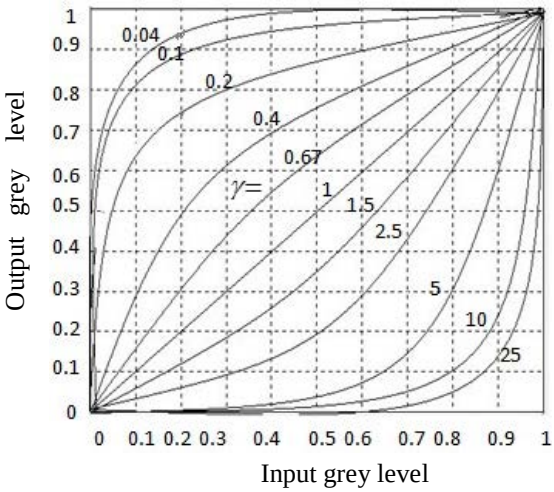


Fig. 5 The gamma transformation of grey level

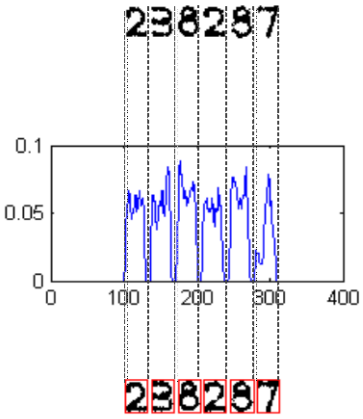


Fig . 6 Images segmentation with projection method

The top-hat transformation with appropriate structure elements can effectively eliminate the influence of uneven background. Figure 4 presents the process of top-hat transformation operation. Moreover, gamma transformation could selectively enhance the contrast of low grey region or high grey region based on γ. The gamma transformation is shown in figure 5.

- $\gamma > 1$， contrast of high grey region is enhanced;
- $\gamma < 1$， contrast of low grey region is enhanced;
- $\gamma = 1$， original image remains unchanged.

3.2 Image Segmentation

The recognition method can only identify a single character each time, therefore, characters in an image need to be segmented. We use vertical projection method finding the boundaries between characters to achieve the segmentation. After binaryzation and de-noising operation , the integral has been done along vertical direction in the image, the results as following

$$f_k = \sum_{i=0}^{n-1} \varphi(i, j_k) \tag{3}$$

Where, f_k is the number of features in column j_k, $\varphi(i, j)$ is the binaryzation image.

By comparing the integral results, the minimum value of local area $V_{\min}$ can be determined , and y_k is one side of the character boundaries.

$$V_{\min} = \min\left\{\sum_{i=0}^{n-1}\varphi(i, j_k)\right\}, y_k = j_k \mid f_k = V_{\min} \tag{4}$$

Where, $j_k = 0,1,...,m-1$, and m, n are respectively the width and height of the image. By this way, the boundaries of each image can be determined by y_k and the image can be segmented into sampling image characters based on y_k. Figure 6 presents the segmentation method.

The segmented character images are different in sizes, in order to be identified with the recognition algorithm, it is necessary to make them with same format[Jiao, Ye, &Huang 2009]. The operation is completed with image zooming and normalization transform in this paper.

3.3 Recognition

The character recognition methods based on different classifiers have been proposed in some literatures, and mainly include template matching method[Connell, & Jain, 2001], according to the structural features of characters to recognize [Dubey, 2010; Kim, 2003], based on support vector machine [Rajkumar, 2012; Bhowmik, 2009] and neural network character recognition [Wei, 2011; Hussain, & Kabuka, 1994], etc. Among these methods, Bp neural network is advantage in nonlinear data processing, fault tolerance and autonomous learning, it is suitable for steel label characters recognition. Consequently, a three layers Bp neural network algorithm is provided in this paper, and there are input layer, hidden layer, and output layer in the Bp neural network , as shown in Figure 7.

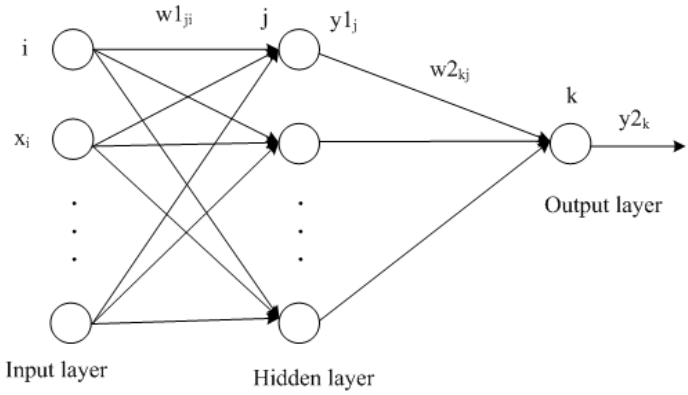


Fig. 7 Bp neural network topology

Defining x_i as the input sampling information of one neuron in input layer, and the number of the input samples is n. The number of neurons in hidden layer and output layer are respectively s and m, and the corresponding transfer functions in hidden layer and

output layer are respectively f_1 and f_2. Giving the input vector and target vector are respectively X and T. The process of forward information transformation is as follow.

The output of the neuron j in hidden layer is

$$y1_j = f_1(\sum_{i=1}^{n} w1_{ji} x_i + b1_j); j = 1, 2, ..., s \tag{5}$$

The output of the neuron k in output layer is

$$y2_k = f_2(\sum_{j=1}^{s} w2_{kj} y1_j + b2_k); k = 1, 2, ..., m \tag{6}$$

The error function is

$$e_k = \frac{1}{2}\sum_{k=1}^{m}(t_k - y2_k)^2 \tag{7}$$

The values of weight factors and back propagation errors(BPE) are calculated with gradient descent method in this paper. Bp neural network weight adjusting process actually is the adjustment of the BPE. The BPE from the neuron k to neuron j is determined by the multiplying result between output layer error e_k and the first-order derivative of f_2, so the BPE described as $\delta_{kj} = e_k f_2^{'}$. Furthermore, the variation of weights $\Delta w2_{kj}$ in hidden layer can be obtained by the BPE. In the same way, the variation of weights $\Delta w1_{ji}$ in input layer can be obtained. In addition, the transfer function is $f(x) = \frac{1}{1-e^{-x}}$ in this paper. After the parameters are determined and some sample training executed, the characters recognition can be achieved with the BP neural network classifier.

4 Experiment

4.1 Experimental Environment

With the proposed methods, some experiments have been done in the Baosteel steelmaking plant, and the experimental environment is shown in Figure 8. The equipments mainly include a set of marking machine, one monochrome camera FLY-PGE-13S2M-CS, one colour camera SQ-S20C-H30, a set of metal halide lamp, a set of MIDOPT FS 100 band-pass filters, and a computer(with CPU 3.0, Memory 2G).The molten copper is printed on the billet section to form the label characters in the continuous casting process, and the spectrum of the lighting is close to sunlight, the lamp is waterproof, dustproof, and high temperature resistance. The MIDOPT FS 100 includes more than seven band pass filters , the filters can block or pass the light with wavelengths from the ultraviolet to infrared.

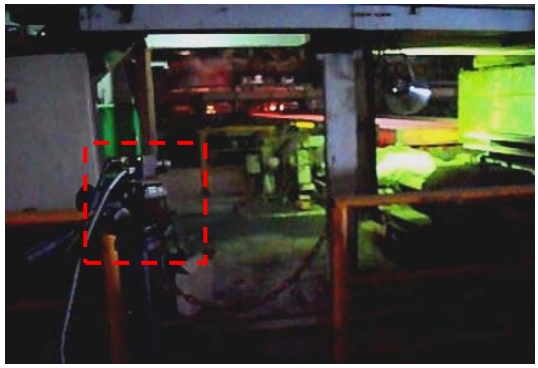
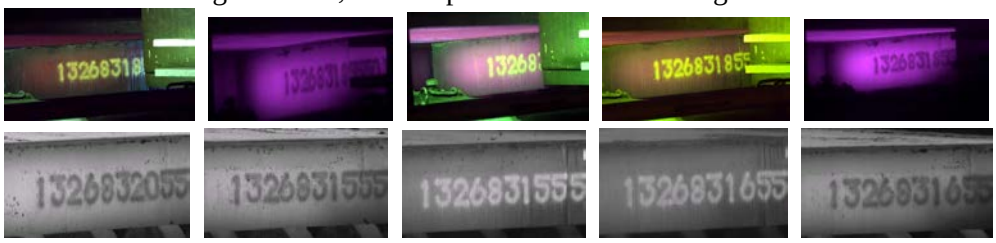


Fig. 8 Experimental environment

4.2 Image Acquisition and Segmentation

In order to compare the quality of images captured in different temperatures, with different filters and illuminations. Some marked information images were captured with the monochrome camera and colour camera respectively, and the effects of the images captured with filters(e.g., BP324,BP550, etc) and without filters are shown in figure 9, the temperature of the continuous casting billets is about 1100℃. Figure.10 partly presents the relationship between wavelength and transmission of band pass filters. In addition, to observe the influence of filters to image quality under lower temperature, some images were captured with the colour camera, multi filters, and without illumination of the lamp for the billets cooling to 550℃, the comparison is shown in Figure 11.



Without filter BP324 BP550 BP590 BP850

Fig. 9 Effects of billets images captured with filters and without filter at 1100℃

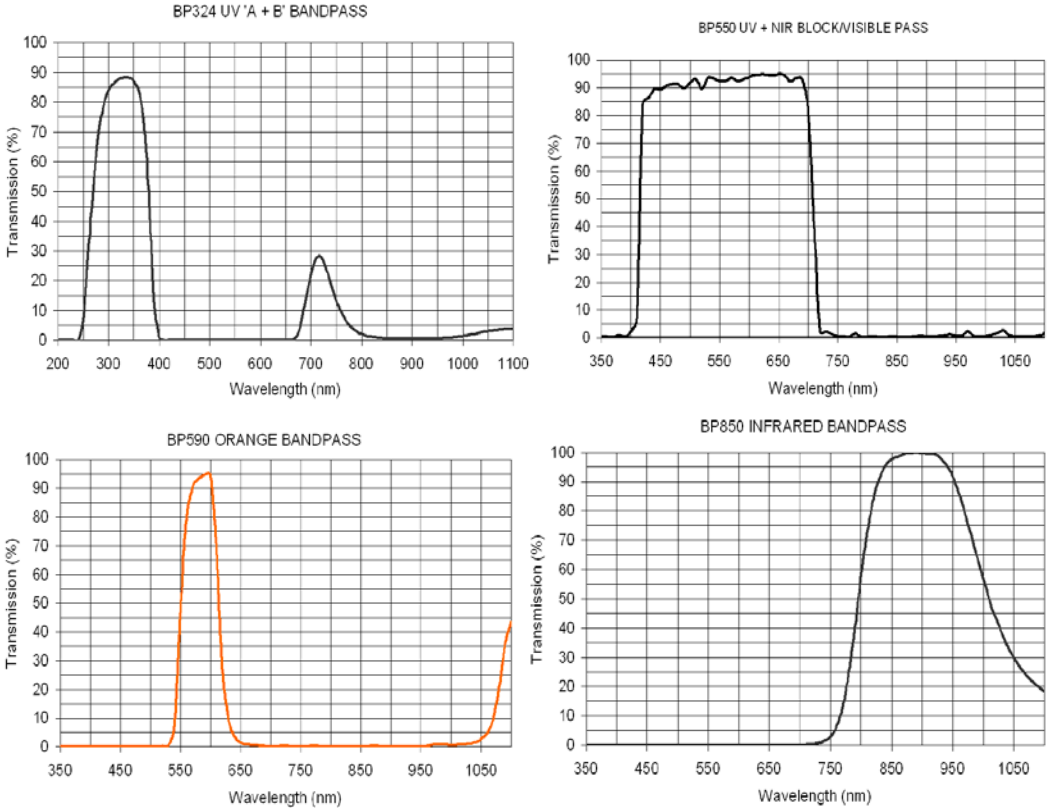
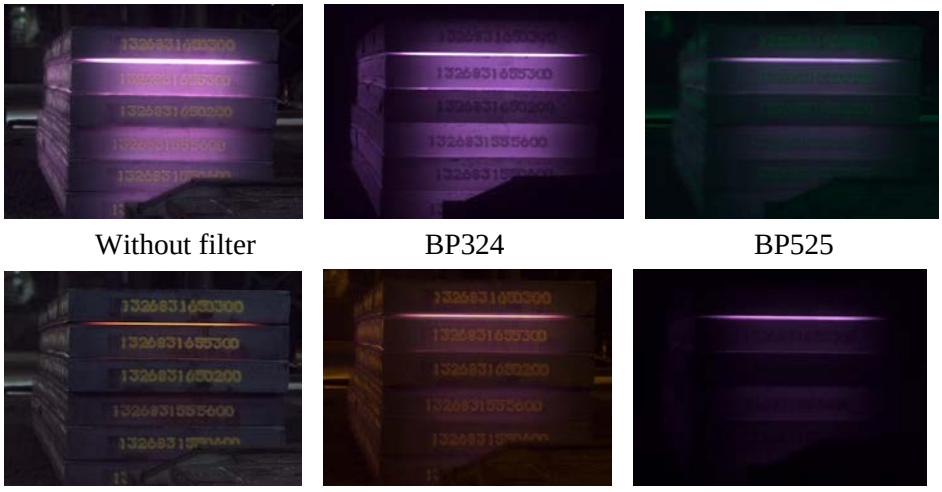


Fig. 10 Curves of wavelength and transmission of band pass filters



Without filter BP324 BP525

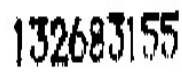
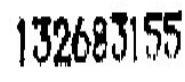
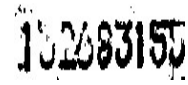
BP550 BP590 BP850

Fig.11 Images captured for billets at 550℃ with different filters

According to the effects of images captured in different situations(shown in figure 9 and figure 11), we can see that there are some noises in the images captured without

filter, whether by the monochrome camera or colour camera. However, the contrast of some images has been enhanced by using certain filters (such as BP550, BP590), these filters effectively blocked some wavelength light and let the light with wavelength around marked characters fully pass. In this experiment, the marked information is copper yellow, and the passing wavelength of filter BP550 and BP590 mainly includes this bandwidth light(shown in figure 10). Therefore, the images captured by cameras with filter BP550 and BP590 are more clear than others. Additionally, the quality of images also can be improved by the proposed pre-processing method. To compare the effects of segmentation for images captured in different situations, some segmentation experiments have been done, and Table 1 presents part of segmentation results for original images and enhanced images. Figure 12 presents the segmentation accuracy of images captured in different situations, segmented with or without pre-processing cases, and the WF means without filter.

Table 1 Segmentation comparisons for original images and enhanced images

Pre-processing operations	BP590		BP324	
Enhancement	Original image	Enhanced image	Original image	Enhanced image
Gray images				
Binaryzation and de-noised images				
Segmented images				

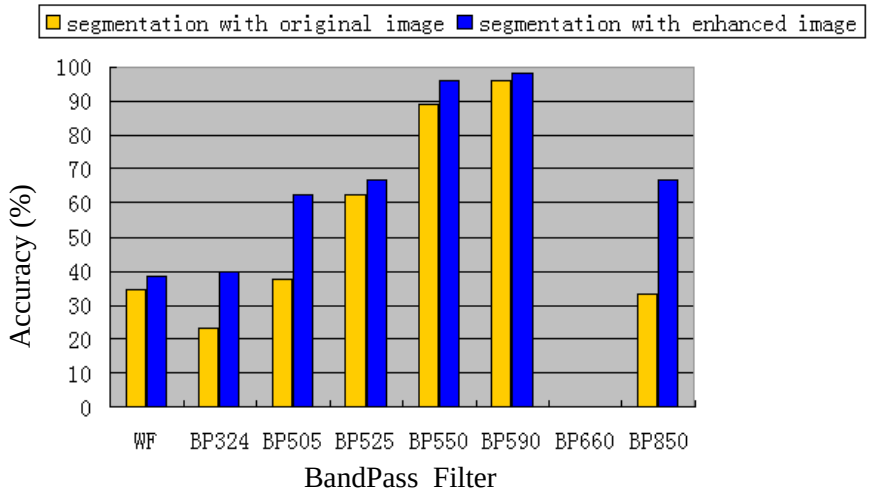


Fig.12 Segmentation accuracy of images with different capturing and processing situations

In term of the results in table 1 and figure 12, the segmentation accuracy of images captured by cameras with BP550 and BP590 filters is very high, and the filters have blocked some distracts from noises and the segmentation operation is more easy and effective. However, as for the images captured by cameras with other filters, the segmentation accuracy has improved after the pre-processing operation(e.g., Enhancement, de-noising, etc), but the total segmentation accuracy is still very low.

4.3 Recognition Test

According to the BP neural network recognition method proposed in this paper, each segmented sample image was normalized into the same size 15 × 6 (height × width) pixels, and the grey value of every pixel is the input vector of each node in input layer, so there are 90 input nodes in the BP neural network. Furthermore, the candidate characters for recognition are the digital numbers 0~9, therefore, there are 10 nodes in output layer. Considering the convergence of the learning and training process, designing 10 nodes in the hidden layer and setting the initial weights of neural network is a random number between -1 and + 1.

In the recognition test, the marking information areas of billets were captured online by the monochrome camera with different filters and under the illumination of the metal halide lamp, and about 150 frames were segmented for recognizing the marked string. Table 2 presents recognition results of the marked string on billets. Furthermore, to check the character recognition efficiency of the proposed system, 80 frames captured with BP550 and BP590 filters were selected and segmented for identifying the single characters 0-9, the results were recorded in Table 3.

Table 2 Recognition accuracy and time consumption with different filters

Filters	Central wavelength （nm）	Recognition Accuracy of Strings （%）	consumption time （s）
Without	---	59.25	0.2080
BP324	324	63.27	0.2327
BP505	505	78.82	0.2340
BP525	525	83.66	0.2252
BP550	550	87.75	0.2386
BP590	590	93.34	0.2338
BP660	660	0	0
BP850	850	70.42	0.2447

Table 3 Recognition accuracy and consumption time for single characters

Characters	Recognition accuracy of characters （%）	consumption time （s）
0	97.53	0.0598
1	95.77	0.0593

2	96.83	0.0606
3	96.41	0.0600
4	97.12	0.0601
5	95.46	0.0551
6	95.29	0.0575
7	96.16	0.0588
8	96.67	0.0591
9	95.43	0.0621

By the analysis of the results in Table 2, although the same image segmentation and recognition algorithm was applied, the identifying differences are significant for images captured in different situations. The recognition accuracy is higher for images captured with some filters(e.g., BP550, BP590, etc) which let the wavelength of light around the colour of the marked information fully pass, and block out much of the background light. However, the recognition rate is very low for some images captured with filters mainly passing ultraviolet or infrared(e.g., BP324, BP850, etc.), some even can not be segmented and identified (e.g., images captured with filter BP660). Consequently, to get a better segmentation and recognition effects, the performances of the lighting and filters should be matching with the property of the marked information on steel materials. According to the statistical results in Table 3, the recognition accuracy of a single character is higher than 95%, and the consumption time of recognition was about 60 milliseconds by using BP550 and BP590 filters. It suggested the proposed character recognition algorithm could effectively and efficiently identify the digital characters marked on the billets.

5 Conclusions

Due to the complex manufacturing processes and long production cycle in steel industry, it is valuable for steelworks to improve production efficiency, reduce costs, strengthen the market competitiveness of enterprises with the intelligent manufacturing system. In this paper, the label characters marking and management method for steel materials has been studied, furthermore, a kind of steel products coding, management and tracking framework in different manufacturing stages has been proposed. By this way, the full life cycle of a product, from the billet manufacturing to the final products, can be tracing with the marked information identifying and tracking system.

The manufacturing environment of steel plants has many unfavourable factors for label information marking and identifying, such as high temperature and inaccessibility, so automatically printing the information on steel materials and recognized them is very necessary, especially for hot steel materials. In this paper, a kind of online marking and machine vision identifying method has been provided, and according to a variety of detection and recognition situations, a set of images acquisition system has been designed to get higher quality images.

With the proposed method, some experiments have been done in BaoSteel steelmaking plants to recognize the marked information on hot billets, and the results show that the differences of images quality are significant in different capturing situations(e.g., different temperature, with different filters, etc.), if the performances of the image

capturing devices match with the property of marked information, it can improve the images contrast between the marked information and the steel materials background, and this is helpful for images segmentation and characters recognition. Moreover, the captured images were pre-processed, segmented, and identified with the proposed method, and the results also suggest that the enhancement operation can partly rise up the accuracy of image segmentation, the proposed character recognition algorithm could effectively and efficiently identify the digital characters marked on the billets. Finally, the proposed methods and framework have provided a helpful exploration in obtaining fundamental data with machine vision for the intelligent manufacturing system in steelworks. However, there are many kinds of marker information printing methods for different products in steel plants , for instance, the marking machines, the colour and character formats of the marked information are quite different, so there are still some challenges for the label characters marking and recognition. In the future study, it will be very important to develop the robust recognition algorithms for different kinds of marked information and set up a set of adaptive image capturing equipment suitable for high temperature, dusty environment.

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