A survey of machine vision-based monitoring methods for abnormalities in molds

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Abstract. Anomaly monitoring in the mold is a mean to ensure its efficient and stable operation. At present, there are many methods for detecting abnormalities in molds, such as tonnage or strain signal analysis, ultrasonic or magnetostatic detection, and machine vision inspection. This paper compares the advantages and disadvantages of the above methods, lists the existing abnormalities of machine vision mold monitoring methods, and the two major problems (illumination changes and camera vibration) in the process of monitoring solutions are summarized. At the end, the paper summarizes and analyzes the development direction and key points of this field.

1. Introduction

A mold is a cavity tool with a certain shape and size. Combining with various systems or auxiliary mechanisms in the mold, all kinds of materials are filled to the mold cavity and industrial parts with specific shape, size, function and quality can be produced. The mold will have higher machining accuracy when running normally as well as the processed products will have higher stability. However, various abnormalities in the interior of the mold can cause abnormal operation of the mold, resulting in workpiece damage, waste products, and even processing equipment damage, machine shutdown, causing significant economic losses. Traditional manual detection is prone to fatigue due to long-term staring, and it is difficult to avoid failures in time. Therefore, the monitoring of abnormalities in mold is of great significance [1]. The contents of anomaly monitoring in the mold include waste residue, abnormal shedding, spatter of foreign bodies, deformation or shedding of mold parts, etc.

There are many ways to monitor abnormalities in molds. The commonly used method of on-line monitoring is analysing the tonnage characteristics collected by a sensor (as shown in Figure 1.) installed on the connecting rod or column of the press. Lei Ye et al. [4] came up with a novel feature selection and classification method to improve the detection and classification performance of multiple types of mold failures. Paynabar K et al. [5] proposed a multi-channel analysis method based on independent multi-linear principal component analysis to monitor the mold working process, fault detection and fault diagnosis. All of the above methods are used to collect signals using acceleration or pressure sensors. Since it is easy to collect, the sensor is easy to install and calibrate, the signal contains rich information and some other advantages, for many mold using. The biggest problem is that it cannot solve the detachment of the parts on the mold and the residuals of the processing waste, etc., which can only be detected after hitting and can't be prevented in advance.
Ultrasonic and magnetostatic detection can also be used in the on-line quality monitoring of some mold production processes. He B B et al. [6] used non-destructive ultrasonic to monitor the process of polymer injection molding, not only to obtain information on the state of solidification of the polymer, but also to determine whether the mold was properly released after molding. Zhao P et al. [7] proposed a non-destructive on-line monitoring method for monitoring the injection molding process by collecting and analysing signals from injection molds, and integrated ultrasonic testing techniques to measure the cavity pressure to monitor whether the molds are operating normally. Tao Z et al. [8] used static magnetism to monitor the vibration during continuous casting to analyze whether the casting mold was operating normally. In addition, capacitive sensors, displacement sensors, temperature and humidity sensors, etc., [9] could also monitor different molds. The ultrasonic and magnetostatic detection can reduce the problem of mold accuracy reduction caused by the installation of sensors, at the same time, it can perform quality monitoring. However, the problem of this method is that it is difficult to detect the problems such as falling off of parts, spatter of foreign bodies, and the application scope of detection is relatively narrow.

In recent years, machine vision technology has been increasingly used in the process of monitoring the production status of processing equipment. Since the advantages of non-contact, high efficiency, and a wide range of detection spectrum, it is widely used in precise positioning, precision detection, automated production, and anomaly monitoring [10].

This paper summarizes the existing anomaly monitoring methods based on machine vision, and gives the prospect of the machine vision technology in the field of anomaly monitoring in the mold. The rest of the paper is organized as fellow: The second section describes the existing technology of anomaly monitoring based on machine vision technology in the mold; The third section compares and analyzes the existing solutions to the key problems of anomaly monitoring in the mold; Finally, the fourth section summarizes the next development direction and key point in the field.

2. Related Work

The typical machine vision based mold monitoring system is shown in Figure 2. According to the actual demand, it is divided into three parts: image acquisition and processing part, signal transmission control part and illumination part [11]. With good illumination, the camera acquires a clear image and passes it to the main processor for processing. During this time, the signal transmission control section controls the illumination, the mold, and the feedback mold information to the main processor.
Manufacturing Process Control Systems

Main Processor with Image Processing Software

Camera(s)

Illumination

Monitor

Mold

Figure 2. The typical machine vision based mold monitoring system.

Wang P J et al. [12] proposed a method of mold protection based on machine vision. The difference method is used to obtain the difference values image of the foreground and blank background images of the injection mold to calculate the pixel qualified rate in each ROI (Region of Interesting), so as to judge whether there is any foreign body in the mold before the mold is closed. In addition, near-infrared lighting and background automatic updating are adopted to solve the negative effects of ambient light intensity changes and vibration on the detection results. Chi TY et al. [13] considered that the location error and the change of ambient brightness would result in a high false alarm rate. Therefore, offset correction and dynamic safe range learning are used to overcome the change of image location error and environment brightness, and the anomaly monitoring of the mold is realized.

Mao F et al. [14] put forward a method based on scatter grams to detect foreign bodies, which is used to realize automatic protection during mold production. The scatter plot with grayscale as a variable is established for the detection image, and the probability distribution and the regression relationship of two images corresponding to the pixel grayscale are analysed so as to achieve illumination invariant. The regression curve was constructed using B-spline, and the width of confidence interval was obtained by deviation statistical histogram to detect the false matching pixels representing the foreign substance. The wavelet multi-resolution analysis method is used to decompose the same order wavelet with two images respectively, and the approximate image of the edge detail is obtained, so that the subsequent foreign body detection can eliminate the influence of the mismatch between the images. Thus, the robustness of illumination and geometrical deviation are obtained.

Hu F et al. [15] considered that the large vibration during the mold monitoring process resulted in a high false alarm rate, and proposed a method for judging the abnormality of the injection mold and whether the product was defective. In order to resolve illumination changes, a new geometric relationship-based global context (GRGC) feature was adopted for rematching after initial SIFT matching in the image registration step. Finally, the detection target is extracted by using the differential and threshold segmentation method.

Zhang L C et al. [16] proposed a new algorithm for fast and high-resolution matching of images based on integrated grey and local contour information. The image is divided into sub-images, the histogram matching was performed to determine that weather the similarity of the histogram was less than the histogram threshold, and then the mean of the grey value and its standard deviation were compared. Yang W et al. [17] performed pre-processing, template matching and cross-correlation of the injection mold cavity to monitor abnormalities in the cavity of the injection mold, analysed the situation of missed inspection which is resulted from a small amount of plastic residue, and proposed improvement suggestions.

Bai F et al. [18] designed the hardware system for real-time monitoring of molds, and segmented the obtained images to extract the objects to be monitored in the system. Adaptive grey-level threshold segmentation, layered saturation binary method and open-loop algorithm denoising method are
adopted to eliminate "pseudo-target region", other target area contour information is extracted, finally using region growing method to obtain product information from the image. The whole system can realize high precision, high stability of the mold multi-area monitoring and product detail detection. Yang Y et al. [19] proposed a systematic approach to combine digital image processing (DIP) with model-free optimization (MFO) for quality optimization and mold monitoring in the injection molding process. The DIP technology was used to detect the common surface defects such as shrinkage of the molded parts, and the edges of the mold were marked by the edge detection method. The defect is quantitatively measured and fed back to the MFO algorithm, and the MFO algorithm is used to determine the best setting to eliminate the defect.

Cao M H et al. [20] came up with a method for monitoring a foam mold using machine vision. After obtaining the image, the image is pre-processed and matched with the template image, spot detection is carried out on the acquired interest area, which successfully solves the problem of frame line missing and dislocation in online monitoring. Butt S I et al. [21] proposed an automatic positioning and monitoring system for sand casting molds based on machine vision. The casting molds of different casting positions and different radius are located and identified, and the residue as well as other abnormalities in the mold are monitored.

Table 1. shows the comparison of the existing method of anomaly monitoring in the mold based on machine vision with the methods described in the first section.

| Methods                  | Scope of Application | Detection Accuracy | Detection Speed | Impact on Molds                | Protective for Molds                                                                 |
|--------------------------|----------------------|--------------------|----------------|-------------------------------|---------------------------------------------------------------------------------------|
| Traditional manual detection | The majority of molds | Medium             | Medium         | None                          | In a short period of time, high-precision speed monitoring can be achieved. However, the accuracy and precision of monitoring will be greatly reduced when working long hours |
| Tonnage or strain signal analysis | The vast majority of molds | High               | Fast           | Additional sensors on the mold may affect the mold | The long-term data collection of the mold can diagnose the health of the mold, but it can't carry out the early warning and shutdown for the sudden problems and can't detect the quality of the products |
| Ultrasonic and magnetostatic detection | Only a few specific molds at present | Medium             | Fast           | Small                         | The quality of the injection molded parts can be monitored, and whether the quality of the molded parts can be removed normally, but it's less protective of the mold |
| Machine vision detection   | The vast majority of molds | High               | Relatively fast | Small, or none                | The long-term data collection of the mold can diagnose the health of the mold through data mining. It can provide early warning and shutdown for sudden problems and can detect the defects of the processed products at the same time |

Through the above comparison, it can be found that machine vision can provide early warning and shutdown for sudden problems in the mold under high precision and relatively high speed. Some methods can simultaneously monitor the quality of products. So it replaces traditional manual detection better.
3. Main Problems in Mold Abnormality Monitoring

For the abnormality monitoring in the mold, according to the above content, the most common methods at present is mainly the template matching difference method. However, this method often fails in the complex environment of the mold. There are two main reasons:

(1) Due to the change of the production environment, the ambient light intensity varies in different situations, which is reflected in the different grey levels at the same point in the scene, resulting in misjudgement.

To solve this problem, Table 2. shows the solutions to the change of illumination in the mold:

| Solution       | Implementation Method                                                                 |
|----------------|---------------------------------------------------------------------------------------|
| Equipment improvement | By using CMOS image sensor that can detect near-infrared light in combination with filter and a near-infrared lamp, the effect of visible light during detection can be effectively eliminated |
| Algorithm improvement | Based on the scatter diagram with grey-level variables, the probability distributions and regression relationships of the corresponding pixels in the two images are analysed with strong stability |
|                 | Using the method of dynamic range safety learning, recording the normal state as a reference, setting the tolerance value and tolerance area size, and automatically updating it to eliminate the effects of changes in light |
|                 | Using a new geometric relationship-based global context (GRGC) feature, which is globally vector normalized to keep the descriptor invariant to illumination |

(2) Due to frequent mechanical collisions during the operation of the mold, strong vibrations may occur, which may result in the image acquisition device being unable to guarantee that there will be no geometrical deviation in the images acquired at different moments. Especially in the common template matching method, slight misalignment may also bring about a large impact and cause misjudgement.

To solve this problem, Table 3. shows the solutions to the camera's jitter deviation:

| Solution       | Implementation Method                                                                 |
|----------------|---------------------------------------------------------------------------------------|
| Equipment improvement | Using a vibration-isolated camera support structure or using a camera-supported structure independent of the mold can be better to eliminate deviations caused by camera vibration, but it cannot eliminate the effects of mold vibration and other factors on the image |
| Algorithm improvement | Using the background update technology/offset correction, the foreground image and the corresponding background image will be updated or offset correction with weighted background image when the image detection is completed and it is qualified, but the algorithm has a general processing capacity for the large bursts of vibration |
|                 | The wavelet multiresolution analysis method is adopted to decomposed the same order wavelet with two images respectively, and the approximation image of the edge detail is obtained, which eliminates the deviation in the difference process, but the detection capability of the smaller foreign body is general |
|                 | The global context (GRGC) feature contains two components: the SIFT descriptor and the global descriptor. The global descriptor eliminates the local similar feature ambiguity, thus achieving high accuracy of registration, but the entire process takes a long time |
|                 | Using the cross-correlation method, the similarity degree of the template image and the image to be detected is calculated to judge whether there is an abnormality in the module. It does not really deal with the deviation |
caused by vibration, so the accuracy is relatively low, and the ability to handle larger vibrations is generally
Other methods are mainly to extract the ROI, and perform specific analysis on the ROI, or perform template matching and template difference monitoring, such as anomaly monitoring and quality monitoring. This method is more biased towards quality monitoring and also has some anomaly monitoring capabilities.

4. Summarization and Prospect
For the anomaly monitoring in molds, the application of machine vision technology can ensure the high stability and high efficiency of the mold. Now existing detection method can overcome the effects of illumination change and image vibration, however, there are still some general problems about the poor detection accuracy of small foreign bodies and the real-time performance of some methods.

For the current machine vision-based monitoring methods for abnormalities in molds, there are the following development prospects:
(1) The quality monitoring of the processed products is carried out while the anomaly monitoring of the mold is completed;
(2) While ensuring the accuracy of the test, it is necessary to ensure the real-time performance of the test;
(3) In the static environment, the mold detection is relatively mature, and the anomaly monitoring of the mold under dynamic environment should be considered, such as the dynamic mold of injection mold, the progressive die, etc.;
(4) The universality of the method and apply to processing equipment under similar circumstances should be improved.

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