The estimation of the laser point temperature based on CNN (Convolutional Neural Network)

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Abstract. For the requirements of the laser temperature in additive manufacturing, there is a high precision and high heat need in the industry. The method is proposed to estimate the temperature of laser point, which is based on CNN. In this method, a model of CNN is carried out. The collected laser thermal radiation images are used to train the model. Image recognition and isotherm estimation can be obtained by the trained model. The conclusion can be verified by the experiment. The isotherm and temperature of the laser can be measured efficiently in this method.

1. Introduction

With the combination of AI, Automation Control and additive manufacturing, the additive Manufacturing improved by intelligent methods has been a new research hotpot. Zhang jie et al [1] creatively applied CNN to the fire video image detection problems. The fire can be recognized and located by images. For the issue of laser point temperature detection, Lu xiaofei et al [4] analyzed the infrared optical characteristics of the temperature radiation image. The temperature of target equivalent radiation can be measured by the image segmentation and background modeling technology. Yu lingling et al [4] developed a series of laser temperature field detection system based on high speed CCD. According to the transformation relationship of grayscale-temperature, the collected grayscale image of laser temperature can be transformed into a two-dimensional distribution of temperature field. In this way the temperature detection is implemented. There are some shortages in traditional methods for isotherm image recognition of the laser point and some progresses in CNN in image recognition field. According to these, a method based on CNN can be designed. This method is used for automatic recognition and temperature estimation of laser isotherm image. In this method, the problem of laser point temperature detection can be solved in the complex environment.

2. CNN Modeling

2.1 CNN

Convolutional Neural Network is composed of input layer, output layer and multiple hidden layers. Some special operations are carried out in the hidden layer to solve the problems of neural network (over-parameterized) in image processing. The operations are including convolution and pooling.
2.1.1 Convolution Layer
The main function of convolution layer is to extract features from the input data. The filters of convolution layer are used in this process. The general formula of convolution is as follows.

\[
W_{out} = \frac{W_{in} - W_{filter} + 2P}{S} + 1
\]

\[
H_{out} = \frac{H_{in} - H_{filter} + 2P}{S} + 1
\]

Where \( W \) and \( H \) are the value of image’s weight and height. The relevant parameters of the input and output image are represented by subscript input and output respectively. The relevant parameters of the Convolution Kernel are represented by subscript filter. \( P \) is short form of padding, which means the image border filling. If the Same mode is used, the value of \( P \) is the number of boundary layers added to the image. If Valid Mode is used, then \( P=0 \).

2.1.2 Pooling Layer
A lot of image feature information is extracted by convolution layer. The feature information is mostly similar as the neighbor regions’. Assuming that all of the information is reserved, the information redundancy could be caused. It is hard for computers to calculate. Pooling operation is used for filtering the information which is the best to express the image feature. Though pooling operation, the amount of data would be reduced and the data characteristics could be maintained. The general formula of pooling is as follows.

\[
W_{out} = \frac{W_{in} - W_{filter}}{S} + 1
\]

\[
H_{out} = \frac{H_{in} - H_{filter}}{S} + 1
\]

Where \( w \) and \( h \) are the value of characteristic pattern’s weight and height respectively. The relevant parameters of the input and output characteristic pattern are represented by subscript input and output respectively. The step size of the sliding window is represented by \( S \). The depth of the input feature graph is consistent with the depth of the sliding window.

2.2 CNN structure
The CNN structure is shown in Figure 1.

![CNN structure](image)

**Figure 1. CNN structure**

An image data is input into the input layer. The feature information is extracted by convolutional layer. Pooling layer is used for filtering the feature. The operations of convolution and pooling are performed twice. After these operations, the feature information is extracted better. The data width and height are reduced, and data depth is increased. The result of the last pooling layer is input into a two-layer connected layer. Finally, the images will be classified and recognized.

2.3 The recognition and estimation of the isotherms of laser point.
Two aspects are in the isotherms estimation of laser point based on CNN, including model training and model testing. The large number of laser point temperature radiation images is collected for model training. The model can be trained by using the training set and saved for estimation. Then the test set can be imported. Comparing the data, the results can be outputted. The flow chart can be shown as...
follow.

![Flow Chart]

Figure 2. The estimation flow chart of the isotherms of laser point which based on CNN

### 3. The estimation of the isotherms of laser point which based on CNN

#### 3.1 Distribution of laser radiation temperature field

The substance whose temperature is above absolute zero is ceaselessly radiating infrared energy around. The infrared energy and the distribution by wavelength are mostly dependent on surface temperature of the substance. Therefore, the surface temperature can be accurately obtained by measuring the infrared energy radiated\(^5\).

An actual radiation temperature infrared chart is shown in Figure 3. For the radiant surface of homogenous materials, the isotherms of laser point can be equivalent to the temperature field composed of a series of concentric circles. Different isotherms are represented by different ring contours. The temperature is same on a same circle. The temperature gradually decreases from the center to the outward. The highest temperature is in the center.

![Image of Temperature Field]

Figure 3 The image of temperature field of laser point

#### 3.2 Image preprocessing

The temperature radiation area of the laser point can be approximated to circular areas of different sizes. Besides, there are some minor differences on the edge. Temperature images of laser point collected are usually colorful images. Some image preprocessing should be implemented including gray-scale, binarization and de-noised. After image preprocessing, the binary image for subsequent model training can be got.

#### 3.3 Feature extraction and feature training

The area of the laser point isotherms is just a part of images. For keeping the accuracy of the training model, the images need to be segmented. Contour features of temperature images are extracted to
ensure the accuracy of the subsequent training model.

3.4 Image matching
Comparing test set with collected training set, the similarity can be used for judging the effect of training. The ways for calculating the similarity are including Perceptual hash algorithm and Histogram algorithm. Both two algorithms have some degree of miscalculation. For improving the accuracy, the two methods are used in combination.

3.5 Image recognition
The similarity value $S$ of the two images can be calculated. Comparing with the set similarity threshold $S_{th}$, the determination whether the two are the same picture can be implemented. The criterion is as follow.

Identify results :
\[
\begin{cases}
    \text{The two images are the same image} & S \geq S_{th} \\
    \text{The two images are not the same image} & S < S_{th}
\end{cases}
\]

3.6 The estimation of isotherm
The results of image recognition can be obtained. Assuming that the testing image is the temperature radiation image of this laser point, there is the proportional relationship between the test image and the training image in the area of the circle enclosed by the isotherm.

\[
\frac{T_{test}}{T_{train}} = \frac{S_{test}}{S_{train}} \quad (3)
\]

The isothermal temperature of the test image can be calculated by the known isotherm temperature. The relationship between the radius and the area of circle is as follow.

\[
S = \pi r^2 \quad (4)
\]

The linear relationship of the circle’s area can be converted into the square relationship of the circle’s radius.

\[
\frac{T_{test}}{T_{train}} = \frac{r_{test}^2}{r_{train}^2} \quad (5)
\]

Using the value of the radius, the estimate temperature of the isotherms can be obtained.

4. Experiment processing and results

4.1 Image preprocessing
Image preprocessing of the training set can be implemented. In Figure 4, a) is an approximately circular image of flame radiation from the original collection. The border of the laser is reserved by grayscale process and binary process. b) is the process result.

![a) Artwork b) binary image](image)

Figure 4. The results of the image preprocessing

4.2 Model training
The process can be carried out collecting a large number of temperature radiation images of the same laser point. Due to the existence of the error factor, some slight differences will be appeared in the
contours of every image. According to the fitted circular area, the image segment can be carried out and keep only the circular area. In this way, the success rate of identifying is improved. The diversity of image samples can be enriched by changing contrast and brightness randomly. The characteristics of the thermal radiation area are reserved by training model of CNN. To train a large number of models, different hyper-parameters are deployed. The parameters depend on the collected training data, the quality of the data and the analysis of the results in the training process. The model with the highest accuracy will be used finally. The feature of the image is basically reflected by the weight of each layer in the training process. Therefore, the accuracy can be improved to achieve better results by fine-tuning and using pre-training model.

4.3 The recognition and estimation of the isotherms
The reserved model is deployed for detecting. The image to be recognized is input into the model. The judgment is performed by calculating the image similarity between the measured images and the training images. The experiment is implemented four times. An image in the selected training set is displayed in Figure 5.

![Figure 5. The training image](image)

Assuming that this isotherm of radius is $140 \text{pix}$ and the temperature is $2500 \degree C$, the four output testing images are shown in the Figure 6.

![Figure 6. The testing images](image)

The similarity value of each testing image can be calculated by comparing with the training image. Assuming that the similarity threshold is set to 85%, the result of judgment is compared with a threshold. If the result is matched, the temperature can be obtained by (5). The results of testing experiment are shown in Tab. 1.

| Testing images | Similarity (%) | Whether or not | Temperature (°C) |
|----------------|----------------|----------------|------------------|
| Test_img1      | 59.90          | No             | ---              |
| Test_img2      | 99.96          | Yes            | 2224.6           |

Table 1. The results of testing experiment
| Test_img3 | 86.72% | Yes | 4041.3 |
|----------|--------|-----|--------|
| Test_img4| 65.82% | No  | ---    |

It can be seen from Table 1. Values of similarity between text_img1 and text_img4 are lower than 85%. It means that these laser images are not classified to the testing laser image. And Values of similarity in text_img2 and text_img3 are upper than 85%. It means that these laser images are classified to the testing laser image. The temperature can be calculated.

5. Conclusion
Aiming at the problem of laser temperature estimation in additive manufacturing, CNN in deep learning is deployed in this paper. Training and recognizing are performed by collecting laser isotherm images and CNN. High accuracy of recognition is obtained by the trained CNN model. The temperature of the testing image is approximately obtained by using the testing image. The effectiveness of the method can be verified by the experiment.

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