A Detection and Identification Method Based on CNN for Laser Point Thermal Radiation

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Abstract. Aiming at the high demands of temperature and precision in the aspect of additive manufacturing, a method based on CNN was proposed for estimating measurement. The network was trained through the collected laser thermal radiation images for image recognition and isotherm estimation after modeling a CNN. The experimental conclusion verifies that the isotherm detection and temperature estimation of the laser point can be efficiently implemented in proposed method.

1. Introduction
In the wake of the fusion among of Automation Control, Image Processing and Intelligent Manufacturing, the research that intelligent recognition methods attached to the additive Manufacturing has been a research direction with a deep potential. Zhang jie et al [1] worked on image detection problems for forest fire videos through using the CNN. In the paper, the fire in the capture image can be recognized and located by the deep learning method. Aiming at the infrared radiation, Lu Xiaofei et al [2] has analyzed the laser point temperature distribution. They measured the light of the laser point through the image segmentation and distinguished it from the noise pixels by the background modeling. Rong ping et al [3] developed a high speed CCD detection system that applies the transformation relationship between temperature and grayscale for the temperature detection. In this system, the laser grayscale image caught by the CCD during the printing process can be transformed into a two-dimensional matrix which represents the temperature distribution of the laser point infrared field.

In view of the adverse factors in above methods in the thermal image recognition and temperature detection and the progresses of CNN, a detection method combined with CNN was proposed to address those issues. In this paper, infrared image recognition and temperature estimation were automatically obtained in the intricate situations of the 3D printer.

2. Detection Modeling for Laser Point

2.1. CNN
Convolutional Neural Networks consists of an input layer, multiple hidden layers and an output layer for detected the laser point in this research. Operations including convolution and pooling are implemented in multiple hidden layers to cope with the problem of too many parameters.
2.1.1. Convolution Layer
The convolution layers, as the feature filters, are to extract feature images from the input laser temperature image. The formulas of convolution were shown as following.

\[
\begin{align*}
    W_{\text{out}} &= \frac{W_{\text{in}} - W_{\text{filter}} + 2P}{S} + 1 \\
    H_{\text{out}} &= \frac{H_{\text{in}} - H_{\text{filter}} + 2P}{S} + 1
\end{align*}
\]

Where \(W\) and \(H\) are width and height of thermal maps. The parameters related about the input maps and output results are indicated by the variables whose subscript is input and output. Meanwhile, the parameters related about kernels in convolution layers are represented by the variables whose subscript is filter. And the parameter \(P\) means Padding, which is the filling on the image border. Assuming that Same Mode was selected, the value of \(P\) is an addition in the boundary of convolution layers. Besides, Valid Mode was deployed, \(P\) is nonexistent.

2.1.2. Pooling Layer
Feature information of isotherm map is extracted over convolution layers. The extracted image information is probably similar in adjacent elements after the operation. Assuming that the data about the temperature of the laser point are reserved as much as possible, the situation of redundancy could be existence, leading to the fact that it is hardly to estimate the laser point temperature. Aiming at this issue, pooling is generally carried out for obtaining the information to represent features. The data characteristics could be reserved and a mass of redundant data would be cut down by the way of pooling operation. The main formulas are shown as following.

\[
\begin{align*}
    W_{\text{out}} &= \frac{W_{\text{in}} - W_{\text{filter}}}{S} + 1 \\
    H_{\text{out}} &= \frac{H_{\text{in}} - H_{\text{filter}}}{S} + 1
\end{align*}
\]

Where \(w\) and \(h\) are width and height of feature map respectively. The relationship of input and output in each pooling layer are expressed by the index input and output. \(S\) means the step of the sliding window for extracting the laser point characteristics. And the depth variable of each sliding window is matched with the feature graphs after convolution layer.

2.2. The Form of Detection modeling
The form of CNN modeling for detecting the laser point proposed in the paper is shown in Figure 1.

![Figure 1. Detection modeling](image)

After a thermal map is input into detection modeling, a series of processes are implemented in the CNN. Features of the laser point about temperature will be collected by the convolution kernel in convolution layer. And pooling layer is effected for increasing the computing speed. As shown in figure, twice processes of convolution and pooling are used in an iteration. After those, width and height of the feature image are decreased, while the depth is accumulated. After the last and deepest pooling layer, the result is put into a connected layer for classifying and estimating the laser point temperature.
2.3. The laser point identification by isotherm map.
There are two steps in the laser point identification based on CNN, including model training for learning the feature of the isotherms and model testing for verifying the accuracy of the temperature estimation. The images divided into training set and test set. The training set is collected to train CNN model for estimating the temperature. And the other will test after training the model. Comparing with the results obtained from the trained model, the precision can be obtained. The flow chart can be shown in Figure 2.

![Flowchart of laser point identification](image)

Figure 2. The flow chart of the identification for thermal features

3. Processes of Estimation about the Laser Point Isotherms

3.1. Image preprocessing
The temperature field caused by the laser point can be regarded as a series of different isotherms with a same centre in a radiant surface of homogeneous material. The regions covered with a similar color are in the approximately temperature in the figure. An infrared distribution image of the actual laser point is shown in Figure 3.

![Infrared distribution image of laser point](image)

Figure 3. The infrared distribution image of the laser point

As mentioned above, the infrared image of the laser point can be approximately regarded as a series of circles with different radius over the background. Some processes of image preprocessing can be carried out for binarization and de-noised. The different colors will be used to distinguish the variation of the temperature. After those, the binary image training can prepare for subsequent model training.

The area to identify just covers a part of the region on an image. The images need to be segmented
to cut the useless area for improving the recognition speed.

3.2. The temperature estimation of laser point

Comparing with the labels of the sample, the similarity can be judged after estimating. The calculation can be carried out through Histogram algorithm and Perceptual hash algorithm in traditional method. However, some deviations will exist in judging the similarity. Therefore, two methods are combined for improving the accuracy.

The similarity $S$ on two images in the sample can be evaluated by the combined judgment method. The determination whether they belong to a same classification can be obtained through comparing with the similarity threshold $S_{th}$. The criterion method is as following.

\[
\text{criterion result : } \begin{cases} 
\text{Two maps belong to a same classification. } S \geq S_{th} \\
\text{Two maps don't belong to a same classification. } S < S_{th}
\end{cases}
\]

According to the result of laser point identification and assuming that the criterion result is true, there is a proportional relationship existence between the test samples and the training samples. The temperature of the test samples can be calculated by the area of the laser point temperature distribution.

\[
\frac{T_{test}}{T_{train}} = \frac{S_{test}}{S_{train}} \tag{3}
\]

Where $T$ is the temperature of the laser point and $S$ is the area of the thermal radiation. Due to the thermal distribution shape of the laser point, a geometrical relationship existence in the laser area can be approximately expressed as following.

\[
S = \pi r^2 \tag{4}
\]

According to Eq. (3) and Eq. (4), the formula between the temperature and the area can be converted into the formula between the temperature and the radius of the area as:

\[
\frac{T_{test}}{T_{train}} = \frac{r_{test}^2}{r_{train}^2} \tag{5}
\]

The estimate temperature of the laser point can be obtained by using the radius.

4. Experiment Processing and Results

4.1. Image preprocessing

The result of binarization processing was shown as Figure 4. In Figure 4, a) is an approximately map of laser point region. The boundary information of the simulating temperature distribution is reserved by the binary process, which is shown as b).

![Figure 4. Binarization processing](image)

4.2. Model training of the identification

The capturing process was implemented to get a mass of thermal distribution maps for edge detection. Due to the differences between the actual distribution and the standard circle, some slight deviations will be discovered during the process of image matching. At the part of the process of fitting, the
process of segment can be just coped with and reserved the part of the laser point area by the original capture image. In this way, precision of region identifying will be improved. Images of changing contrast and brightness randomly are used for training the CNN for enriching the diversity of image samples. The characteristics of thermal radiation in the images are extracted by using CNN. In order to cope with training the CNN model, different initial parameters setting are test. The quality of parameters depends on the collected image and the training process. While training the CNN with the images of laser temperature distribution, the feature is basically extracted by the kernels of each convolution layer.

4.3. The result of laser point identification
The samples are put into the identification model that has been trained and reserved for detecting and recognizing. The process of matching is implemented four times in a specified experiment. Figure 5 displays one of images.

![Figure 5. One of the training image](image)

In the figure 5, the thermal radiation of the laser point is $120\text{pix}$ in the image and the represented temperature is $2000^\circ\text{C}$. There are the four testing samples named Test-$n$ shown in the Figure 6.

![a) Test1 b) Test2 c) Test3 d) Test4](image)

Figure 6. Partial testing images

The similarity between each sample in the test set can be obtained by the proposed method. In the experiment, the threshold of distinction is set to 80%, the evaluation is compared the result with the threshold. The temperature can be calculated by Eq. (5), if the evaluation is matched with a certain one in the training set. The partial results of testing samples are listed in Table 1.
Table 1. The evaluation of testing sample

| Testing samples | Similarity | Identification results | Temperature(℃) |
|-----------------|------------|-------------------------|----------------|
| Test1           | 45.87%     | No                      | ---            |
| Tes2            | 95.24%     | Yes                     | 2114.8         |
| Tes3            | 90.45%     | Yes                     | 1854.5         |
| Test4           | 55.44%     | No                      | ---            |

The results can be seen following Table 1. Similarity of text1 and text4 are lower than 80%. These samples are not identified to the testing laser samples. Beside, text2 and text3 with an upper than 80% of the similarity value are identified to the laser samples. Then, the temperature of laser can be estimated by the temperature estimation formulas.

5. Conclusion
Aiming at the importance and issue of laser thermal radiation detection in additive manufacturing, this paper proposes a deep learning method for coping with recognizing the laser point through the temperature distribution. Training of the temperature recognizing model is performed by using the collecting laser thermal radiation maps in this method. The high accuracy of identification can be obtained by laser point images and the proposed CNN modeling. The thermal radiation distribution of the actual laser point can be approximately obtained by using the temperature estimation formulas after matching through CNN. The experiment illustrates that this method is of a high accuracy and effectiveness.

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