HARBIN INSITITUTE of TECHNOLOGY

Master's thesis opening report

Title: Welding Quality Prediction based on deep learning and multi-information sensing

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Discipline: Material Engineering

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Catalogue

1. Introduction

1.1. Research Source

This research is part of the project—Laser Welding Technology for Complex Projectile Components. The project, approved by the National Defense Science and Technology Bureau, is one of the Chinese “13th Five-Year Plan” research projects (No. 2). Through the research of this project, we can break through and master the key technologies such as the laser welding microstructure control method and process technology of XX high temperature titanium alloy complex XX components and high power laser flexible welding system integration. In addition, it can also help to rapidly promote the development of laser welding technology for complex components in the field of national defense technology, ensure the development of a new generation of weapons and equipment represented by XX, improve the development level of complex components of XX weapons and equipment, and improve the new XX weapons and equipment.

1.2. Background and Significance of the Research

Laser welding is a highly efficient and precise welding method using a high energy density laser beam as a heat source. It has the characteristics of high energy density, low thermal damage to materials, high processing precision, etc., which can significantly reduce the workload of subsequent processing. At the same time, laser welding is also easy to integrate, automate, and flexible. These excellent properties make it widely used in many manufacturing fields such as aerospace, automotive, and marine [1, 2]. However, laser welding is a complex nonlinear time-varying process. The unstable factors will seriously affect the welding quality. Therefore, it is urgent to improve the research level of the real-time control technology of the laser welding process. The online measurement and analysis of the welding process parameters are It is the key to realize automatic control and ensure the quality of welding. The weld quality is closely related to the penetration condition. Most of the weld defects such as pores and cracks are formed in the case of poor penetration (not penetration, over penetration, etc.), and the factors affecting the penetration state of the weld are diverse. Such as laser power, welding speed, defocusing amount, metallurgical reaction, etc. Existing off-line inspection methods are difficult to ensure a well-welded weld during the welding process. Therefore, research on on-line monitoring technology for weld penetration status is crucial.

The laser high energy beam acts on the surface of the material, and the pool-like region formed by melting the material in the weld zone is called the molten pool. During the welding process, the surface morphology of the molten pool carries a wealth of information, which can reflect the stability of the welding process, the penetration state of the weld, etc. Therefore, the sensing of the surface morphology of the molten pool has far-reaching significance. The characteristic parameters of the molten pool strongly influence the shape, metallographic structure, mechanical properties and stress deformation of the joint, which ultimately affects the joint quality level, which has always been a concern of researchers [3]. The characteristic parameters of the molten pool include geometric characteristic parameters of the molten pool, temperature field information and the like. Analysis of the geometric characteristics of the molten pool (length, width and area) is an important way to monitor the quality of laser welding [4]. Duan Aiqin [5] studied the relationship between the "small hole", the geometric parameters of the front and back molten pool and the quality of deep-melting welding. Laser deep-fusion welding is often accompanied by the generation of plasma, which is formed by the ionization of metal vapor. It contains a wealth of dynamic information about the welding process and is an important research direction for online monitoring of welding quality. Therefore, it is a very important way to judge the weld penetration state by studying the molten pool, small holes and plasma information to predict the weld penetration state.

In the laser welding process, the interaction between the laser and the material is carried out in the molten pool and small holes. The visual observation is used to directly observe the small holes in the molten pool, and a wealth of information related to the welding quality can be obtained. And the visual method belongs to non-contact monitoring, which has the advantages of high monitoring accuracy and easy automation. Direct monitoring of weld pools with visual images has become an important research and application direction. It can be used for weld seam tracking, welding process stability monitoring and penetration control, etc., with unique advantages [6-7]. In recent years, with the development of visual sensor technology and computer image processing technology, the application of machine vision has become more and more widely. The use of visual methods to monitor the quality of laser welding has attracted the attention of experts and scholars at home and abroad.

The pool image collected by means of visual sensing often contains a large amount of noise interference. This is because welding is a high-energy, high-heat process, accompanied by many complex physical phenomena such as plasma and splashes, which are imaged in the photosensitive device and superimposed on the image of the molten pool. Huge interference. At present, the measurement methods of the molten pool geometric parameters [8-9] do not consider the influence of interference, and often produce some erroneous measurements, leading to misjudgment of the welding quality. In order to more accurately measure the geometric characteristics of the molten pool, it is particularly important to find an image processing algorithm that can remove interference well.

The laser welding process has the key common problems of many interference factors and difficult quality monitoring, resulting in unstable weld quality and unsatisfactory welding effect, which has become a bottleneck restricting the further development of laser welding technology in the manufacturing industry. To achieve on-line monitoring of the quality of laser deep-fusion welding processes, the following two scientific issues must be addressed:

(1) Under the action of high energy density (106W/cm2) laser beam, thick plate material will form a strong interference environment composed of high concentration plasma cloud, strong light, plume, soot and noise. How to pass sound and light in this environment The rapid and reliable capture of ultrasonic, visible, ultraviolet and infrared radiation signals during the welding process is the first scientific problem to be solved by online monitoring of welding quality.

(2) The original signals such as sound, light and electricity collected by the sensor are generally discrete and irregular. How to effectively pre-process the collected signal and establish a corresponding functional relationship with the welding quality, real-time and reliable feedback welding quality is another Scientific issues yet to be resolved.

2. Related Works

2.1. Visual Monitoring of the Welding Process

A lot of research has been carried out on real-time monitoring of laser welding quality at home and abroad, especially in developed industrial countries. Detecting and analyzing the various signals generated during the welding process from the interaction zone between the laser and the material has always been an important means of monitoring the welding process. In the laser welding process, it is accompanied by the generation of sound, light, electricity and other signals. The acoustic signals are mainly laser-induced plasma audible signals and other ultrasonic signals. The optical signals are mainly laser-induced plasma radiation and molten pool. The regional light radiation, electrical signals are also related to the plasma, mainly refers to the variation of the electric field in the welding area caused by the plasmon oscillation [10-11].

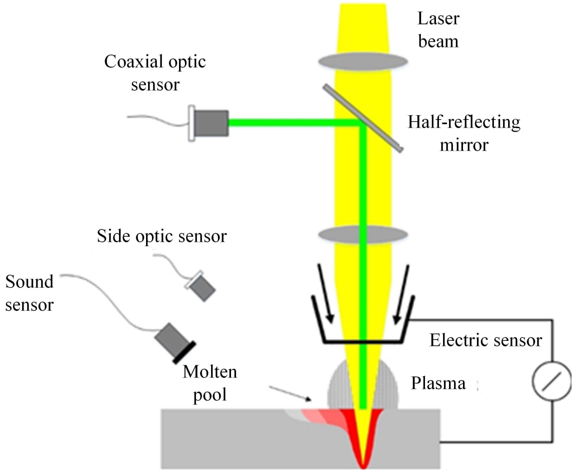


Figure 1. Laser welding process quality monitoring

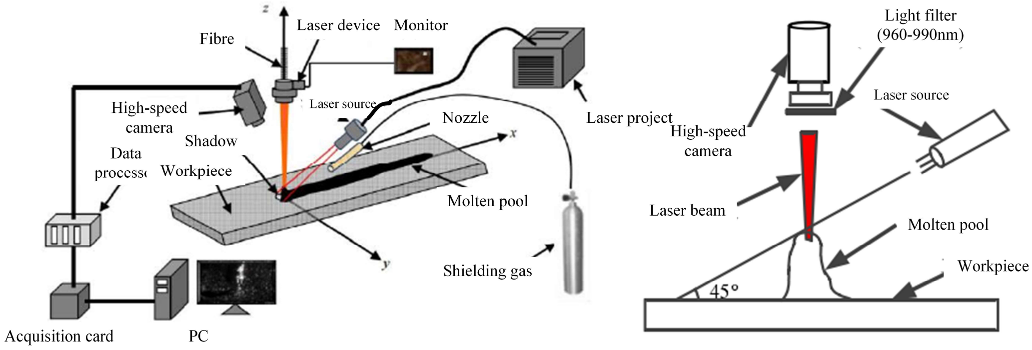
The visual monitoring information during the welding process mainly includes the shape of the molten pool, the small holes and the plasma. Using advanced visual monitoring technology (coaxial or rangefinder) to visually capture weld pool, small holes and plasma topography, a large amount of dynamic information containing weld quality is available. Therefore, in terms of visual monitoring, domestic and foreign scholars have carried out a lot of fruitful research work and formed many achievements.

2.1.1. Visual Monitoring Method during Welding

According to the angle of the collected optical signal, the laser welding visual monitoring system can be divided into coaxial acquisition and rangefinder acquisition [12]. Laser welding visual monitoring systems can be divided into active monitoring and passive monitoring according to the presence or absence of auxiliary light sources [13]. Coaxial monitoring means that the monitoring system acquires image signals from the direction of the molten pool and the small hole image in the welding area and in the direction of the coaxial line of the laser beam; the side axis monitoring refers to the image of the molten pool and the small hole in the welding area of the monitoring system. One side, a monitoring method at an angle to the axis of the laser beam. Active monitoring is a way to increase the auxiliary lighting system in the welding area; the passive monitoring method is to add no auxiliary lighting system, and only rely on the optical radiation imaging generated by the small holes in the welding pool to monitor.

(1) Side monitoring

Gao and others from Guangdong University of Technology established an active rangefinder monitoring system to obtain the shape of the molten pool and establish the stability of the weld pool morphology and weldment state [14]. The monitoring system built and its monitoring principle are shown in Figure 2. During the welding process, the molten pool protrudes from the surface of the workpiece, and the laser light source is irradiated on the welding area, and the other side of the molten pool forms a shadow due to the shielding of the auxiliary light source by the molten pool. The high-speed camera is used to monitor the shadow generated by the molten pool, which indirectly reflects the change of the shape of the molten pool. The method of side axis monitoring can establish the relationship between the shadow of the molten pool and the welding state, but this method is insufficient. Monitoring the shadow of the molten pool first is an indirect method with errors in monitoring. Secondly, in the welding of small power thin plates, the molten pool area is relatively stable, and the molten pool does not appear obvious protruding phenomenon. Therefore, the adoption of this method has certain limitations. There is also a method of bypass monitoring to directly monitor the small hole area. C. Brock et al. used an 850 nm laser source as an auxiliary light source to build an active side-track monitoring system to directly monitor the small hole area of the weld and establish the relationship between the small-pore plasma and the welding quality [15]. The method of the paraxial acquisition is used for monitoring, and the molten pool and the small hole image are distorted, and the distortion needs to be restored by the image processing algorithm. This will increase the difficulty of image processing, reduce the speed of the operation, and bring some errors.



a) Monitoring diagram b) Monitoring principle

Figure 2 the system and principle of the active side axis monitoring

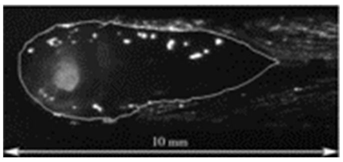
（2）Coaxial monitoring

Yung C. Shin et al. used a green laser light source with a wavelength of 530 nm as an auxiliary light source to build an active coaxial monitoring system, collecting molten pool and small hole images, and using different images of the head and tail of the molten pool. Processing algorithms are extracted separately [16]. The melt width information can be obtained by this method. Hyungson Ki et al. used a high-speed camera as an imaging device, used a 532 nm laser source as an auxiliary light source, collected small holes and through-hole images, directly measured small holes and through-hole images, and analyzed small holes at different welding speeds. Inclination [17]. B. Regaard et al. used an 800 nm laser source as an auxiliary source to collect small holes, penetration holes, and molten pool images [18].

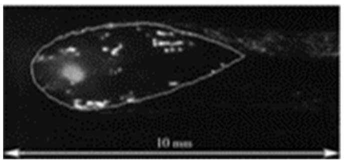
Through the above-mentioned domestic and international visual methods, it can be seen that at present, many small holes, penetrating holes or molten pool areas are independently studied, and the image processing method is used to calculate the radius or area of the small holes and the penetrating holes. Algorithms, or only for partially acquired images, have less research on the accuracy and speed of image processing. Coaxial monitoring provides more accurate weld pool, pinhole information, and the ability to capture through-hole images. When constructing a monitoring system, a green light source with a wavelength of about 532 nm or an infrared light source with a wavelength of about 808 nm is often used [19-21].

2.1.2. Molten Pool and Keyhole Monitoring

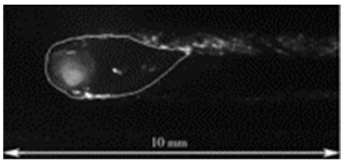
In domestic research, Gao Xiangdong et al. [22] of Guangdong University of Technology photographed the infrared thermal image of the molten pool of 10KW high-power laser deep-melting welding process through high-speed camera system, and found that the parameters such as melting width and small hole area are closely related to the stability of the welding process. Zhang Xudong et al. [23] of Tsinghua University [23] used a CCD camera to take a two-dimensional image of a small hole in a different penetration state during the process of CO2 light welding of 1 mm thick cold-rolled low carbon steel, and found a circular spot in the two-dimensional image of the small hole. The appearance and size change and the gradation change trend of gray scale curve show obvious regularity. On the basis of this, through the time domain and frequency domain analysis, the coaxial optical signal under different penetration states is studied when the workpiece thickness changes. The law of change, and the use of the characteristics of the gray image of the small hole image is related to the penetration depth; Meng Xuanxuan et al [24] of Huazhong University of Science and Technology use auxiliary devices such as active light source and optical narrow-band filter to utilize the high-speed camera technology for the fiber laser welding process. The molten pool and small holes were photographed, and a clear image of the molten pool and small holes was obtained, as shown in Figure 3, and fiber laser welding under different laser powers. The actual size of the molten pool and small holes, the high-speed camera picture and weld penetration fluctuation and weld surface morphology were analyzed. The high-speed camera can be used to monitor the weld depth change; Shandong University Gao Jinqiang et al [25] for stainless steel Nd : YAG laser welding, built a coaxial vision detection system, obtained the molten pool and small hole image, and designed the image processing algorithm according to the characteristics of the molten pool and the small hole image, respectively, determined the search for the molten pool and the small hole Starting point and search criteria; Liu Yajing et al. [26] analyzed the digital image processing method and proposed corresponding images according to the characteristics of the original image of the coaxial visual sensing of the molten pool and the small hole collected by the coaxial monitoring system. The processing flow, the processing algorithm of the weld seam tracking is proposed, which not only realizes the monitoring of the welding quality including the melting width and the penetration state, but also realizes the integrated monitoring of the welding quality and the weld seam tracking.



a) P = 3KW



b) P = 2 KW



c) P = 1 KW

Figure 3.Pool and keyhole images obtained at different laser powers

There are many related researches abroad. In foreign research, the German Photonics Technology Research Institute [27] analyzed the correlation between plasma plume and small hole behavior in laser metal welding, and obtained the difference between the small hole area and the weld penetration. The laser power, the variation law under the welding speed. The University of Nuremberg, Germany [28] conducted an experimental study on fluid dynamics in laser metal welding, and analyzed the effects of welding speed, laser power on the flow velocity of the molten pool, and the influence of different flow rates on the welding quality.

2.1.3. Plasma Signal Monitoring

In laser deep-fusion welding, the laser beam is continuously incident on the material of the welding workpiece, causing a large amount of evaporation of the material, and the metal vapor plume ejected in the small hole further absorbs the laser energy and then ionizes, thereby generating a plasma. Studies have shown that the formation of plasma has a great relationship with the shape of small holes and molten pool during laser deep-fusion welding, and it is accompanied by the generation of signals such as sound and light. Therefore, on-line monitoring of signals such as plasma signal sound and light is achieved. Quality monitoring is very feasible [29-30].

At present, the monitoring of plasma signals is mainly based on high-speed imaging. Due to the generation, rapid change and relatively complicated shape of the plasma cloud during the welding process, the camera is generally required to have high resolution, fast scanning speed and strong anti-interference ability. In addition, the camera is often difficult to photograph for the internal plasma of the aperture, so the welding process monitoring uses only the plasma cloud data above the bath.

Zhang Xudong et al. [31] of Tsinghua University in China photographed the shape of the opening of the small hole and the surface characteristics of the weld under the four penetration conditions of the infusible, only the molten pool, the moderate penetration and the over penetration through the high-speed camera. The plasma signal is particularly strong when the molten pool is only moderately penetrated; Yu Fulin et al. [32] of Huazhong University of Science and Technology used the fast Fourier transform to analyze the laser-induced plasma optical signals of non-penetrating welds. The intensity of the deep-fluctuated weld section shows a downward trend, and the dominant frequency peak in the spectrum of the optical signal disappears. Duan Aiqin et al. [33] of Beijing Institute of Aeronautical Technology found changes in photo-induced plasma optical signals and welds. The permeability is closely related. In the case of weld penetration, the photo-plasma is stable and the intensity change is relatively small. When it is not penetrated, the optical signal changes greatly and is unstable; Cai Yan, Shanghai Jiaotong University, etc. [34] Using high-speed photography to obtain a continuously changing photo-induced plasma image during the welding process, it is found that when the weld is not penetrated, the height and area of the photo-induced plasma are significantly greater than the penetration state; The area of the photo-induced plasma fluctuating in the unpenetrated state is about 400 Hz; Jiang Meng et al. [35] of Harbin Institute of Technology observed that the plasma gradually weakened as the ambient pressure decreased, and the vacuum environment The strong suppression effect of laser welding plasma is one of the reasons for the increase in the penetration depth of vacuum laser welding and the change in weld formation. Wang Chunming of Huazhong University of Science and Technology studied the relationship between laser-induced plasma optical signals and penetration in non-penetrating laser deep-fusion welding [36].

Park.Hyunsung et al. studied the relationship between plasma and spatter signal and welding quality in laser welding process. The IR and UV photoelectric sensors were used to collect the plasma signal in the welding area, and the quality of welding was judged. 37]. Kawaguchi et al. used optical sensors to monitor the plasma generated during laser welding deep-welding, studied the relationship between plasma signals and weld porosity defects, and suppressed the generation of pores by studying changes in laser power [38]. Jeng, J Y and so on used infrared radiation detector and ultraviolet radiation detector to monitor the infrared radiation and plasma ultraviolet signal generated in the small hole, and studied the relationship between plasma ultraviolet radiation signal and weld width [39]. Migamoto et al. studied the dynamic behavior of plasma in the two states of laser welding, so as to achieve the relationship between welding penetration and other welding quality according to the fluctuation of plasma [40].

2.2. Welding Process Quality Prediction Method

The weld quality is closely related to the penetration condition. Most of the weld defects such as pores and cracks are formed in the case of poor penetration (unpenetration, over penetration, etc.), and the factors affecting the penetration state of the weld are diverse. Such as laser power, welding speed, defocusing amount, metallurgical reaction, etc. Existing off-line inspection methods are difficult to ensure a well-welded weld during the welding process. Therefore, research on on-line monitoring technology for weld penetration status is crucial.

The molten pool contains a large amount of welding quality information. According to statistics, when the welder judges whether the welding process is normal and adjusts the parameters, more than 80% of the information comes from direct observation. In manual arc welding, a skilled welder judges the surface of the liquid pool to adjust the welding parameters and control the welding process to a predetermined penetration state, thereby obtaining a proper weld shape and weld quality. If the manual operation is simulated by the visual inspection system, the penetration state is judged by the front detection, which has great practical value.

From the front side detection, the camera and the welding gun can be fixed together, and the installation is simple to implement, which is convenient for practical welding engineering applications. Therefore, the front molten pool is detected, and the penetration state is determined by the molten pool information to become a research direction. The front visual inspection of the molten pool has been applied to various welding methods, such as arc welding and laser welding. A large amount of molten pool information can be obtained through frontal vision, thereby judging the shape and penetration of the weld.

In terms of prediction and judgment methods, researchers have tried to break through the traditional methods in recent years, and introduce BP neural network recognition model and support vector machine into the prediction research of actual penetration of arc welding process. The neural network has strong nonlinear fitting ability, can map arbitrarily complex nonlinear relations, and has simple learning rules and is convenient for computer implementation. It has strong robustness, memory ability, nonlinear mapping ability and powerful self-learning ability. Therefore, it has many applications in the field of welding. The input layer is generally information such as the length of the molten pool, the width of the molten pool, and the area of the molten pool. The output layer is a parameter that needs to be predicted or classified, such as a penetration state, and the hidden layer simulates the transmission and activation of information by the neurons.

Gao Jinqiang [41] of Shandong University used the ordinary CCD camera to take the image of the GTAW molten pool, and extracted the parameters such as the width of the molten pool, the half length of the molten pool, the area behind the molten pool and the tow angle of the molten pool, and established the front molten pool geometry based on the neural network. A model of the relationship between shape parameters and backside melt width. Chen Wuzhu et al. [42] of Tsinghua University studied the relationship between the weld penetration state and the gray-scale curve of the small hole image under different laser powers through the process experiment. It was found that the center position of the small hole image began to appear low gray in the "moderately penetrated" state. The plaque image, the corresponding gray distribution becomes a concave curve in the middle; Zhang Chenglei [43] of Hunan University obtains the image of the small hole area by CCD camera, and extracts the contour of the small hole by the gray image processing algorithm, with the diameter of the bottom of the small hole d The ratio d/D to the top diameter D is used to determine the penetration state.

Kovacevic [44] of the University of Kentucky used a high-speed camera ten-laser-assisted screw to detect a clear image of the GTAW molten pool. It was found that the length of the molten pool and the trailing angle contained certain penetration information, and the size information of the molten pool was established based on the neural network. Model with a wide melt on the back. Zhang Gang [45] of Lanzhou

University of Technology used the difference in beam reflection characteristics between the surface of the molten pool and the surface of the workpiece to measure the dynamic change information of the surface of the molten pool, and obtained the dynamic change information of the free surface width and depth direction of the GTAW molten pool. Fan C et al. [46] designed a three-way vision sensor to detect GTAW pool images from the front, upper and back directions, extracting the pool edge based on wavelet transform and Canny operator, and segmentation curve fitting based on polynomial function. The information of the edge of the molten pool is restored, and the Pm algorithm is used to control the penetration depth. The University of Kentucky Welding Research team [47] developed an innovative method for measuring the 3D size of the molten pool surface, illuminating the laser matrix onto the molten pool, and reflecting the laser lattice onto the imaging surface through the specular reflection of the molten pool, finding the laser lattice The change can reflect the shape of the weld pool, providing an optimal model for predicting the length, width and convexity of the surface of the three-dimensional weld pool.

2.3. Current Problems

(1) On-line monitoring of weld pool, penetration and small holes is mainly based on machine vision, but due to interference from plasma, glare, radiation (feather), smoke and random vibration, the acquired images are more Severe noise, it is difficult to clearly identify the characteristics of the molten pool and small holes, and because of the fast laser welding speed of the robot (5~15m/min), the real-time requirements of the monitoring system are particularly high. Therefore, the necessary research work can be carried out in the optimization of the image denoising filtering algorithm and the intelligent identification of the weld features, so as to improve the image quality.

(2) In addition, the relationship between the acquired image information and the quality of the weld is still at the level of qualitative analysis, and the numerical analysis between the two is relatively small, lacking practicality.

(3) The relationship between the signal of the molten pool, the small holes and the plasma and the welding quality is still in the experimental research stage. At present, the relevant research results are only used to qualitatively analyze the welding process state under off-line conditions, which can not be used as the evaluation basis for welding quality, and can not be used as the control parameter for on-line monitoring of weld quality. It is still too early for mature industrial applications.

(4) At present, the weld penetration prediction model is mostly based on BP neural network. Different from the CNN-based deep learning network, the captured image is directly input as the network input. The BP neural network needs to extract the shape features of the molten pool image first. As a network input, how to select effective shape features requires the relevant personnel to have strong professional knowledge. And a lot of practical experience. In addition, the BP neural network also has many

shortcomings such as many training parameters, easy over-fitting and high complexity.

3. Research Content

Under the auspices of the National Defense Science Research Program—Diamond Welding Technology for Complex Projectile Components (Project No. JCKY2016204B204). This paper carries out research on the following aspects:

In this paper, the laser welding process is taken as the research object. The multi-angle and multi-visual sensor visual inspection technology is adopted to observe the visual images of the molten pool, small holes and plasma from the front and side of the workpiece, extract the edge of the detection object, and analyze the dynamic behavior of liquid molten pool, keyhole and plasma cloud. an effective model for penetration prediction based on molten pool images is realized using CNN-based deep learning network. The main contents include:

1. Construct a fiber laser welding multi-information sensing visual inspection system and design an image edge extraction algorithm.

(1) Study the synchronous triggering technology of multi-CCD camera, select the appropriate filter system, and realize the synchronous detection of the molten pool and plasma information in the laser welding process.

Specifically, it includes: selecting appropriate CCD high-speed camera camera and data acquisition device to ensure simultaneous acquisition of multiple information, measuring the wavelength range of interference signals such as plasma and metal vapor during laser welding of high-temperature titanium alloy, and researching different blue, green and red colors. Band filter effect to choose the optimal filter scheme.

(2) Select an appropriate auxiliary light source, and study the influence of the wavelength and illumination angle of the auxiliary light source on the image quality to obtain the best molten pool image.

(3) Design an image processing algorithm to obtain molten pool and plasma geometric size information.

Specifically, the molten pool and the plasma image collected by the CCD high-speed camera are pre-processed by applying gray processing and filtering, and then different edge detection algorithms such as Canny and Sobel are compared to extract a clear molten pool, a small hole, and a heat affected zone. contour.

2. The processing of visual image information and its correlation with the back penetration state.

(1) Study the effects of laser power, welding current, welding speed and defocusing amount on the geometry of the front molten pool;

Specifically, the method includes: using a control variable method, individually changing a welding parameter, collecting a molten pool image; defining a physical quantity related to the geometric shape of the molten pool image, and quantitatively analyzing the influence of the processing parameter on the physical quantity.

(2) analyze the correlation between the characteristics of the molten pool and the plasma image and the penetration state;

Specifically, it analyzes the geometric characteristics of the molten pool and plasma image under different penetration conditions, and establishes its related qualitative correspondence.

3. Based on the deep learning convolutional neural network mathematical model, a reliable prediction of the back penetration state with the front molten pool image as input is realized.

(1) classify the front molten pool images of different penetration states, and establish an effective training database of laser welding front molten pool images and penetration states;

Specifically, it includes: through a large number of welding tests, analyzes the influence of the weld penetration state on the welding quality, and according to this, classifies the penetration depth according to the interval, and corresponds one-to-one with the molten pool image to establish the training of the molten pool image and the penetration state. database.

(2) According to the morphological characteristics of the front weld pool of laser welding, analyze the characteristic performance of different convolutional neural networks in the deep learning algorithm, carry out model tuning and verification, and improve the prediction reliability;

Specifically, it analyzes and compares the characteristics of the molten pool image corresponding to different penetration states, tests the feature extraction effect and classification effect of different depth convolution models, optimizes the corresponding model and verifies it, and improves the reliability of the result prediction.

(3) Exploring the correlation between plasma geometry and penetration state during laser welding, and assisting in predicting weld penetration.

Specifically, the method includes: analyzing the characteristics of the plasma image, establishing a training database of the plasma image and the penetration state, selecting a corresponding deep learning model, and testing the prediction effect of the model.

4. Completed Works

(1) A coaxial and range CCD image acquisition system was built, and the molten pool, small holes and plasma images were collected.

(2) The correlation between welding parameters and molten pool image is preliminarily studied. It is found that the laser power has little effect on the molten pool within a certain range; when the welding speed increases, the width and length of the molten pool decrease rapidly first. After 3m/min, the reduction trend is gentle, as shown in Figure 4.

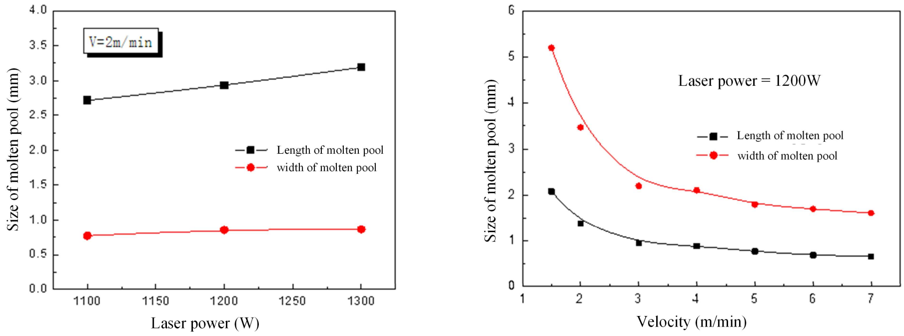


Figure 4. Curve of the size of the molten pool

(3) The correlation between welding parameters and plasma images was preliminarily studied. It was found that the plasma size was larger when the laser power was larger. As the speed increases, the plasma changes significantly.

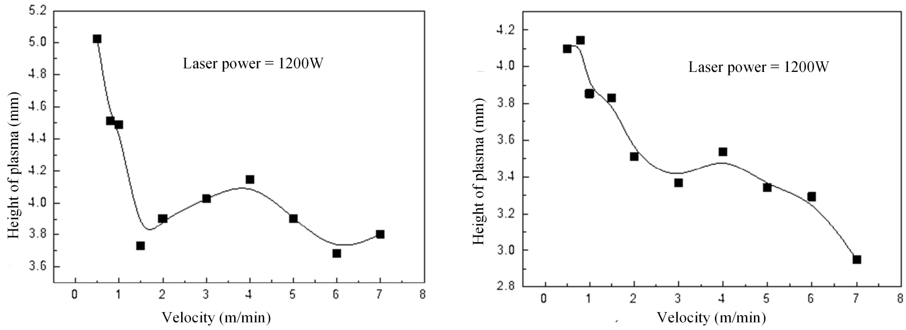


Figure 5. Variation of plasma characteristic quantity with welding speed

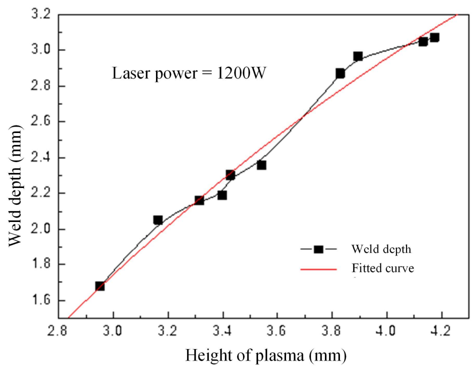


Figure 6 Correspondence between weld penetration and plasma

Figure 5 shows the variation of the plasma characteristic quantity with the welding speed. Under the condition of laser power of 1200W, the welding speed increases, the plasma height and width decrease significantly, and the absolute amount of change is large. Figure 6 shows the corresponding relationship between weld penetration and plasma. The black line is the actual relationship. The red line is the curve obtained by the fitting method. It can be seen from the figure that the plasma height has a nearly single linear response to the weld penetration. relationship.

5. Research Scheme and Schedule

5.1. Research Scheme

In order to realize the on-line monitoring of laser welding quality, a set of fiber-optic laser welding active coaxial monitoring system is firstly built. The appropriate filter and auxiliary light source are selected through experimental research to ensure the clear coaxial weld monitoring image of the weld pool area. Then the corresponding filtering, edge detection and so on are used to process the acquired image, then the variation law of the molten pool image under different process parameters is studied. Finally, the depth of the welding algorithm is used to predict the welding quality, namely penetration depth, melting width and defects.

According to the research content of the project, the project intends to use the research method combining experiment and theoretical analysis. The overall research idea is shown in Figure 7.

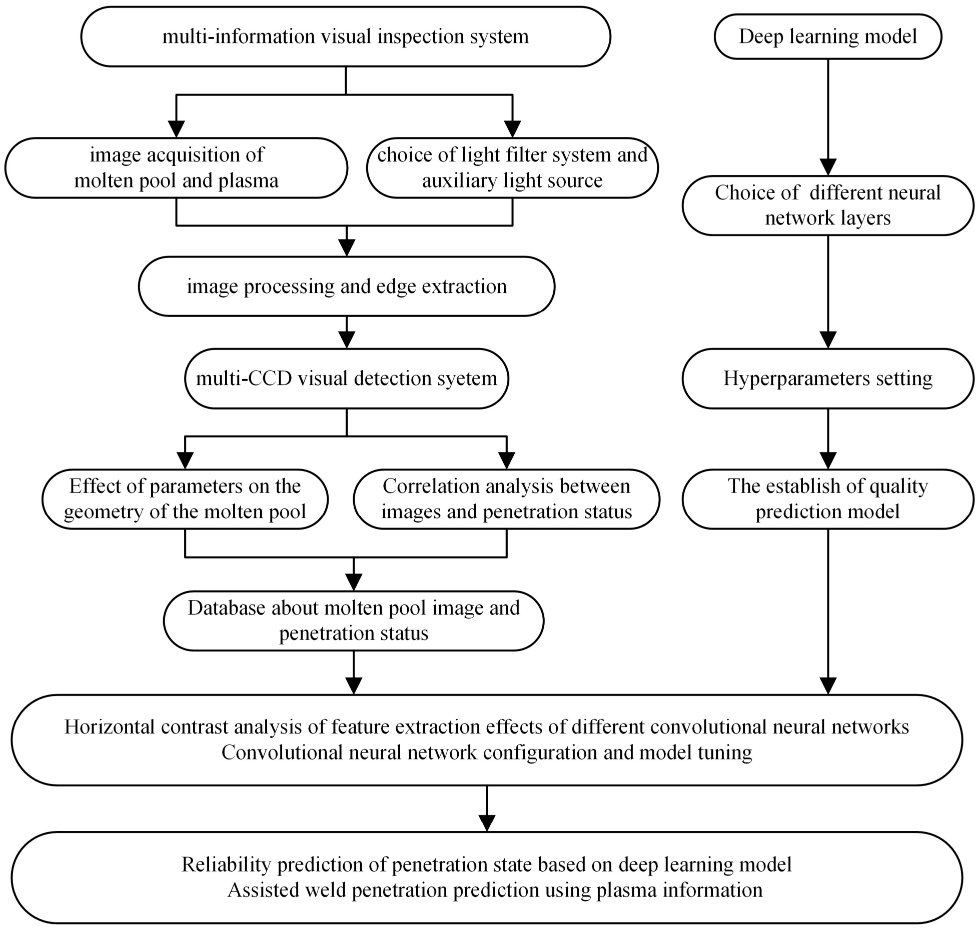


Figure 7 The overall research ideas of the subject

Focusing on the above research ideas, the specific experimental implementation plan and technical approach of the project are as follows:

5.1.1. Build Fiber Laser Welding Active Coaxial and Side Monitoring System

When building a monitoring system, the key is to select the appropriate filter and auxiliary light source. The 532nm and 808nm bands are used in the welding monitoring experiments. In this paper, narrow-band filters of 532nm and 808nm are selected respectively. The coaxial monitoring images of the collected pool areas are compared and the appropriate filters are selected. The choice of the auxiliary source is mainly based on the choice of the wavelength of the source. The method of machine vision monitoring laser welding mostly uses light sources of 532 nm and 808 nm as auxiliary light sources. In this paper, it is proposed to use a narrow-band filter with central wavelengths of 532nm and 808nm for coaxial monitoring experiments without additional auxiliary light source.

The processing of the weld pool image is a requirement for real-time monitoring of the welding process. The shape of the weld pool can reflect the stability of the welding process and some process phenomena to a certain extent. In the real-time monitoring process of welding, the shape of the molten pool is captured and quickly judged, and then the problem is judged and adjusted accordingly. The most basic requirements for real-time monitoring. Therefore, it is required to be fast and accurate in the image processing of the weld pool. The molten pool image processing is mainly divided into three steps: (1) image preprocessing; (2) quick judgment of contour lines; and (3) molten pool feature parameter extraction. In the image preprocessing, image enhancement and noise removal are mainly used, and the threshold method and the Canny operator method are often used to judge the contour line.

5.1.2. Correlation Analysis of Parameters, Molten Pool Image and Welding Quality

In the analysis of welding quality correlation, the effects of laser power, welding speed and defocusing on the molten pool image are studied separately. Then the relationship between image features and welding quality is studied, the welding quality is analyzed, and the defects and molten pool images are classified.

5.1.3. Deep Learning for Welding Quality Prediction

In the depth learning to predict the welding quality, firstly establish the matching relationship between welding parameters, molten pool, plasma image and welding quality such as penetration, melting width and defects to form a training database; then, between different depth learning networks Make a selection, and on this basis, modify the network model according to the actual situation; finally, test and optimize the network model.

5.2. Expected Goals

This research intends to establish a set of fiber-optic laser welding active coaxial online monitoring system to realize the image collection of the weld pool area during the welding process and extract the weld depth, the width and the shape of the weld pool in real time, and realize the laser based on deep learning. Real-time monitoring of welding quality, establishing the relationship between penetration depth and melting width of laser welding welds.

5.3. Research Schedule

Date	Tasks
June 2018	Determine the direction and topic of the paper
July – August 2018	Literature collection and analysis Structure framework and content writing
September 2018	Complete the opening report
October 2018 – March 2019	Do experiments Analyze data
April 2019	Complete the interim report
April – May 2019	Build quality prediction model using deep learning
May – June 2019	Consult the instructor Further modify the thesis
June 2019	Complete the thesis and master's defense

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