RESEARCH ON PATH RECOGNITION OF WELDING MANIPULATOR BASED ON AUTOMATIC CONTROL ALGORITHM

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ABSTRACT: The intellectualization, automation and flexibility of welding technology have gradually become the important processing technology of innovative manufacturing industry. The large-batch application of welding manipulators makes up for the poor environment and lack of personnel, but the weld bead path recognition and manipulator control are the key technologies to realize the intelligent development of welding manipulators. Based on the automatic control algorithm of PD controller and enhanced learning controller, the study deals with intelligent path recognition of welding manipulator controlled by manipulator. The results show that it is more feasible to choose the visual predictive control algorithm with constraint and the reliability of servo control system is stronger. The trajectory planning and tracking in the welding process of welding manipulators are realized by transferring the rotation angle, angular velocity and angular acceleration of each joint of the manipulators. After adding the enhanced learning controller, the tracking errors of the manipulator joint are obviously reduced, and after each iteration of the SARSA algorithm, the errors are further reduced, and the variation of the errors shows periodic repetition.


1 INTRODUCTION

In recent years, with the strong support of the State, industrial manipulators have been rapidly developed as intelligent manufacturing equipment in high-end equipment manufacturing, and have been widely used (Jodas et al., 2013). At present, China has surpassed Japan to become the largest industrial manipulator market in the world. By the end of 2017, the total amount of China’s manipulators has exceeded 420,000, which means that China's manipulator industry is in the stage of blowout development (Kang et al., 2010). With the development of innovation drive and deepening reform, China has increasing demands for manipulators and higher technical level of manipulators (Chi et al., 2017; Tsai, 2014; Zhao et al., 2016). The demand of industrial production also requires the manipulators to have stronger environment adaptability and intelligence, including the ability of environment perception, decision-making and autonomous control (Lorsakul et al., 2009). We can add the sensors with different requirements into the control system of the manipulators to realize the intelligent operation and control of the manipulators so that the manipulators can be adapted to the changeable working environment, and independently accomplish tasks (Boyali et al., 2015; Budiharto et al., 2011). Welding is an important processing technology to realize material connection in manufacturing industry, and a lot of problems have emerged, including small amount and multiple batches of welding, poor environment and lack of personnel (Hu et al., 2014). Since the 1980s, China has put the can be adapted to the changeable working environment, and independently accomplish into many industries such as spray painting, arc welding, spot welding, assembly and handling, but the level of intellectualization is low, and China still remains a big gap with abroad in system, coordination and weak manufacturing technology (Shah et al., 2018; Sun et al., 2017; Wang et al., 2012). Along with the development of intelligent manipulators, the sensor technology, control system and multi-agent group control technology of welding manipulators develop towards intelligence and information (Yang and Kwon, 2008). Industrial manipulators can realize automation, flexibility and intellectualization of welding, but the problem of welding path recognition and autonomous control is prominent (Mateo et al., 2016). Based on the automatic control algorithm, this study deals with the welding path recognition and tracking control of the welding manipulators and analyzes the visual predictive control of the six-degree-of-freedom manipulators.
under various constraints. Finally, combining with the trajectory tracking control method of the manipulators, an enhanced learning compensation control strategy based on the SARSA algorithm is proposed.

2 WELDING PATH RECOGNITION AND TRACKING CONTROL OF THIN STEEL PLATE WELDING MANIPULATORS

2.1 Visual control method for butt weld

Automatic recognition of welding seam is the core of intelligent welding. In this section, a high-precision and flexible visual tracking control method is proposed for the welding manipulators of thin steel plate welding seam (Park et al., 2012; Wang and Ye, 2017; Djedai et al., 2017). At present, artificial welding easily leads to visual limitation deviation, which may lead to inconsistent welding quality of the same welding seam.

Moreover, the poor welding environment in the production workshop results in low welding production efficiency, which will directly affect the welding quality and production efficiency of the thin steel plates (Jou et al., 2015).

Figure 1 is a structural diagram of a vision system. The laser tube emits point light sources to form stripe light, and diffusely reflects the light above the workpiece. The camera captures the stripe light in the form of different weld grooves and calibrates the spatial parameters of the welding seam and the target position of the weld feature points in the image according to the vision system. The welding manipulators can be controlled by a computer to perform accurate welding. Figure 2 is a flow chart of welding identification. Firstly, the camera and encoder are initialized, the forward direction coordinate X is obtained at a short distance after recording a frame image, and the offset coordinate Y and the height coordinate Z are obtained by processing the image. The coordinate of the current welding spot is thus determined and the manipulators are controlled by the motion controller to weld the spot. In the process, the image processing is completed by a computer, and the image processing of the computer includes four parts: image preprocessing, image feature extraction, image feature filtering and data communication. Finally, it is handed over to the controller and the executive part.

2.2 Tracking control system for space welding seam

The space welding seam tracking control system consists of a gantry structure support, a vision sensor, a welding equipment and a main control PC, wherein the gantry structure support is used for calibrating coordinate axes, and the main control PC is used for processing images and obtaining the space coordinates of points (Park & Lee, 2012). In order to refine the deviation of the controller of the weld tracking control system in the X and Y axes, it is necessary to adjust the deviation of the two sub-controllers in the X and Y directions. In order to realize the tracking control better, an incremental PD controller is selected, and the error and output signals of the controller respectively correspond to the image error and the motor pulse signals, that’s, the control method with pulse equivalent is as shown in Equation 1:

\[
p(k) = S\left[Kp\left[e(k) - e(k-1)\right] + Kie(k)
+ Kd\left[e(k) - 2e(k-1) + e(k-2)\right]\right]
\]

Where, \(p(k)\) is pulse output at \(k\) time; \(S\) is pulse equivalent and \(e\) is deviation.
According to the above algorithm and image processing, we select a thin plate with a weld width of 1 mm and acquire one frame of images every 1 mm in 230 mm along the X axis of the welding seam, so that a series of feature point identification data can be obtained. Figure 3 shows the detection and actual numerical value image of a recognition point in Y and Z direction. It can be seen that the movement in the X direction is 230 mm, and the errors in the Y direction and the Z direction are very small, and higher accuracy and stability can be obtained.

![Detection value vs. Actual value](image)

Figure 3. Detection - actual feature point identification data curve

### 3 VISUAL PREDICTIVE CONTROL OF A SIX-DEGREE-OF-FREEDOM MANIPULATOR WITH MULTIPLE CONSTRAINTS

#### 3.1 Visual servo control frame of manipulator

Figure 4 is a pinhole model of a camera through which light projects a three-dimensional scene onto a two-dimensional image plane, with object distance, image distance and focal length satisfying the geometric relationship of object point imaging:

$$\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$$  \hspace{1cm} (2)

Assuming that the plane where the camera is located is the imaging plane, the coordinates of any point \((Xw, Yw, Zw)\) in the space on the camera plane are \((Xc, Yc, Zc)\), and the geometric relationship of the point P on the image is:

$$x = f \frac{Xc}{Zc}, y = f \frac{Yc}{Zc}, f = \frac{Zc}{Zc}$$  \hspace{1cm} (3)

In order to design the visual servo controller based on image, it is necessary to learn the visual system control diagram of image. It’s expected that the image features are transmitted to the visual controller, and the position of the steel plate is adjusted through the joint controller - the manipulator - joint controller. The image processing is performed by the camera and the image feature information is acquired by the computer after the camera shots. The obtained image features are compared with the expected image features, and the position of the steel plate is adjusted again through the joint controller - the manipulator - joint controller to achieve expected image features.

![Pinhole model of the camera](image)

Figure 4. The pinhole model of the camera

#### 3.2 Design of visual servo controller based on prediction framework

In the actual design process, the visual servo controller is required to have certain speed constraints, field of view constraints and actuator joint angle constraints. Figure 5 is a structural block diagram of the control system, which is composed of a visual predictive control system, and manipulator and visual system. The visual predictive control system is an output system of a predictive model, and can feed back to an optimization module to realize final output through multi-step testing, as shown in Equations 4, 5 and 6:

**Error representation:**

$$e(i, k) = e(k), i = k, k = 1, \ldots, k + Np - 1$$  \hspace{1cm} (4)

**Expected eigenvalue representation:**
\[pd(i,k) = r - e(i,k), \ i = k, k = 1, \ldots, k + Np - 1\] (5)

Optimal control sequence:
\[v(k) = U(i), \ 0 \leq i \leq Np\]
\[\text{if } J(U(i)) \text{ is minimum for } U\] (6)

The control system designed in this study is the category of predictive control system, which has three remarkable characteristics: multi-step test, rolling optimization and feedback correction. In the simulation experiment, the sampling period is 40ms and the image acquisition frequency is 25frames/s. The manipulator system simulates a six-degree-of-freedom manipulator. The joint variables of six-degree-of-freedom are \(-160^\circ \sim 160^\circ, -225^\circ \sim 45^\circ, -45^\circ \sim 225^\circ, -110^\circ \sim 70^\circ, -100^\circ \sim 100^\circ\) and \(-266^\circ \sim 266^\circ\) respectively. If the image features are not taken into account under the control constraints, the corresponding linear velocity and angular velocity trajectories can be obtained by the predictive control system. Figure 7 is an unconstrained trajectory of the linear velocity of the camera, and Figure 8 is an unconstrained trajectory of the angular velocity of the camera. It can be seen that when the initial position deviates greatly from the desired position, the manipulator of the actuator mounted on the end of the camera cannot reach the predetermined image feature position. Furthermore, it can be seen from both figures that the change in the trajectory of the image is very dramatic, indicating that it is possible that some image feature points have moved away from the view of the camera, and that the speeds \(v_x, v_y,\) and \(v_z\) exceed the conditions of the control constraints in both figures. Therefore, it is more feasible to select the visual predictive control algorithm with constraints, which also reflects the reliability of the servo control system.

![Figure 5. Control system block diagram](image)

**Figure 5. Control system block diagram**

![Figure 6. Unconstrained trajectory of the camera's line speed](image)

**Figure 6. Unconstrained trajectory of the camera's line speed**

![Figure 7. Unconstrained trajectory of camera head angular velocity](image)

**Figure 7. Unconstrained trajectory of camera head angular velocity**
4 TRAJECTORY TRACKING CONTROL OF THE WELDING MANIPULATOR

4.1 Trajectory tracking control of the manipulator and basic principle of reinforced learning

The welding manipulator is controlled by the trajectory tracking control system of the manipulator, and the high nonlinearity and uncertainty are the two difficulties in the dynamics of manipulators, which lead to the great uncertainty in the control of the welding manipulators. In the research of traditional trajectory tracking control, PD controller design method is generally adopted, but the adaptive ability of this method to working environment, load and external disturbance is limited, so it cannot adapt to accurate and precise trajectory control. According to the Lagrangian mechanics, the dynamics equation of the manipulator can be established for N joints of the manipulator:

\[ M(\theta)\ddot{\theta} + V(\theta, \dot{\theta}) + G(\theta) + F(\theta') + T_d = \tau \]

Where, \( \theta, \dot{\theta} \) and \( \ddot{\theta} \) represent the rotation angle, the rotation angular velocity and the rotation angular acceleration of the manipulator joint, respectively.

In the process of controlling manipulator welding by manipulator trajectory control system, it is necessary to realize trajectory planning and trajectory tracking by means of computer system, in which trajectory planning is to realize the precise position of end position by rotation of each joint of the manipulator, mainly by mobilizing the rotation angle, angular velocity and angular acceleration of each joint. The main reason of trajectory tracking is that there may be a deviation between the execution trajectory and the actual trajectory of the manipulator, so it is necessary to control the trajectory in the process of trajectory tracking.

Figure 8 is a neural network compensation control diagram of the manipulator. In order to compensate for the error caused by the nonlinear control of the manipulator trajectory, a three-layer feedforward neural network is used for compensation, and the compensation algorithm corresponds to the control law of the calculation torque control.

The basic idea of reinforced learning is that an agent learns control or decision strategy from existing database. Its system structure includes external environment, control action and agent (controller). The external environment feeds back reward signal to the agent (controller), and the agent (controller) acts on the external environment through control action. The SARSA algorithm is most commonly used in reinforced learning, and it is a strategy algorithm, achieving the final requirements through constant iteration of functions.

4.2 Trajectory tracking control strategy of manipulator based on SARSA

Figure 9 shows a manipulator trajectory tracking control system scheme based on SARSA. The system scheme is composed of an enhanced learning controller, a PD controller and a manipulator, and can realize deviation control and compensation control in calculation control. In the process of operation, the enhanced learn controller will face two states: the state of the manipulator and the desired position and speed of each joint of the manipulator. SARSA is a function iterative algorithm. In order to improve the iterative speed, recursive neural network with internal feedback structure is selected to improve the iterative speed. In the simulation experiment of the SARSA tracking control, the expected trajectory and the tracking trajectory of two joints of the manipulator are compared, in which it is found that the tracking error of the manipulator joint is obviously reduced when the enhanced learning controller is added, the errors of the SARSA algorithm are further reduced after the iteration of each cycle, and the variation of the error exhibits periodic repetition.
CONCLUSIONS

Based on the automatic control algorithm of PD controller and enhanced learning controller, the study deals with the intelligent path recognition of welding manipulator controlled by the manipulator, and achieves the following concrete experimental conclusions:

(1) In order to realize the tracking control better, the incremental PD controller is selected, and the error and output signals of the controller correspond to the image error and motor pulse signals respectively.

(2) When the initial position deviates greatly from the expected position, the manipulator of the actuator mounted on the end of the camera cannot reach the predetermined image feature position, and the servo control system is more reliable.

(3) After adding the enhanced learning controller, the tracking errors of the manipulator joint are obviously reduced, and after every iteration of the SARSA algorithm, the errors are further reduced, and the variation of the errors shows periodic repetition.

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REFERENCES


