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Based on Sliding Mode Variable Structure Neural Network Tracking Control of Six Axis Laser Additive Manufacturing Robot

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Abstract: *This paper proposes a sliding mode variable(SMV) structure neural network tracking control of six-axis laser additive manufacturing (LAM) robot. Firstly, the six axis LAM robot is designed by SOLIDWORKS software. The three dimensional workspace of the LAM robot is simulated by MATLAB. Then, the stability of the LAM robot control system is proved by the Lyapunov-Krasovskii functional (LKF). Finally, the LAM robot control system is established by using the SMV neural network control algorithm. According to the simulation results, the LAM robot trajectory tracking effect is expected the satisfactory trajectory. And the LAM robot position error is very fast to zero, which proves the SMV structure adopted in this paper. The effectiveness of the six-axis LAM robot is verified by SMV structure neural network tracking control.*

Key Words: *SMV neural network, tracking control, six-axis LAM robot, Lyapunov-Krasovskii functional.*

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I. INTRODUCTION

Additive manufacturing, commonly known as 3D printing technology. Additive manufacturing technology is an emerging technology of modern advanced manufacturing technology, and has been studied by many researchers in recent years. Additive manufacturing began in 1860, and it was sculptured through photographs [1]. Due to the development of computer and optics, the additive manufacturing has developed rapidly. Additive manufacturing technology has four key technologies: VAT photopolymerization, powder bed fusion, material extrusion and adhesive injection. Aburaia [2] studied the use of SOLIDWORKS software design in conjunction with the new concept of industrial robots, designed a low-cost four-state additive manufacturing robot that performs some simple actions. Semini [3] studied a new type of quadruped robot applied to additive manufacturing technology and controlled it with hydraulic technology, and experimentally learned that additive manufacturing is more effective than traditional manufacturing. Pinkerton [4] analyzed the development trend of additive manufacturing for the future industry, first explained the type and role of laser additive manufacturing (LAM) in today's additive manufacturing technology, and highlighted the prospects for LAM. At the same time, arc welding robots also belong to a type of additive manufacturing. These are some researchers on arc welding robots.

Researchers have studied the arc welding robot. University of Nottingham used arc welding additive manufacturing for industrial robots and six-degree-of-freedom rotary joints. The computer controlled them and monitored the parts in real time during processing to ensure the surface quality of the parts. Spencer [5] studied that adding a plurality of degrees of freedom joints on the basis of the conventional robot can significantly improve the degree of flexibility of the obstacle avoidance function of the robot. On the one hand, the trajectory tracking control of robotic arm is a central issue in the robotic area and has received a great deal of attention in the past decade. On the other hand, delays are variable and unbounded in SMV neural network control systems. $H\infty$ tracking control [6] was focused on uncertain or unknown robotic system, it has a good effects. But it need complex mathematical operations. Many researchers studied the dynamical behaviors of neural networks with robotic control system. For example, Chen [7] studied the tracking control problem for an uncertain n-link robot with full-state constraints. They utilized Lyapunov-Krasovskii functional (LKF) to analysis stability. W.THOMAS [8] studied the real time control which learning the dynamics of a five axis industrial robot. And the experiments results clearly presented that the memory the learning controller to get the low error within a few trials. WEI [9] proposed the inverse kinematics problem of manipulator base on adaptive neural fuzzy inference system. The method advantage is that posses of faster learning rate, high identifying precision and better real-time ability. Pedro [10] utilized an accelerometer-based system to control an industrial robot. And these accelerometers are attached to the people arms so that recognize arm gestures and postures, which used as input in the control of the robot. MIYAMOTO [11] studied a model contains a feedback loop plus an neural network model of motor system. The model advantages is that could control faster movements.

The remainder of the paper is structured as follows: In Section 2, the problem description, three assumptions, a definition and a basic lemma for the considered SMV neural networks model are presented. In Section 3, a suitable error filter is obtained for the SMV model. In Section 4, one example is provided to show the application of the developed results. Conclusions and future work are given in Section 5.

II. PROBLEM STATEMENT

In this paper, a six axis LAM robot based on sliding mode variable (SMV) structure neural network trajectory is designed and verified by KUKA robot. Firstly, the six-axis LAM robot is designed three dimensional modeling by SOLIDWORKS software in this paper. The three dimensional modeling is shown in Figure 1.

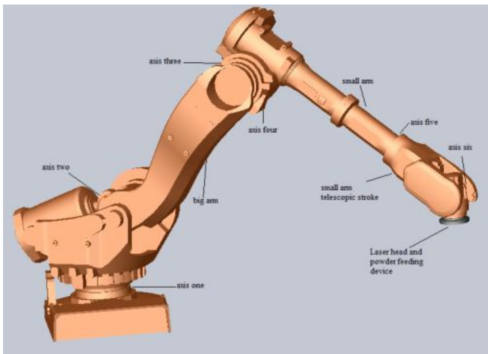

Figure 1. The six-axis LAM robot three dimensional modeling is designed by SOLIDWORKS

The simplified model of the LAM robot is shown in Figure 2.

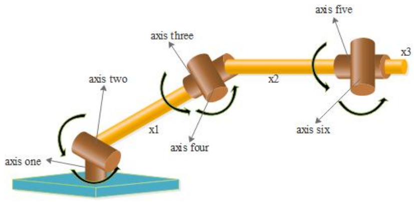

Figure 2. Six-axis LAM robot structure diagram

Where x_1, x_2, x_3 represent the Big arm, Small arm, Laser head and powder feeding device.

As shown in Figure 2. The x_1 big arm is isolated from the ground so that it can rotate freely for the boom pitching action. The actuator has a large moving range, which is suitable for the LAM robot to be far away from the nozzle powder feeding target. The arrows in the Figure 2 all represent the direction of rotation or the direction of movement, and servo motors are installed in the objects. x_2 represents the small arm, which enables the arm to perform the arm tilting action. x_3 stands for the laser head and powder feeding device, which is the action of the nozzle finally approaching the powder feeding target. The above actions are designed to minimize the nozzle powder feeding trajectory error. The three dimensional working range of the LAM is simulated by MATLAB is shown in Figure 3.

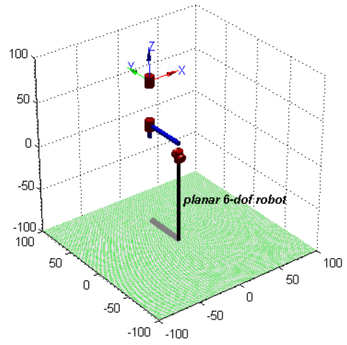

Figure 3. Robot arm initial position

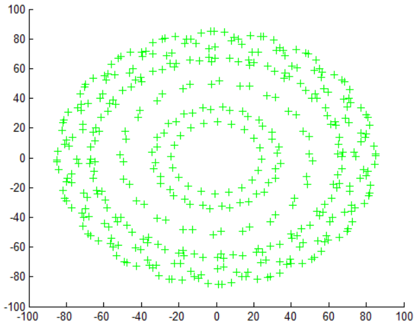

Figure 4. XY,YZ and XZ working space

After the initial position of the LAM robot is determined by MATLAB simulation. As shown in Figure 4, the distribution of the nozzle powder feeding points of the robot on the plane XY, YZ and XZ. The nozzle powder feeding points of the LAM robot on each plane no dead point, and the nozzle powder feeding points of each surface are consistent. It shows that the arc welding robot of this design has a good manufacturing effect, and thus it can be concluded that the LAM robot is feasible.

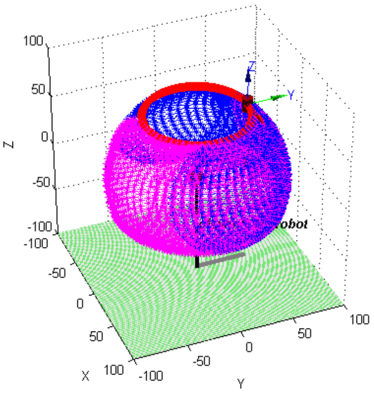

Figure 5. Robotic arm three dimensional workspace

Figure 5 shows that three dimensional distribution of the nozzle powder feeding points of the LAM robot. It can be concluded from the distribution of the nozzle powder feeding points in the Figure 5 that the nozzle powder feeding points of the LAM robot are evenly distributed.

The LAM robot has six axes, but the lowermost rotation axis in the space does not play a important role with the extension axis and the rotation axis of the end holder, so the three axes are omitted in this paper for analysis. resulting in a simplified diagram of the LAM robot is shown in Figure 6.

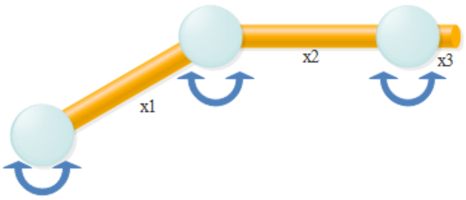

Figure 6. Simplified mechanical arm structure diagram

It can be seen from Figure 6 that the waist does not have much effect in the pitching motion of the big arm, the small arm, and the nozzle powder feeding device track of the LAM robot. The pitching action is determined. Therefore, when studying the dynamic model of the LAM robot, the influence of the waist can be ignored. The rotating shaft part of the six axis LAM robot is composed of two spatial position axes, which the two axes are combined into one axis capable of 360 degree rotation. A six axis LAM robot is simplified into a three axis LAM robot.

On this basis, the speed and position of the boom also determine the accuracy of subsequent operations. Therefore, it is especially important to study the speed error and position error of the boom. The accuracy of the boom determines the accuracy of subsequent actions. The function of the arm and arm telescopic arms is to adjust the tiny position of the nozzle powder device, so the speed error and position error of these two parts are not studied in this paper. However, the error map of the big arm, the small arm, and the nozzle powder feeding device after motion will be obtained to see if the system is stable.

III. NEURAL NETWORK CONTROL FOR ROBOT BASE ON SLIDING MODEL

So the system is simplified three axis mechanic arm system. Consider the following three axis LAM robot dynamic equation:

$$\begin{cases} M(q)\ddot{q}+C(q,\dot{q})\dot{q}+G(q)=\tau \\ G(q)=G_f(\dot{q})+\tau_d(t,q,\dot{q}) \end{cases}$$

(1)

where $q,\dot{q}$ is the displacement and velocity vector of the joint, $M\left(q\right)$ is a positive definite pair matrix, $C\left(q,\dot{q}\right)$ is the centrifugal and Coriolis force term, $G\left(q\right)$ is the friction moment array, τ_d is external interference, τ is the joint torque

Lemma 1: $M(q)$ satisfy $X^T[\dot{M}(q)-2C(q,\dot{q})]X=0$, $\forall X\in\Re^n$ this condition.

Assumption 1: In equation (1), the motor side disturbance τ_d is bounded and bounded, which is $\|\tau_d\|\le D$, where D is a known constant.

Assumption 2: The joint angular displacement, angular velocity, output angle of the reducer, and angular velocity of the fruit picking robot system can be measured, which is

$q,\dot{q}$ can be measured.

Remark 2.1:

For system (1), the following assumptions are given:

For the system (1), the following full order neural network control for robot base on sliding model

$$\begin{cases} M(q)\dot{s}+C(q,\dot{q})s=-\tau+f(\alpha) \\ f(\alpha)=M(q)\ddot{q}_r+C(q,\dot{q})\dot{q}_r+G(q) \end{cases}$$

(2)

Assumption3 Each activation functions $f_i(\cdot)$ $(i=1,2,...,n)$ is bound and satisfies the following condition:

$$l_i^- \le \frac{f_i(\alpha_1)-f_i(\alpha_2)}{\alpha_1-\alpha_2}\le l_i^+,$$

$$i=1,2,...,n,\alpha_1,\alpha_2\in\Re^n,\alpha_1\ne\alpha_2,$$

(3)

where l_i^-, l_i^+ are some constants.

Remark 2.2: l_i^- and l_i^+ can be positive, negative, and zero.

Where define e is joint angle error, so $s = \dot{e} + \Lambda e$ is tracking position error. q_r is the ideal trajectory, Λ is the positive matrix.

IV. STABILITY ANALYSIS

Proof : choose the LKF is the

$V = \frac{1}{2} s^T M(q) s$, deriving time along the trajectory of the system (1),

$$\dot{V} = s^T M(q)\dot{s} = s^T[f(\alpha) - \tau - C(q,\dot{q})s] = s^T[f(\alpha) - \tau - C(q,\dot{q})(\dot{e} + \Lambda e)] < 0$$

Because of LKF stability method, so we can get the control system is asymptotic stability.

V. NUMBERICAL EXAMPLES

In this section, one example is given to demonstrate the benefits of the proposed method.
Consider a three-neuron SMV neural network with the following parameters:
We can get the simulation parameters as below: $m_0 = 1kg, m_1 = 0.1kg$, $g = 9.8, l = 0.5$, $\alpha_0 = 2, \beta = 1, \varphi = 100$.
Assumption the system friction and turbulent is as below: $F_f = [0.2\,\text{sgn}\,\dot{q}_1 \quad 0.2\,\text{sgn}\,\dot{q}_2]^T$ $\tau_d = [q_1 \dot{q}_1 0.3\sin t \quad q_2 \dot{q}_2 0.3\sin t]^T$

And the bar one expected joint angle and velocity is: $[q_1 \quad \dot{q}] = [\sin t \quad \cos t]$.

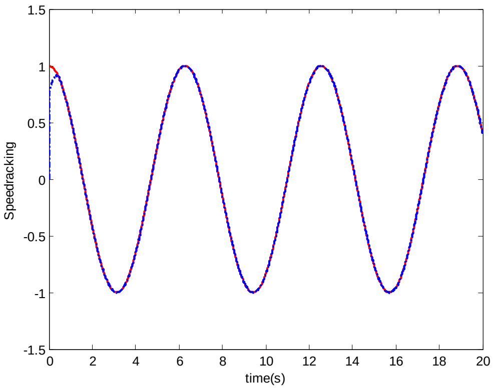

Figure 7. The big arm speed tracking curves of sliding-model neural network

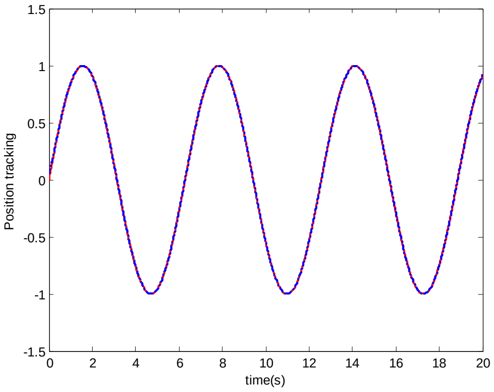

Figure 8. The big arm position tracking curves of sliding-model neural network

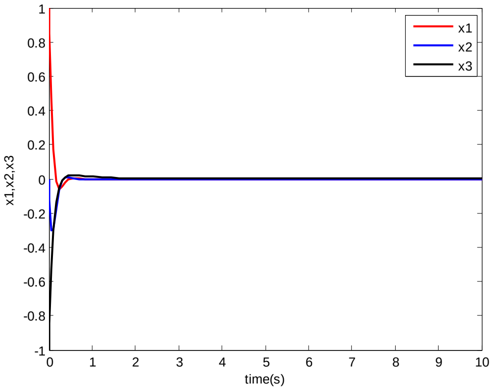

Figure 9. Boom, arm, and arm extension arm position error

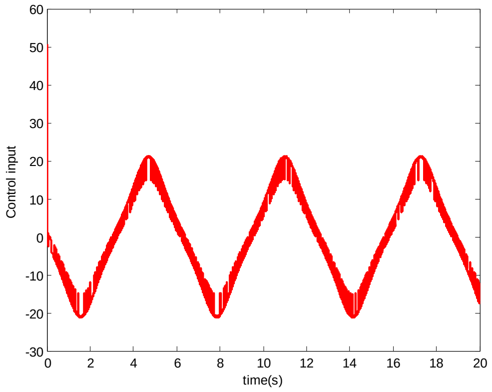

Figure 10. The control input

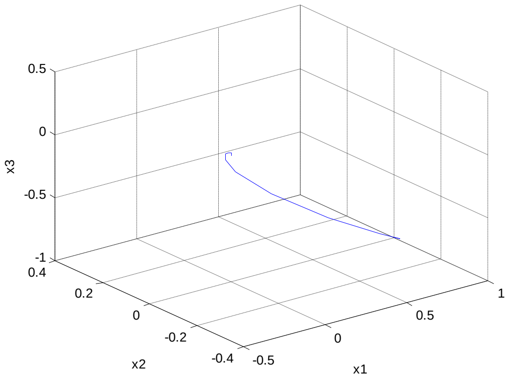

Figure 11. The end effector space trajectory

From the above results, it was simulated by MATLAB software that the control system was designed using the SMV structure neural network. Figure 7 shows the trajectory tracking of the boom speed. It can be seen from the Figure 7 that the speed of the boom itself is close to the ideal speed, and it has good tracking performance. The tracking speed of the boom speed trajectory can meet the design requirements. Figure 8 shows the trajectory tracking of the boom position. It can be seen from the Figure 8 that the trajectory of the boom position coincides with the ideal trajectory at the beginning, and the trajectory tracking effect is very good. It has good tracking performance, and the trajectory tracking effect of the boom position can meet the design requirements. Figure 9 shows the position error of the boom, arm and arm telescopic arm. Figure 9 represents the error between the position of the boom, arm and arm telescopic arm after the completion of the welding point and the ideal position. It can be seen from the Figure 9 that the position error quickly approaches zero and has good stability. The LAM robot control system designed in this paper has good stability. Figure 10 shows an input signal of the system with randomness. Figure 11 shows a certain trajectory of the end effector in space. It can be seen that the space trajectory of the LAM robot has good continuity, and the nozzle powder feeding effect of the LAM robot is also better. In summary, the design of the six axis LAM robot control system controlled by the SMV neural network is stable, and the tracking speed of the boom and position trajectory is good, which has a certain generalization.

VI. CONCLUSIONS AND FUTURE WORK

This paper proposes a SMV structure neural network tracking control of six axis LAM robot. Via a new LKF, a new state estimator is established such that the error system is global asymptotically stable. It is also pointed out that a trajectory tracking has a good effect. The simulation result shows that our conclusions are feasible and effective.

REFERENCES

[1]. W. Gao et al., "The status, challenges, and future of additive manufacturing in engineering," Computer-Aided Design, vol. 69, pp. 65-89, 2015.

[2]. M. Aburaia, E. Markl, and K. Stuja, "New concept for design and control of 4 axis robot using the additive manufacturing technology," Procedia Engineering, vol. 100, pp. 1364-1369, 2015.

[3]. C. Semini et al., "Additive manufacturing for agile legged robots with hydraulic actuation," in Advanced Robotics (ICAR), 2015 International Conference on, 2015, pp. 123-129: IEEE.

[4]. A. J. Pinkerton, "Lasers in additive manufacturing," Optics & Laser Technology, vol. 78, pp. 25-32, 2016.

[5]. J. Spencer, P. Dickens, and C. Wykes, "Rapid prototyping of metal parts by three-dimensional welding," Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, vol. 212, no. 3, pp. 175-182, 1998.

[6]. Y.-C. Chang and B.-S. Chen, "A nonlinear adaptive H/sup/spl infin//tracking control design in robotic systems via neural networks," IEEE Transactions on Control Systems Technology, vol. 5, no. 1, pp. 13-29, 1997.

[7]. W. He, Y. Chen, and Z. Yin, "Adaptive neural network control of an uncertain robot with full-state constraints," IEEE transactions on cybernetics, vol. 46, no. 3, pp. 620-629, 2016.

[8]. W. T. Miller, R. P. Hewes, F. H. Glanz, and L. G. Kraft, "Real-time dynamic control of an industrial manipulator using a neural network-based learning controller," IEEE Transactions on Robotics and Automation, vol. 6, no. 1, pp. 1-9, 1990.

[9]. L.-X. Wei, H.-R. Wang, and Y. Li, "A new solution for inverse kinematics of manipulator based on neural network," in Machine Learning and Cybernetics, 2003 International Conference on, 2003, vol. 2, pp. 1201-1203: IEEE.

[10]. P. Neto, J. N. Pires, and A. P. Moreira, "Accelerometer-based control of an industrial robotic arm," in Robot and Human Interactive Communication, 2009. RO-MAN 2009. The 18th IEEE International Symposium on, 2009, pp. 1192-1197: IEEE.

[11]. H. Miyamoto, M. Kawato, T. Setoyama, and R. Suzuki, "Feedback-error-learning neural network for trajectory control of a robotic manipulator," Neural networks, vol. 1, no. 3, pp. 251-265, 1988.

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