Research on adaptive H-Infinity tracking for inhibition fluttering of picking robot arm

Zhiyong Zhang[1], Hongli Guo[2*], Lvwen Huang[1], Xiaoting Zhang[1]

[1]*College of information Engineering, Northwest A&F University, Yangling, Shaanxi, 712100, China*

[2]*College of Mechanical & Electronic Engineering,Northwest A&F University, Yangling, Shaanxi, 712100, China*

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Abstract

This paper aim at solve issue that conventional frequency domain theory is unsuitable for MIMO system and LOG theory is unsuitable for model perturbation, we commit to the research on H-infinity stability and focus on discuss design principles of H-Infinity stability system and methods on Riccati equation or inequality solution. As for the uncertainty and external interference, we discuss two-output equation or an algebraic Riccati state feedback equation using character on Riccati equation. According to the state space theory, we derive the controller to make structural equation to meet the requirement of state feedback and observer, and then draw suboptimal solutions in the form of engineering management experience. To reduce the impact on interference to control stability by selecting the appropriate interference attenuation coefficient γ, so that its stability could be casted to meet harvest scene.

Keywords: H-infinity, Riccati equation, Interference attenuation coefficient, Domain theory

1 Introduction

Since the state space has been greatly developed, LQG feedback design methods based on quadratic optimal regulator and the Kalman-Bucy filter theory were emerged, these method required control system precise mathematical model to ensure its robustness. If the system model unfit with uncertain external environment, it is necessary for statistical properties of the interference signal known or assumed to be white noise with if-then condition, or robustness design LQG will become poor. However, the interference signal often change with picking environment variability in the actual picking environment, it is difficult to predict the interference statistics in advance. For above reasons, LQG algorithm on the application of the picking robot arm is persuasive, but actually not ideal [1]. As for the interference signal LQG unreasonable restrictions problem, Zames specially designed a famous H-Infinity. He firstly put the interference signal of SISO system into a finite set known signal energy, then deserved feedback controller meeting the closed-loop system, screening a minimal impact on the system disturbance that the minimum H-infinity norm of the sensitivity function.

Douat L. R. and Queinnec [2] obtained the H-infinity optimal controller by solving two Riccati equation, and then proposed a simplified equation for the state space H-Infinity controller, which is equal to the order for the generalized object. Later state feedback $H\infty$ was proposed by solving an algebraic Riccati equation, but mathematics and computation is very powerless because of using the state space method, and later the rapid development of computer technology and software toolbox control theory appeared to overcome complex calculations shortcomings, so that it could better solve two problems in design stability which are unsuitable MIMO system design and model perturbation, in recent years, it has become a hot research in control theory field and has made some practical application results. Related literature [3-4] indicated to build accurate mathematical model from external interference has been unrealistic, but it must be thought illumination, shelter as the uncertainty case, the picking robot arm control system can meet the requirements of the desired stability. Penne and R, Smet E [5] established one simplified dynamic equations of piezoelectric flexible manipulator and its control system model to design active vibration control system for active vibration control of flexible manipulator by using a piezoelectric element analysis model methods. Later they also established a linear system dynamics equation using time domain precise integration method on solving state equations and algebraic Riccati equation, therefore by using the control disturbance attenuation theory for control strategy of power system set to study. Qiu Q. et al [6] applied H-infinity control strategies aiming at 2-DOF manipulator unstructured uncertainties, the design global tracking controller of two arms inhibit fluttering. These analyzes provided inspiration & reference on continuous research and development for robust control theory uncertain systems. Therefore, this paper describe the maximum gain from the limited input energy to the output energy according to transfer function H-infinity norm of the picking robot arm, and Sahli N, Moulin B [8] was optimized through the norm of the transfer function

* ***Corresponding author*** e-mail:hongliguo1975@126.com

as the objective function, composed by criterion of Riccati inequality to determine the solvability of control problems [9-10], the interference with the limited power spectrum has minimal impact on the stability of the desired output.

2 Picking robot arm controller design

As for picking robot arm control systems based H-infinity theory, whether interference control problem or robustness stability problems, can be summarized the closed-loop stability system and made the closed-loop transfer function matrix H-infinity minimum or less than a given value from the feedback controller problem [11],it can to design the controller in this way. Using time domain design theory method based on Riccati equation to solve a state feedback or 2 output feedback algebraic equation, derive the controller based on the state space representation with observer plus state feedback form of controller[12]. Considering the time domain is due to comprehensive rigorous theoretical system design owning optimal control theory LQR / LQG approaching the characteristics concept. So it is ape to achieve the optimal or suboptimal robustness in many fields for most researchers to enforce the stability of controller design.

2.1 THE STANDARD DESIGN ON H-INFINITY

In the study of the various H-infinity control optimization problems ,we found H-Infinity controller is divided into state feedback controller and output feedback controller according to the source measured signal, but in anyway, it need to reduce to the standard design problems in the way of actual controlled object model and design requirements. The related study [13-15] has been found that regardless of robust stabilization problem, the sensitivity minimization problem, mixed sensitivity optimization problem, three freedom degrees problems, tracking problems, the model matching problem, filtering problem and many other control problems are all attributed to the H-Infinity control problem, which will produce a far-reaching impact on control theory. The Following is the general H-Infinity tracking control method for picking robot arm

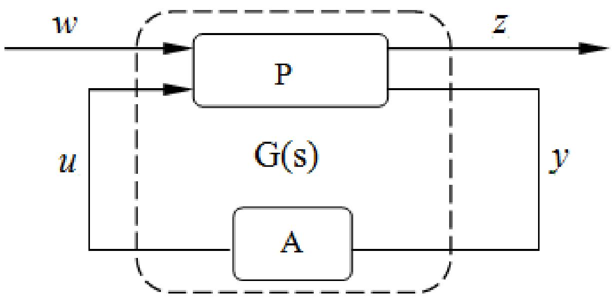

FIGURE1 The general H-Infinity tracking control method for picking-arm

Figure1 stands on the general problem of H-Infinity control block diagram. Where P includes three drive arm joints and its general object weighting function is defined as

$$\begin{bmatrix} z \\ y \end{bmatrix} = P\begin{bmatrix} w \\ u \end{bmatrix} = \begin{bmatrix} P_{11} & P_{12} \\ P_{21} & P_{22} \end{bmatrix}\begin{bmatrix} w \\ u \end{bmatrix}, \quad (1)$$

where $w \in R^r$ represents the external input signal, $z \in R^m$ is controlled output signal, $u \in R^p$ denotes a control signal, $y \in R^q$ represents table measurement signal.

Considering equation (1) shown as the closed-loop system transfer function G(s), also known as augmentation controlled object, actually determined by the input signal from u , w to output signal z , y . Transfer martix including weighting function and the actual controlled object. The state space can be illustrated as following

$$\begin{cases} x = Ax + B_1 w + B_2 u \\ z = C_1 x + D_{11} w + D_{12} u \\ y = C_2 x + D_{21} w + D_{22} u \end{cases}, \quad (2)$$

where x denotes n dimensional state variables, u is p dimensional state variable, w is r dimensional state variable, y is q dimensional state variable, z is m dimensional state variable, the equation (1) can also be written as

$$G(s) = \begin{bmatrix} w \\ u \end{bmatrix} = \begin{bmatrix} G_{11}(s) & G_{12}(s) \\ G_{21}(s) & G_{22}(s) \end{bmatrix} = \begin{bmatrix} A & B_1 & B_2 \\ C_1 & D_{11} & D_{12} \\ C_2 & D_{21} & \mathrm{D}_{22} \end{bmatrix}, \quad (3)$$

wherein, H-Infinity control is equal to the performance on positive definite controller

$$U = Ky \quad (4)$$

where K stands on controller, considering closed loop control system for the picking arm will be stable, the norm of the transfer function from w to z is minimum

$$T_{zw} = G_{11} + G_{12} K (1 - G_{22})^{-1} G_{21} \quad (5)$$

Namely, to solve the following equation

$$\mathrm{Min}\|T_{zw}\|\infty . \quad (6)$$

Equation (5) denotes H-Infinity control problem, if given γ>0, Equation (6) will be written as

$$\|T_{zw}\|\infty < \gamma . \quad (7)$$

Therefore, the above equation indicate sub-optimal control problem.

If H-Infinity norm of equation (5) and (6) is rewritten H_z norm, namely $\mathrm{Min}\|T_{zw}\|_z$ or $\|T_{zw}\|_z < \gamma$, the algorithm then is called as H_z algorithm, LQG algorithms. As for the known G(s), H-Infinity suboptimal will be solvability through the seek tentatively suboptimal solution, repeated descending γ, making γ close to γ_0, explore the optimal solution approximation solution.

Another equation (7) is equivalent to

$$\left\| \frac{1}{\gamma} T_{zw} \right\|_\infty < 1 \cdot \tag{8}$$

However, $(1/\gamma)T_{zw}$ is equal to the augmented controlled object actually

$$G_\gamma(s) = \begin{bmatrix} \gamma^{-1}G_{11}(s) & G_{12}(s) \\ \gamma^{-1}G_{21}(s) & G_{22}(s) \end{bmatrix}. \tag{9}$$

Also, with the negative feedback controller G(s) consist of close-loop transfer function shown as Figure2, the case γ=1 will be only considered on the controller design.

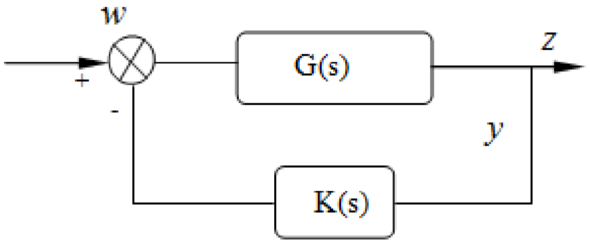

FIGURE2 The schematic diagram of H-Infinity close-loop control for picking-arm

2.2 GENERAL SOLUTION OF OUTPUT FEEDBACK

Assuming augmented control object matrix meet the following conditions [18]:

(1) (A,B_1) and (A,B_2) are stable pair,

(2) (C_1,A)and (C_2,A) are detectable pair

(3) $G_{12}^T[C_1 \;\; C_{12}] = [0 \;\; I]$

(4) $D_{21}[D_{21}^T \;\; B_1^T] = [I \;\; 0]$

(5) G_{12}(s) and G_{12}(s) have no zeros points on the imaginary axis.

(6) D_{11}=0 and D_{22}=0

The following can be obtained from the equation (3)

$$G(s) = \begin{bmatrix} A & B_1 & B_2 \\ C_1 & 0 & D_{12} \\ C_2 & D_{21} & 0 \end{bmatrix}. \tag{9}$$

Theorem 1 Assuming the augmented control object (8) meet the conditions (1)-(6). There exits controller *K*(s) shown as Figure 2, which close-loop system stabilize, moreover the sufficient and necessary condition for $\|T_{zw}\|\infty < 1$ is set up

(1) Riccati equation has a semi-positive definite solution, making the array stable

$$A^T X + XA + X(B_1B_1^T \text{-} B_2B_2^T)X + C_1^T C_1 = 0. \tag{11}$$

(2) Riccati equation has positive semi-definite, so the following array is stable

$$AY + YA^T + Y(C_1^T C_1 \text{-} C_2^T C_2)Y + B_1B_1^T = 0. \tag{12}$$

(3) Riccati equation

$$\gamma_{\max}(XY) < 1. \tag{13}$$

If the condition (1) - (3) established for the augmented controlled object (10), the H-Infinity standard solution is given by the following equation

$$K(s) = \begin{bmatrix} A + B_1B_1^T \text{-} Z^{-1}LC_2 + B_2F & \text{-}Z^{-1}L \\ \text{-}F & 0 \end{bmatrix}, \tag{14}$$

where $F = B_1^T X$, $L = YC_2^T$, $Z = I\text{-}XY$

2.3 PICKING ROBOT ARM TRACKING CONTROLLER DESIGN

Seen from the H-Infinity tracking controller shown as Figure3, the output *y* tracks reference input *r*, the controlled object *P*(s) is known, the controlling input of the object *u* namely *r*, *y* is generated by the forward channel controller C_1, the feedback controller C_2, respectively.

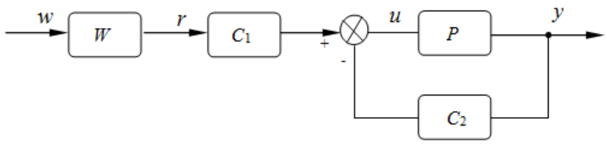

FIGURE 3 The schematic diagram of H-Infinity tracking control for picking-arm

Where *r* denotes a finite energy instead of an known input signal, *r* denotes a signal in the equation of $\{r | r = Ww, w \in H_2, \|w\|_2 \le 1\}$, H_2 indicates the set components of all finite energy signal

$$H_2 = \left\{ w(t) \middle| \left[\int_0^\infty w^*(t)w(t)dt \right]^{\frac{1}{2}} \le +\infty \right\}. \tag{15}$$

In the course of tracking control, the controller *P* and *W* are known, but C_1 and C_2 remains to be further designed, the tracking error *r* and *y* are the actual controlled variables pursuit smallest error tracking system, taking $\|r\text{-}y\| + \|\rho u\|$ into the following equation objective function of the system, which corresponds to the signal.

$$z = \begin{bmatrix} r\text{-}y \\ \rho u \end{bmatrix}, \tag{16}$$

where ρ denotes the weighting factor greater than 0 Therefore, regarding the objective function minimization problem as the key issue on picking arm tracking

$$\sup_{w \in BH_2} \|z\|, \tag{17}$$

where BH_2 denotes H_2 unit sphere. If we transfer tracking control issue on picking robot arm to standard H-Infinity control issue, we may obtain

$$z=\begin{bmatrix} r\text{-}y \\ \rho u \end{bmatrix},\ v=\begin{bmatrix} r \\ y \end{bmatrix}, \tag{18}$$

u and v as control signals and external input signals, respectively. The equation on controller and the generalized controlled device is shown as following

$$\begin{bmatrix} z \\ v \end{bmatrix}=\begin{bmatrix} r\text{-}y \\ \rho u \\ r \\ y \end{bmatrix}=\begin{bmatrix} W & \text{-}P \\ 0 & \rho I \\ W & 0 \\ 0 & P \end{bmatrix}\begin{bmatrix} w \\ v \end{bmatrix}, \tag{19}$$

$$u=\begin{bmatrix} C_1 & C_2 \end{bmatrix}\begin{bmatrix} r \\ y \end{bmatrix}. \tag{20}$$

K and G are correspondingly shown as

$$G=\begin{bmatrix} G_{11} & G_{12} \\ G_{21} & G_{22} \end{bmatrix}, \tag{21}$$

where $G_{11}=\begin{bmatrix} W \\ 0 \end{bmatrix}, G_{12}=\begin{bmatrix} \text{-}P \\ \rho I \end{bmatrix}, G_{21}=\begin{bmatrix} W \\ 0 \end{bmatrix}, G_{22}=\begin{bmatrix} 0 \\ P \end{bmatrix}$, $K=\begin{bmatrix} C_1 & C_2 \end{bmatrix}$, now, Figure3 shown as the tracking problem can be converted to standard problem.

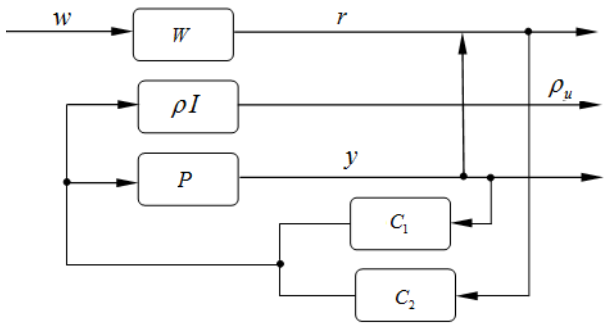

FIGURE 4 The schematic diagram of standard H-Infinity tracking control method

3 Design on H-Infinity controller picking robot arm

The Picking robot arm is regarded as a highly nonlinear control system, according to [15] description of the transfer matrix H_2 norm that is the gain of control system showing that the existence of a positive definite solution $H_2<\gamma$ of the Riccati equation on the necessary and sufficient conditions. As described the above, if the gain of non-linear system is greater than $\gamma(\gamma>0)$, the control system (11) is the dissipation. Actually, on the certain conditions, stable system can be detected, no zero, which meet the necessary conditions that gain is less than γ. The necessary conditions and the range of linear systems is consistent. By analysing on nonlinear systems (10), if $r^2 I\text{-}d^T(x)d(x)\geq 0, \forall x\in R^n$ is established, then $w(x)$ can be taken as

$$\omega(x)=\frac{\sqrt{2}}{2}\left[r^2 I\text{-}d^T(x)d(x)\right]^{1/2}. \tag{22}$$

Therefore, $w(x)$ is invertible matrix, according to Equation (12), $l(x)$ can be represented as

$$l(x)=\text{-}\frac{1}{2}\omega^{\text{-}1}(x)\left[L_g V(x)+h^T(x)d(x)\right]^T, \tag{23}$$

Substitute the equation (25) into the first relationship of equation (8), *V(x)* meets the inequality condition

$$L_f V(x)+\frac{1}{2}h^T(x)h(x)+\frac{1}{2}[L_g V(x)+h^T(x)d(x)] \times[r^2 I\text{-}d^T(x)d(x)]^{\text{-}1}[l_g V(x)+h^T xd(x)]^{\mathrm{T}}\leq 0. \tag{24}$$

Therefore, we can deduce Theorem 1, there exit the following theorem.

Theorem 2 If the optimal solution on the equation (7) is established, for nonlinear picking arm system (25) meet the semi-definite storage system consisting of a smooth function differentiable conditions make it necessary and sufficient dissipation conditions for the inequality (26), has the positive semi-definite solution. If $d(x)=0$, then inequality (26) can be expressed via the following inequality:

$$L_f V(x)+\frac{1}{2\gamma^2}L_g V(x)L_g^T V(x)+\frac{1}{2}h^T(x)d(x)\leq 0, \tag{25}$$

equivalently:

$$\frac{\partial V}{\partial x}f(x)+\frac{1}{2r^2}\frac{\partial V}{\partial x}g(x)g_g^T(x)(\frac{\partial V}{\partial x})^T+\frac{1}{2}h^T(x)h(x)\leq 0. \tag{26}$$

If the system dissipative coefficient $\gamma>0$, on the nonlinear system (25) $d(x)=0$ conditions, storage function *V(x)* is smooth- differentiable making the dissipation γ necessary and sufficient condition for inequality (27) meet semi-positive definite function *V(x)*. If the system gain L_2 is less than γ, so the system is dissipated. Therefore the system (27) is greater than picking arm gain γ sufficient condition still exists positive semi-definite function meeting the inequality (27). To discuss the nonlinear picking arm system, there exits the following equation

$$\begin{cases} \dot{x}=f(x)+\Delta f(x)+[g(x)+\Delta g(x)]u+[k(x)+\Delta k(x)]d \\ y=h(x) \end{cases}. \tag{27}$$

As equation (27) have shown strong anti-jamming attenuation performance, while meeting performance index of H-Infinity, then there must be a smooth differentiable positive definite function *V(x)*=0 be up to the control law *u=u(x)*,the following inequality holds

$$HJI = V_x[f(x)+\Delta f(x)]+\frac{1}{2}V_x[k(x)+\Delta k(x)][k(x)+\Delta k(x)]^T V_x^T$$
$$+V_x[g(x)+\Delta g(x)]u+\frac{1}{2}h^T(x)h(x)\le 0 \quad . \; (28)$$

Namely, from the system disturbance d to the output y are less than or equal gain γ, where $V_x = \partial V / \partial x$. According to related description of the mathematical model 3-DOF picking robot arm, we can obtain the uncertain environment dynamic model picking robot arm

$$u = M(q)\ddot{q}+C(q,\dot{q})\dot{q}+G(q)+F(\dot{q})+d \,, \tag{29}$$

where M denotes $M(q)\in R^{3\times3}$, C denotes $C(q,\dot{q})\in R^{3\times3}$, G denotes $G(q)\in R^3$, F denotes $F(\dot{q})\in R^{3\times3}$ related physically significant have be illustrated before. u denotes the input moment vector for 3 joints, as for $\forall T>0$, interference variables $d\in[0,T_2]$.

Taking into account parameters uncertainty for picking robot arm control system including the external operating disturbances environment, moreover different harvesting conditions allocated with different requirements on 3 arm joints, we regards the external interference as one part of the uncertainty via H-Infinity stability control strategy.

3.1 UNCERTAINTY AND ANTI-INTERFERENCE STRATEGY

Referenced by the literature [13-17], we can regard the uncertainty and external interference as one the inseparable whole. The system interference is defined as

$$u = M_0(q)\ddot{q}+C_0(q,\dot{q})\dot{q}+G_0(q)+F_0(\dot{q})+\omega \,, \tag{30}$$

where $f(x)=\begin{bmatrix}\dot{q}\\ -M_0^{-1}(C_0\dot{q}+G_0+F_0)\end{bmatrix}$, $g(x)=\begin{bmatrix}0\\ M_0^{-1}\end{bmatrix}$, $\omega^{'}=\begin{bmatrix}0\\ M_0^{-1}\omega\end{bmatrix}$.

Learned from equation (30), anti-interference controller can be obtained

$$u_1 = g(x)^{-1}[-f(x)+\ddot{x}_d+k_1\dot{e}+k_2 e] \,, \tag{31}$$

where x_d denotes expected trajectory for picking robot arm, k_1 and k_2 represent constants. So system errors can be expressed as

$$\ddot{e}+k_1\dot{e}+k_2 e = -\omega' \,. \tag{32}$$

If ω'=0 =0, then there exit no interference and uncertainty for picking robot arm, now $\lim\limits_{t\to\infty} e(t)=0$, showing that the tracking errors restrain gradually. If $\omega'\neq 0$, the compensation control can be considered to add $u_2(t)$, then, we may obtain the close–loop system expression as

$$\ddot{e}+k_1\dot{e}+k_2 e = u_2(t)-\omega' \,. \tag{33}$$

If the equation (33) is adapted to state space equation, it can be expresses as

$$\begin{cases}\dot{e} = Ae+Bu_2-B\omega' \\ y=e\end{cases} , \tag{34}$$

where $A=\begin{bmatrix}0 & 1\\ -k_1 & -k_2\end{bmatrix}$, $B=\begin{bmatrix}0\\1\end{bmatrix}$.

Assumming the Lyapunov function $V(t)=0.5\ e^T pe$, where $V(t)>0$, as for $\forall>0, V(0)=0$ p is a positive definite solution for the Riccati equation

$$A^T P+PA-\frac{2}{\beta}pBB^T p+\frac{1}{\gamma^2}pBB^T = -Q \,. \tag{35}$$

Equation (35) with the premise of positive definite solution is $\beta\le 2\gamma^2$, where γ denotes the interference attenuation, assuming $u_2=-\frac{1}{\beta}B^T Pe$, where $\beta>0$, now, we may testify compensate controller u_2 meets the stability index of H-Infinity system for equation (35).

Firstly, according to the equation (35) of close-loop err system, derivate Lyapunov function $V(x)$ and compare equation (36), we can gain the equation (37), Then integrate both side of equation (37) and gain the inequality as following.

$$\int_0^T e^T Qedt \le \gamma^2\int_0^T \omega^T\omega' dt \,, \tag{36}$$

using $y=e$, therefore $\max\limits_{\omega\in L_2}\frac{\|y(t)\|_{L_2}}{\|\omega^{'}(t)\|_{L_2}}\le\gamma^2$, it can be proved that equation (33) to be robust disturbance rejection performance, namely, we can gain L_2 is less than the given positive γ from interference ω' to system output y, furthermore, if the less γ is, the quickly interference attenuate ,the better H-Infinity stability is, therefore we can take full advantage of attenuation rate γ to gain the optimal control stability.

$$\dot{V}(t)=\frac{1}{2}\dot{e}^T pe+\frac{1}{2}e^T p\dot{e}=$$
$$-\frac{1}{2}e^T Qe-\frac{1}{2}(\frac{1}{\gamma}B^T pe-r\omega^{'})^T(\frac{1}{\gamma}B^T pe-r\omega^{'})+\dot{e}^T pe+\frac{1}{2}\gamma^2\omega^T\omega^{'}\le -\frac{1}{2}e^T Qe\frac{1}{2}\gamma^2\omega^T\omega^{'} \,. \tag{37}$$

4 The experimental simulation and analysis

4.1 EXPERIMENTAL DESCRIPTION

Picking robot arm model diagram is shown as Figure7, where m_1, l_1 and q_1 respectively represent mass, length and the angle of upper arm, m_2, l_2 and q_2 denote mass, length and angle of forearm, m_3, l_3 and q_3 respectively denote mass, length and angle of picking arm, J_1, J_2, J_3 represent the moment of inertia of above 3 arms. By the simulation, it is assumed q=[q_1,q_2], $\tau = [\tau_1, \tau_1]^T$ the model of picking robot arm can be represented by the equation (2), where $G(q)$, $M(q)$ and $C(q,\dot{q})$ can be represented as

$$M(q) = \begin{bmatrix} \theta_1 + \theta_3 + 2\theta_2 \cos q_2 & \theta_3 + \theta_2 \cos q_2 & \cos q_2 \\ \theta_3 + \theta_2 \cos q_2 & \theta_3 & \theta_2 \cos q_2 \\ \theta_1 + \theta_3 + \theta_2 \cos q_2 & \theta_1 + \theta_3 osq_3 & \theta_3 \end{bmatrix}. \quad (38)$$

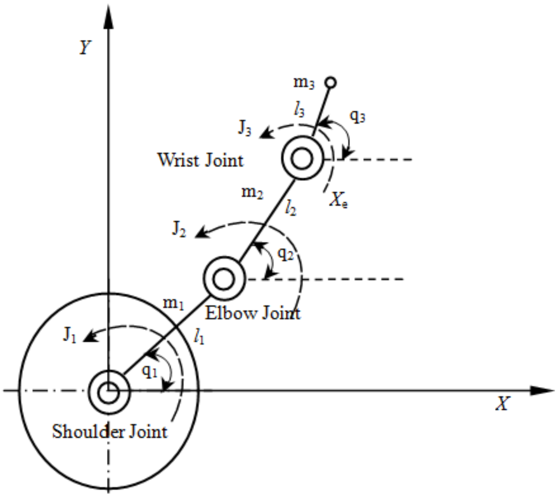

FIGURE 5 The model schematic diagram of picking-arm

$$C(q,\dot{q}) = \begin{bmatrix} -\theta_2 \dot{q}_2 \sin q_2 & -\theta_2(\dot{q}_2 + \dot{q}_1)\sin q_2 & \dot{q}_2\dot{q}_3 + \dot{q}_1\dot{q}_2 \sin q_2 \cos q_3 \\ \theta_2 \dot{q}_1 \sin q_2 & 0 & (\dot{q}_2\dot{q}_1)\cos q_2 \\ \dot{q}_2 + \dot{q}_3 \cos q_2 & \dot{q}_1 + \dot{q}_2\dot{q}_3 \cos q_3 & 0 \end{bmatrix}. \quad (39)$$

Assuming $G(q)$=0,then define the parameter vector

$$\theta = \begin{bmatrix} \theta_1 \\ \theta_2 \\ \theta_3 \end{bmatrix} = \begin{bmatrix} (0.42m_1 + m_2 + 0.58m_3)l_1^2 + J_1 \\ 0.68m_2 l_1 l_2 + 0.22m_3 l_3^2 \\ 0.25m_2 l_2^2 + J_3 \end{bmatrix}. \quad (40)$$

Derivative the inertia matrix of the matrix

$$\dot{M} = \begin{bmatrix} -2\theta_2\dot{q}_2 \sin q_2 & -\theta_2\dot{q}_2 \sin q_2 & \dot{q}_2\dot{q}_3 + \dot{q}_1\dot{q}_2 \cos q_2 \\ -\theta_2\dot{q}_2 \sin q_2 & 0 & -\dot{q}_2\dot{q}_1 \cos q_2 \\ \dot{q}_2 + \dot{q}_3 \sin q_2 & \dot{q}_1 + \dot{q}_2\dot{q}_3 \sin q_3 & 0 \end{bmatrix}. \quad (41)$$

Select equation (41) as the picking robot arm the system's physical parameter vector, then the regression matrix can be gained

$$\Phi = \begin{bmatrix} \ddot{q}_1 & 2\ddot{q}_1 \cos q_2 - 2\dot{q}_1\dot{q}_2\dot{q}_3 \sin q_2 + \ddot{q}_2 \cos q_2 & \ddot{q}_1 + \ddot{q}_2 \\ \ddot{q}_2 & \ddot{q}_1\ddot{q}_3 \cos q_2 - \dot{q}_1^2 \sin q_2 \cos q_3 & \ddot{q}_2 + \ddot{q}_3 \\ \ddot{q}_2 + \ddot{q}_3 & \dot{q}_1 + \dot{q}_2\dot{q}_3 \sin q_3 & \ddot{q}_1 + \ddot{q}_3 \end{bmatrix}. \quad (42)$$

5.2 EXPERIMENTAL METHODS

Using experimental data for picking robot arm to validate stability and effectiveness of H-Infinity algorithm, the specific physical experimental parameters for simulation experiments extracted from [17, 18] were taken different disturbance attenuation coefficient to observe 3 picking arm joint trajectory tracking situation, two different interference attenuation coefficient were taken and analysis simulation comparison, other simulation parameters are chosen as $\beta = 3\gamma^2, p = \begin{bmatrix} 6 & 2 \\ 2 & 6 \end{bmatrix}$, the control effect are revealed in Figure 8, Figure 9 and Figure 10 shows. And in order to verify the stability of the control results, the three drives joints are respectively applied the same sinusoidal disturbance signal, and the 3 joints are made with and without H-Infinity control simulation comparison, the control results are shown as Figure 11, Figure 12 and Figure 13.

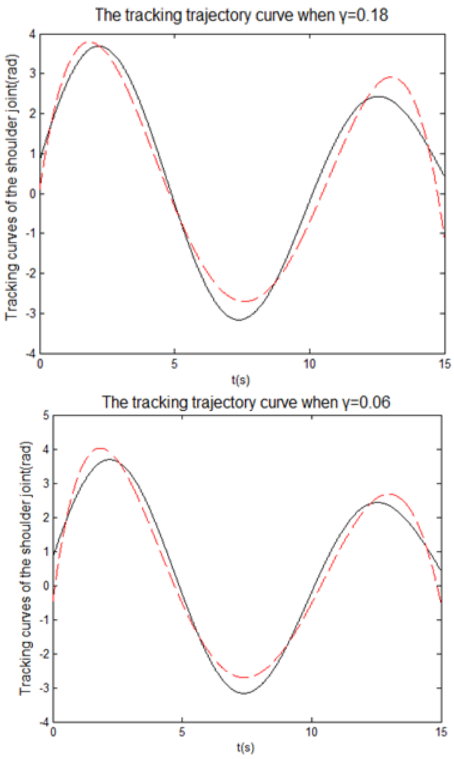

FIGURE 6 Tracking curves of the elbow joint

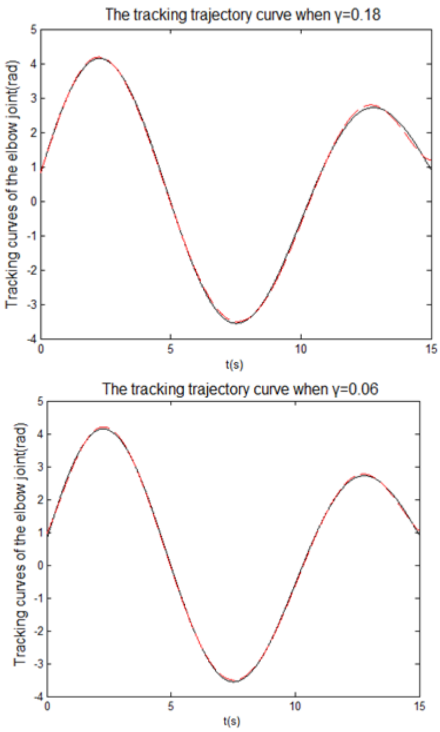

FIGURE 7 Tracking curves of the elbow joint

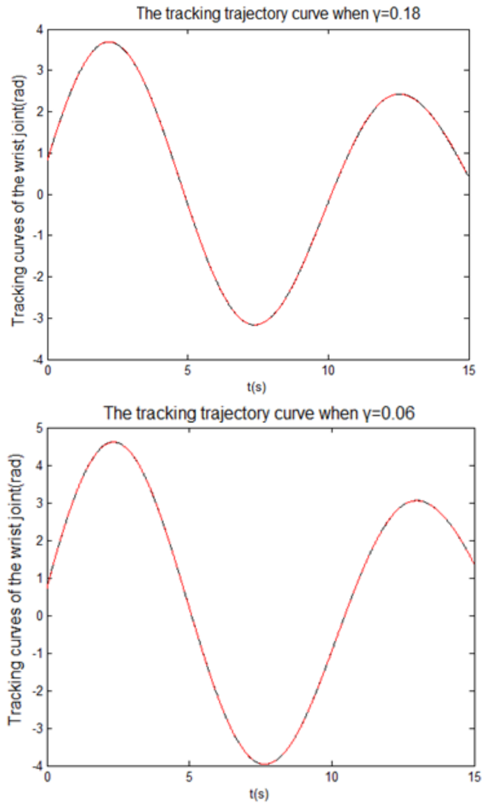

FIGURE 8 Tracking curves of the wrist joint

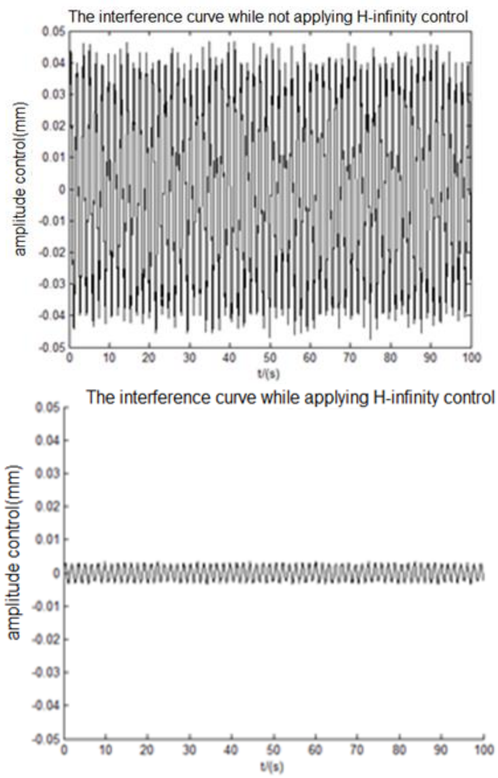

FIGURE 9 Response curves of the shoulder joint for disturbance

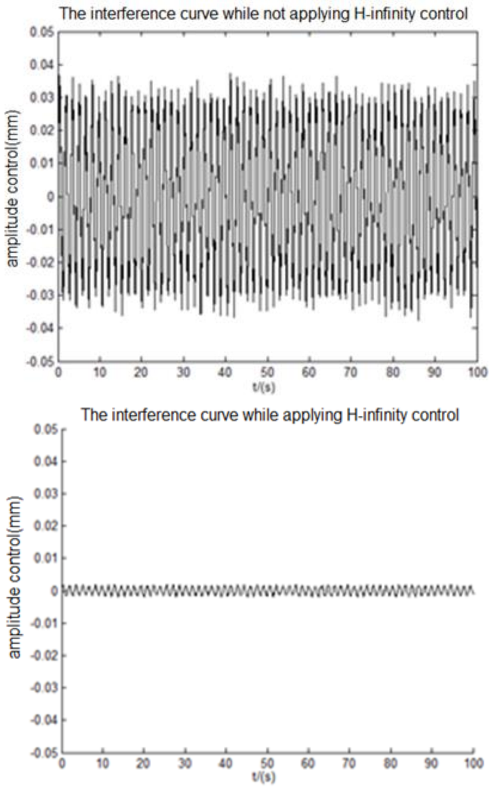

FIGURE 10 Response curves of the elbow joint for disturbance

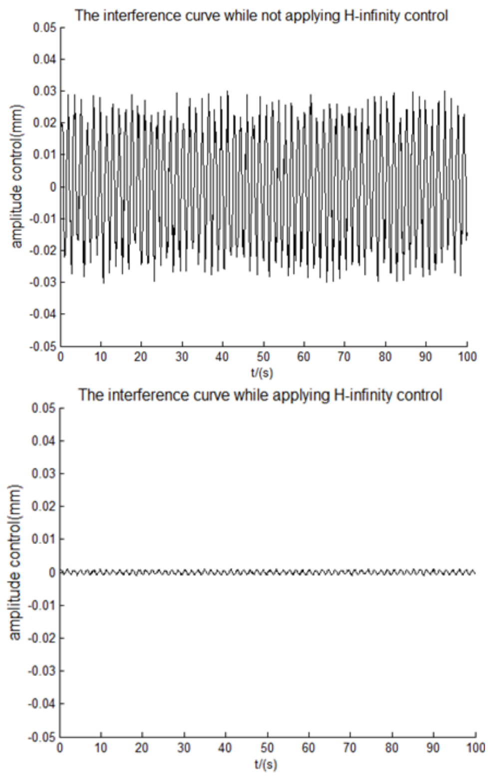

FIGURE 11 Response curves of the wrist joint for disturbance

Figure 8, Figure 9 and Figure 10 represent respectively the trace err for the shoulder, elbow and wrist. Simulation results showed that the joint stability is related to disturbance attenuation coefficient γ, the smaller the disturbance attenuation, faster disturbance attenuate, better system track, stronger its stability is, but γcannot be taken a unlimited less. Therefore, we need to choose a more suitable small disturbance attenuation coefficient to satisfy the final desired requirement. Meanwhile, the best wrist tracking, the tracking error is almost zero to better guarantee crawling and picking stability, enable to avoid fruit injury, elbow joint followed, which tracking error is less than 1%, maximum error emerge in shoulder joint, for which lie the bottom to maintain the other two joints steadily. Figure 11, Figure12 and Figure13 respectively represent interference output response curve of shoulder, elbow and wrist joints, it can be seen by contrasting the presence or absence from H-Infinity control, if H∞ control is applied to the system, the transition time for each arm is a large shorten and the steady state amplitude decrease significantly, showing a good static quality. the system vibration is reduced within 1.5%-3% of the original sinusoidal signal. The comprehensive FIGURE8-FIGURE13 shows that H-Infinity controller can guarantee high dynamic and static quality, strong robustness to model error interference suppression for picking arm closed-loop system. It is great theoretical and practical significance to improve the system stability.

5 Conclusion

This paper aims to do with external interference and uncertainty problem for picking robot arm by solving the two-output Riccati equation, and adjust the appropriate interference control to reduce interference attenuation effect on its stability and design the adaptive H-Infinity controllers. The system can satisfy specific control stability requirements. Simulation results show that the adaptive controller has strong interference adaptability to environmental disturbances uncertain within 1.5% -3%. The controller on the fluttering inhibition for picking robot can be extended to other similar stability control applications.

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Authors

Zhiyong Zhang

Current position, grades: Lecture
University studies: Fundamental Digital Circuit, Fundamentals of Robot technology, Controlling Technique for Programming
Scientific interests: Intelligent detecting and control, agricultural robot, and agricultural information technology
Publications:
Experience: The B.Sc.degree in agricultural engineering in 1999, the M.Sc. degree in agricultural Engineering in 2004, and the Ph.D. degree in agricultural engineering from Northwest A&F University, Yangling, Shaanxi, China, in 2012.

Hongli Guo

Current position, grades: Lecture
University studies: Theoretical Mechanics, Fundamentals of Robot technology, Controlling Technique for Programming
Scientific interests: Mechanical design and manufacturing and electromechanical integration design.
Publications:
Experience: The B.Sc.degree in agricultural Engineering in 1999, the M.Sc. degree in Processing and storage engineering of agricultural products in 2004

Lvwen Huang

Current position, grades: Lecture
University studies: Computer Control System, Fundamentals of Robot technology, Controlling Technique for Programming.
Scientific interests: Intelligent system and image processing.
Publications:
Experience: The B.Sc. degree in automation engineering in 1999, the M.Sc. degree in signal and information processing from the Xi'an University of Technology, Xi'an, Shaanxi, China in 2005, and the Ph.D. degree in Agricultural Electrification and Automation from Northwest A&F University, Yangling, Shaanxi, China, in 2013.

Xiaoting Zhang

Current position, grades: Lecture
University studies: Fundamental Digital Circuit, Fundamentals of Robot technology, Reliability Engineering
Scientific interests: Intelligent system, database and Management Information System.
Publications:
Experience: The B.Sc.degree in Economic Information Management of Xi'an Petroleum Institute, Shaanxi, China in 2001, the M.Sc. degree in agricultural economic management of Northwest A&F University, China in 2009.