ISSN (ONLINE): 2454-9762
ISSN (PRINT): 2454-9762
Available online at www.ijarmate.com

International Journal of Advanced Research in Management, Architecture, Technology and Engineering (IJARMATE)
Vol. 8, Issue 1,January 2022

Multidisciplinary Integrated Practical Teaching—Taking Robot as an Example

Jing Lei[1], Jia-Qing Song[2]

School of Mathematics and Statistics, Taishan University, Tai'an 271000, China [1]

Virtual Experiment Simulation Center, Taishan University, Tai'an 271000, China [2]

***Abstract*—Modern science and technology have the remarkable characteristics of multidisciplinary integration, which puts forward new challenges and requirements for the talent teaching and training. This paper puts forward the importance and existing problems of cultivating students' interdisciplinary integration innovation ability, and takes the design of output feedback control for a robot as an example, in order to illustrate the importance and the method of interdisciplinary integration teaching.**

***Index Terms*—Advanced education, multidisciplinary integration, practical teaching, robot.**

I. Introduction

The development direction of modern manufacturing industry is the integration of computing, communication, control and other disciplines, which makes it urgent for the specialty of information and computing science to cultivate talents with interdisciplinary integration and innovation ability [1]-[5]. The original talent training mode can no longer meet the needs of economic and technological development. The main problems are: (1) The curriculum is lack of systematic ability oriented design; (2) The teaching mode focuses on knowledge transfer, and the teaching link lacks comprehensive practice link; (3) The implementation approaches for multi-disciplinary integration and comprehensive training of professional skills and professional quality are lack. In view of the above problems, this paper puts forward a new professional teaching mode under the framework of multi-disciplinary integration. It takes a robot control design as an example, introducing the use of physical and mathematical knowledge to convert the robot's physical model into mathematical model, and further the functional differential knowledge and control theory knowledge to design the robot control. Moreover, computer skills are employed to carry out programming simulation experiments. In this way, physics, mathematics, cybernetics and computer disciplines are integrated to solve practical application problems, which reflects the importance of cultivating interdisciplinary integration talents and how to integrate the multidisciplinary into teaching [1]-[2].

Artificial intelligence and robotics have been included in undergraduate and graduate courses in colleges and universities at home and abroad. Colleges and universities vigorously develop new majors that meet the needs of national strategic development, focusing on cultivating a large number of high-tech talents to help the development of national science and technology. In various activities of college students' innovation and entrepreneurship, robot competition has become the mainstream competition for engineering students that attracted a lot of teams. The robot competition is divided into service robots, UAVs, simulation robots and other robots, which span the knowledge systems of computers, electronic information, artificial intelligence, automation and other disciplines [3]-[5]. This paper focuses on the robot teaching mode of multi-disciplinary integration. We take an example to show how to integrate multidisciplinary in teaching. We utilize physics, mathematics, control theory, computer technology to design an output feedback control for a robot.

II. Physical-Mathematical Modelling

The physical-mathematical model of a robot is given by

$$\begin{bmatrix} \dot{x}(t) \\ \dot{y}(t) \\ \dot{\theta}(t) \end{bmatrix} = \begin{bmatrix} \cos(\theta(t)) \\ \sin(\theta(t)) \\ 0 \end{bmatrix} v(t) + \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} w(t) + \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix} d(t) \quad (1)$$

[6]-[7], where x and y are position coordinates of the robot, θ is the direction angle relative to x-axis, and d is a disturbance affecting robot motion. v is the horizontal speed of robot and w is the angular speed of the wheel rotating around the vertical axis, which are the controls to be designed for robot.

The physical-mathematical model of the target satisfies

$$\begin{bmatrix} \dot{x}_d(t) \\ \dot{y}_d(t) \\ \dot{\theta}_d(t) \end{bmatrix} = \begin{bmatrix} \cos(\theta_d(t)) \\ \sin(\theta_d(t)) \\ 0 \end{bmatrix} v_d(t) + \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} w_d(t) \quad (2)$$

Denote the tracking error as

$$e(t) = \begin{bmatrix} \cos(\theta(t)) & \sin(\theta(t)) & 0 \\ -\sin(\theta(t)) & \cos(\theta(t)) & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_d(t) - x(t) \\ y_d(t) - y(t) \\ \theta_d(t) - \theta(t) \end{bmatrix} \quad (3)$$

Then, the mathematical model of tracking error is given by

ISSN (ONLINE): 2454-9762
ISSN (PRINT): 2454-9762
Available online at www.ijarmate.com

International Journal of Advanced Research in Management, Architecture, Technology and Engineering (IJARMATE)
Vol. 8, Issue 1,January 2022

$$\dot{e}(t)=\begin{bmatrix} v_d(t)\cos(e_3(t))-v(t)+e_2(t)w(t)-\cos(\theta(t))d(t) \\ v_d(t)\sin(e_3(t))-e_1(t)w(t)+\sin(\theta(t))d(t) \\ w_d(t)-w(t) \end{bmatrix} \quad (4).$$

III. CONTROL THEORY UTILIZATION

Design two feedback linearization controllers as follows

$$v(t)=v_d(t)\cos(e_3(t))-u_1(t),\quad w(t)=w_d(t)-u_2(t) \quad (5)$$

Replacing the controllers in (4) by (5) and simplifying it yield

$$\dot{e}(t)=\begin{bmatrix} 0 & w_d & 0 \\ -w_d & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} e(t)+\begin{bmatrix} 1 & 0 \\ 0 & 0 \\ 0 & 1 \end{bmatrix}\begin{bmatrix} u_1(t) \\ u_2(t) \end{bmatrix} + \begin{bmatrix} -\cos(\theta_d(t))d(t) \\ \sin(\theta_d(t))d(t) \\ 0 \end{bmatrix} \quad (6)$$

Our aim is to design the controls that ensure the error system (6) stable in the presence of disturbance.

Denote the system (6) in a compact form

$$\dot{e}(t)=Ae(t)+Bu(t)+f(d(t)),\quad y(t)=Ce(t) \quad (7)$$

where

$$A=\begin{bmatrix} 0 & w_d & 0 \\ -w_d & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix},\quad B=\begin{bmatrix} 1 & 0 \\ 0 & 0 \\ 0 & 1 \end{bmatrix},\quad C=\begin{bmatrix} 1 & 0 & 0 \end{bmatrix}$$

$$u(t)=\begin{bmatrix} u_1(t) \\ u_2(t) \end{bmatrix},\quad f(d(t))=\begin{bmatrix} -\cos(\theta_d(t))d(t) \\ \sin(\theta_d(t))d(t) \\ 0 \end{bmatrix}$$

Corresponding to (7), an observer is constructed as

$$\dot{\hat{e}}(t)=A\hat{e}(t)+Bu(t)+f(d(t))+H[y(t)-C\hat{e}(t)] \quad (8)$$

where $H=\left[a_1/\varepsilon, a_2/\varepsilon^2, a_3/\varepsilon^3\right]$, a_1,a_2,a_3 are to be decided and to guarantee the eigenvalues of $\bar{A}=\begin{bmatrix} -a_1 & w_d & 0 \\ -a_2 & 0 & 1 \\ -a_3 & 0 & 0 \end{bmatrix}$ Hurwitz, and $0<\varepsilon<1$ is the observer parameter to be specified. By exploiting control theory, the main results of this paper are achieved.

Theorem 1. Under the state feedback control

$$v(t)=v_d\cos(e_3(t))-K_1e(t),\quad \omega(t)=\omega_d-K_2e(t) \quad (9)$$

the robot (1) tracking the target path (2) is input-to-state stable, where $\begin{bmatrix} K_1^{\mathrm{T}} & K_2^{\mathrm{T}} \end{bmatrix}^{\mathrm{T}} \triangleq K=-R^{-1}B^{\mathrm{T}}P$, P is the unique solution of Riccati equation

$$A^{\mathrm{T}}P+PA-PBR^{-1}B^{\mathrm{T}}P+Q=0 \quad (10)$$

and Q is a positive semi-definite matrix. In particular, when the disturbance is attenuated, the robot (1) tracking the target path (2) is exponentially stable.

Proof. Note that substituting $u_1(t)=K_1e(t)$ and $u_2(t)=K_2e(t)$ into (5) results in the state feedback control (9). With the control $u(t)=Ke(t)$, the closed-loop system of (7) is

$$\dot{e}(t)=(A-BR^{-1}B^{\mathrm{T}}P)e(t)+f(d(t)) \quad (11)$$

Note that the unforced system $\dot{e}(t)=(A-BR^{-1}B^{\mathrm{T}}P)e(t)$ is exponentially stable. The stability of (11) depends on the boundedness property of disturbance, i.e., $\|f(d(t))\|$. Due to the continuously differentiability and global Lipschitz property of f, the closed-loop system (11) is input-to-state stable. In particular, when the disturbance is attenuated, $\|f(d(t))\|$ approaches to zero asymptotically. Thus, the tracking error is exponentially stable, implying that the robot tracks target path exponentially stably. The proof of Theorem 1 is completed. □

Theorem 2. There is an $\varepsilon^*>0$ such that for $0<\varepsilon\le\varepsilon^*$, under the output feedback control $u_1(t)=K_1\hat{e}(t)$, $u_2(t)=K_2\hat{e}(t)$, and $u_3=\bar{B}\hat{e}(t)$ with $\bar{B}=\begin{bmatrix} 0 & -1 & 0 \end{bmatrix}^{\mathrm{T}}$, based on the observer (8), the robot (1) tracks the target path (2) in an ultimately bounded way. In particular, when the disturbance is attenuated, the robot (1) tracks the target path (2) in an exponentially stable way.

Proof. Denote a scaled estimation error $\eta=\begin{bmatrix} \eta_1 & \eta_2 & \eta_3 \end{bmatrix}^{\mathrm{T}}$ with $\eta_1=(e_1-\hat{e}_1)/\varepsilon^2$, $\eta_2=(e_2-\hat{e}_2)/\varepsilon$, and $\eta_3=e_3-\hat{e}_3$. Differentiating both sides of the scaled errors yields the scaled estimation error equation $\varepsilon\dot{\eta}=\bar{A}\eta+\delta(\varepsilon,\eta,d)$, where $\|\delta\|\le\bar{L}\|\eta\|+M$ due to the properties of the disturbance d and the function f. Define a Lyapunov candidate function $V=\eta^{\mathrm{T}}\bar{P}\eta$, where $\bar{P}$ is positive definite solution of $\bar{A}^{\mathrm{T}}\bar{P}+\bar{P}\bar{A}=-I$. The derivative of εV along the scaled estimation error (11) deduces

$$\begin{aligned} \varepsilon\dot{V} &= \varepsilon\dot{\eta}^{\mathrm{T}}\bar{P}\eta+\eta^{\mathrm{T}}\bar{P}\varepsilon\dot{\eta}=-\eta^{\mathrm{T}}(\bar{A}^{\mathrm{T}}\bar{P}+\bar{P}\bar{A})\eta+2\varepsilon\eta^{\mathrm{T}}\bar{P}\delta \\ &\le -\tfrac{1}{2}\|\eta\|^2+2\varepsilon M\|\bar{P}\|\|\eta\|\le-\tfrac{1}{4}\|\eta\|^2,\quad \forall\|\eta\|\ge 8\varepsilon M\|\bar{P}\| \end{aligned}$$

for $\varepsilon\bar{L}\|\bar{P}\|\le 1/4$. According to control theory, the following holds

$$|e_i-\hat{e}_i|\le\max\{b/\varepsilon^{i-1}\exp(-at/\varepsilon),\varepsilon^{4-i}cM\},\quad i=1,2,3 \quad (12)$$

for some positive constants a,b,c, which indicates that the estimation errors are ultimately bounded. In particular, when the external disturbance is attenuated, M approaches to zero as time increases. From (12), it indicates that the estimation error is exponentially stable. In this case, the output feedback ensures the robot tracking the target path in an exponentially stable way. The proof of Theorem 2 is completed. □ .

IV. COMPUTER PROGRAMMING SIMULATION

In simulation part, we will using Matlab to program and validate the effectiveness of the designed control. The target path is set of a circle, where the central coordinates is given by

ISSN (ONLINE): 2454-9762
ISSN (PRINT): 2454-9762
Available online at www.ijarmate.com

International Journal of Advanced Research in Management, Architecture, Technology and Engineering (IJARMATE)
Vol. 8, Issue 1,January 2022

$$x_d = x_c + R\sin(w_d t), \quad y_d = y_c - R\cos(w_d t)$$

Choose the center at $(-3,3)$. Take $R = 3, w_d = 1/3$. Then, $v_d = 3\times 1/3 = 1$. From the relationship between w_d, v_d and θ_d, we get $\theta_d = 1/3t$. The circle equation becomes

$$x_d = -3 + 3\times\sin(\tfrac{1}{3}t), \quad y_d = 3 - 3\times\cos(\tfrac{1}{3}t)$$

The disturbance is set by an attenuated signal $\exp(-t)$. We design the observer with $a_1 = 3, a_2 = 3/26, a_3 = 3$ and treating the disturbance as a known one. Choose the parameters $\varepsilon = 0.1, 0.01$, respectively. The output feedback controls (9) are designed with

$$K_1 = \begin{bmatrix}-1.2168 & 0.7208 & 0\end{bmatrix}, \quad K_2 = \begin{bmatrix}0 & 0 & -1\end{bmatrix}$$

The simulation is conducted with the initial states

$$\big(x(0), y(0), \theta(0)\big) = (-3-\sqrt{3}/2, 1/2, -\pi/6)$$

and $e(0) = \big(1, 0, \pi/2\big)$. Fig. 1 depicts the robot tracking path, where the blue lines are that under state feedback control and the yellow ones are that under output feedback control with $\varepsilon = 0.1, 0.01$, respectively.

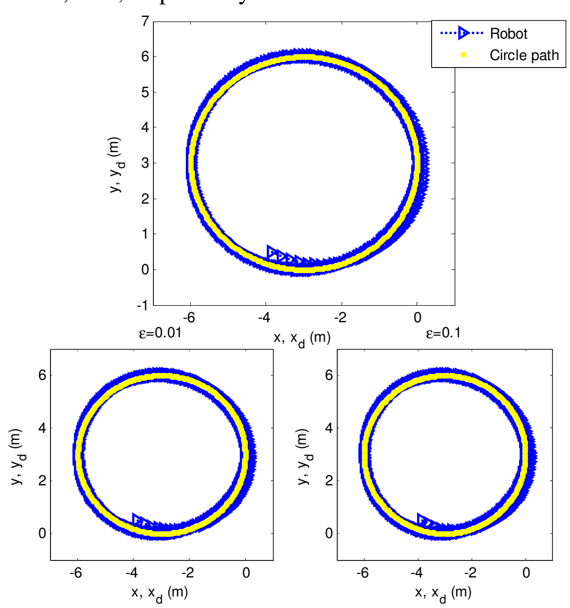

Fig. 1. The robot tracking a circle path.

V. CONCLUSION

This paper presented a teaching mode of multi-disciplinary integration. It took a robot design example to show how to integrate multidisciplinary in teaching. It applied physics, mathematics, control theory, computer technology to design controls for a robot.

In future, we should implement the construction concept of new engineering, rely on the self-developed teaching platform, and create a new talent teaching mode and curriculum system, which provides a systematic teaching reform for students' training.

ACKNOWLEDGMENT

This work was supported by Teaching Reform and Research Project of Taishang University in 2021: Research on Constructing the Information-Based Teaching Mode and Course System of the Information and Computing Science Speciality.

REFERENCES

[1] M. Ge, Y. Du, and J. Liu, "Exploration and practice of big project practice platform under multi-disciplinary integration. Science," *Technology and Innovation*, vol. 23, pp. 10-12, 2021.
[2] Q. Zhang, "Resource breaking and integration under the background of subject integration teaching," *Educational Theory and Practice*, vol. 41, no. 32, pp. 51-54, 2021.
[3] J. Zhang, S. Wang, M. Li, and R. Wang, "Exploration on innovation and entrepreneurship practical education of information management and information system specialty," *Computer Education*, vol. 9, pp. 77-80, 2021.
[4] D. Xu and T. Pan, "Research and Practice on multi-dimensional teaching model of motion control course group," *Science and Education Guide*, vol. 26, pp. 110-112, 2021.
[5] L. Li, L. Zheng, F. Ma, and N. Xu, "Research on the construction of practical teaching system of robot engineering specialty based on the integration of industry and education," *Research on Higher Engineering Education*, vol. 4, pp. 88-92, 2021.
[6] J. Lei, P.-J. Ju, and J.-Q. Song, "Modeling and optimal control for WMR systems with control delay," *Integrated Ferroelectrics*, vol. 207, pp. 138-147, 2020.
[7] X.-L. Bai and J. Lei, "Active suspension control by output feedback through extended high-gain observers." *Ferroelectrics*, vol. 548, pp. 185-200, 2019.

Jing Lei received the B.S., M.S., and Ph.D. degrees in Information Science and Engineering from Ocean University of China, in 2003, 2007, and 2010, respectively. She is a professor at Taishan University. Her research interests include control theory and application, computer application technology. Email: elizabethia@126.com.

Jia-Qing Song received the Bachelor of Economics from Shanghai University of International Business and Economics in 1991. He is an experimenter in Taishan University. His research interests include simulation experiment. Email: jiaqing_song@126.com.