Study on the Coherent Course Project for Robot Engineering Major

Wende Ke*, Yongsheng Ma, Yiming Rong, Dong Lu, Chengzhi Hu, and Yexu Huang

Department of Mechanical and Energy Engineering, Southern University of Science and Technology, Shenzhen, China
*Correspondence: kewd@sustech.edu.cn (W.K.)

***Abstract*—Robot engineering is a newly approved engineering major in China in recent years, and its talent training focuses on whether students have the ability to analyze problems, be innovative and solve real problems in the robot. This paper describes the necessity of using coherent course project to test what students have learned, how to design the coherent course project and analyze its implementation. Three courses – Robot Modeling and Control, Embedded System and Robot, and Robot Operating System were taken as examples to illustrate in more detail. At the same time, we also discuss the difficulties when dealing with course projects. The efforts we tried in it proved that the coherent course project really help students to learn and use certain technologies positively. In fact, we believe that the designs of coherent course projects we have carried out and what we have experienced can truly be taken as useful references for those related majors in universities.**

***Keywords*—coherence, course, project, innovation, practice**

I. Introduction

The technology research and development in the robot field, the manufacturing and usage with robots in the industrial application show a country's level in high-end scientific and technological innovation. In order to promote the continuous development of robot technology, China's Ministry of Industry and Information Technology, the National Development and Reform Commission and other fifteen departments officially issued the "Fourteenth Five-Year Plan of Robot Industry Development [1], proposed the goal of "by 2025, China will become the source of global robotics technology innovation, high-end manufacturing cluster and new highland of integrated application", and the requirements of "supporting universities and research institutes to cultivate professional and complex high-end talents".

Colleges and universities are undertaking the task of frontier exploration and high-end talent training when driving the robot technology innovation and development. The specialty of robot engineering has an important mission in teaching, practice, innovation and entrepreneurship, localization and internationalization in our new engineering education. It promotes the continuous progress of science and technology in China by cultivating outstanding engineering talents [2–4]. In combination with the development trend of robot technology, since 2016, China's Ministry of Education has approved the robotics engineering major (code: 080803T) as a new undergraduate major, and announced 323 undergraduate universities that have launched this major [5]. In response to it, many colleges and universities have carried out talent training in robot engineering education and achieved relevant results [6–8].

Since its approval in 2019, the major of robot engineering in the Department of Mechanical and Energy Engineering of Southern University of Science and Technology aims to cultivate leading talents who have a solid scientific foundation, excellent innovation and practice ability and broad international vision. The students are trained to comprehensively apply the theories and methods of robots and related disciplines and solve major scientific problems and engineering challenges in the future. They will also serve the emerging frontier scientific and technological fields, meeting the requirement of future demand in cutting-edge technologies and basic industries. Therefore, how to improve students' cognitive level, practical innovation ability, forward-looking ability in industry development, and the ability of problem analysis and solving, has become the problem that must be faced in talent training. By analyzing the course features of robot engineering, such as its continuity of knowledge, the course project evaluation method for students was designed.

II. Features of Coherent Course Project of Robot Engineering

Robots are the combination of multiple disciplines, involving mechanics, materials, automation, computer science, electronics, sensor, image processing, artificial intelligence, bionics and other fields. The robot engineering major is composed of general courses, professional basic courses, professional core courses and professional elective courses. The general courses mainly include general compulsory courses and general elective courses. For example, the compulsory courses cover advanced mathematics, probability and mathematical statistics, linear algebra, advanced physics, computer programming, etc., which is the basis of the engineering. The elective courses include analog circuits, digital circuits, ordinary differential equations, etc. The above

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required courses and elective courses lay a good foundation for students' mathematical analysis ability and certain engineering application ability in their engineering studies.

In the stage of professional basic courses, students will come to learn "major-closer" courses, such as Fundamentals of Mechanical Design, CAD and Engineering Drawing, Manufacturing Engineering Cognitive Practice, Theoretical Mechanics, Material Mechanics, etc. These courses provide support for the fields related to materials and mechanics. As the following course of Digital Electrical and Analog Electronics, the Fundamental of Circuits supports the fields of automation control. At this stage, the student's learning scope is narrowed appropriately, with certain focus, and his professional depth is increased. Now students are ready to enter the basic scope of major, and prepare for the study of core professional courses.

The major core courses cover the common and key knowledge in the field of robot, involving robot modeling and control, pattern recognition, machine learning, engineering machine learning foundation, cooperative robot learning, sensors and actuators, robot drive system, embedded system and robot, etc., from the fundamental knowledge (i.e., motion planning) to the superior one (i.e., visual image recognition, machine learning, human-computer interface, intelligent control, coordination and cooperation, etc.). At this stage, students will further understand the features of robot system and prepare for focus on one field.

Professional elective courses, with the definite direction and certain scientific research goal, are closely related to the teachers' own scientific research. These courses show the progressiveness and research frontier of the robotic. For example, the Micro Robot mainly describes the research methods and achievements about micro/nano robots and human capsule robots; the Soft Robot mainly describes how to make robots with intelligent materials, such as dielectric elastomer, ionic polymer metal composite, shape memory alloy, shape memory polymer, etc., in which their motion features are analyzed and their motions are controlled through light, heat, gas, magnetism, flow, etc.; the course of walking robot mainly describes the motion control methods for single legged, bipedal, quadruped and multi legged robots; the Autonomous Robot system mainly describes the robot multi-agent technology, such as BDI (Belief, Desire, Intention) related models, involving stress, planning, decision-making, communication, conflict resolution, etc.; the Robot Operating System mainly describes the stable real-time communication mode of multi node robot, and how to apply in the fields of unmanned vehicles and mechanical arms. In this learning stage, Students gradually enter the certain definite field and carry out more in-depth frontier research.

In general, the major of robot engineering takes the basic courses (especially the mathematics and electricity) as the analysis means, the professional basic courses and professional compulsory courses as the overall system, and provides students with appropriate choices and guidance for the follow-up study and research through the professional elective courses, which reflects the good connectivity of the main learning line and the completeness of the knowledge system.

III. The Necessity of Implementing the Coherent Course Project

A. Features and Requirements of Robot Engineering

We know the tight connection between theoretical knowledge and practical innovation of robot engineering. After entering the stage of basic course, students will master both the theoretical analysis, modeling and parameter calculation, and robot experiments and practical innovation. Taking the basic course Mechanical Design as an example, its learning content covers plane, connecting rod, gear train, transmission, bearing, spring, etc. So it not only assesses students' theoretical analysis, calculation ability and drawing ability, but also requires students to be able to model and calculate stability and stress conditions through tools such as SolidWorks, Finite Element Analysis etc. Furthermore, according to robot design goals, students shall conduct machining and assembly tests in the form of engineering drawings, and complete the robot prototype with specific requirements. In fact, this process is only the part of robot structure design. Subsequent courses such as motor control and intelligent control also put forward higher requirements for students' practical ability.

B. Requirements for Innovation

The professional theoretical courses are helpful in analyzing the mathematical, physical basis and motion characteristics of robots. In terms of practical engineering science research problems, we shall coordinate with practice and innovation issues. The cultivation of practical innovation ability comes from the combination of theoretical knowledge, brainstorming and the whole process implementation of the project. Theoretical knowledge we hold indicates the feasibility of the research direction, though the brainstorm helps to establish new functions and technical routes, and the whole process implementation of the project implementation. So it is obvious that the coherent course project comprehensively reflects the teaching content of the corresponding course, and fully verifies the students' understanding and application ability of the knowledge of the course by building a project goal that is suitable for the certain application needs.

C. Support for Teachers' Scientific Research

When teaching professional elective courses, it is necessary for instructors to relate their scientific research and research results. The appropriate instructors should be professional industry experts who have worked many years in the robot field. With their experiments and achievements, these instructors have deep understanding and forward-looking ability of the current situation and development trend of the robot industry. They are good at combining basic professional knowledge and hot issues with the industry research, and are able to give various

kinds of knowledge involved in the professional courses. Taking the course Micro Robot in SUSTECH as an example, the robot body is small in size and light in weight, and the motion control forms are mainly electromagnetic, micro propeller driven, wing flapping, plane vibration, etc. The course instructors have made remarkable research achievements in this subdivision field and are able to setup the projects that are highly targeted and effective to this course. Besides these, some necessary research platforms and tools can be provided in their research laboratories, which is conducive to students to develop course projects and achieve valuable results.

IV. Evaluation of Coherent Course Project

Although the scores of the final paper-based examination can measure what students learn, that is more important for them to really master the course by doing projects, which asks for whether they are excellent enough to analyze and solve problems in the robot industry. In fact, curriculum project included in one course means that students need to carry out a lot of research and development work in practice and innovation. So, at this time, if the final paper-based examination is added, it will inevitably increase their learning pressure, which is not conducive to students' dedication. Therefore, the examination needs to be adjusted. Based on this, students' final scores consist of experimental scores, homework scores, attendance scores, and course project scores, among which the proportion of the course project scores should be up to 60% or even more to highlight its necessity.

When formulating the curriculum project, it is recommended to set a higher goal that is full of workload but close to the course. That is to say, some difficulties and complexities in the project are necessary. Most professional principles to achieve this goal come from the course itself (for example, 70–80%), and the rest comes from instructors' own research and cutting-edge progress (for example, 20–30%). The purpose is to promote students' enthusiasm and initiative, evaluate their mastery of the course, improve their practical understanding of application and significance of the knowledge in practice and innovation, and help them to pay more attention to the research progress involved in the course.

When releasing the project requirements, the instructors should divide the general goal into subordinate goals, assign them with appropriate scores. For example, the main goal of the course Robot Modeling and Control project is to design a micro manipulator. No matter what scene the robot is applied to, its subordinate goals include: (1) derivation of forward and inverse kinematics equations (15%); (2) dynamic equation derivation and joint force transmission (15%); (3) mechanical structure design of robot (20%); (4) using MatLab to simulate and calculate kinematics, dynamics and trajectory planning (20%); (5) Arduino based robot motion control (30%). For each subordinate goal, further scoring and subdivision are also made if necessary. For example, in "Arduino based control of robot motion (30%)", the subdivision goal include: (1) smoothness of motion trajectory (25%); (2) damping effect of robot (25%); (3) target clamping and placement accuracy (25%); (4) work efficiency (25%). This arrangement from top to bottom helps to guide students to gradually complete and optimize the work in more detail. In the project defense, students are required to demonstrate the ideas, simulation data, methods and prototypes. In the delivery stage, they will be requested to submit project reports, prototypes, source codes, slides, photos, videos and other materials.

V. Implementation of Coherent Course Projects

A. Accuracy

In the major of robot engineering, the main teaching line of the course content are based on the professional talent training plan, reflecting the teaching progressive forward and backward, close connection and gradual deepening in courses. Each course project should be fully considered with its prerequisite courses and follow-up courses, and is limited to the scope of teaching topics on the basis of consistency. Although the similar contents in project are permitted, it shall be appropriate and not to be excessive, for it will reduce the learning effect for students. Therefore, the relevant instructors should fully communicate with each other before the designing course project, mainly focus on what have been mentioned in courses while determining topics, and try to avoid excessive involvement in different courses.

B. Accumulation for Next Projects

When the course project is over, there are some necessary steps to handle. For example, the scores shall be fed back to the students; the robot prototype with clever ideas will be kept for both the demonstration and prepared for the next course project; other robot prototypes will be disassembled and all kinds of consumables, accessories and related tools will be kept for storage indexed by category for reuse next time; the project documents, slides, photos and videos, reports will be kept too, which will be helpful for the next round of projects and make iteration of robot design.

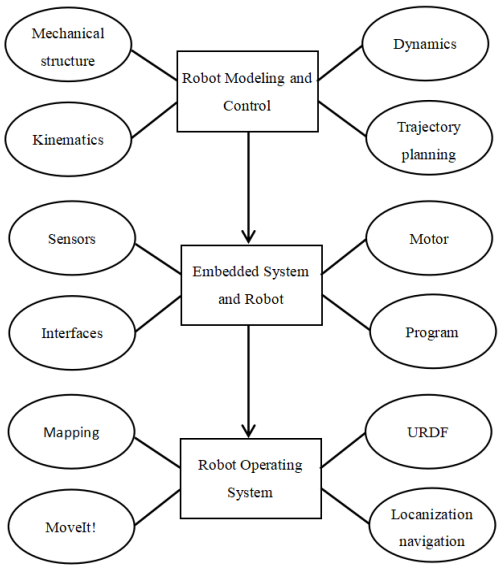

Figure 1. Relations among coherent course projects.

C. Cases of Course Projects

Take three courses – Robot Modeling and Control, Embedded System and Robot, and Robot Operating System as examples. In terms of the coherent course projects, the course project of Robot Modeling and Control focuses on kinematics, dynamics and path planning, the course project of Embedded System and Robot focuses on embedded programming control, and the course project of Robot Operating System focuses on indoor positioning navigation and mechanical arm operation. These three courses show the clear continuity of the learning process for students. The relations among these course projects are shown in Fig. 1.

In the course Robot Modeling and Control, students are requested to build a micro mechanical arm. Based on what they have learned in class about the mechanical structure, kinematics, dynamics, trajectory planning, etc., students develop the mechanical arm, through brainstorm for functions such as stacking, sorting, loading and unloading, and clamping, and determine whether it is suitable for industrial production lines, airport baggage consignment, nucleic acid sampling, garbage automatic classification etc. So maybe four degree of freedom handling robots, six degree of freedom nucleic acid sampling robots, production line sorting robots, parallel robots, etc., are selected and designed. Then the structural morphology, deduction of kinematics and dynamic equations are carried out. Students will select step motors with reducers and/or servo motors as joint control motors, and use MatLab for path planning calculation and analysis. Some specific robot prototypes are made. In order to achieve simple control operation, they use the Arduino for motor control. This development board is easy for those beginners to learn, but its main frequency is low at 16MHz.

The course project of Embedded System and Robot covers clock management, interrupt, timer, serial communication, AD (analog to digital conversion), DA (digital to analog conversion), etc. STM32F767 is the preferred controller. As an industrial level controller, its main frequency of is high at 216MHz, with stable performance, powerful functions, and numerous interfaces. For Differential driving vehicles, their software is developed based on HAL (Hardware Abstract Layer) library in C language. Their hardware involves ultrasonic sensor, infrared sensor, color sensor, DC reduction motor, etc. The vehicles are mostly amounted with mechanical arms and wheeled trolleys. In fact, the micro mechanical arms have been made in the course Robot Modeling and Control. As the four-wheel differential structure, the trolleys are easy to assemble. It can be realized by using acrylic plates equipped with DC reduction motors. The appropriate sensors are selected. What the students need to do next is to write programs for controlling the mechanical arm, operate the vehicles according to the predetermined motion track, or control the vehicles to automatically track the black line on the ground through photoelectric sensors and color sensors.

The course project of Robot Operating System mainly focuses on the localization and navigation of vehicle combing with mechanical arm. The small industrial personal computer is installed with the Ubuntu 18.04 and Melodic operating system platform. So the system allows to use USB (Universal Serial Bus) with CAN (Controller Area Network, Area Network Controller) and control the motor in the primary control mode. Sometimes students will use both STM32 embedded control board and computer altogether. In design stage, students compile robot simulation model based on URDF (Unified Robot Description Format) language, build map for localization and navigation in Rviz and Gazebo simultaneously, and control the motion of the manipulator in the MoveIt simulation environment. After the simulation verification, the model will be migrated to the real robot with appropriate setting of joints, linear velocities and angular velocities. The parameters of collision, friction and inertial are used to build the indoor environment map by two-dimensional lidar that helps to achieve the path planning and collision free movement from the starting point to the goal position. When in goal position, the mechanical arm mounted on vehicle is able to grab items and place them at the expected position.

So it is obvious from the above three course projects we can arrange the main line for these three courses. The robot mechanical structure is the basis of the embedded control and the latter is another basis of indoor localization and navigation. These arrangements definitely help students focus on every stage of consequent courses step by step, in which the coherent main line shows the inner connectivity between courses.

VI. Conclusion

In the past three years, we have made progress in the coherent course projects of robot engineering major as follows:

(1) In the coherent course projects, some prototypes (mechanical arm, robot with feet, bionic multi-finger hand, underwater robot, micro nano robot, soft robot, etc.) have been created, and students' research papers (such as IROS-IEEE/RSJ, International Conference on Intelligent Robots and Systems, etc.) have been published. Furthermore, based on these prototypes, some students have won First Prizes in International Underwater Robot Competition, RoboCom International Robot Developer Competition, IEEE Software Robot International Competition Mobile Robot Project, China Robotics and Artificial Intelligence Competition, etc.

(2) The coherent course projects are helpful for students to understand professional knowledge and explore robotics deeply, improve the innovation ability and practical skills, consider carefully about their potential research direction and pay more attention to the development of robotics.

(3) The coherent course projects are as the start for students to carry out practical design and innovative activities. With the guidance of teachers, they may enter the scientific research earlier, with interest in hot fields and key technologies of robotics. Even they have the opportunities to participate in some advanced research

missions, and exchange and cooperate with global research teams.

At the same time, when carrying out the coherent course project, the following aspects shall be paid attention:

A. How to Ensure "The Excellence for Erveryone" in Class with Many Students

At present, the student amount is less than 40 in class, which makes it flexible for face-to-face communication. As the student amount increases in class, the communication time with everyone will be reduced definitely. So how to make students get high quality in class is the primary challenge that we have to face. Maybe we need to plan carefully, get more assistance and arrange tasks precisely.

B. Start as Early as Possible

Due to the busy research and development tasks in course projects, students are forced to spend almost all of their free time, especially before the final defense at the end of the semester. So it is suggested to arrange course projects as early as possible in the semester (such as the fourth week or earlier), which ensures that students have enough developing time.

C. Financial Support

In the development of course project, many kinds of consumables are required. Perhaps it will cost much. It is suggested to prepare a budget plan in more detail, and reuse those consumables for saving money.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Wende Ke, Yongsheng Ma, Yiming Rong, Dong Lu, Chengzhi Hu, Yexu Huang conducted the research; Wende Ke wrote the paper; all authors had approved the final version.

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