Academic Education Publishing House
Higher Education and Practice Vol. 1 No. 5, 2024

Teaching Reformation and Practice of "Robot Operating System" Course Based on "Major-Ideology-Creativity-Research-Application"

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Abstract: The integrated education model of major and innovation integration aims to cultivate students who not only master the latest technologies but also apply and effectively transform them, in order to meet new quality productivity for compound and innovative talents. Therefore, in order to cultivate the innovation ability of students majoring in new engineering, the teachers have determined the reformation idea of "Major-ideology-innovation-research-application" in the practice of teaching reformation of the "Robot Operating System" course. Through optimizing the knowledge system, deepening ideological and political elements, cultivating innovative thinking, promoting innovative achievements, and researching experimental devices, a closed-loop innovative talent training model has been formed. To further promote the reformation of new engineering curriculum teaching, we are committed to cultivating outstanding engineering and technological talents with patriotism, global vision, innovative spirit, and practical ability, and serving the development of new quality productivity with high-quality talent cultivation as the main force. Experiments illustrate that this innovation provides useful exploration for teaching revolution of the integration of specialized and creative education, and can be referenced by other professional courses.

Keywords: Major Innovation Integration; Robots; Course Ideology and Politics; Innovation Ability; Submerged Learning and Training

1. Introduction

The report from the 20th Party Congress emphasized the need to deeply implement strategies for national development through science, education, talent enhancement, and innovation-driven growth. Innovation serves as the driving force of our era, while entrepreneurship forms the foundation of progress. As pivotal centers for talent development, colleges and universities play a critical role by integrating the essential elements of technology, talent, and innovation. To meet the growing demand for multidisciplinary and innovative talent, these institutions must actively pursue reforms in innovation and entrepreneurship education. Within this framework, enhancing the teaching and learning capabilities in new engineering disciplines is especially crucial.

Robotics technology has become a key logo of technological innovation of one nation. Robots can be divided in to different classes according to specific applications, such as industrial, service, agricultural, and underwater robots, etc. To manage the diverse hardware resources across these different types, a unified software platform is essential for supporting the development and management of robotic applications. This need led to the creation of the Robot Operating System (ROS). ROS, an open-source system, has obtained widespread recognition and adoption among researchers globally. Many universities, both domestic and international, have integrated ROS into their curricula and practical training programs. For students specializing in robotics, mastering ROS is crucial, as it allows them to apply theoretical knowledge to real-world systems, making it an indispensable tool in robotics development. ROS provides essential functionalities similar to traditional operating systems, such as hardware abstraction, device control, execution of common functions, inter-process communication, and package management. Additionally, ROS offers tools and libraries for writing, compiling, and running code across multiple computers. It covers nearly every aspect of robotics, from controlling motors and sensors at the hardware level to managing high-level robotic motion. Therefore, the course on "Robot Operating System" plays a significant role in the curriculum of robotics engineering programs.

Since the beginning of this course in our university from 2021, the course has faced several key challenges:

(1) the curriculum has not adequately fostered innovative awareness, thinking, and problem-solving abilities of students, particularly in integrating these skills with their engineering expertise. This has limited their capacity to effectively apply innovative thinking to solve engineering problems.

(2) Robotics engineering, as a highly interdisciplinary and collaborative field, still relies on traditional teaching resources. There is a shortage of high-quality experiments, timely courses, and supporting platforms that align with the demands of this new discipline. Although our university began admitting students to the robotics engineering program in 2020, we have yet to establish a comprehensive experimental platform to complement the "Robot Operating System" course, limiting opportunities of students for hands-on practice.

(3) Sophomores often lack foundational knowledge in mechanical design, automation control, and sensors, leading to anxiety and apprehension when tackling topics like motion planning.

To address these issues, the course team has spent the past three years developing a teaching approach driven by innovation and supported by practical outcomes. This approach focuses on five key dimensions to cultivate abilities of students in specialized knowledge, critical thinking, creativity, research, and application, ultimately enhancing the overall quality of talent development in the field of new engineering.

2. General Guidelines

Based on the initial teaching experiences of the "Robot Operating System" course, the course team developed a teaching approach centered on "Driven by innovation, enriched by achievements". This approach emphasizes explaining concisely and plenty of practice, integration of ideological education, and the promotion of Submerged learning and training. By encouraging the accumulation of innovative results and the development of self-designed experimental devices, the team established a comprehensive, closed-loop teaching system that integrates specialized knowledge, critical thinking, creativity, research, and practical application, as illustrated in **Fig. 1**.

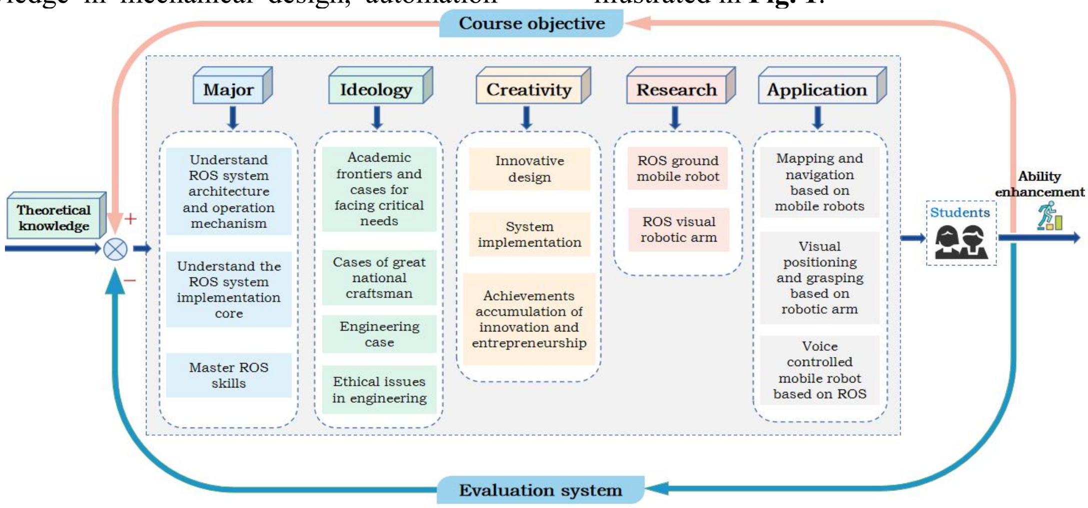

Figure 1. Closed-Loop Teaching System of "Major-Ideology-Creativity-Research-Application"

3. Student Analysis

This course is designed for sophomores majoring in robotics engineering and is offered in the fourth semester. It consists of 32 class hours, without any dedicated lab sessions. A preliminary assessment of the students revealed the following:

(1) the students possess a solid foundation in mathematics and have developed logical reasoning and programming skills through courses in C++ and Python. This has prepared them to write basic algorithmic code, providing a strong practical base for the course.

However, over 80% of the students lack experience in robot design.
(2) About 10% of the students have gained a basic understanding of ROS through innovation training activities. They have used microcontrollers for programming in robotics competitions, their knowledge of higher-level robot algorithms is limited. Nevertheless, they show significant interest in ROS and are eager to apply what they learn in this course to future robotics innovation competitions.
(3) Students are aware that the course will culminate in the independent design of a robot model based on their ideas. This has generated considerable interest, with many hoping to gain valuable skills and knowledge through the course.

4. Teaching Reform and Practice

The teaching objectives of the ROS Robot Operating System course focus on three key aspects: principles, technology, and application. the principles involve understanding the architecture of ROS system and its operational mechanisms. the technology aspect covers the core implementation of the ROS system, while the application focuses on acquiring practical ROS skills. These three components are interconnected and mutually reinforcing.
To address challenges in teaching the ROS course and to meet the demands of new engineering talent development, we have undertaken a curriculum reform that emphasizes practical, interdisciplinary, and sustainable design. the main elements of this reform include: ① Integrating practical exercises with theoretical content to enhance the course's applicability. ② Extending the scope of instructional content to foster students' innovative thinking and abilities. ③ Ensuring the sustainability of the course by aligning it with the goals of fostering innovation and entrepreneurship.

4.1 Knowledge hierarchy

The introduction provides an overview of the development of robotics, highlighting the evolution of ROS and its implications for the future of robotic intelligence. It also discusses the challenging beginnings of Chinese robotics industry and its rapid technological advancements, incorporating elements of patriotic education to inspire students' sense of national pride, mission, and responsibility. Following this, the course introduces ROS, guiding students through its installation, configuration, and hands-on practice. Chapters 2 to 7 cover the ROS architecture, communication framework, commonly used simulation tools, and programming examples in roscpp and rospy, along with important considerations. Chapter 8 explains coordinate transformations (TF) and the unified robot description format (URDF). Chapter 9 explores the fundamentals of SLAM, including key algorithms like Gmapping and Hector SLAM, etc. Chapter 10 discusses Adaptive Monte Carlo Localization (AMCL) method and the basic principles of navigation. Each of these ten chapters integrates practical exercises with theoretical knowledge, accompanied by periodic tests and design assignments to ensure that the course objectives are met.

4.2 Ideological and Political Elements

"Robot Operating System" is a course combining of theory and practice, which needs to deeply explore the resources of ideological and political education, and incorporate them into both theory and practice in a "Moisten things silently" way. Therefore, the teaching team combined with the characteristics of the new engineering courses after careful reading and organizing, deeply excavated the ideological and political elements in the course, from "academic frontiers and major demand-oriented cases", "cases of great national craftsmen", "engineering cases" and "ethical issues in engineering" are integrated into the teaching.
(1) **Cutting-Edge Research and Real-world Applications:** This section illustrates the transformative impact of robotics on modern life by highlighting global innovations, particularly those that have significantly altered or even revolutionized our ways of living and working. the discussion focuses on ten current frontiers in robotics, including embodied intelligence with vertical large models, humanoid and quadruped biomimetic robots, 3D perception models and multimodal information fusion, new core components and dexterous manipulation, brain-computer interfaces, integrated myoelectric and micro-nano robots, medical and rehabilitation robots, commercial service robots, robot operating systems/cloud platforms, swarm robotics, and

robots designed for specialized scenarios such as military, firefighting, agriculture, nuclear industries, and space exploration. In addition, the course covers key developments in soft artificial muscles, intelligent skins, brain cognition, knowledge graphs, and collaborative robotics. To deepen students' interest and sense of purpose in the field of robotics, the section also addresses national strategic needs and critical challenges, using case studies to instill confidence and bolster their courage and determination to overcome obstacles.

(2) **Example of the deeds of a great national craftsman: the** typical deeds of academician Jiang Xinsong, a "great national craftsman", was introduced into the classroom. Academician Jiang is known as the "Father of Chinese Robotics" for his pioneering contributions in the field of robotics in China. Now, Chinese artificial intelligence industry is still "thirsty for talents", and continues to call for "great national craftsmen". the spirit of excellence and hardworking behind "craftsmanship" still needs to be recognized, and even in the era of artificial intelligence, all industries still need this spirit to inspire generations of robotics researchers to love their jobs and create excellence.

(3) **Engineering cases:** Firstly, we will list the cases in the history of Chinese robots, such as the "Wooden Taurus" in the Romance of the Three Kingdoms, the service robot "Haibao" in the World Expo, the manned submersible "Jiao Long", and various robots in the 2022 Beijing Winter Olympics, so that students can understand the inventions and achievements in the field of robotics in ancient China and modern China. the "Jiao Long" manned submersible and the various robots for the 2022 Beijing Winter Olympics will enable students to understand the inventions and achievements in the field of robotics in ancient China and modern China. Taking the snake robot and rehabilitation robot developed by the academic group as examples, we will introduce the key issues and technical difficulties in system design, sensor selection, upper layer algorithm design, and system debugging of robotics projects in the actual engineering field, so that students can have a systematic engineering understanding of the project development, and at the same time, they can understand the importance of the teamwork spirit.

(4) **Ethical Issues in Engineering:** This section introduces students to the ethical complexities surrounding robotics by exploring the "Three Laws of Robotics", their definitions, classifications, and applications, as well as future developments in the field. It highlights the interdisciplinary connections between robotics and fields such as mechanical engineering, control systems, computer science, electronics, artificial intelligence, and ethics. As robots are endowed with more human-like characteristics, they bring significant ethical challenges, including job displacement, privacy concerns, safety and liability issues, and biases and discrimination. Balancing the benefits of automation with the ethical dilemmas it presents is a complex task that requires collaboration among technologists, policymakers, ethicists, and society at large. Students should recognize the immense potential of AI-driven robots while maintaining a strong commitment to ethical standards, ensuring that robotics serve humanity positively rather than causing harm.

4.3 Submerged Learning and Training

To cultivate innovative thinking of students, the instructor assigned a robot model design project at the beginning of the course. Students were encouraged to gradually develop their ideas for a robot model as they progressed through the lectures. After learning about URDF robot model design, simulation, localization, and navigation, students were tasked with designing their robot models based on their own innovative concepts or the requirements of upcoming competitions they plan to enter. This approach aimed to enhance their engagement and learning outcomes. the project further included tasks such as environment modeling and mapping for navigation. At the end of the semester, students were required to submit a report, along with a video of their robot in action and the associated code. the report had to highlight the inspiration behind their design and reflect on their experiences and learning outcomes from the project. Below are examples of designs from four students.

(1) the lunar rover in **Fig. 2** refers to the three-legged Jinwu in Chinese mythology, which is the name of the god bird that drives the solar rover in ancient Chinese myths, and the three

wheels represent the three legs of the Jinwu, with a universal wheel in front to control the direction, so the choice of the three-legged Jinwu as a reference expresses the students' good wishes for the development of the country, the school and the college.

Figure 2. Lunar Rover Robot

(2) the robot in **Fig. 3** is designed with reference to the appearance of the Mars rover, and the body is rectangular, equipped with three wheels mounted under the chassis of the trolley, of which the first two wheels are the active wheels responsible for movement and steering, and the wheel at the end is mainly responsible for balancing the body. the wheels can rotate infinitely around a single axis. There is a "solar panel" on the left and right sides. the top is equipped with a camera.

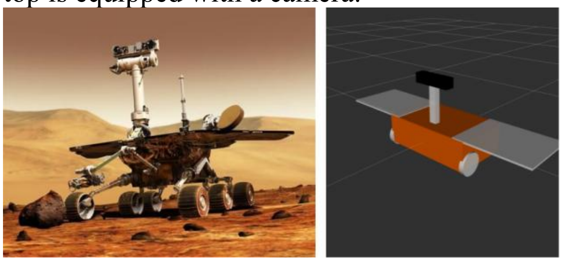

Figure 3. Mars Rover Robot

(3) In **Fig. 4**, the robot is designed referred to the appearance of a three-winged fighter aircraft, with a columnar fuselage formed by the crossing of two rectangular bodies, equipped with a three-layer structure of the front wing and a two-layer structure of the tail. the front wing is responsible for movement, and the tail is mainly responsible for balancing the fuselage. Two wheels are mounted under the front wing, which can rotate around a single axis, and a LiDAR and a camera are fixed on the nose for mapping and obstacle avoidance.

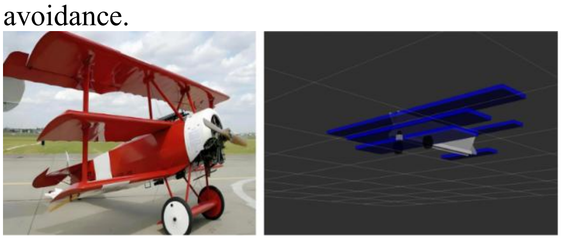

Figure 4. Three-Winged Fighter Aircraft

(4) the robot in **Fig. 5** is designed referred to KUSA Tech unmanned sweeper. the four wheels are Mecanum wheels, allowing the robot to achieve omnidirectional motion. the sensor part includes LiDAR and IMU.

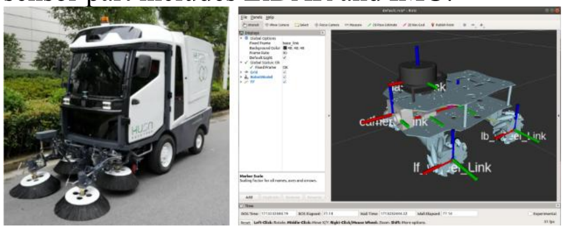

Figure 5. Cleaning Robot

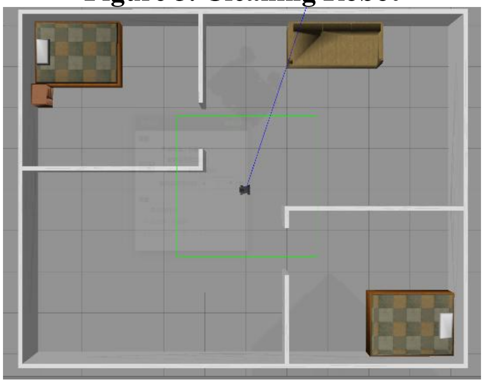

Figure 6. Simulation Environment Built in Gazebo

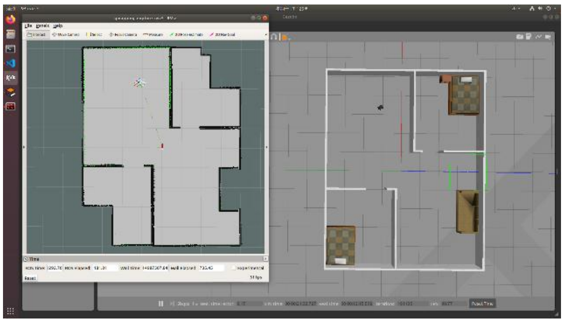

Figure 7. Autonomous Mapping

Students are also required to realize the robot's motion, mapping and navigation functions based on the model. **Fig. 6** and **Fig. 7** give the simulation of the Gazebo environment building and the effect of autonomous map building from the designer's report in **Fig. 5.**

According to the template of homework, students are required to express their experience completing the homework. These reflections reveal that students can independently researched extensive references and foundational code from the ROS open-source community, leading to the creation of innovative robot models. They also shared the challenges faced during the design and debugging period and the solutions, emphasizing the importance of discussions with teachers and team members. From these expressions, it is obvious that the training significantly contributed to students' development of creativity, innovative skills, and teamwork. This training has laid a solid foundation for future robotics engineering courses and innovation competitions.

4.4 Innovation Achievements Promoting

The objectives of ROS course are closely aligned with the foundational requirements of various competitions, such as RoboMaster, RAICOM, China University Intelligent Robot Creative Competition, and China Robotics and Artificial Intelligence. As described in Section 3.3, the course actively guides students in designing robot models for practical applications and provides training in simulation skills. Moreover, after completing the course, students are encouraged to advance their initial designs by creating physical robot models. Outstanding projects are recommended for participation in robotics-related student innovation competitions. If selected by entrepreneurs, students may receive guidance for patent applications, with all associated costs covered by the companies. To date, students have achieved significant success in innovation competitions. And the entrepreneurial project of grade 2020 student wins the “Outstanding Project Award” and participate a project roadshow in Shenzhen. Totally, the participation rate in innovation and entrepreneurship activities among robotics engineering students exceeds 75%.

4.5 Self-Developed Equipment Accumulation

At the beginning of the establishment of robotics engineering major in our university, laboratory resources were limited. Thus, the teaching team adopted a closed-loop educational approach centered on “Major-Ideology-Creativity-Research-Application”.
They encouraged students to build on the foundation provided in the “Robot Operating System” course by developing hardware systems tailored for ROS. For example, based on the simulation of a cleaning robot presented in Fig. 5, students constructed a hardware system for a robot design competition. This system enabled functionalities such as autonomous mapping, path planning, full coverage cleaning, and real-time monitoring. Now, we have accumulated equipments, as shown in **Fig. 8**. These robots facilitate experiments in tasks like “mapping and navigation in unknown environments” and “obstacle avoidance and navigation in dynamic environments”, etc.

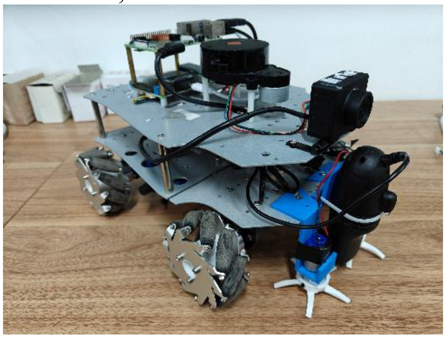

Figure 8. Autonomous Cleaning Robot

The hardware system of this cleaning robot mainly includes the cleaning robot chassis, the main control core module including STM32F407VET6 and Raspberry Pi 4B, the sensor part including LIDAR and IMU, and the cleaning module including the side brush and cleaner parts.
The software system for the autonomous cleaning robot was designed using ROS as the development platform. the mapping algorithm integrates the Gmapping algorithm learned in class with the explore-lite autonomous exploration algorithm. It also combines IMU and odometry data using an extended Kalman filter to estimate the robot's position and orientation accurately, even in complex environments. For global path planning, the system employs a “bow” shaped coverage strategy. This strategy uses a grid map of the two-dimensional environment, adjusting the map according to the robot's dimensions and assigning vitality values to each grid based on predefined rules. This approach guides the robot's movements, ensuring comprehensive coverage and minimizing redundant paths during cleaning. In addition to global planning, the cleaning robot features side brushes and a vacuum cleaner to achieve thorough cleaning. the hardware system and simulation model of the robot have been developed, and corresponding simulation test environments have been finished for both real and simulated conditions to evaluate the robot’s functionality.

5. Evaluation and Reform Effect

To assess the effectiveness of the course reform, the teaching team regularly conducts surveys during the mid-point and at the end of the course. the surveys reveal that over 90% of students find the current teaching model highly effective. They report significant improvement in practical skills, with the course providing a solid foundation for participating in technology competitions and completing their graduation projects. the alignment of teaching objectives, plans, and implementation has enhanced students' interest and abilities. Notably, the reform measures, particularly the "specialization, thinking, creativity, research, and application" framework, have significantly improved students' professional skills and entrepreneurial capabilities. the successful outcomes of this reform may also be applied to other professional course reforms.

6. Conclusion

This paper explores the course reform mode under the "major and innovation integration" approach, proposing the "Major-Ideology-Creativity-Research-Application" teaching method. This approach shifts traditional teaching concepts and methods, enhancing both teacher innovation and the overall teaching environment. It is crucial for improving the major and innovative skills of robotics of engineering students and advancing the reform and development of robotics education. Through three years of practical teaching with the "Robot Operating System" course in our university, we have found that this teaching method effectively stimulates student interest, enhances their research and practical skills, and boosts their innovative abilities. This approach lays a solid foundation for cultivating versatile talent in the field.

Acknowledgments

Funded Project: The Undergraduate Exemplary Teaching Reform Research Project of Shenyang Aerospace University (Integration of Specialization and Innovation).

References

[1] Wen Qu, Chunli Wang, Fei Chen. Reform of Teaching Content for Robot Operating Systems under the Background of New Engineering [J]. Computer Educatio, 2021, 11:42-45.
[2] Bin Gao, Zhihuai Miao, Ying Wang, Construction of robotic innovation practice course with ROS [J]. Laboratory Science. 2021, 24(5):86-89.
[3] Chunxu Hu. ROS Robot Development Practice [M]. Beijing: Mechanical Industry Press, 2018.
[4] Joseph L. Essential for Beginners to Robot Operating Systems [M]. Beijing: Mechanical Industry Press, 2021.
[5] Quigley M, Conley K, Gerkey B, et al. ROS: an open-source Robot Operating System [C], ICRA workshop on open-source software, 2009.
[6] Junhao Xiao, Huimin Lu, Xiaobo Xue, Xiaohong Xu. Integrating the Robot Operating System (ROS) into Undergraduate Practical Education [J]. Science and Technology Innovation Herald, 2016, 22:157-160.
[7] Mingxiao Sun, Xiao Wang, Jun Hu, Tiantian Luan, Pengfei Liu. Design of experimental teaching platform based on multifunctional autonomous mobile grasping robots [J]. Experimental Technology and Management, 2024, 41(4):140-145.
[8] Shuai Wang, Yunzhou Zhang, Chengdong Wu. Construction on practical course of robot operating system based on scientific research projects [J]. Experimental Technology and Management, 2019, 36:188-192.