DESIGNING AND IMPLEMENTING COMPONENTS FOR AN AUTONOMOUS RESEARCH VESSEL IN AN RDI COURSE

Amin Majd, Juha Kalliovaara, Tero Jokela, Jarkko Paavola

Turku University of Applied Sciences

ABSTRACT

A new Research, Development and Innovation (RDI) course has been developed and piloted for engineering students at Turku University of Applied Sciences. The course content is related to ongoing RDI activities in the research group for Wireless communication and cybersecurity. This paper describes the course implementation and skills learned by the students and the relation of the course to CDIO standards 5, 6 and 8. Tight RDI and teaching integration in the course ensures that the topics and concepts are relevant for the students when entering working life. It was observed that the project based group work led to improved learning outcomes.

KEYWORDS

RDI, Innovation pedagogy, engineering, teamwork, CDIO standards: 5, 6, 8

INTRODUCTION

The Turku UAS' pedagogical approach is called innovation pedagogy. Innovation pedagogy is based on the CDIO (Conceive, Design, Implement, Operate) framework Penttilä and Kontio (2016).

Innovation pedagogy is a teaching approach that emphasizes creativity, critical thinking, and problem-solving skills. The approach is characterized by a focus on real-world, hands-on learning experiences that challenge students to think outside the box and come up with creative solutions to real-world problems. Innovation pedagogy allows students to apply what they have learned in the classroom to real-world situations.

Innovation pedagogy and the CDIO framework are effective approaches to teaching that emphasize the importance of experiential learning, collaboration, creativity, and problem-solving. By using these approaches, teachers can help students develop the skills and knowledge they need to thrive in a rapidly changing world.

At Turku University of Applied Sciences (Turku UAS), we are building an autonomous research vessel. Building an autonomous vessel requires multitude of different skills and methods to apply them to real-world problems.

We are piloting a Research, Development and Innovation (RDI) course for the final year students, where the students are given tasks related to autonomous research vessel development. In the RDI course, we implement mainly the following CDIO standards:

- Standard 5: Design-Implement Experiences
- Standard 6: Engineering Workspaces
- Standard 8: Active Learning

In this paper, we describe the RDI course and the skills learned by the students. Also, how the relevant CDIO standards are fulfilled in this first implementation of the RDI course is discussed. The different levels of fulfilling the standards can be found for example in the self-assessment rubric found for example in Bennedsen, Georgsson, and Kontio (2016)

AUTONOMOUS RESEARCH VESSEL

Digitalization and increased levels of autonomy in transport can help in creating sustainable, safer, more efficient, and more reliable service chains to meet the requirements for a better quality of life and global prosperity. The enabling technologies for autonomous vessels already exist: artificial intelligence, sensor fusion and deep learning for computer vision tasks. The problem lies in how to utilize and combine these existing technologies.

The teachers have analyzed the autonomous research vessel development project and identified potential tasks for the students based on their knowledge and skills. The students form project groups and select the tasks that are most interesting for them. The students are given freedom to plan and execute the tasks as the group decides.

Autonomous vessels need to obtain accurate situational awareness to support their decision-making. The challenge in situational awareness is the lack of information about surroundings of the autonomous vessels. Object detection using computer vision in maritime environment is a very challenging task due to for example varying light, view distances, weather conditions and sea waves. No single sensor is able to guarantee sufficient reliability or accuracy in all different situations. Combining data from different sensors and by providing complementary information about the surrounding environment is one solution to provide higher accuracy.

Data annotation for object detection algorithms and the Robotic Operating System 2 (ROS2) –services used to control and collect the data from the sensors of the vessel were identified as potential topics for students. A crucial enabler for autonomous and remote controlled vessels is wireless connectivity. The connectivity solution must consist of several different wireless systems, be bidirectional, reliable, intelligent and guarantee sufficient communication link capacity for different use cases, such as observing and controlling the vessel. One student group worked on the data annotation, one on the ROS2 services, and two student groups were working on studying the operational reliability and capacity of different state-of-the-art wireless systems, such as 5G and Wi-Fi6.

RDI Course

The RDI course offers students project topics related to RDI activities within TUAS research groups. It is a 10 ECTS credit point course, offered for final year students. The projects are implemented in groups of around 5 people. The groups execute the project with weekly status and tutoring meetings with the teachers and 14 hours of group working time per week. Finally, a report on the project and the solution and results are returned. The assessment of the course is based on the report, peer-assessment of the students and teacher evaluation. In the peer-assessment the students grade the other students in the same group.

In this section the projects offered for the students of Data Networks and Cybersecurity study path are presented. We have a total of three different topics: i) wireless technologies, ii) sensoring and iii) data annotation. In total we had four student groups, two in wireless topics, and one in the other ones.

Wireless technologies

Working efficiently within a field involving wireless technologies requires several skills. Wireless technologies involve the use of radio frequencies to transmit data and information without the use of physical cables or wires. Technical expertise is important for professionals working in wireless technologies. It involves having a strong understanding of the underlying technical and physical principles and how different wireless systems operate. Computer skills are necessary, as many wireless technologies involve the use of computer systems and software, so professionals working in the field of wireless technologies should have strong computer skills, including proficiency in programming languages and experience with computer hardware and networking. Working with wireless technologies can often involve troubleshooting and problem-solving, so it is important for professionals to have strong analytical and critical thinking skills in order to identify and resolve issues.

The above skills are taught to the students in various courses during the studies, and the RDI course discussed in this paper binds them together in an engineering project spinned from real requirements stemming from active RDI projects that involve industry. Implementing wireless connectivity for an autonomous vessel involves several key steps: i) determining the connectivity requirements, ii) selecting a suitable wireless technology, iii) installing the necessary hardware on the vessel, iv) configuring the wireless connection, v) testing the wireless connection and vi) maintaining the wireless connection.

The wireless connectivity related student projects of the latest implementation of the course touch upon the selection of the wireless technology and testing the wireless connectivity tasks for the autonomous vessel developed in the research group.

In the course, one group of students was given the task to compare the performance of two modern wireless connectivity systems, 5G and Wi-Fi6 to form a base for the selection of wireless connectivity for the autonomous vessel. The group designed the measurements, set up the equipment and performed the measurements. Wi-Fi6 measurement setup in anechoic chamber is shown in Figure 1. Finally, the group produced a report of the project. The student group organized itself and had the autonomy of working procedures. The task of the teacher tutor was to provide the students with the equipment, guidance and technical knowledge on the studied

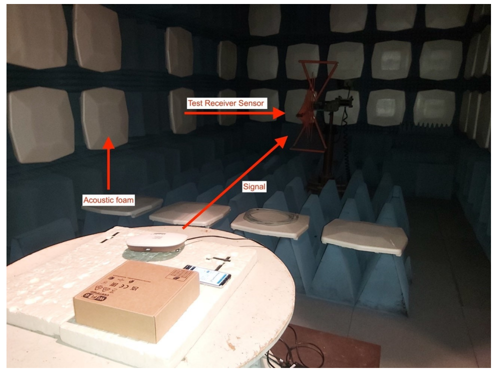

Figure 1. The anechoic chamber used in the Wi-Fi6 measurements.

systems.

The other student group was assigned the task of performing extensive 5G radio measurements in the 5G test network at TUAS[https://www.tuas.fi/en/services/products/5g-test-network-turku/]. Measurement device is shown in Figure 2. Further, the task was to enhance and develop efficient procedures for performing the measurements. From the autonomous vessel development point of view the main target was to fine tune the measurement procedures to allow for comprehensive measurements efficiently when the vessel connectivity will be studied later in marine environment.

From the projects, the teams gained further experience on hands-on measurements of radio systems, problem-solving skills, teamwork practices, analysis of the experimental data and reporting work, all of which will be useful for them in modern project-oriented work-life. Also, the research group gained knowledge from the performed projects, thus increasing collaboration between teaching and RDI activities in a natural way.

Figure 2. Measurement device for the 5G measurements.

Sensoring

The initial idea for the sensoring group project topic was to gather, process, save and visualize data from a chosen sensor of the autonomous research vessel. The group could choose the sensor from multitude of options, after which the goals for the project would be defined according to the skillset of the group. The group had a good mixture of skills in both programming and with working the physical devices.

The group decided that the first of possibly several sensors would be a Teledyne DALSA Calibir 640 thermal camera, shown in Figure 3. Thermal cameras can detect heat signatures, which makes them useful for seeing objects and people in complete darkness. This can be useful for applications such as night vision, search and rescue, and surveillance.

The project team was given access to the camera as well as a software package with an interface for the camera to store images or video as well as publish images to a topic in ROS2 system.

Figure 3. Teledyne thermal camera.

ROS2 is an open-source software framework that is used to build and control robotic systems. It is designed to support the development of complex robotics applications and provides a set of tools and libraries that make it easier to build, test, and deploy robotic systems. ROS2 provides a publish-subscribe messaging system that allows different parts of a robotic system to communicate and share data with each other.

ROS2 is designed to be modular, which means that it can be broken down into smaller, reusable components that can be easily combined and integrated into larger systems. This is ideal for creating the ROS2 modules for the autonomous research vessel, as the students can create modules for smaller parts of the system which can then be integrated into the full system.

To collect data from sensors using ROS2, the group had to do the following :

- Set up a sensor and connect it a computer running ROS2.
- Write code to read the sensor data and publish it to a specific topic in ROS2.
- Write code to subscribe to the relevant topic and receive the sensor data as it is published.

Figure 4. An example of a person detected from the thermal camera image. The confidence level of the detection is 61%. This rather low confidence level occurs due to the partial occlusion of the person.

- Use tools and libraries provided by ROS2 to process and analyze the sensor data.

Sensors can thus publish data to a specific topic, and other parts of the system can subscribe to that topic and receive the data as it is published. The thermal camera was set up to publish the data to an Image type topic, from which it could be stored in ROS bag or JPEG formats or used in real-time for object detection. A subscriber was created to use the real-time data from the thermal camera to successfully detect objects using Yolov5 algorithm. Yolov5 guide for creating/training object detection models and using them was created by the project group as a learning experience. Used Yolov5 dataset was trained on thermal camera dataset which consists of thermal images 640x480 of cars and people as a proof of concept for future use cases. Figure 4 shows an example of a person detected from the thermal camera image.

To add an RGB network camera to the vessel sensoring system, a ROS2 node to capture a Real Time Streaming Protocol (RTSP) stream and publish its frames into a ROS2 topic was developed by the students, as well as a ROS2 subscriber node that receives the published frames. This can be used for object detection and storing data from normal visible light cameras.

An inertial measurement unit (IMU) is a device that measures and reports a body's specific force, angular rate, and orientation in three-dimensional space. The IMU can thus be installed to the sensor, so that it can be used to determine the orientation, rotation and movement of the sensor. This information can be used to determine the actual location of an object detected from the sensor. ROS2 nodes for publishing the IMU data from a SparkFun u-blox NEO-M8 device, integrating IMU and GPS and Dead Reckoning Module, were programmed by the students to provide the camera sensors the IMU information. This information can be fused later to the sensor information to provide better accuracy in detections.

The IMU also reports the GPS location information, so that we know our location on the map. A Python interactive notebook using the Cartopy mapping module was written to display the location coordinates on a map, with colored terrain maps provided by Stamen. Another module, Concavity, by Mlichter2 is used to extract a concave hull of a set of coordinates to better represent the geographic area that the coordinates fall into and could in the future be used as a filter or query parameter for various Geographical Information Systems (GIS) systems.

The project work has given the students diverse tasks, which result in excellent learning outcomes in several different engineering topics:

- Experience with programming in ROS2, including writing and debugging code in languages such as Python and C++. This gives the students problem-solving skills as they worked to identify and resolve issues that arose during development.
- Learning the methodology to collect data from various sensors using ROS2, and processing and analyzing this data using ROS2 tools and methods.
- Experience on how to integrate different components of a sensor data collection and storing system into a larger system using ROS2's infrastructure for distributed systems.
- An understanding of the principles and techniques of robotics, automation and different sensors and how to apply this knowledge to the design and implementation of a sensor data collection and storing system for an autonomous research vessel.

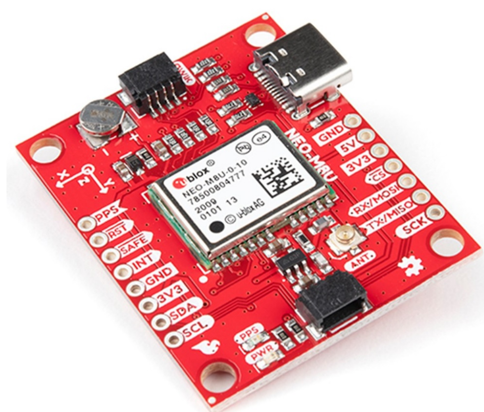

Figure 5. SparkFun u-blox NEO-M8 GPS and Dead Reckoning Module.

DATA ANNOTATION

Machine learning is used to detect or predict the behaviour of a system. There are different applications in machine learning, such as forecasting problems, object detection, natural language processing, etc. All these applications involve the following steps: 1) Collect and annotate a dataset ,2) Preprocess the dataset, 3) Choose a machine learning model and training algorithm, 4) Train the machine learning model, 5) Evaluate the performance of the model, and 6) Fine-tune the model.

The process of labelling means data annotation. In the image recognization project, data annotation is typically needed for object detection using images because it provides the model with the necessary training data to learn how to recognize and classify different objects in the images Loni et al. (2021). There are several challenges in annotating images, as annotating images can be time-consuming in large datasets Kliper-Gross, Hassner, and Wolf (2011). Also, it is critical to ensure that images are labelled consistently to avoid confusion and improve the model's accuracy, and the last challenge is that different annotators may have different interpretations of the objects.

Being a data scientist is an exciting goal for computer sciences students in their future job. With a simple search, they can find many open positions for the data scientist job, but there is a big

Figure 6. Annotated image

question here. Have students trained with the most required task for these jobs during their studies? To answer this question, we need to define what data scientists spend the most time doing Press (2016).

1. Cleaning and organizing data 60%
2. Collecting data set 19%
3. Mining data for patterns 9%
4. Refining algorithms 4%
5. Building training sets 3%
6. Others 5%

The standard university course syllabus covers Mining data, refining algorithms and building training sets (just 16% of data scientist tasks).

In the R&D course, we offered our students to do some data labeling tasks based on a semi-automatic tool to improve their skills and knowledge about the process.

The data was collected in the summer of 2022 by a research group at Turku University of Applied Sciences. The data is captured videos by two cameras for three days in Dalsbruk (Finland). In addition, the Matlab ground Truth labeller offered students to speed up their labelling process and perform it more accurately Kendler and Fishbain (2021). A group of five students worked on this project for three months, and they labelled 36 hours of videos for the idea of ship and boat detection. The labelled data has six different object categories, ships, motor boats, sailing boats, floating objects, signs, and sea marks. In this project, students worked as a team to practice more group work. During the project, they faced different challenges and learned how to keep forward an actual project as a group. In the end, the results of their works will be published at a scientific conference.

CONCLUSIONS

This paper has introduced an RDI course based on Turku UAS innovation pedagogy approach. It mainly implements CDIO standards 5, 6 and 8. Standard 5 focuses on design-implement experiences, while Standard 6 specializes more on the use of engineering learning workspaces, tools and methods to analyze and optimize engineering systems and Standard 8 focuses on active learning.

The CDIO standards are implemented in the course by providing the students with hands-on projects where they work on realistic engineering related tasks using relevant engineering tools and methods. In the projects, the students have built physical systems and prototypes, conducted wireless measurements in real networks, annotated machine learning data and developed required pieces of software to make their solutions functional. Group work promotes collaborative learning and learning from each other, as each student has slightly different talents and interests. The students also learned skills on project management and collaborating with external partners, such as personnel working in the related research and development projects at Turku UAS.

We think that the course presented itself as a successful model for increasing student engagement and learning motivation. The teamwork played a key role in this success, and we believe that this kind of learning has a positive impact on learning skills that are required for the students entering the working life in engineering field. The students of the course reported feeling supported and accountable to their peers during the process. The teamwork led to good learning outcomes as the students were able to learn from each other and benefit from diverse perspectives within the team.

A self-assessment rubric was created by the teachers of the course to evaluate students' performance in problem-solving skills, communication skills and teamwork. The students used the rubric to self-assess their own performance and provide feedback on the course. This helps identifying the areas where the students are struggling and where they might need more support from the teacher. The rubric also allows the teachers to evaluate the effectiveness of the teaching methods and adjusting them to better fit the students' needs in the future implementations of the course.

REFERENCES

Bennedsen, J., Georgsson, F., & Kontio, J. (2016). Updated rubric for self-evaluation (v. 2.1). In *The 12th International CDIO Conference* (Vol. 140).

Kendler, A. F. S., & Fishbain, B. (2021). Automated ground truth labeling for object detection. *www.mathworks.com*.

Kliper-Gross, O., Hassner, T., & Wolf, L. (2011). The action similarity labeling challenge. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, *34*(3), 615–621.

Loni, M., Zoljodi, A., Majd, A., Ahn, B. H., Daneshtalab, M., Sjödin, M., & Esmaeilzadeh, H. (2021). Faststereonet: A fast neural architecture search for improving the inference of disparity estimation on resource-limited platforms. *IEEE Transactions on Systems, Man, and Cybernetics: Systems*.

Penttilä, T., & Kontio, J. (2016). Integrating innovation pedagogy and the CDIO approach – Towards better engineering education. In *The 12th International CDIO Conference* (p. 949).

Press, G. (2016). Cleaning big data: Most time-consuming, least enjoyable data science task, survey says. *Forbes, March*, *23*, 15.

BIOGRAPHICAL INFORMATION

Amin Majd (PhD and DSc) received his first Ph.D. degree in artificial intelligence from the University of Turku, Turku, Finland, in 2019, by developing a hybrid metaheuristic optimization method and his second Ph.D. degree in computer science from Åbo Akademi University, Turku, in 2021, by developing the DIANA as safe and efficient navigation of autonomous vehicles. He is currently a Senior Advisor at Turku University of Applied Sciences, Finland, on smart swarms of autonomous vehicles with a broad background in computer science. He is professional in solving high-dimensional complex problems by applying meta-heuristic optimization methods, machine learning, deep learning, and parallel computing on the problems.

Juha Kalliovaara, PhD received the B. Eng degree from Turku University of Applied Sciences in 2008, and the M.Sc. (Tech.) and D.Sc. (Tech.) degrees in wireless communications from the University of Turku, Turku, Finland, in 2011 and 2017. He is currently a Chief Advisor at the Turku University of Applied Sciences Wireless communications and Cybersecurity research group. His research interests include 5G and 6G technologies and field trials, autonomous systems in marine environments, robotic operating system and machine learning.

Tero Jokela, PhD received the M. Sc. (Tech.) and D. Sc. (Tech.) degrees in telecommunications from the University of Turku, Finland, in 2005 and 2010 respectively. He is currently a Senior Researcher with the Turku University of Applied Sciences wireless communications and cybersecurity research group. His research interests include 5G and 6G technologies, communication algorithms, Software Defined Radio, autonomous systems and cyber security.

Jarkko Paavola received the Doctoral degree in technology in the field of wireless communications from University of Turku, Finland in 2007. He is currently a research team leader and a principal lecturer with Turku University of Applied Sciences, Turku, Finland. He also holds adjunct professor position in Åbo Akademi University. He has over 60 scientific articles from the field of wireless communications. His current research interests include autonomous systems, 5G technologies especially from the vertical end-user perspective, and cybersecurity.

Corresponding author

Amin Majd
Turku University of Applied Sciences
Dept. of Engineering and Business
Joukahaisenkatu 3, 20520 Turku
Finland amin.majd@turkuamk.fi