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Application of a self-propelled autonomous aquatic robot for environmental education

Uldis Zaimis*

Liepaja University, Institute of Science and Innovative technologies, Latvia

Abstract. Environmental protection in education poses challenges for both teachers and students due to its multidisciplinary nature, involving data acquisition, transfer, data structuring, virtual environment deployment, database access, and data protection. These complexities hinder the preparation of course assignments, and using simulations and modeling as a substitute for technical performance is not recommended for pedagogical reasons. Employing a mobile robot as a data source offers several advantages. Firstly, the data acquisition process becomes transparent, as sensor readings align with intuitively predictable values based on the robot's trajectory. Secondly, a coherent data structure is formed, connecting diverse data types such as time stamps, coordinates, and sensor readings (e.g., temperature, air and water quality, lighting, distance). Thirdly, the solution's applicability for environmental monitoring purposes can be easily demonstrated. This study proposes the development of an environmental monitoring solution that employs a self-propelled robot (driving, floating, flying) to obtain readings of environmental parameters. The proposed project solution in education provides many opportunities in data acquisition, processing, transfer, visualization and opens the field for interpretations.

1 Introduction

The ever-increasing importance of the competence approach in education at different levels (beginning, middle, professional, higher) marks new steps in the preparation of tasks and especially in the linking of individual parts of tasks, where the following parts logically form one whole and complement each other. In this work, it is intended to develop a complex solution for monitoring environmental parameters, where readings of environmental parameters are obtained on the basis of a self-propelled robot (driving, floating, flying), they are linked to GPS coordinates in an open environment or to a selected coordinate system in closed space, transferred to a remote database ("cloud") and data processing takes place there - in a virtual environment, a map is filled with information about the readings, optimal movement trajectories are calculated, warnings are developed for approaching the edge of the area, and commands are given for controlling the robot. Different project development methods allow students to demonstrate skills in areas such as mechatronics, data transmission and reception technology, electronics, information technology, programming, database management, data visualization and interpretation.
Different authors interpret the goals of competence-based education differently, for example, the authors mention the following explanation:

1) competence - ability, area of problems, phenomena that someone should manage [1];
2) competence – awareness [2];
3) competent - it is a recognized expert on a specific issue that has competence;
4) willingness - consent to do something (risk assessment), desire to contribute
(risk dissemination) [1, 3].

Elsewhere, the approach is defined differently other authors believe that "Competency-based education focuses on outcomes of learning" [4].
According to Lakstigala et al [5]: "… it should not be forgotten that the employee should regularly develop all the skills needed for work".

Many authors have already written about the applications of robotics in education. Challenges such as increasing interest in science and engineering [6], increasing multidisciplinary capabilities [7], application of ICT [8] and others are highlighted. The emergence of the digital generation requires not only functionality, but also modern data visualization [9] and interface design [10]. Participants may also be interested in related fields such as micro-positioning [11] and amateur rocketry [12].The offered example of environmental education based on robotics and cloud computing provides comprehensive assistance to course instructors and enables students to expand the skills learned in theoretical courses, useful in IT, mechatronics, data quality, mathematical statistics, data transmission and signal processing studies. and useful in study project

* Corresponding author: uldis.zaimis@liepu.lv

courses. The work developed meets the requirements of the competence approach in a modern, problem-solving-based higher education system in the technical field.

2 Methodology

2.1 The objectives to be achieved and tasks to be solved

When proposing and presenting examples of environmental education based on robotics for data mining, possible application goals can be:
1) the ability to obtain data;
2) the ability to redirect and store them on a remote server in the "cloud";
3) the ability to use them effectively.
To achieve the set goals, it is necessary to solve the following tasks:
1) ensure the operation of the data mining platform - the ability of the robot to move along certain coordinates and perform a survey of the room or area;
2) ensure continuous data flow from sensors;
3) arrange data transmission technologies;
4) configure the database on the server;
5) an essential step of cloud computing - cloud-based data processing for process management;
6) perform data visualization according to the request - in real time or after extraction.
It is desirable to formulate goals and tasks as precisely as possible, while students can choose the hypothesis and ways of achieving it (technology) according to their level of knowledge and technical capabilities.

2.2 Multidisciplinary approach

The discipline (course) of cloud computing in education often causes difficulties for teachers and students - it is determined by the multidisciplinary approach, which requires data acquisition, transfer, arrangement of data structures, placement of the executable file in a virtual environment, access to the database and a data protection solution. All this creates difficulties in the preparation of course assignments, where an additional challenge is the technical performance, which for pedagogical reasons is not recommended to be replaced by simulations and modelling.

In the proposed solution, students must complete a self-propelled robot (it can be driving, floating or flying), here it is preferable to use an existing device with installed drive and electrical engineering elements - power supply, engine, drivers and data processing and transmission device. It is also desirable to have sensors available for data acquisition.

The use of a mobile robot as a data source can be evaluated positively for several reasons. First, the data acquisition process is clearly visible - the obtained sensor readings correlate with intuitively predictable values because the trajectory of the robot is visible and in most cases the values of the readings can be predicted. Secondly, a data structure is logically formed, where data of different meanings are connected - time stamp, coordinates and readings of sensors (temperature, air quality, water quality, lighting, distance, etc.). Thirdly, the usefulness and application of the solution for environmental monitoring purposes is easily explained.

2.3 Difficulties in environmental education using robotics and cloud computing

The proposed cloud computing project idea raises several problems and complications. First, the question arises about the sensor data processing and robot control platform. Arduino family controllers or, for example, Raspberry Pi family microcomputers are widespread. If the former work immediately after power-up and are fail-safe, this operating system-based microcomputer can cause quite a few interruptions and errors in operation. Analog data acquisition will also be difficult, analog-to-digital converters (ADC) will have to be used, which complicates the installation. It is best not to use complicated sensors and USB tools (transmitter-receiver for mobile communications, high-speed GPS receiver, photo/video camera, etc.), it is better and easier to use simple controllers (Arduino, ESP, STM families, RPi Pico, etc.).

Second, the data transmission or transmission technology is important. It is always more efficient to provide data transfer for storage and visualization in real time; it is also a guarantee that some data will be preserved if something goes wrong at the end of data mining. The data transmission speed will be important here - the narrower the radio frequency band, the lower the data transmission speed and the more limited the transmission of photo/video information will be. For example, LoRa technology at a frequency of 433, 868 or 900 MHz will be able to transmit numerical information at a distance of a few kilometres with repetition once a second but will not be sufficient for video streaming. GSM or other high-speed communications with a high carrier frequency can be used there.

Thirdly, attention should be paid to the type and accuracy of the data to be obtained. For example, environmental monitoring will not require an accuracy greater than a tenth of a degree, just as the drone's flight height does not need to be measured in millimetres. Students are not always aware that transferring unreasonably accurate data and using an incorrectly selected data type not only increases the memory resources used, but also reduces the transmission speed.
Fourth, the highest level in cloud computing is to create an executable file in the "cloud" that performs calculations and controls the robot. The speed of data exchange is critical here. Not all student groups reach this level, and the best solutions can serve as examples for others.

It is recommended to use the algorithmic approach at all stages of the project implementation - study the data flow and technical characteristics, mark the necessary transformations in the characteristic points, specify the program libraries to be used for the data processing tools (there are especially many of them for the Python programming language) and agree on the visualization requirements, which often take a lot of time and resources.

3 Results

Several subsections describe a successful cloud computing project that acquires water area data from a self-propelled floating robot with automatic trajectory assignment with GPS coordinates.

3.1 Self-propelled water monitoring robot equipment

In one version (Figure 1), a home-made simple body is chosen for the water body monitoring robot, in which a power unit (lithium batteries) and an electric motor of sports models are placed, and in the second case - a ready-made boat model body, which already has engines with propellers and control drivers, it remains only connect the battery pack, sensors and transmission device.

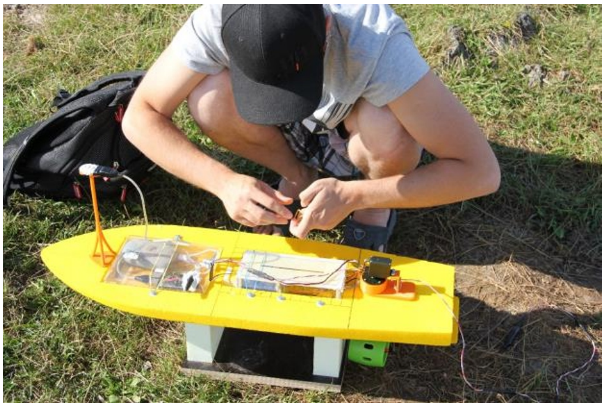

Fig. 1. Self-made boat model, equipped with propulsion and control equipment and data transmission.

Fig. 2. Industrially produced boat model, equipped with sensors and controls.

The self-propelled robot is equipped with a whole series of sensors. Table 1 describes the sensors installed on the robot, their meaning and use.

Table 1. Equipment with sensors.

Sensor	Application of the sensor
GPS	Provides vehicle positioning data points, obtains coordinates connecting each sensor for later use in 3D mapping
Sonar altimeter	Hydrological factor that affects other characteristics of the aquatic environment, such as sunlight intensity, oxygen availability, temperature, nutrient content
Hydrogen Power (pH)	Indicates the acidity or alkalinity of the environment, which affects the metabolism of hydro-ecosystems, e.g., solubility of chemical substances, rate of environmental chemical reactions, corrosivity of underwater infrastructure, physiology of invertebrate exoskeleton
Oxidation-Reduction Potential (ORP)	Shows the probability of gaining Electrons because of reduction (reducing agents) or losing electrons because of oxidation (oxidizing agents)
Temperature	An abiotic ecological factor that significantly controls the survival and comfort of organisms, and thus forms the entire ecosystem setting
Total Dissolved Solids (TDS)	Integrative indicator for assessing water quality - electrical conductivity data indirectly reflect the total amount of solids dissolved in water, indicate the presence of salts and various pollutants in the water area
Dissolved oxygen	Limiting ecological factor in aquatic ecosystems: the presence of gaseous oxygen in waters is crucial for the survival of almost all hydrobionts
Turbidity	Water clarity indicator, i.e., its optical quality: water can be transparent or cloudy, muddy, brown. Water clarity can be reduced by the presence of suspended solids and dissolved coloured substances

3.2 Data visualization

Data visualization plays an important role in every project. It makes an impression on the client or subject teacher if it is a learning project. Here are some examples of data visualization; of course, it is effective if the data is visualized in real time, where 3D maps are drawn on the screen and it is possible to change the readings of this or that sensor. IT solutions can provide warnings about the violation of the threshold value of this or that parameter by colouring the area in a different color, giving a written warning or an audible signal.

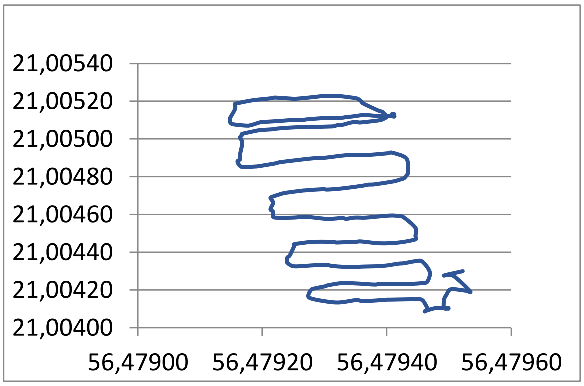

Fig. 3. The trajectory of the boat.

Fig. 4. Position of the trajectory in the environment.

Figure 3 shows the trajectory of the water monitoring robot, created from GPS sensor readings, while Figure 4 shows the path on the map. Today's IT solutions enable the trajectory to be automatically drawn on the background of the map. Interesting examples of data visualization are given in Figures 5 and 6 - they show sensor readings, which can be collected in real time, and can also be displayed after monitoring activities in the environment.

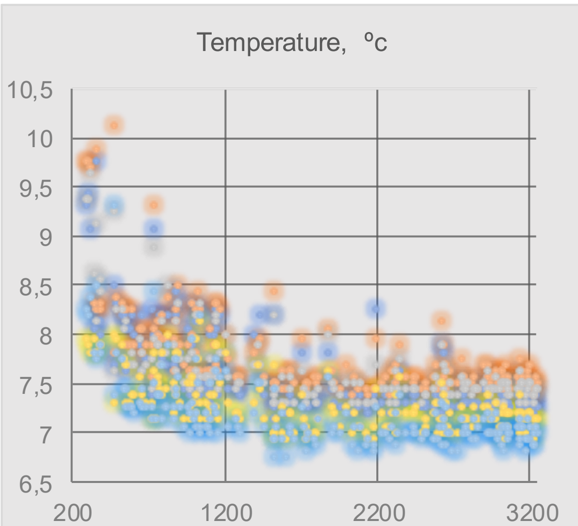

Fig. 5. Temperature readings depending on depth.

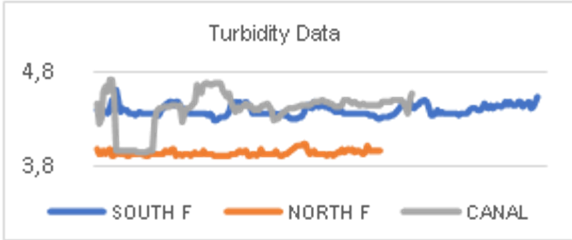

Fig. 6. Examples of Turbidity and TDS readings.

4 Conclusions

The offered example of cloud computing provides complex assistance to course instructors and enables students to expand the skills learned in theoretical courses, it is useful for IT, mechatronics, data quality, mathematical statistics, data transmission and signal processing studies and useful for study project courses. The work developed meets the requirements of the competence approach in the modern problem-solving-based higher education system in the technical field.

The proposed complex example of student work in groups or individually provides ample opportunities for those involved in education:

1) learn the elements of mechatronic solutions, their compatibility, sustainable applicability;

2) encourages thinking more broadly, forecasting potential problem areas;

3) forces to carry out development at the algorithm level, and only then to specify the solution;

4) provides for the completion of the project.

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