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Research Article

Teaching Effective Techniques for Incorporating Edge Computing in Biomedical Applications with Biomedical Students

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Abstract : This case study demonstrates the potential of integrating the Edge Impulse platform into project based learning for biomedical technology students for edge computing consept. The use of the Edge Impulse platform as a project-based teaching and learning approach for biomedical students has been shown to significantly enhance student learning performance and experiences. The platform allows students to develop practical skills and deepen their knowledge while also providing opportunities for students to apply their projects in real-world settings. This study provides valuable insights on how to effectively improve learning for biomedical students using the Edge Impulse platform. The study focuses on a course designed using the Edge Impulse platform, where students design and develop prototype devices and systems. The course begins with the learning of basic hardware and culminates in students creating a complete prototype system. The study showcases the prototype devices and systems developed by students at the end of the course, demonstrating how the use of Edge Impulse platform improves students' practical skills and enables them to apply their projects in real-world settings. Furthermore, it highlights how this approach contributes to students' self-development and acquisition of skills that can be used in their future careers. Thus, the use of this platform can lead to new ideas and experiences which may open new horizons for biomedical research and the development of integrated devices in the current world.

Keywords : Architectures for educational technology system, Cooperative/collaborative learning, Data science applications in education,Improving classroom teaching, Teaching/learning strategies

1 Introduction

This study examines the application of edge computing in the biomedical field, particularly focusing on its instructional applications for students. Edge computing addresses the need for small-scale data processing, reducing the data transmitted over networks, thereby cutting transmission costs, alleviating network bandwidth pressure, reducing the energy consumption of local equipment, and enhancing processing efficiency [1], [2]. This approach is particularly beneficial for biomedical device companies, reducing data processing costs while increasing device performance and efficiency [3].

In the biomedical field, edge computing finds numerous applications. For example, edge computing-enabled sensors and smart devices can collect and analyze real-time data within the body. Data analytics facilitated by edge computing can aid in early disease diagnosis, determining treatment options, and monitoring treatments [4]–[8]. Machine Learning (ML), powered by edge computing, can analyze biomedical images and sound data in real-time [9]–[11]. Robotics and virtual reality applications benefit from the high performance and scalability provided by edge computing, useful in surgical operations and medical training [12]–[14]. The Internet of Medical Things (IoMT), supported by edge computing, plays a crucial role in real-time data collection and analysis in hospitals and home settings [15], [16]. Furthermore, edge computing enables the development of advanced portable technologies for real-time health monitoring [17], [18] and telemedicine applications, facilitating remote medical consultations and monitoring [19], [20].

These examples underscore the versatility of edge computing in various biomedical applications. Its capacity for real-time data collection, analytics, and ML will further propel research and development in this field.

The aim of this study is to elucidate the use of edge computing in biomedical fields for students, creating innovative solutions and providing rapid feedback. The Project-Based Learning (PBL) method, by affording students hands-on experiences in real-world projects, enhances engineering understanding, problem-solving abilities, self-efficacy beliefs, and collaborative learning skills in biomedical device technology students [21], [22]. The PBL method also aids in developing practical skills and

interdisciplinary thinking beyond theoretical knowledge, improving the performance of students with lower achievements [23].

In Edge Impulse projects, specialized wireless communication-enabled microcontrollers are essential to provide students with practical experiences based on real-world projects [24]. Cost-effective, small-sized, and high-processing power hardware platforms like the Arduino Nano BLE 33 are ideal for the PBL paradigm in biomedical fields. This platform not only facilitates hands-on experiences and enhances engineering understanding but also ensures efficient information processing with minimal cost and energy consumption. The Arduino Nano BLE 33 has been utilized in Edge Impulse trainings, serving as a foundational tool for advanced learning systems. Edge Impulse, an online platform designed for easy data collection, deep learning model training, and deployment to embedded and edge devices, supports the aforementioned biomedical solutions. While targeting business sector customers for Edge ML solutions development, Edge Impulse also fosters a research-friendly and class-friendly environment.

The integration of microcontrollers and AI applications in biomedical education is pivotal in imparting practical skills and enhancing educational processes. AI's role in personalizing educational materials, assessing student performance, and providing interactive learning experiences is increasingly recognized. For instance, Zawacki-Richter et al. (2019) offer an overview of AI applications in higher education, exploring their effective use and pedagogical evaluation [25]. Similarly, Sak and Suchodolska (2021) analyzed AI's current use in nutrient science research, demonstrating its application in biomedical sciences, particularly nutrition and dietetics [26]. Briganti and Le Moine (2020) discussed the application of AI-powered medical technologies in clinical practice and education, providing insights into integrating AI into medical education [27].

2 Experimental Methods

2.1 Overview of Arduino Nano 33 BLE

Arduino Nano 33 BLE is a small, low-cost microcontroller board that is based on the 32-bit ARM Cortex-M0+ SAMD21 microcontroller. It is designed to be compatible with the Arduino software development environment, making it easy for users to program and control various electronics projects. The board features built-in Bluetooth Low Energy (BLE) connectivity, enabling wireless communication with other devices and internet connection capabilities. Additionally, it has a built-in USB to serial converter for easy programming and communication with computers. The board offers a variety of digital and analog input/output pins and supports peripherals like timers, PWM, and I2C. Arduino Nano 33 BLE is equipped with sensors including a 9-axis IMU, temperature, and light sensors, suitable for environmental data gathering and powered by the low power Arm Cortex-M0+ processor, making it ideal for battery-powered projects. This board is extensively used in IoT devices, robotics, and home automation systems.

2.2 Project-Based Teaching Concept

The success of the project-based teaching paradigm is closely tied to the design of the projects that students undertake. Projects should align with students' prior knowledge and be appropriately challenging to maintain interest and motivation. This section outlines the course structure and describes the series of projects that embody our project-based teaching approach. Hardware for these projects is provided by the Edge Impulse TinyML Kit, allowing students to engage with sensors, actuators, and other devices necessary for real-world applications. Students can program using their choice of sensors and devices, facilitating the development of solutions for actual problems and enhancing their programming skills.

2.3 Course Content

The Microcontroller course, a three-credit, semester-long course offered to students in the Biomedical Device Technology department, introduces Internet of Things (IoT) technologies and applications. Topics covered include IoT concepts and architecture, communication mechanisms, IP stack, 6LoWPAN adaptation, protocols, operating systems, sensors, and actuators. The course aims to equip students with the ability to create and utilize IoT applications, requiring no prior hardware experience, although basic programming knowledge is beneficial.

2.4 Project Design

The project-based teaching approach implemented in this curriculum involves semester-long project work. Using the "divide and conquer" methodology, projects are designed in a series of three specific projects: Fall Detection, Cough Monitor, and Machine Vision with Low Cost Camera Modules. Projects are carried out individually or in teams of two, fostering both individual and teamwork skills. These projects are structured to challenge students and enhance their programming skills while providing real-world problem-solving experiences.

2.5 Fall Detection

Using the TinyML-based Arduino Nano 33 BLE, this project develops a fall detection device utilizing ML technology. Data from an accelerometer or motion sensor is processed to train ML algorithms and analyze subsequent data. The project uses the

Arduino Nano 33 BLE Sense board to detect falls, send alerts, and communicate via Bluetooth with a mobile app. The solution achieves a 95

2.6 Cough Monitor

This project develops a solution for monitoring the cough frequency and intensity in individuals with chronic obstructive pulmonary disease (COPD) using the Arduino Nano 33 BLE Sense. A TinyML model classifies cough sounds, and a BLE service on the device increments the cough count for each detection, with data transmitted to the cloud for analysis.

2.7 Machine Vision with Low Cost Camera Modules

Students implement image processing applications using an external VGA camera module paired with the Arduino Nano 33 BLE, supported by Edge Impulse. The project demonstrates how to acquire image data, create an ML model, and perform image classification, training the model with known data to control prediction accuracy.

3 Results

During the 2022 fall semester, 10 students in the classroom used the Arduino Nano 33 BLE platform. An informal survey conducted at the start of the class revealed that none of the students had prior experience with the hardware. Hence, we utilized training and learning materials extensively to impart basic knowledge and skills about hardware. We continuously monitored and analyzed the students' performance to identify the subjects each student found challenging or understood well. After each project, student projects were evaluated and feedback was provided, leading to suggestions for enhancing the content and execution of the projects. This approach significantly improved students' understanding of the hardware and the effectiveness of project realization.

3.1 Project 1: Sensor Module Data Handling

Project 1 focused on increasing students' confidence in working with microcontroller hardware and development environments. It involved data recording with the LSM9DS1 nine-axis Sensor Module (IMU Accelerometer, Gyroscope, Magnetometer) on Arduino Nano BLE. Students learned to organize, configure, and operate the recorded data with ML algorithms and hardware/software tools, enhancing their problem-solving skills. The project aimed to provide hands-on experience and prepare students for future challenging projects. Students successfully completed this project, creating datasets from drop trials with data from 10 volunteers including acceleration and rotation data, acquired at a 200 Hz sampling rate. One student attempt from Project 1 is illustrated in Figure 1.

3.2 Project 2: Cough Detection System

Project 2, a more advanced and challenging project, involved detecting and reporting people's coughs. It aimed to teach students how to use, structure, and read sound data for sound detection, enhancing their software development skills. All 10 students successfully completed this project, with six understanding basic audio data concepts such as frequency and pulse well, while four excelled in using pre-built software components. Figure 2 shows sample audio data from this project, highlighting the complexity of mathematical and multidimensional analysis for students.

3.3 Project 3: Object Classification with Machine Vision

In the final project, all students were able to correctly use a camera to classify selected objects such as bananas, oranges, and apples. The project results of the classification process are presented in Figure 3. Additionally, nine students successfully completed their proposed prototype systems, using their mobile phones for data recording and testing, with one student achieving partial completion. These outcomes demonstrate that increased accessibility enhances student success.

4 Discussion

The effective implementation of the project-based teaching and learning (PBL) paradigm necessitates the careful design of projects. This process involves a thorough understanding of the scientific and engineering subjects that students need to learn, as well as an insightful assessment of their academic backgrounds. Therefore, in designing the projects, it is crucial to meticulously evaluate students' prior knowledge, interests, and abilities. The difficulty level of the projects is adjusted accordingly to foster engagement and motivation. In this context, we utilized Edge Impulse, a platform known for its efficiency in collecting, analyzing, and learning from sensor data in IoT or embedded systems. Edge Impulse aids in data sampling, feature extraction, and the creation of learning models, making it an essential tool for our curriculum.

Furthermore, to assess the effectiveness of the PBL approach, a comprehensive survey was conducted at the end of the course. This survey aimed to collect feedback from students about their learning experiences, focusing particularly on the application and relevance of the projects they engaged in. The survey results were highly positive: 85% of the students reported enhanced technical skills and understanding of the subject matter. Remarkably, 90% of respondents found the Arduino Nano BLE 33

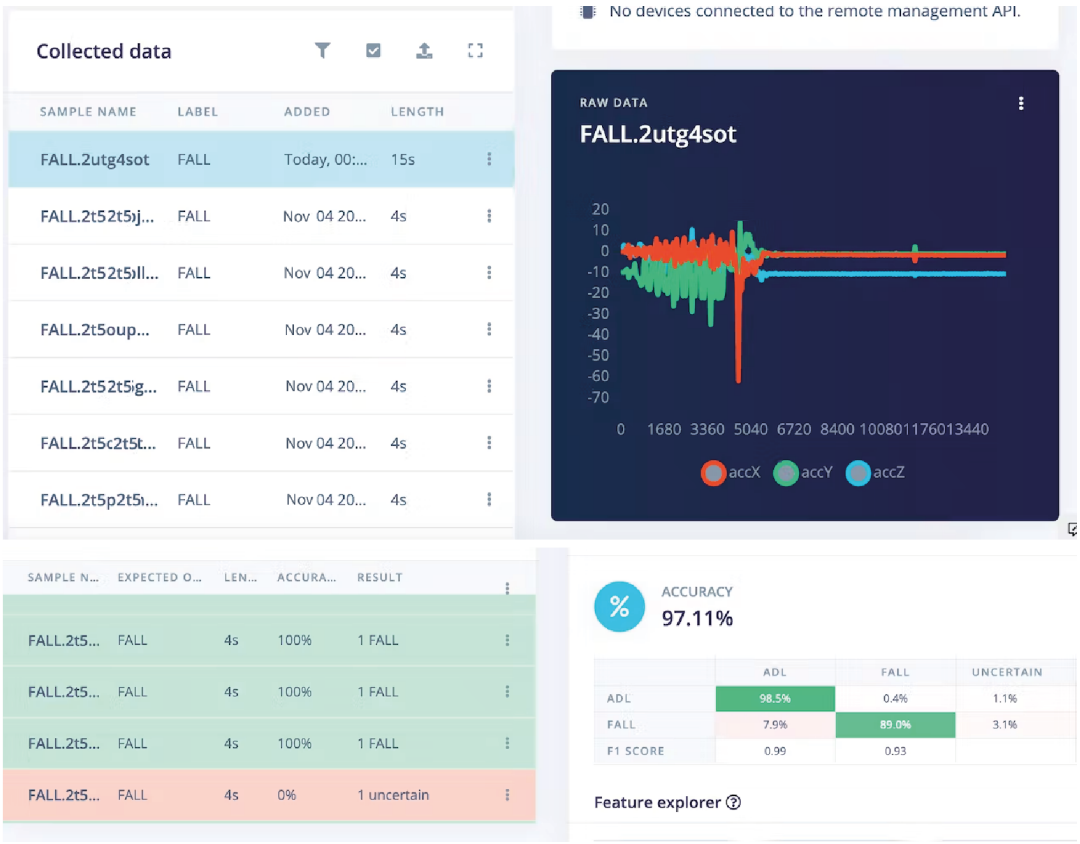

Figure 1: Student essays of Project 1

platform user-friendly, while 80% agreed that the projects aligned well with their learning styles. Additionally, 75% of the students recognized the relevance of these projects in preparing them for their future careers.

These feedbacks are invaluable as they not only validate our educational strategy but also provide critical insights for further refining our course design. Consequently, the combination of Edge Impulse and Arduino Nano BLE 33 has proven to be an innovative and effective platform, especially beneficial for students who typically have no prior hardware training or experience before taking this course. These platforms offer students opportunities to progressively develop hardware skills. Our strategy involves designing a series of projects with increasing levels of difficulty, enabling students to incrementally acquire and enhance their hardware skills.

Based on these survey findings, it is evident that the Edge Impulse and Arduino Nano BLE 33 platforms have significantly enriched student learning and experiences. The practical skills and theoretical knowledge gained through these projects are likely to be crucial in the students' future professional lives. This approach exemplifies how the use of technology in education can contribute to student success and motivation.

5 Conclusions

In this article, we have shared our experiences with the use of the Arduino Nano BLE 33 platform in a university course focused on Edge Impulse for students. The platform has been instrumental in providing an engaging and dynamic learning environment, well-suited to the course's demands. The potential of the prototype systems developed by the students in being transformed into practical biomedical products has been clearly demonstrated at the end of the course.

Through our project-based teaching and learning paradigm, we have observed significant development in students' abilities to successfully complete projects using the Edge Impulse technology on the Arduino Nano BLE 33 platform. Students not only acquired skills but were also able to generate new ideas and implement them effectively. Based on these observations, we strongly recommend the incorporation of the Arduino Nano BLE 33 platform into courses that aim to enhance students' practical and theoretical knowledge in similar fields. The platform not only supports the educational objectives but also stimulates innovation and creativity among students, making it an invaluable tool for educational purposes.

Authors' Contributions

Yeliz Durgun (YD) and Mahmut Durgun (MD) collaboratively designed the structure of the study. YD conceived the idea and was responsible for executing the field research along with laboratory analyses. MD fabricated the device, carried out the

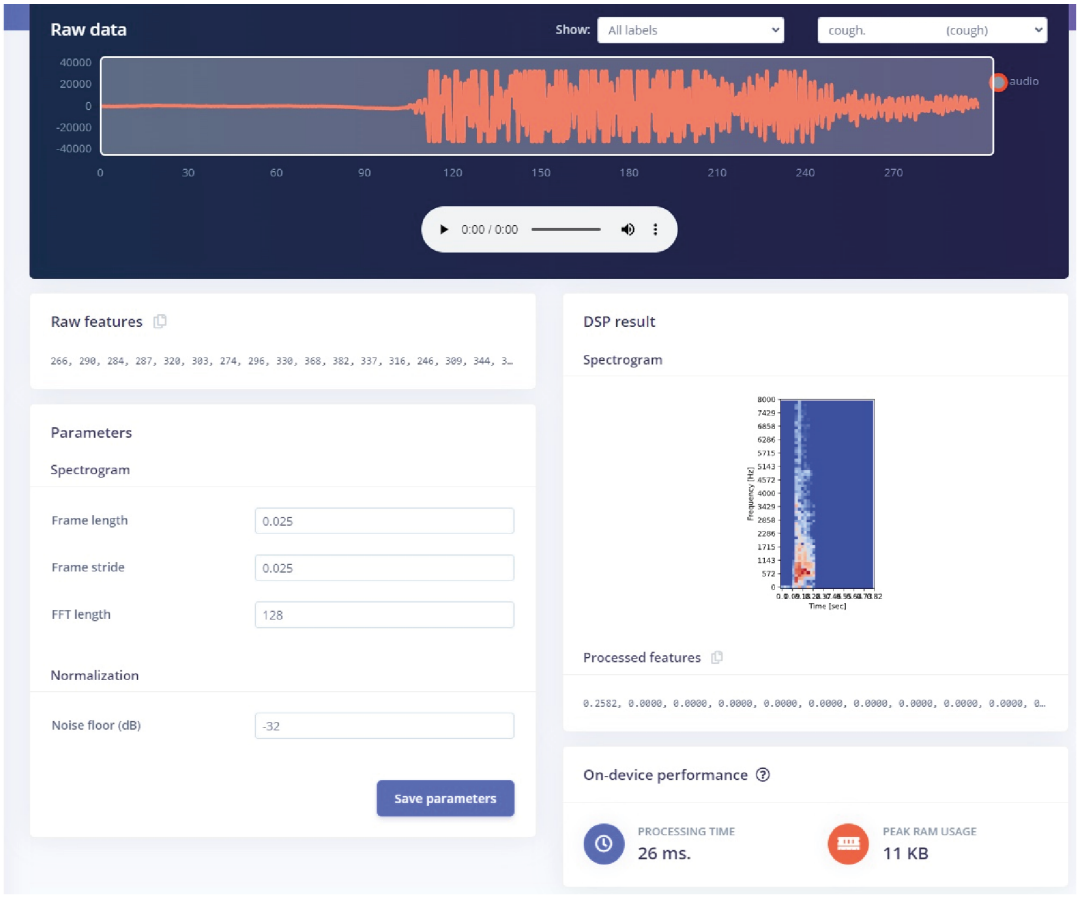

Figure 2: Student essays of Project 2

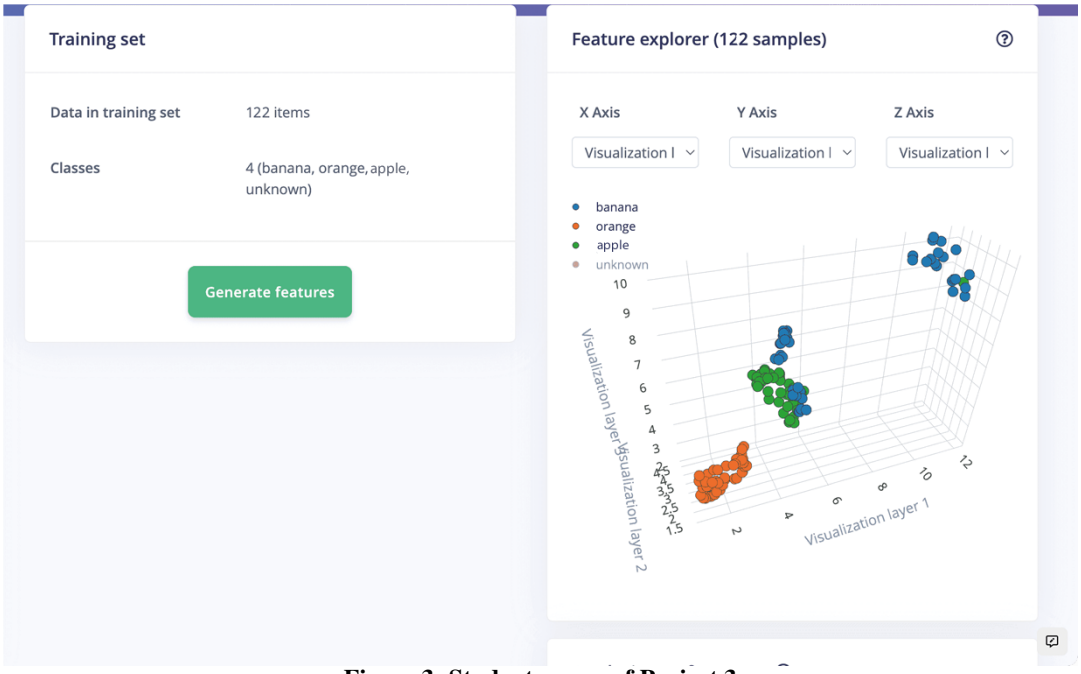

Figure 3: Student essays of Project 3

experimental work, performed the theoretical calculations in collaboration with YD, and took the lead in writing the manuscript. Both authors have read and approved the final manuscript.

Competing Interests

The authors declare that they have no conflict of interest.

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