The object of research is the application of multimedia technologies to support literacy learning in the Kazakh language through interactive tools based on the integration of IoT and Web technologies. The problem addressed is the lack of effective, interactive tools for learning correct spelling and pronunciation in the Kazakh language adaptable to different user roles and levels. This study focuses on the development of a multimedia, interactive educational system aimed at enhancing literacy and promoting active language acquisition. To design aimed system in hardware side an ESP8266 microcontroller was used. 74HC165 shift registers, pull-up resistors are also installed on each button to ensure signal stability. A server side software solution built on the Laravel framework. Communication between the microcontroller and the server is established using the WebSocket protocol, a secure connection between the hardware device and the server is provided through the MAC address. The server runs in a Docker container using the Nginx and supports user roles such administrator, teacher, and student. The results obtained include a working prototype of learning system that allows users to complete tasks in five interactive modes. The results show that the integration of real-time hardware input with a flexible server-side architecture improves user engagement and learning personalization. The features of the solution are its real-time two-way communication via Websocket, role-based access, modular design in Docker, and support for Kazakh language content. The solution is intended at supporting educational institutions, kindergartens, and remote learning environments for learning letters and words, advancing digital education practices, and improving adaptable methods and technologies for the development of IoT based educational tools

Keywords: interactive system, multimedia, ESP8266, Websocket, Laravel framework, IoT, language learning

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DEVELOPMENT OF A LITERACY ENHANCEMENT SYSTEM BASED ON IOT AND WEB TECHNOLOGIES: INTEGRATION OF ESP8266 AND LARAVEL

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1. Introduction

The education sector is currently experiencing a global shift towards digitization. Therefore, digital technologies are being widely adopted in this field. This trend enables the enhancement of teaching quality and design of educational systems adapted to the individual abilities of learners, expanding educational resources. The introduction of Internet of Things technologies (Internet of Things, IoT), which are an integral part of digitization, into the education system, is becoming relevant.

IoT technologies are a set of tools that enable to collect, process data and as well as decision-making, by connecting physical devices and sensors to the Internet. In the field of Education, IoT technologies pave a wide path to monitoring the learning process, analyzing student activity and outcomes, making learning interactive and creating a personalized educational environment.

Contemporary education increasingly relies on educational platforms, smart classrooms, distance learning systems, and multimedia learning tools. A significant position is occupied by the technologies of the Internet of things. IoT is

a network of devices interconnected in physically or virtually, providing the ability to interact with devices at any time, and from any location.

The integration of real-time data exchange into educational IoT systems represents a relevant research area that requires the development of approaches aimed at improving speed of response, functional flexibility, and adaptability of such systems. The combination of these factors forms the foundation for developing interactive educational platforms capable of adapting to diverse pedagogical scenarios that emphasizes the scientific relevance of this topic.

The relevance of the topic is explained by global educational tendencies in the field of education, including the fast growth of multimedia learning systems and the intensive implementation of digital technologies, also increasing integrations of IoT solutions into the learning process. Simultaneously, the applied value of these studies consists in the use and study of modern technological solutions for early stage education, where acquiring fundamental literacy skills in the Kazakh language plays a key role for subsequent academic success.

2. Literature review and problem statement

IoT solutions are now extensively used across various domains, including improving living standards, managing household appliances, industrial automation, monitoring the environment, agriculture, logistics, healthcare, and particularly education. Especially such concepts as smart homes, smart cities, smart energy, smart industry are successful examples of IoT applications. In paper [1] the potential of IoT devices and cloud services highlights for large-scale data gathering and smart city applications. Such an architectures supports to the efficient utilization of resources, reduction of operational costs, enhancement of citizens' quality of life, optimization of infrastructural processes and also establishes a basis for sustainable development and the implementation of innovative solutions. However, the study overlooks the potential application of such technologies in education. The integration of IoT-based ecosystem into learning processes could open up opportunities for adaptive and personalized learning, efficient monitoring of the learning process and the creation of flexible digital environments that more appropriately serve the necessities of learners. Study [2] provides significant insights into IoT architectures and integration approaches applicable to system design. The authors highlight benefits such as process automation, optimized power consumption, enhanced safety and increased user convenience, along with the use of layered architectures and protocols like MQTT, CoAP and HTTP to guarantee extensibility and compatibility. It is necessary to investigate the implementation of versatile architectures and protocols to enable practical applications in educational contexts. Research in [3] demonstrates the efficacy of applying sensor data processing and real-time data exchange for smart city application. This approach is particularly important for providing prompt response and stable monitoring. Such principles may also be beneficial in educational systems, so exploring and customizing these architectures, as well as recognizing effective approaches to integration, could assist in building of interactive and intelligent learning environments responsive to student activity and providing adaptive support for the learning process.

The basis of IoT technologies is machine – to-machine communication (M2M), but modern implementations process real time data across millions of interconnected devices and sensors [4].

The IoT architecture consists of three main layers: Things (devices and sensors), gateways (protocols such as Bluetooth, ZigBee) and the cloud system (Wi-Fi, mobile network, wireless communication realized through Edge Computing). IoT applications are divided into item-oriented, internet-oriented, and semantic-oriented in terms of functionality. The primary objectives of IoT is remote monitoring, optimization, automation, and maintenance with a user-friendly interface.

IoT systems collect information through various sensors and actuators, analyze it and then transmit the data via wireless communication. This technology enables to create a smart environment and monitor the learning process in real time. IoT is not only a tool for collecting and transmitting information, it is a key driver in modernizing the educational ecosystem [5–8].

In paper [5] the application of Internet of Things (IoT) technology in education and introduce the concept "Internet of Educational Things (IoEdT)" in this direction. Describes the most important areas of IoT in the education system, such as creating an intelligent learning environment, monitoring student behavior, remote monitoring, improving security systems, and automating the learning process. The study provides an overview on using of IoT technologies at levels ranging from preschool education to higher education, and provides specific examples. The article also raises such topical issues as the individualization of the educational process through IoT, support for students in marginalized groups, Information Security and the adoption of sensors worn on the body. The authors note that the study of the IoEdT concept in terms of data collection, analysis and integration of sensor technologies aimed at improving education is a promising area. However, the overview also notes that, despite the promising potential of IoT, there is a need for solutions and actual results that ensure personalized interaction and adaptation to different age groups and educational contexts. In addition, it does not address technical aspects such as real-time data exchange or simplified system deployment that leaves significant gaps in practical implementations. In our research, the implementation of user roles, real-time interaction, and convenient system deployment problems are addressed.

In [6] the impact of implementing Internet of Things (IoT) technologies at higher education institutions is investigated. The study is mainly aimed at identifying the extent to which IoT technology contributes to the formation of a smart educational environment, as well as its advantages and difficulties. The authors propose an assessment model consisting of six hypotheses based on the Romanian higher education system and validate it using the model of structural equations (SEM). The results of the study show that IoT has a positive impact on improving the learning and learning process, but its impact is still limited. At the same time, it is noted that data security and information infrastructure vulnerabilities pose a serious threat to the implementation of IoT on a large scale. At the same time, it is noted that data security and information infrastructure vulnerabilities pose a serious threat to the implementation of IoT on a large scale. This study contributes both theoretically and practically to understanding the capabilities of IoT technologies in the field of education, particu-

larly transition toward smart universities. This study focuses solely on the application of IoT within the context of higher education without the adaptation of such systems to other educational levels. There is a noticeable gap in development of systems oriented to primary and preschool education, that underscores the need for further research in this field to expand the scope the range of educational scenarios and increase the practical relevance of such solutions in contemporary educational contexts.

In article [7] the researchers explore the importance of integrating Internet of Things (IoT), artificial intelligence (AI) and 5G technologies in the transition of the education system toward smart education. The aim is to identify key problems in the traditional education system and provide effective solutions through smart devices and technologies. The results demonstrate that using IoT and AI technologies can improve the quality of education through solutions such as smart lesson schedule, smart attendance, smart assessment and security. In addition, the study also considers the social and technical barriers that may hinder the implementation of an IoT-based smart education system. The review does not consider an in-depth consideration of specific practical solutions and implementation approaches for IoT systems for educational platforms, and there is a need for a integrated hardware-software architecture designed to provide real-time data exchange.

The researchers in [8] comprehensively explore the possibilities of using Internet of Things (IoT) technology in creating a sustainable and intelligent education system. The objective of the study is to identify how IoT can be effectively integrated into the educational environment by school administrators, teachers, and students, and to develop a sustainable smart school model. To achieve this aim, the authors considered the issues of using IoT technology in the education system, the key barriers to their implementation. The researchers note that IoT is a transformative tool capable of driving paradigm shifts within the education system.

To overcome these barriers, it is necessary to develop a secure architecture to ensure the safety and confidentiality of data transmission, implement a scalable infrastructure to enhance the system's reliability and ease of deployment, and integrate IoT solutions to preserve human involvement in the learning process.

Several studies highlight the significance of the implementing modern IoT technologies within the education system, particularly in application-oriented contexts. The authors advocate for the development real projects focusing on the smart learning environments, e-learning [9] and distance education management systems, remote Labs [10], augments and virtual learning tools, wireless robotic education platforms [11], attendance tracking systems [12], and IoT-based educational services. At the same time, the key advantages of integrating IoT technologies into the education are the creation of realistic, safe and responsive simulation environments; enhanced engagement through gamified content delivery; and reduced reliance on costly educational equipment. Based on the analysis of the above-mentioned scientific studies, it can be concluded that, despite successful technical implementations, issues of comprehensive integration such systems often remain unresolved, particularly in terms of secure, data transmission, scalability, reliability, and real-time operation.

The integration of Internet of Things (IoT) technologies into the educational process significantly expands the possibilities for automation, interactivity and personalized learning. However, current research in this area remains limited. In particular, existing IoT based educational solutions often lack rich content, offer limits instructional modes, and are insufficiently adapted to different languages. These limitations hind the comprehensive development and effective implementation of IoT in education.

A review of the analyzed literature demonstrates that while IoT technologies have been deployed with success in diverse domains such as smart cities, smart homes and real-time systems, their adoption into education still scarce and inconsistent. Existing works on IoT ecosystems emphasize scalability, interoperability and real-time data exchange, supported by layered architectures and protocols. These approaches supply significant findings into resource optimization, automation and security management which could be adapted to the educational domain.

At the same time, studies in the education's context confirm the growing relevance of the Internet of Educational Things, but also highlight significant challenges. Current solutions are often insufficient in terms of educational content, limited in languages and learning modes and do not resolve essential hurdles such as secure data handling, ease of deployment and the balance between automation and meaningful human involvement in the learning process. Moreover, there remains a clear gap in the technical and architectural domains: detailed models, design methodologies and engineering frameworks are largely absent, preventing the establishment of integrated IoT based solutions in education.

Thus, there is an evident necessity for further research into designing integrated hardware-software IoT architectures specifically designed for early stage educational use. Such efforts should explore adaptive, scalable and secure solutions capable of expanding the variety of learning scenarios, supporting personalization and enhancing accessibility across different educational contexts. This direction appears essential for realizing the complete capacity of IoT in fostering interactive, intelligent and sustainable digital learning environments.

3. The aim and objectives of the study

The aim of this study is to develop and investigate a multimedia interactive learning system architecture based on the ESP8266 microcontroller and real-time Websocket communication with a Laravel-based server, identifying the mechanisms of data exchange and interactive engagement that enhance adaptability and personalization of learning. In practical terms, this will be enable the development of an accessible and scalable educational tool that improves personalization, supports multiple modes of interaction and ensures seamless integration of IoT technologies into learning process.

To achieve this aim, the following objectives were accomplished:

– to define hardware architecture and build a prototype device on a board using the ESP8266 microcontroller, buttons and shift registers to support physical user interaction;

– to develop and configure the user roles through a web interface enabling teachers to manage content and students to perform learning tasks;

– to select and implement interactive learning modes adapted to different educational scenarios;

– to establish stable communication between the device and the server using the WebSocket protocol, enabling real-time and synchronous data transfer.

4. Materials and methods

4. 1. The object and hypothesis of the study

The object of the study is the application of multimedia technologies to support literacy learning in the Kazakh language through interactive tools based on the integration of IoT and Web technologies.

The research hypothesis was that the integration of hardware-software architecture based on IoT technologies into educational systems will significantly improve interactivity, personalization, and efficiency in literacy training by enabling real-time connectivity, optimizing resource utilization, and supporting differentiates roles and different modes of learning.

Simplifications adopted in the study are the absence of mechanisms for calculating of scores for correct answers, it will be used voice feedback. Furthermore, the hardware design is based on prototype board that imposes limitations on durability and portability.

4. 2. Hardware

The ESP8266 microcontroller is used to control the system and enable data transferring. It is an integrated circuit that allows to combine the processor, RAM, peripheral interfaces into a single chip. It features 1024 KB of Flash Memory and was selected primarily for its built-in Wi-Fi module, enabling Internet connectivity [13–15]. The ESP8266 supports two different modes: P2P (as a client) and soft-AP (as an access point). The operating frequency is 2.4 GHz according to the 802.11 b/g/n standard [16–18].

B3F-4055 clock buttons are used as interactive elements in the system. The buttons are connected to the microcontroller through 10 kOhm resistors that act as pull-ups. It switches the input state from logical “1” to “0” upon activation. Since the number of available GPIO pins on the microcontroller is limited, button inputs are extended performing 74HC165 shift registers. Although the specified register is eight-bit, cascading them allows to increase the number of buttons to be connected [19].

4. 3. Web server

The web application was developed using the Laravel framework based on the PHP programming language. The main feature of the PHP language is ability to integrate PHP, HTML, CSS within a single file. Despite this, Laravel framework is able to keep projects clean and scalable. Laravel operates on the basis of MVC architecture between model, view and controller components. It is also possible to work lightly with the URL path in the framework at the expense of the routing mechanism [20–23].

The Eloquent mechanism ORM (Object-Relational Mapping) performed to work with databases. This approach reduces redundant code, speeds up improvement, and increases the robustness of the system by reducing the likehood of errors [21, 25 ,24]. For managing libraries, dependencies, the Composer package manager is used. It not only installs third-party libraries, but also paves the way for updates and compatibility management. AdminLTE can be named as one of the dependencies used in the developing of a web application. It includes tables, diagrams, forms, etc.

A MySQL database was used to store important data necessary for a web application. It allows to optimize and effectively manage the structure of information, instantly find data, ensure their integrity, while preserving information such as User, Device, Task parameters [26]. At first, special classes called «seeders» are used to initialize and populate the database.

The web application operates over the HTTP protocol. Wich facilitates client-server communication using a request-response model. It supports basic operations such as data retrieval, insertion, updating, and deletion, its reliance on repeated requests for interaction can result in inefficient resource usage. Therefore, the WebSocket protocol is used, which allows to establish a continuous connection between the microcontroller and the web application to perform the data transferring task. This reduces latency and minimizes server load by eliminating the need for repetitive HTTP requests. Developing a WebSocket server in PHP would result in overloading the RAM and processor. Therefore, the Go programming language was chosen for server-side WebSocket development. Go`s concurrency model, based on lightweight goroutines, allows for the simultaneous management of thousands of Websocket connections with significantly lower resource consumption compared to traditional approaches [27, 28].

One of the main components of modern web systems is web servers. It is the software responsible for processing HTTP requests from users, routing data, transferring dynamic and static resources, and interacting between the client and the server [29]. The most popular and frequently used web servers are Apache HTTP server and Nginx. Especially often Apache is used with PHP due to its wide functionality, flexible configuration, dynamic connection of modules. However, Apache creates a separate thread for each new connection, which increases the resource consumption and reduces the speed of system operation. For this reason, the Nginx web server was chosen for the project. Because during the operation of the proposed system, high activity is expected from the user, which means that the transferring of data between the client, server and microcontroller will be intensive. In this context, Nginx plays a critical role in ensuring system stability and minimizing latency.

Secondly, the architectural design of the project involves not only of Laravel based web application but also WebSocket server implemented in Go, along with a client-facing web interface. Nginx effectively, manages and distributes various requests across ports and services, thereby ensuring efficient communication and resource utilization [14]. It delivers static Blade resources to Laravel using FastCGI, to the WebSocket server via HTTP, and to the client.

The third reason relates to portability within the system, Docker technology is used streamline deployment and facilitate future development and scalability. The Nginx server is easily integrated with Docker. Docker reduces resource consumption and allows to create a single server with multiple containers [15, 30]. Docker Compose tool is used to manage containers. It enables for starting, stopping, configuring the operation of containers and get the system structure in the form of a YAML file. This file is used to add, modify new services.

5. Results of developing multimedia learning system based on ESP8266 and Laravel integration

5. 1. Hardware platform design based on ESP8266

The hardware component of the system as mentioned in the previous section used a 74HC165 shift register to process

incoming signals from the ESP8266 microcontroller, B3F-4055 buttons. Each shift register consists of eight inputs, and their Q7 output forms a cascading circuit, connecting to the QH input of the next shift register. This approach was implemented to solve the problem of the limitation in the number of Input\ Output pins of the microcontroller. The schematic diagram of the device designed using Proteus software is shown in Fig. 1.

Pull-up resistors were used to achieve the stability of the signal to be extracted from the buttons. When a button is pressed, the logic level at the corresponding input of the register changes, thereby altering the state of the register, and upon receiving a request, the current states of all connected registers are sequentially transmitted to the microcontroller. The device assembled on the breadboard is shown in Fig. 2.

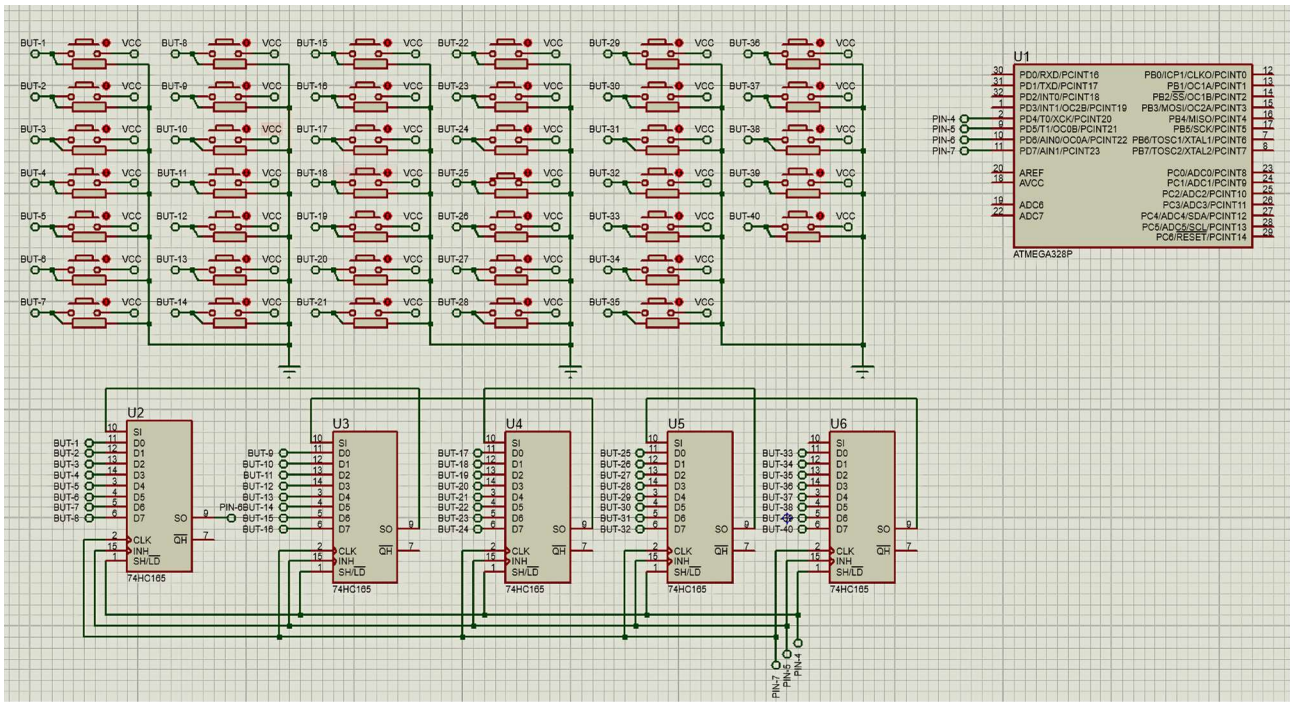

Fig. 1. Scheme of the hardware component of the system using Proteus

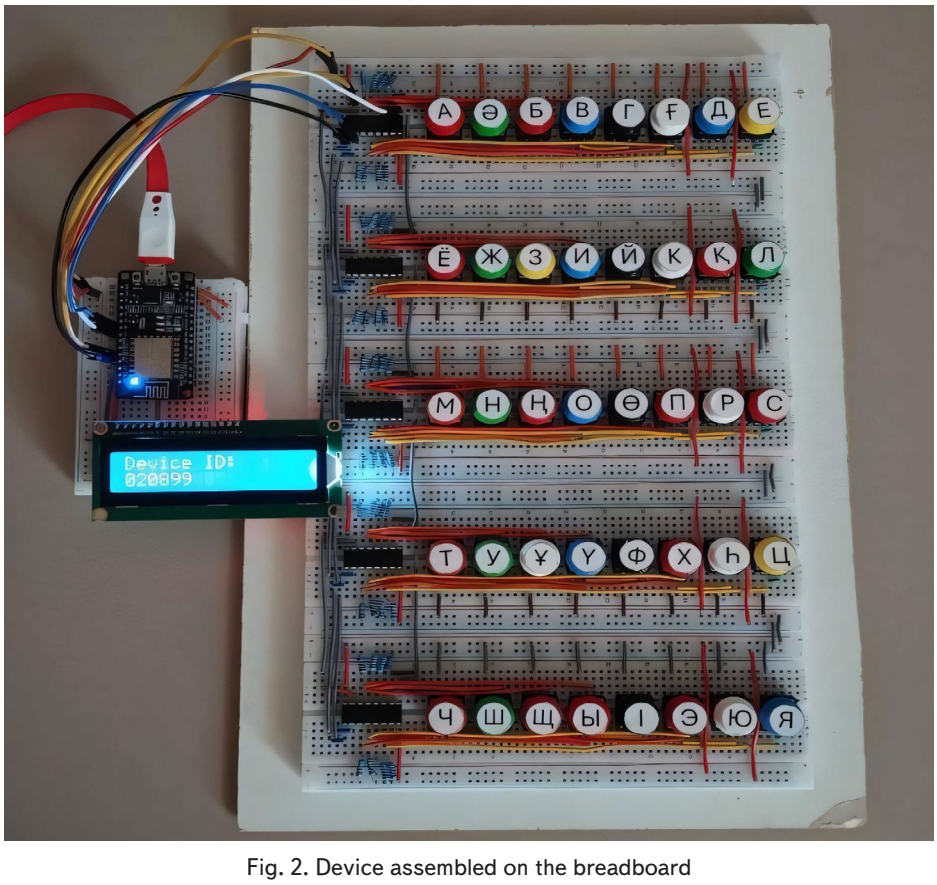

Fig. 2. Device assembled on the breadboard

To start the operation of the hardware device, first of all, necessary to connect the microcontroller to the Wi-Fi network. After successfully connecting to Wi-Fi, the MAC address of the device is displayed on the LCD display.

5. 2. Implementation of roles in the Web interface

Three different roles were considered in the proposed system: administrator, teacher and ESP user. The administrator role has the ability to manage letters, words, categories and images. Through the role of a teacher, the management of the educational process, registration of users is carried out. The ESP user performs memorization and tasks prepared by the teacher. The database, created using MySQL, consists of eleven tables, and it is possible to see it in the ER diagram in Fig. 3: users, words, letters, categories, categories_has_words, tasks, settings, devices, esp_users, pictures.

Further, the next step was the development of a web application in Laravel. The AdminLTE library, imported through Composer, was utilized to organize the authentication and authorization processes. Also, a user interface page for the “esp_users” table was styled using CSS. However, a registration page for administration did not created. Adding a new administrator is done in Laravel using the Artisan tool. They can only work with words, letters, categories, pictures tables (Fig. 4).

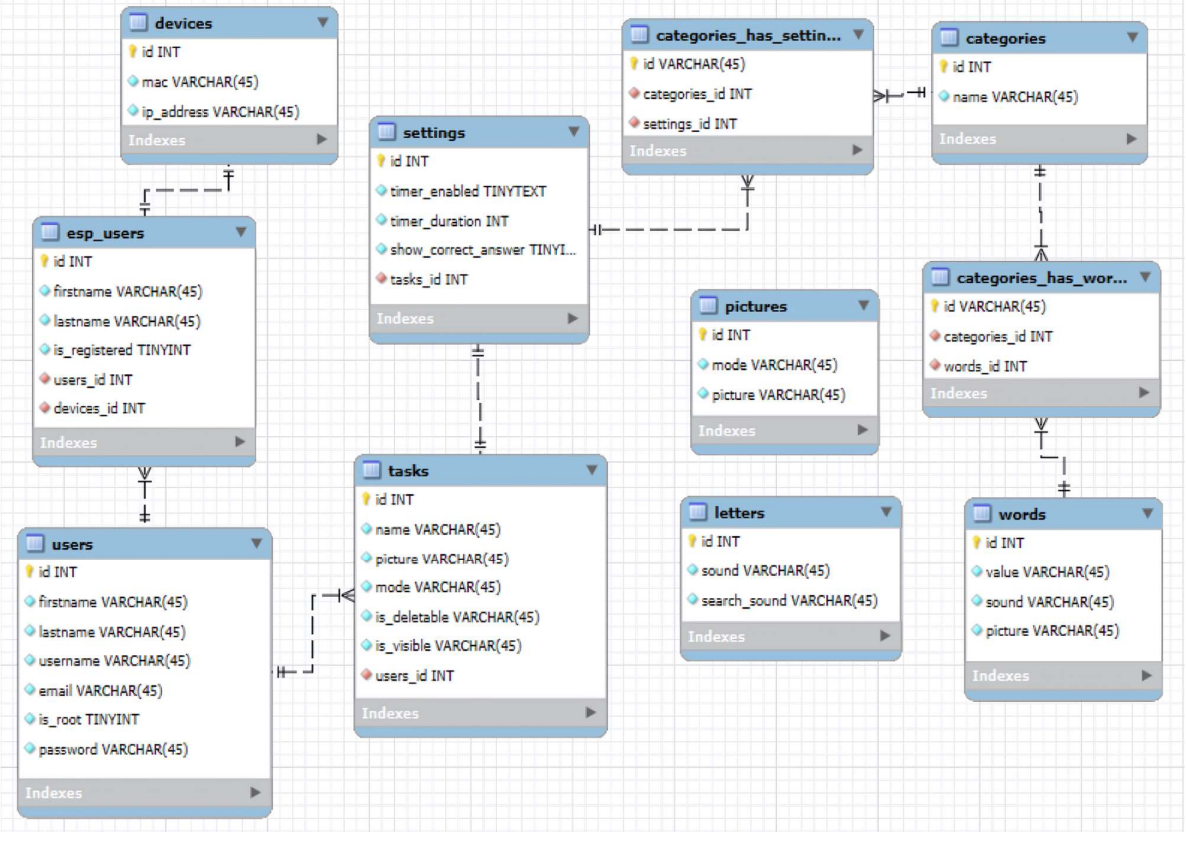

Fig. 3. Database ER diagram

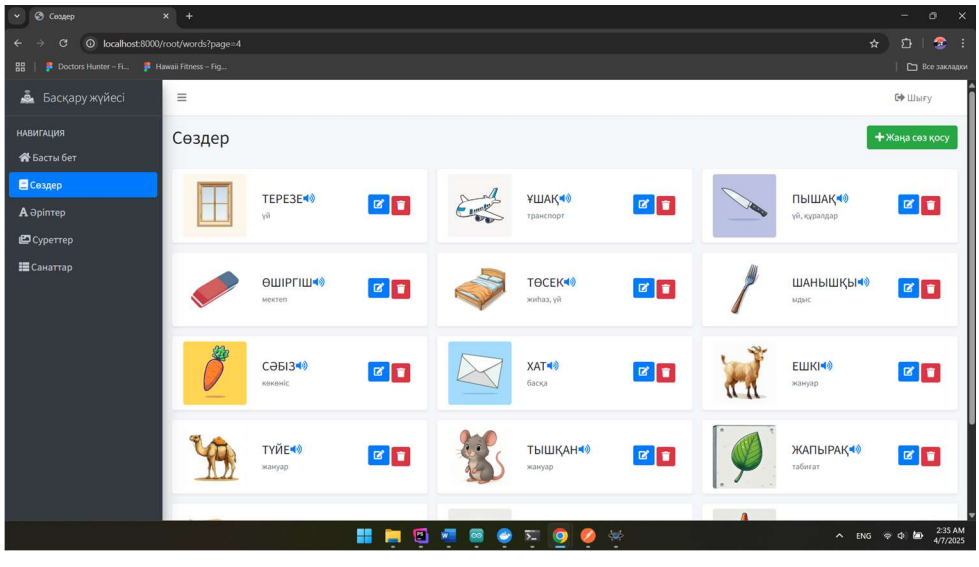

Fig. 4. Web interface for word management

Next, the authorization of the role of the teacher is made and the page for managing is designed. They work with esp_users and tasks tables. In addition, teachers have the opportunity to choose the name of the assignment, images and modes of study (Fig. 5).

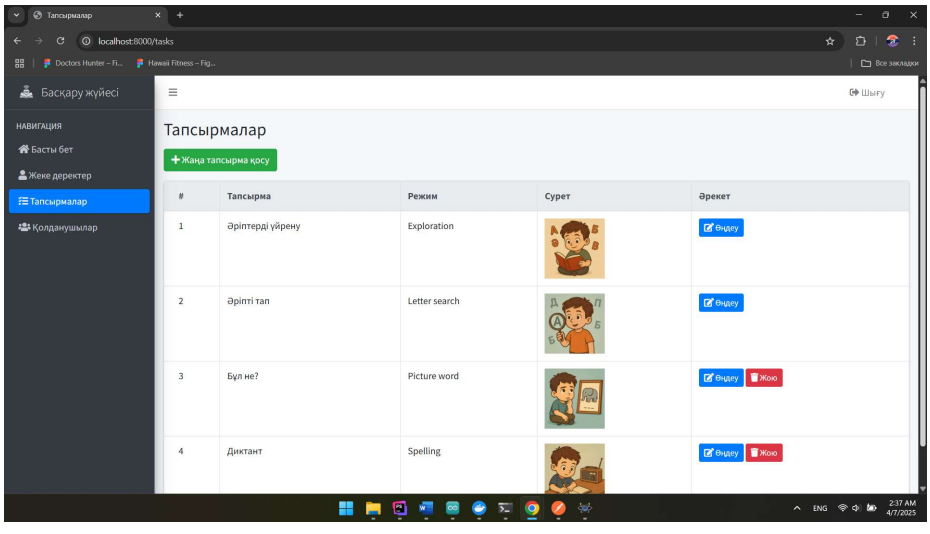

Fig. 5. Web interface for task management

In the next step, the ESP user management page was designed. A mechanism was implemented to generate a username and password.

ESP users is logged into the system by two steps. After the user logs into the system, the connection with the «device table» is checked. If this connection is not detected, it is necessary to send to the device page and enter the ID indicated on the LCD display. Only after that it is possible to return to the home page, open tasks, and use the device. Along with this, the exit button and ID change button were placed at the bottom of the home page.

Docker compose was used to connect the applications used in the system in a single environment as a single application. Laravel, MySQL, Nginx, WebSocket are defined in single file and configured to be implemented simultaneously in one container.

Users are provided the ability to complete tasks across five distinct training modes, managed through the «tasks» and «settings» tables.

5. 3. Design and implementation of interactive modes for literacy training

Interactive modes were created to help learners train reading and writing skills. The system contains of letter recognition, sound-to-letter matching, word formation tasks. Each mode is supported by audio-visual feedback, making learning engaging and intuitive.

Exploration mode the letter belonging to the pressed button is voiced and the animation is displayed. This is a convenient mode for the beginners learning the alphabet. The user can hear the letter by sound and see it visually.

In Letter Search mode, a specific letter is pronounced, the user must press the matching button on the board. A feedback is given on whether the answer is correct or not.

In Picture Word mode, an image is displayed on the screen, the user must type the corresponding to the word. This mode is designed to expand vocabulary, increase visual perception and the skill to form words.

In Missing Letter mode, the position of one or more letters in words is omitted. The user must press the missing letter. This mode is aimed at improving analytical thinking, attention.

In Spelling mode, the word is pronounced, but the visual image is not displayed, the user needs to type the voiced word using the buttons on the board.

5. 4. Integration of software and server components via Websocket protocol

The system operates using the «Blade» templating engine, part of Laravel framework, and web interface was developed based on it. Thus, the operation of the system is based on a hydride architecture. Accordingly, the microcontroller provides interaction with the user using a physical device consisting of buttons, the server part of the PHP provides interface control and storage of locations, and the exchange of real-time data in Golang. Fig. 6 shows the architecture of the proposed system.

A WebSocket server in Go has been developed to enable real-time, duplex communication between the ESP8266 microcontroller and clients in the proposed system.

After the ESP8266 microcontroller is connected to the Wi-Fi network, a confirmation of successful connection to the network and readiness for operation is registered using the HTTP initialization request. Further, the IP address and MAC address of the device are stored in the database and used for address routing during data exchange. This is important in synchronizing the states of hardware and software components.

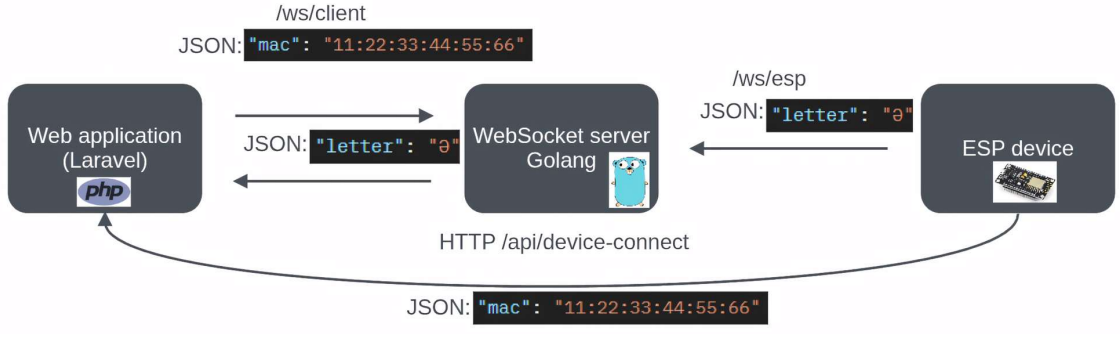

Fig. 6. Proposed system hybrid architecture

After the HTTP request of the device, the connection to the WebSocket server is established, and after pressing the buttons, the letter and MAC address of the microcontroller in JSON format are delivered to WebSocket (Fig. 7).

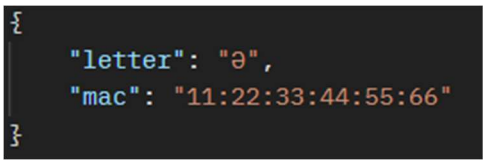

Fig. 7. Example of message in JSON format supplied to WebSocket from a microcontroller

The reason for choosing the JSON format is due to its compatibility with all modern programming languages and ease of processing information on the client and server sides. Accordingly, it is used as a standard approach in systems with multiple devices, as it allows to correctly identify the signal source by MAC address, as well as its content (letter, character). After the user selects one of the learning modes, the web application establishes a connection with WebSocket by specifying the MAC address. And the program in Go provides security by matching the received data by MAC address and sending it only to the appropriate user. By using the MAC address as a linked identifier in conjunction with «sonv», the system capable of simultaneously serving multiple devices and users.

6. Discussion of experimental results on the integration of the ESP8266-based hardware and Laravel-based Web platform

The effectiveness of the proposed system is explained by the integration of real-time communication and role-based interface that ensures smooth interaction between the physical device and the server.

The hardware was developed by utilizing the ESP8266 (China) micro controller and 74HC595 shift registers. The use of the ESP8266 microcontroller and MAC address binding provided a secure and personalized user experience, resulting in consistent performance during the training session. The modular system architecture, combined with the simplicity and flexibility of the ESP8266 microcontroller, enabled efficient task execution and responsive user interaction. The circuit of device was modeled in Proteus and built on a layout board. The designed circuit diagram of the device in Proteus is presented in Fig. 1 and the built prototype of the device is shown in Fig. 2.

The support for administration, teacher and student roles is implemented using Laravel and web interface and tasks and opportunities are presented according to each role This enables role-based access and content management, improving personalized learning. Additionally, the teacher role provides the ability to create and edit or update learning content, thereby addressing the issue of limited educational materials. The developed ER diagram representing the database structure is presented in Fig. 3. Additionally, the teacher's web interface for managing words and tasks is demonstrated Fig. 4, 5.

The learning content can be adapted for Exploration, Letter search, Picture word, Missing letter and Spelling modes, enabling comprehensive interaction with the users, reinforcing letter and word knowledge both visually and audibly. This is realized by integration of the button interface, signal processing, graphical rendering via web application.

The device communicates in real time with the server system developed using the Laravel framework through the WebSocket protocol. The server side Laravel framework, MySQL database, nginx web server, and Docker are hosted in a container environment. The use of Websocket and containerization with Docker ensures a minimization of data transmission delay and simplification of deployment and scaling processes increasing operational reliability under various conditions. The integration of the hardware and Web-server provides the application of the system based on IoT technologies for educational use and addresses the problem of developing an appropriate and implementation approach. The overall architecture of the proposed system is illustrated in Fig. 6 and an example of a JSON message transmitted from the ESP8266 microcontroller to the server through the Websocket protocol is shown in Fig. 7.

Unlike traditional e-learning tools and web-based learning platforms [31], mobile apps [32] that rely solely on touchscreen or mouse input, developed system incorporates a physical device with tactile feedback that reinforces memorization and motor skills. In contrast to HTTP-based systems, the use of real-time communication via Go-based Websocket server also distinguishes this system by reducing latency and enhancing responsiveness, allow duplex communication. Additionally, the role-based interface ensures differentiated access and control.

The proposed IoT system is aimed at use in primary and preschool education, kindergartens where interactive learning with the use of multimedia tools is required. The system ensures secure and confidential data transmission, supports a scalable architecture, and enables integration with existing educational platforms that suitable to implement both in traditional classrooms and in distance learning environments. The developed system can be effectively used in environments with stable Internet access and sufficient infrastructure to support the installation and connection of IoT devices. The educational content can be supplemented in accordance with the specifics of academic programs and the educational objectives to enhance the effectiveness of the study.

One limitation of this study is that the system was tested in a limited user environment with a relatively small group of users. Therefore, broader scalability and adaptability in real conditions across various age group and literacy levels remain to be fully validated.

A notable disadvantage is the proposed system lacks advance analytics for tracking learning progress, which could be added through deeper database optimization and visualization tools. Currently, the device provides voice feedback to inform the user whether the task was completes correctly or not. However, it does not calculate or display scores. Furthermore, the hardware design is based on a prototyping board, which limits durability and portability. Developing a printed circuit board and enclosed casing would enhance usability and resilience.

Future research can explore expanding the system's capabilities with speech recognition, multilingual support, and adaptive difficulty levels using AI. However, these integrations can refer to challenges such as computational demands increasing on microcontrollers, ensuring low-latency data exchange, training of machine learning models with high accuracy. Additionally, scaling of the system for mass de-

ployment will require robust user authentication, secure data handling, and possibly cloud-based infrastructure support.

7. Conclusion

1. A hardware prototype of the multimedia learning system was assembled using ESP8266 microcontroller, forty B3F-4055 buttons and 74HC595 shift registers. The circuit of the device was designed in the Proteus. The resulting device demonstrated stable performance during continuous interaction session and interactivity by providing immediate audio-visual feedback in response to user input.

2. A role-based Web interface was developed using LarŁ avel (PhP, backend), Blade templates, Nginx web-server and tested, supporting teacher and student modes. MySQL was used for storing user data and learning outcomes and an ER diagram was constructed to represent the logical structure of the system and model the relationships between entities. The database consists of 11 tables. The server component was organized in a Docker environment.

3. The system provide to learners the opportunity to come plete tasks in 5 different modes reinforcing knowledge and improve writing, spelling, reading and listening skills:

– exploration mode – it combines audio-visual feedback, facilitating letter recognition and memory retention;

– letter search mode – identifying letters based on sounds with immediate feedback;

– picture word mode – a word formation through interactive image-based tasks;

– missing letter mode – it is required to identify and fill in omitted letters in words;

– spelling mode – typing words based solely on auditory cues.

4. The developed prototype used the WebSocket protocol and MAC address matching to establish a secure and continuous connection between the device and the server. The microcontroller provides interaction with the user using a physical device consisting of buttons, the server part of the PHP provides interface control and storage of locations. The WebSocket server written in Go has been developed to enable real-time, duplex communication between the ESP8266 microcontroller and connected clients in the proposed system to ensure responsive interaction. The system ensured lossless data exchange and immediate response to user inputs.

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Conflict of interest

The authors declare that they have no conflict of interest in relation to this study, whether financial, personal, authorship or otherwise, that could affect the study and its results presented in this paper.

Financing

The study was performed without financial support.

Data availability

Manuscript has associated data in a data repository.

Use of artificial intelligence

The authors have used artificial intelligence technologies within acceptable limits to provide their own verified data, which is described in the research methodology section.

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