Math Balance Aids based on Internet of Things for Arithmetic Operational Learning

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***Abstract*—Industry 4.0 has changed various aspects of human life towards an era heavily influenced by information technology. The impact of industry 4.0 on the education sector has led to the emergence of the term education 4.0. The Internet of Things (IoT) is one of the pillars of industry 4.0. With its capabilities, IoT can provide opportunities to develop innovations in the field of education. Several studies show that teaching aids can improve the quality of learning and learning outcomes. In Indonesia, mathematics is a compulsory subject taught from elementary school to higher education. Previous studies that used mathematical (math) balance aids to help students learn mathematical operations showed positive correlations between the learning process and student learning outcomes in the materials related to arithmetic operations. This study aims to develop an IoT-based mathematical balance tool to support three education 4.0 trends: remote access, personalization, and practice and feedback. This study used modifications of Fahmideh and Zogwhi's IoT development method. There are five phases of IoT development: initialization phase, analysis phase, design phase, implementation phase, and evaluation phase. From each phase of IoT development, IoT-based mathematical balance assistance systems have been successfully built and it complies with the functionality described in the analysis phase. The system performance also shows optimal results with 100% accuracy for reading the student's learning activities. Moreover, it uses less than 10 seconds for processing 1000 data requests.**

Keywords—Arithmetic operation; education 4.0; internet of things development; math balance aids

I. Introduction

In 2009, Jerald summarized that automation, globalization, workplace change, and policies increasing personal responsibility had changed the trend of school student skills known as 21st-century skills [1]. In 2011, the High-Tech Strategy project organized by the German government brought up the term "Industry 4.0" or IR4.0 to promote a new manufacturing revolution based on computerization and the potential of new technologies [2]. The impact of IR4.0 on the education sector has resulted in the emergence of the term "Education 4.0" as a response to the need for educational outcomes that are aligned and meet the needs of IR4.0 [3], [4]. Fisk defines education 4.0 in nine trends, namely (1) anywhere anytime (diverse time and place), (2) personalized learning, (3) free choice (flexible delivery), (4) project-based (modular and projects), (5) field experiences (practical application), (6) data interpretation (why/where not what/how), (7) completely change of exams (evaluated not examined), (8) student ownership, (9) mentoring and peers [3]. Miranda formulates the core components of education 4.0, which are composed of (1) competencies, (2) learning methods, (3) information and communication technologies (ICT), and infrastructure [4].

ICT has a crucial role in the educational system in providing access, distribution, calculation, and collection of information [5]–[7]. ICT revolutionizes the traditional paradigm to a student-centered model, changes the way of teaching, collaborates between educational stakeholders, and creates various innovations in teaching and learning activities. Miranda classifies ICT into two groups based on the basic components and the combination of the basic components of ICT that results in various innovations and new services. One of the technologies from ICT in Miranda's core education 4.0 core component is the Internet of Things (IoT). The ability of IoT to connect various "things" through the Internet network and the ability of IoT to be programmed with computational intelligence provide opportunities to develop innovations in the education sector[8]–[10].

In the field of education, Kassab et al. have summarized in their publication a systematic literature review on the benefits and challenges of IoT in education. [11]. IoT, with its capabilities, can provide various innovation opportunities to improve the quality of teaching and learning activities at various levels of education. One of the criteria used by Kassab in conducting a systematic literature review is Ambrose's seven effective learning principles, namely previous knowledge, knowledge organization, course climate, motivation, mastery, practice and feedback, and self-directed learning [12]. In another study, Saeed et al. summarized the advantages of implementing IoT in higher education to build a smart campus (smart parking, smart inventory, smart student tracking, etc.), as the main component in smart classrooms (interactive whiteboards, attendance tracking system, wireless door locks, etc.), and develop intelligent labs (integrating IoT with LMS) [13]. Although in many publications, the focus of education 4.0 is explicitly for the secondary school or higher education level, in its implementation, the concept and technology of education 4.0 can be applied at various levels of education, starting from the elementary school level.

In Indonesia, mathematics is one of the compulsory subjects taught to students from the elementary school level. Mathematics is crucial for building children's ability to think logically, problem-solving, creativity, and cultural development [14]. However, many studies have shown that mathematics in primary schools in Indonesia is a difficult and frightening subject. This condition occurs due to various factors such as general factors (physiological, pedagogic,

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intellectual, infrastructure, school environment) or particular factors (difficulty understanding concepts, deficiency of arithmetic operation skills, or difficulty understanding context) [15]. Teaching aids in mathematics subjects help motivate students to learn, provide a concrete picture of the concepts of mathematics lessons that tend to be abstract, and help provide an overview of the relationship between mathematics and the surrounding natural conditions [16]. Examples of mathematics teaching aids are mathematical balance aids to help students understand the material for basic operations in mathematics [17]–[22].

Integrating math balance teaching aids with IoT technology will provide added value, especially to support the education 4.0 trend and support one of Ambrose's effective learning principles, namely practice, and feedback. The integration process between teaching aids and IoT has challenges in meeting the characteristics of education 4.0. These challenges include how to identify system functionality (such as remote access, personalized learning, practice, feedback, etc.), how to determine variables and how to measure performance, how to select system components, how to system architecture, how to implement the system, and how to evaluate the system based on system objectives. This study aims to design and implement mathematics teaching aids using IoT technology that can support the education 4.0 trend: remote access, personalized learning, practice, and feedback. This research provides guidelines for developing an IoT-based teaching aid system in various types of subjects or courses to support the implementation of education 4.0.

The structure of this article consists of five sections. The first section discusses the world of today's education and the development of IoT technology, problems in the world of education, especially for learning mathematics in elementary schools in Indonesia, as well as a statement about the purpose of this research. The second section describes the research method applied in this research, starting from the initiation phase to the evaluation phase. The results of system implementation are discussed in the implementation section. The evaluation and discussion section explains the evaluation of the implementation results and discusses the achievements and opportunities for system development in the future. The last section is a conclusion that summarizes the entire section of this paper.

II. Literature Review

This section summarizes the latest opportunities and conditions for the development of IoT in the field of education. There have been several publications that discuss the implementation of IoT with teaching aids at various levels of education. The integration of IoT technology with game tools that support children's gross motoric training for children aged 4-6 years was published by Shonia et al. which integrates bag toss games with IoT [23]. Shonia et al. implement the system and test the system from the aspect of functionality and system performance. System functionality is tested by checking whether the devices can work according to their functions. Testing system functionality includes testing the microcontroller (whether the microcontroller can run a program to calculate game scores), infrared sensor testing (whether the infrared sensor can detect beanbags), testing the Wi-Fi module (whether the Wi-Fi module can send results to the IoT platform via the internet), and LED testing (whether the LED can provide color according to the bag toss hole). Meanwhile, the system performance was tested based on data communication criteria and the accuracy of reading student activity data. System testing involved four children in measuring the condition of their motor development.

Another research study on IoT to support education was published by Rahmanto et al. and by Jati et al., who use the IoT-integrated variant of the hopscotch game [24], [25]. Rahmanto et al. integrate IoT with hopscotch built using puzzle carpet. The IoT component consists of a microcontroller (using Arduino Mega 2560), a vibration detection sensor (piezoelectric ceramic vibrate sensor), a child activity indicator (buzzer), and a communication module (ESP8255-01). Meanwhile, Jati et al. built hopscotch using aluminum foil and capacitive sensors to detect children's activities. The system architecture of the two studies is the same. However, in the research of Jati et al., the game leveling system has been implemented. Game leveling can be managed using a website application. The two systems built were tested based on system functionality and system performance. Both publications test the functionality of the system by testing each hardware component of the system. While the performance test, Rahmanto et al. tested the aspects of reading speed and accuracy of the assessment. Meanwhile, Jati et al., apart from testing system delay and system accuracy, also tested system gameplay. These two studies did not measure children's motor development achievement.

Wajdi et al implemented IoT in drop-box games to help children's gross motor development [26]. The drop box game utilizes a 32cm x 40cm board with 3-5 holes. The ball is placed on the board. The child's task is to move the board to put the ball in the hole on the board. IoT functions to detect incoming balls and evaluate children's activities. The results of the activity will be stored on the IoT platform. The hardware components of this system are a microcontroller, IR obstacle avoidance sensor, buzzer, and drop box board. In this study, Wajdi et al. tested the system hardware's functionality and tested its performance based on two criteria: the accuracy of scoring children's activities and reading speed. In this study, Wajdi et al. proposed an IoT architecture based on four layers: constrained devices layer, console devices layer, communication network layer, and management services layer.

The previously mentioned studies published the integration of IoT with games to support motor development of preschoolers. Setiawan et al. build an IoT system integrated with Kobela aids at the elementary school level [27]. Kobela is an abbreviation of “Kotak Belajar Ajaib” (Magic Learning Box) which is used to support students in learning multiplication and division of numbers in mathematics. In this study, the authors tested the system based on hardware functionality and system performance: accuracy of children's activities and reading speed from sensors to the IoT platform. The integration of teaching aids in physics subjects was developed by Sakinah et al. and Fauzan et al. Sakinah et al. developed integrated props for Lorentz force practice with IoT

[28]. The system built by Sakinah et al. uses magnets and KY-024 module to detect magnetic fields. The data read by the KY-024 module is sent to the microcontroller to be sent to the system. The interaction of teachers and students to the system uses a website-based application. While in Fauzan et al.'s research, the author integrates IoT with free fall props to help students learn the concept of free fall [29]. These studies tested the system based on hardware functionality and system performance.

From the literature discussed, the development of IoT-based learning aids only focused on system development. In these studies, the researchers did not identify comprehensively: aspects of compliance with education 4.0, analysis of system functionality requirements, system performance analysis, system component analysis, system architecture design, system communication design, and system implementation and system evaluation. This study proposes a flexible and comprehensive model for developing an IoT-based teaching aid system that supports the implementation of education 4.0.

III. Proposed Method

The research method used in this study is the IoT development model proposed by Fahmideh and Zowghi. Fahmideh and Zowghi's method was modified in its sub-phases to suit the functionality and operation requirements of educational teaching aids. [30]. This model describes the process of developing an IoT application sequentially. Fig.1. shows the research method for the development of the IoT model. There are five phases in the development of IoT-based mathematical balance aids.

The first phase is the initialization phase. The purpose of this phase: to identify arithmetic operations learning problems that have solutions using IoT-based technology, conduct a literature study to identify development opportunities and current solutions, and examine the feasibility of environmental infrastructure to implement the system. The next phase is the analysis phase. This phase aims to identify functionality to support part of the education trend 4.0, namely free access, personalized learning, practice, and feedback. Designing the system architecture, then connecting between the hardware, designing the data flow diagrams, and designing the database are the goals of the design phase. Detailed explanations and components of the first, second, and third phases are explained in this second section.

After completing the design phase, the next phase is the implementation phase. In this phase, the implementation includes hardware implementation, software implementation, and system integration. The last phase in the research method is the evaluation phase. In the evaluation phase, there are two evaluations carried out. First, activities evaluate the achievement of system functionality that has been implemented. Second is the activity of assessing system performance based on aspects of system accuracy and delay. The two stages are explained in detail in Section III for the implementation stage and Section IV for the evaluation stage.

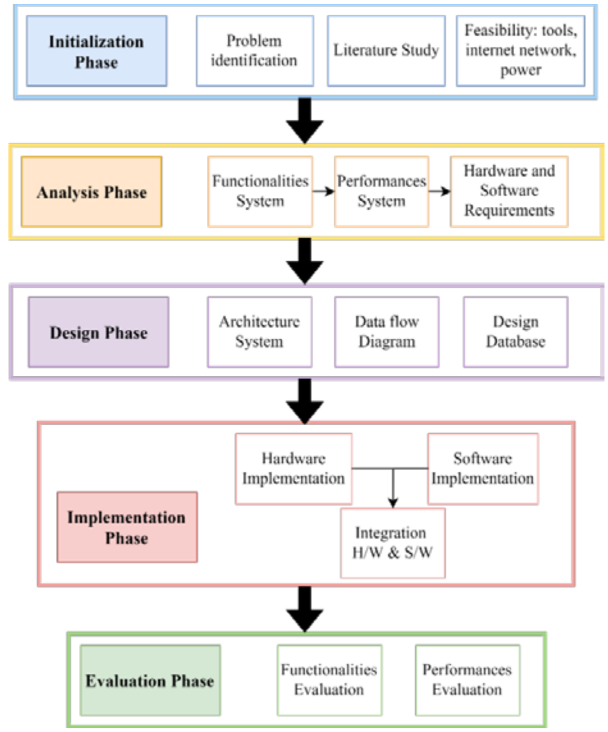

Fig. 1. Method for Integration Mathematical Balance aid with IoT based on Fahmideh and Zowghi [23].

A. Initialization Phase

The initialization phase is the first phase of this research. There are three activities in this phase. The first is to identify the problems of learning mathematics for elementary schools in Indonesia from the perspective of education 4.0. The next activity is to review the study literature to find out the position of this research in the scope of the application of IoT in the education sector. Section II carried out the literature review stage of this study. Checking the feasibility of supporting infrastructure to implement IoT-based solutions is the last activity in this phase. The authors identified problems from publications regarding the effect of using mathematical balance tools on learning outcomes and identification regarding the potential of IoT in providing opportunities for improving the quality of education and changing the character of education in the Industrial 4.0 era is conducted.

The last part of this phase is to check the feasibility of the availability of mathematical balance aids, hardware for IoT such as microcontrollers, and gyroscope sensors, the availability of internet networks in the classrooms, and the availability of electrical networks for the systems in the classrooms. After checking, the result is that all components and infrastructure are available to build an IoT-based mathematical balance teaching aid system.

B. Analysis Phase

The second phase in this research is the analysis phase which consists of three activities. The first activity is to define system functionalities based on research objectives, the second is to determine system performance, and the last activity is to determine hardware and software requirements following the specified functionality.

1) Functionalities system: System functionalities are determined based on research objectives. The objectives of this research are:

- to design and implement mathematical balance aids that students can use anywhere and anytime,
- to design and implement systems that can read and store activity results, and
- to design and implement systems that can provide real-time (i.e., the processing time in the system is less than 1 minute) and accurate feedback, and
- to be available from anywhere and anytime via the internet.

The functionality of this system is as follows:

- The system can be accessed using the internet network.
- The system has an application interface for users to interact with the system
- Mathematical balance aids integrated with IoT
- The system can send data on the results of student learning activities to the IoT platform
- The system has a database that stores student activities
- The system can identify users
- The system can evaluate activities accurately
- The system can display the evaluation results in real-time

2) Performances system: In this research, the evaluation of the system performance using accuracy parameters and delay parameters. The accuracy parameter ensures that student learning activities using mathematical balance aids are assessed correctly. This parameter is essential to determine the results of the feedback given to students. The delay parameter plays a role in ensuring it can meet Ambrose's feedback principle. Students need appropriate feedback immediately so that students can evaluate their activities.

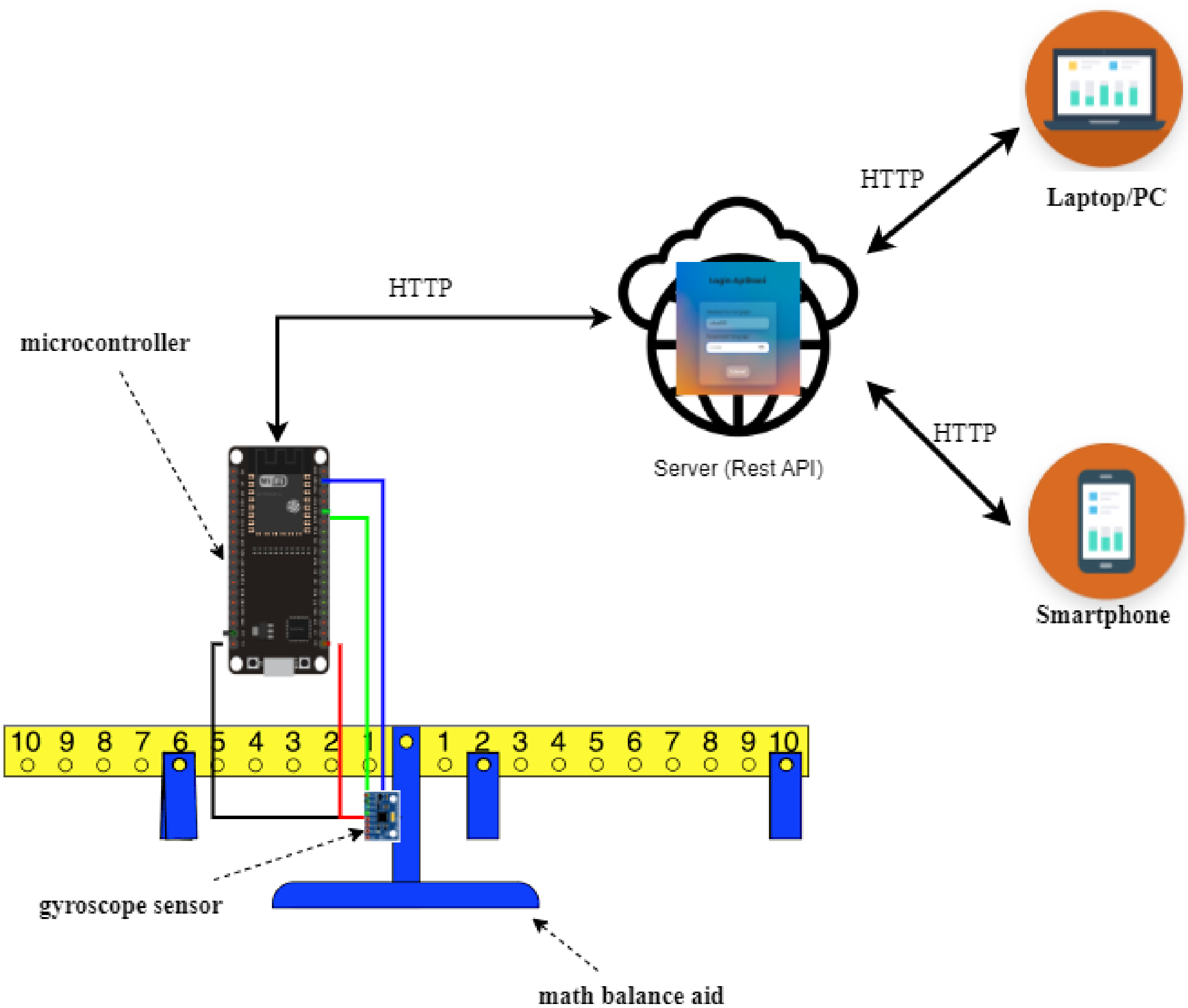

Fig. 2. Architecture System.

3) Hardware and software requirements: Based on the functionality and performance of the system that has been determined in the previous stage, at this stage, the requirements for hardware and software are defined. The hardware and software requirements to build an IoT-based mathematical balance teaching aid system are shown in TABLE I.

TABLE I. HARDWARE AND SOFTWARE REQUIREMENTS

Type	Component Name	Description
Hardware	Math balance Aids	Learning aids to support students learning about arithmetic operations
	Sensor gyroscope	Device for maintaining and measuring X-axis and Y-axis of math balance aids
	Microcontroller (with wire)	Board for receiving data and connecting math balance aids and gyroscope sensors to the application
	Battery or DC power supply	As a source of power to the system
	PC/Laptop/Smartphone	Device to access the application
Software	Web Application	An application that displays the login menu, calibrates the sensor, starts the class, and views the student's score.
	Database	An application for storing student data, grade data, class data, and teacher data
	Platform Communication	An application to connect the system to the internet network

C. Design Phase

The design phase consists of three component designs. The first component design is the system architecture. The system architecture shows how the components system and the communication between system components. The next component design is a data-flow diagram describing the developed application's data flow. Database design is the third component that shows the tables and the relationships between these tables.

1) Architecture system: Fig. 2 shows the system architecture for the IoT-based mathematical balance aids. In the system architecture, there are three components. The end node component consists of a mathematical balance teaching aid, gyroscope sensor, microcontroller, and wire. This component is used for student learning activities. The communication component consists of protocol communication (in this research use HTTP and TCP communication protocols). The website-based application is the last component, which functions to access and display student data, class data, grade data, and teacher/user data.

2) Data flow diagram: The data flow diagram shows the activity or operation of the system based on the data flow. The data flow diagram becomes a reference for designing the database. Fig. 3 shows the data flow diagram in this study, which consists of four functions: login, calibrate the sensor, start the class, and view student scores. In the login function to secure user/teacher data, the system provides additional functionality for credential data.

3) Database design: Database design refers to the data-flow diagram. This research designed the database to store data on student identity, student grades, classes, and users (teachers), and designing relationships between tables. The database label using the Indonesian language. In Indonesian, "murids" means student, "nilai" implies score, and "kelas" means class. There are two collections in the database design. The "murids" collection consists of two tables, namely the "murids" table and the "nilai" table.

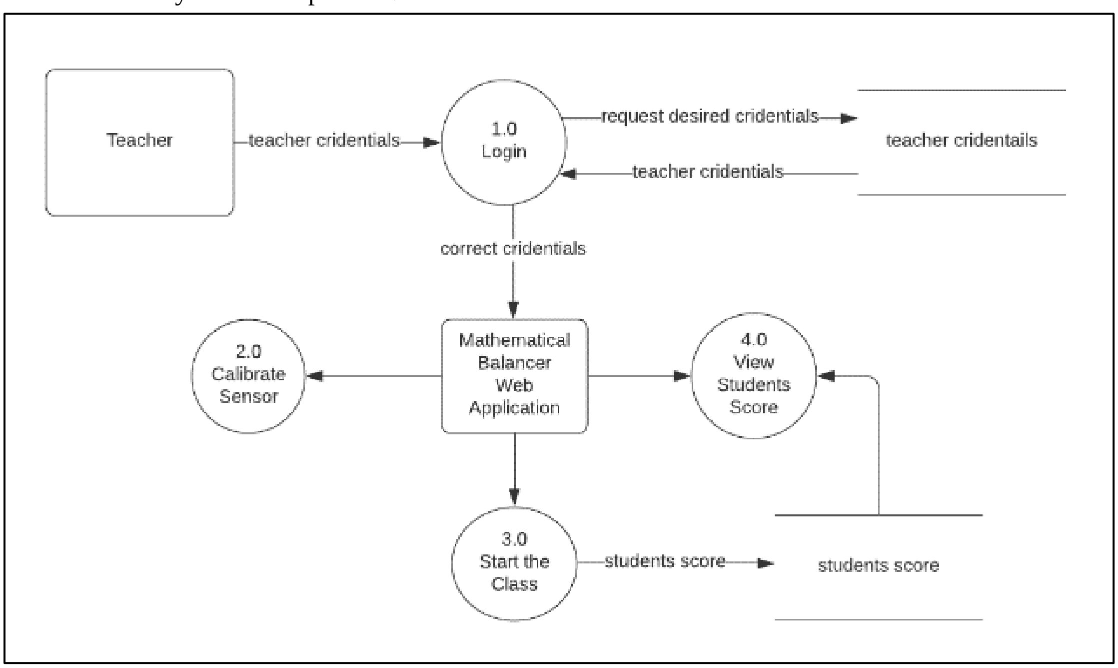

Fig. 3. Data-Flow Diagram.

The "murids" table stores student data such as name, age, and grades. The grades table has a date column, the number of grades (which contains the accumulated student activity grades) column, and the _id of the student column. In the "kelas" collection, there are two tables: the class table and the users' table. “Kelas” table store all registered student ids. The “kelas” table is related to users (or teachers). A user can relate to several different classes. Especially for table users, for data security, this research use salt and hash columns. The database design is shown in Fig. 4.

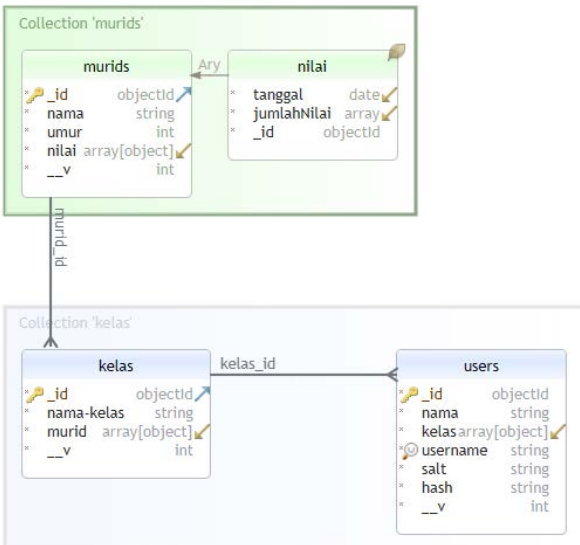

Fig. 4. Database Design.

D. Implementation Phase

The authors implement the system based on the design phase results in the implementation phase. There are three stages of implementation: hardware implementation, software implementation, and system integration. Hardware implementation describes how the author installs the hardware components of the IoT hardware and math balance aids.

The software implementation phase describes the stages of building software components. The stages of software implementation start from creating application interfaces, creating databases, and connecting application interfaces and databases. After the hardware and software components have been successfully implemented, the next step is integrating the two components. The discussion of system implementation is discussed in detail in Section III.

E. Evaluation Phase

The system's functionality and performance is tested in the evaluation phase. System functionality is tested by checking the suitability of system functionality with functionality in the analysis phase. Performances evaluation measures accuracy and delay. Accuracy is evaluated by comparing the student's answers with the expected answers, while for the delay, it will calculate the activity processing time. The author use test cases to evaluate system performance using 10, 100, and 1000 requests per second. A discussion of the evaluation phase is presented in Section IV.

IV. System Implementation

A. Hardware Implementation

Hardware implementation refers to the system architecture in Fig. 2. In implementing hardware components, the first step is to provide mathematical balance visual aids, gyroscope sensors, microcontrollers, wiring, power source support, and other required supporting components. The next step is to combine and configure the math balance aids with the gyroscope sensor. In a static position, all the gyroscope sensor's x, y, and z axes must have a value of 0. After the static position is obtained, the next step is to identify the pinout on the gyroscope sensor (in this study, the type of gyroscope sensor used is MPU6050), such as pins for power, pin for ground, pin for I2C communication, pin for I2C address, and an interrupt pin.

The next step is to prepare the Arduino IDE to program the microcontroller (in this study, the system uses ESP32). Prepare the libraries needed to integrate the ESP32 with the MPU6050 sensor module. After all the libraries have been prepared, the ESP32 and MPU6050 are integrated with the designed schematic diagram. The program is written on the ESP32 to read the axes and accelerometer from the gyroscope sensor. In this step, must ensure that under static conditions, the value of all axes is zero, and the acceleration value on the z-axis approaches the gravitational force value of 9.8 m/s2. For the x and y axes, the value is 0. If there is still a discrepancy in the value, it is necessary to calibrate the sensor.

The mathematical balance aid is integrated with the gyroscope sensor. The system sends data to the internet network to be stored in the system database. Communication between the website and the microcontroller is two-way communication. The system allows setting the gyroscope sensor calibration via the website. The math balance aid is integrated with the gyroscope sensor to read the x, y, and z axes. The system assesses students' answers based on changes in the angle of the gyroscope sensor. The results of the system implementation are shown in Fig. 5.

Fig. 5. Implementation Hardware for Math Balance Aids Integrated with IoT.

B. Software Implementation

The data flow diagram in Fig. 3 is the basis for implementing the software or application in this study. From the data flow diagram, the authors create an application interface design. Website-based applications allow users to access applications via the internet with various types of devices, such as personal computers, laptops, smartphones, or tablets. In this study, the application was built using node.js. The system implementation results are shown in Fig. 6 (a-d).

Fig. 6. (a) Login Page, (b) Calibration Page, (c) Start Class, (d) View Student Score.

Fig. 7. Database Implementation on MongoDB.

Fig. 6 (a) shows the display of the login page. Teachers use the login page to manage class activities for learning mathematical operations using IoT-based mathematical balance aids. Fig. 6 (b) shows a page for performing an application-based scale calibration. Before starting an activity, the teacher must calibrate the device to ensure the device is in a static state. After the class is started by the teacher, the display that appears in the application is Fig. 6 (c). At this stage, students carry out learning activities using IoT-based teaching aids. After completing the learning activity, Fig. 6 (d) shows the results obtained by the students. The database system is built based on the database design described at the design stage. The database system was built using the MongoDB application. Fig. 7 shows the implementation of the database according to the database design. After the interface and database have been successfully implemented, the next step is to integrate the two components.

C. Integration System

The microcontroller has a significant role in the integration process. The microcontroller stores the angle change data on the gyroscope sensor and sends it to a system that has been hosted online. So that student activity data can be accessed by users using various devices via the internet. The implementation phase is complete when all data can be read, stored, processed, and accessed according to the system design.

V. Evaluation and Discussion

This section discusses the evaluation of the system applied in the previous section. This section discusses the potential for improving the systems that have been built and the opportunities for developing IoT-based learning systems in education in the future.

A. Evaluation Phase

1) Functionaliy evaluation: This stage evaluates the functionality that has been defined in Section 2.2.1. The evaluation was conducted by measuring the achievement of functionality in the system. The summary of achieving the functionality defined by the system functionality is shown in Table II.

Testing of website functionality and website menus is carried out using the test case method. The test results for each website's functionality and website menu are shown in Table III.

TABLE II. SYSTEM FUNCTIONALITIES

No	Functionalities	Implementation
F1	The system can be accessed using the internet network.	The authors build a website-based software system so that it can be accessed via the internet and can be accessed with various devices such as personal computers, laptops, or smartphones. The interface of the system is shown in Fig. 6.
F2	The system has an application interface for users to interact with the system	The system has an interface that allows users to perform interactions such as logging in, calibrating teaching aids, starting class activities, and viewing student grades. As shown in TABLE III.
F3	Mathematical balance aids integrated with IoT	Mathematical balance aids are successfully integrated with IoT. System integration with IoT can be seen from the system architecture in Fig. 2. and the system implementation in Fig. 5.
F4	The system can send data on the results of student learning activities to the IoT platform	The results of arithmetic operations learning activities using IoT-based balance aids can be sent to the IoT platform as shown in Fig. 6(d).
F5	The system has a database that stores student activities	The authors implement the database based on the database design in Fig. 4., and the results of the database implementation are shown in Fig. 7.
F6	The system is able to identify users	The system checks the login process to ensure that only authorized users can log in to the system and send error message notification. An example of a login process that does not meet system authentication is shown in the figure
F7	The system can evaluate activities accurately	The system can process the input into the output of the assessment system, as shown in TABLE IV.
F8	The system is able to display the evaluation results in real-time	The system can process the assessment results in real-time with the specified number of requests, as shown in TABLE V.

TABLE III. TEST CASE FOR WEBSITE PAGE FUNCTIONALITIES AND THE TEST RESULTS

No	Functionality	Test Case	State
1	Login	Verify credentials	succeed
2		Sending error message if the credentials are incorrect	succeed
3	Calibrate Sensor	Checking connection from the microcontroller	succeed
4		Sending error message if microcontroller is not connected properly	succeed
5		Generate the angle of inclination value from the microcontroller	succeed
6		Calibrate the sensor and make sure the angle of inclination is 0 radian	succeed
7	Start the Class	The teacher can choose a class to teach	succeed
8		The class name provided by the system is the same as the teacher signed at	succeed
9		The teacher able to start the class after providing class name and the current date	succeed
10		The system only able to process number from zero to ten	succeed
11		The angle of inclination from each student microcontroller are displayed correctly	succeed
12		The system sends the angle of inclination value to database	succeed
13		The system would show error message if the data failed to be sent to database	succeed
14	View Students Score	The teacher can choose a class where he teach	succeed
15		The class name provided by the system is the same as the teacher signed at	succeed
16		The system can process and evaluate the final students score correctly	succeed
17		The system can export the scores to a .xls file	succeed

2) Performance evaluation: There are two aspects to evaluating system performance. The first is to test and evaluate the accuracy between the results obtained from the angle of inclination of the mathematical balance aids with the expected result. The tolerance limit for the angle of inclination in this study was 0.14 degrees. For answers with angles below or equal to 0.14 degrees, the value is 1. In contrast, at angles that exceed the limit, the value is 0. The results of the device testing for five types of questions given to eight children got the results as shown in TABLE IV. For question number one, there is a question of adding the number one to number 2. On one side of the balance tool arm will be given a load on the number 1 and number 2. The student's task is to put the burden on a certain number that is the answer to the question. When a student puts a load on a specific number, and the inclination angle exceeds 0.14 degrees, the student's response is worth 0. The result of this answer is then compared with the expected result. If both the result and expected result are the same, then the tool assesses the answer accurately. For example, a student named Vino Hakim gave an answer that caused an angle of inclination of 0.04 degrees so that the result is worth 1, when compared to the expected result, which is worth 1, so the authors give a valid status.

TABLE IV. ACCURACY OF IOT-BASED MATH BALANCE AIDS

Question	Student	Angle of Inclination (degrees)	Result	Expected Result	Status
1 + 2	Vino Hakim	0.04	1	1	Valid
	Nurul Hasanah	0.09	1	1	Valid
	Violet Mayasari	0.2	0	0	Valid
	Ulya Hartati	0.13	1	1	Valid
4 - 3	Endah Riyanti	0.02	1	1	Valid
	Adinata Mansur	0	1	1	Valid
	Kuncara Januar	0.07	1	1	Valid
	Ilsa Hartati	0.14	1	1	Valid
3 x 2	Vino Hakim	0.17	0	0	Valid
	Nurul Hasanah	0.15	0	0	Valid
	Violet Mayasari	0.31	0	0	Valid
	Ulya Hartati	0.07	1	1	Valid
4 ÷ 2	Endah Riyanti	0.02	1	1	Valid
	Adinata Mansur	0.32	0	0	Valid
	Kuncara Januar	0.12	1	1	Valid
	Ilsa Hartati	0.02	1	1	Valid

The following evaluation is to measure system delay. In this study, the system delay is calculated from the time of reading data from the gyroscope sensor to the microcontroller to accessing the user's device using the internet network. This study uses a simple architecture from one mathematical balance aid to multiple user devices to measure the delay time. In the microcontroller, the authors set the data reading from the gyroscope sensor to 10 milliseconds, and the connection delay from the microcontroller to the WIFI is one second. The speed of WIFI is approximately 10 Mbps. This configuration sends one hundred data from the sensor to the website in less than two seconds. The next is the measurement of a delay from the website to the user's device. By using a web performance test, the test results for 10, 100, and 1000 requests to the system resulted in 100% completed requests and with a total time of fewer than 4 seconds, as shown in TABLE V. Total time required to read a hundred data from the sensors to the application with 1000 requests in less than 10 seconds.

TABLE V. PERFORMANCE TEST RESULTS

Requests	Total Errors	Completed Request	Request/s (per second)	Total Time
10	0	10	97	0.10s
100	0	100	216	0.46s
1000	0	1000	276	3.6s

B. Discussion

The modification of the IoT development method proposed by Fahmideh and Zowghi in this study provides a comprehensive guide for developing IoT-based teaching aids. This study used the development method to build math balance aids to help students learn arithmetic operations. The development of an IoT system based on mathematical balance aids with the proposed method shows the successful integration of mathematical balance aids and IoT functionality to achieve the three characteristics of education 4.0: remote access, personalized learning, and practice and feedback.

Fahmideh and Zowghi's IoT development method does not discuss the specifics of IoT implementation in certain fields. The modification of Fahmideh and Zowghi's method in this study is specifically intended for the field of education. The method proposed in this study provides guidance in identifying the need for IoT integration with education 4.0. In the future, the method in this research can be used to implement IoT with teaching aids at various education levels and various subjects or courses.

Although this study succeeded in building a prototype of an IoT-based math balance aid in accordance with each phase of the proposed method, several limitations have not been resolved in this study. From the aspect of durability and hardware packaging, the system still has to be developed to be more robust. The gyroscope sensor must be corrected in several tests to obtain valid results. In future, research that examines the durability and packaging of the system will be necessary. From the software aspect, applications must be developed by considering aspects of the user interface (UI) and user experience (UX). There is potential for UI/UX development to develop applications for IoT systems by considering user personas and human factor considerations so that the resulting application is an application that is easy, interactive, and convenient for users (teachers, students, and education staff) [31].

Furthermore, from the educational aspect, application development is integrated with existing educational applications to provide comprehensive feedback data. Integrating the system with data science or artificial intelligence to improve the quality of feedback based on student learning activity data is a future research opportunity [32]. Gamification can be combined with the system to increase student motivation or engagement. There are still many opportunities to conduct research on gamification in IoT, especially for education and industry 4.0 [33]. This research is still being tested on a laboratory scale. It needs to be tested in the classroom to determine technology acceptance by teachers, students, or academic staff. This research also provides an opportunity to examine the impact of the system on student learning outcomes. Another aspect that is not discussed in this study is the aspect of data security and privacy. Based on various studies, the security and privacy issue in IoT is one of the biggest challenges in IoT implementation [11], [34], [35]. Activity result data is published on the internet network, which has an impact on the emergence of opportunities for theft or use of data by unauthorized parties.

VI. CONCLUSION

In this study, an IoT-based mathematical balance tool has been successfully developed to support arithmetic operational learning for elementary school students in Indonesia. The purpose of implementing IoT in teaching aids in this study is to design education that supports education 4.0. This study proposes an IoT development method modified from the method proposed by Fahmideh and Zowghi. The IoT development method consists of five stages. The proposed IoT development method defines each stage comprehensively. The first stage is the initialization stage, which identifies research problems, conducts related literature studies, and identifies the feasibility of supporting infrastructure. The second stage is the analysis stage with the following objectives: defining system functionality according to research objectives and defining system performance based on system accuracy and delay. The third stage is the design stage, to determine the requirements for hardware and software. The system architecture, data flow diagrams, and database design are also designed at this stage. The results of the third stage become a reference for the next stage, namely the implementation stage. The evaluation of the system implementation showed that all functionality was successfully implemented with 100% accuracy for reading, recording, and evaluating student activities. While the results of the evaluation of the system performance show system delay for 1000 requests is less than 10 seconds.

ACKNOWLEDGMENT

This work is supported by internal funding from Telkom University.

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