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DEVELOPMENT OF STM32-BASED LINE FOLLOWER ROBOT TRAINER LEARNING MEDIA IN VOCATIONAL HIGH SCHOOLS

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ABSTRACT

This study aims to develop and determine the feasibility of a line follower robot trainer learning media based on STM32 for the subject of Robotic System Control in the Industrial Electronics Engineering Expertise Program at Vocational High Schools in Sampang Regency. The research method used is the ADDIE Research and Development method proposed by Robert Maribe Branch, which includes analyze, design, development, implementation, and evaluate phases. The analyze phase was conducted to obtain the results of the need for learning media that can improve student learning outcomes. The design process was carried out to design electronics such as controllers, sensors, and actuator drivers that are appropriate for the application in Vocational High Schools in Sampang Regency. At the development stage, researchers used the waterfall development method (requirements, Design, Implementation, Verification, and Maintenance) to determine the components, mechanical design, software programs, and to test the line follower robot system. In the implementation phase, a feasibility test was carried out by media experts and direct learning on class XII with a total of 62 participants, including students from the industrial electronics engineering program at Vocational High Schools, Sampang Regency, The evaluate stage used a questionnaire instrument with a four-choice Likert scale to measure respondents' perceptions of the STM32-based line follower robot trainer. The results of the feasibility study of the STM32-based line follower robot trainer learning media are reviewed from two aspects, namely: (1) The quality aspect of the media which obtained an average score of 22.34 in the "WORTHY" category, and (2) The material quality aspect which obtained an average score of 28.51 in the "WORTHY" category. Therefore, the STM32-based line follower robot trainer learning media is suitable for use as a learning medium for the Robotic System Control subject. The results of the pretest and posttest trials show that student learning outcomes can increase by 76.8% after going through STM32-based line follower robot trainer training at Vocational High Schools in Sampang Regency..

Keyword : *ADDIE, Trainer Robot Line follower, Learning Media, STM32*

1. INTRODUCTION

Advancements in digital technology have significantly supported teaching and learning activities during the pandemic that occurred in the last two years. It is undeniable that technological progress has a positive effect on Indonesian students, especially those studying at SMK Negeri 1 Tambelangan (Daryanto, 2010). While students can access additional information on the internet, it is important to note that no matter how sophisticated technology becomes, it cannot replace the role of a teacher in providing direct instruction (Darmawan, 2014). The teacher's role in providing necessary material and guidance for students remains irreplaceable.

Based on observations conducted in several public and private vocational education institutions that offer the Industrial Electronics Expertise Program in Sampang district, the following findings were obtained: (1) The media used for instruction is still an analog line follower robot trainer and has not yet been upgraded to a microcontroller-based line follower robot trainer (Fahmi & Zuhrie, 2021), (2) Students exhibit a lack of caution during practical sessions as they are more accustomed to working with analog line follower robot trainers (Harianto & Santosa, 2019), and (3) Most students do not have access to laptops, and the allocated learning time is not sufficient, resulting in boredom and monotonous learning experiences due to inadequate instructional media (Sujito et al., 2022). These results indicate a "Learning Loss" in terms of learning media infrastructure, wherein the learning media used by teachers fall short of expectations, resulting in stagnant student learning outcomes (Sadiman, 2011).

There have been several developments in line follower robot trainers, ranging from analog line follower robots to microcontroller-based line follower robots (Fathurrohman, 2014). As researchers, we have observed that the development of line follower robots has evolved from using ATMEL microcontrollers to Arduino, and now, with the advancement of technology in the era of Industry 4.0, 8-bit microcontrollers have been replaced by 32-bit microcontrollers in line follower robots. Therefore, in developing line follower robot learning media, we have chosen to use a 32-bit microcontroller, specifically the ARM Cortex 32 (STM32) microcontroller (Setiawan, 2011).

Based on the presented facts, the following problem formulation is obtained: (1) How to develop a line follower robot trainer device based on STM32 for student learning in Vocational High Schools? (2) How does the STM32-based line follower robot trainer function as a learning medium for Robotic System Controllers in Vocational High Schools? (3) To what extent does the presence of a line follower robot trainer based on STM32 increase student learning outcomes in the subject of Robotic System Controllers in Vocational High Schools? and (4) How feasible are the line follower robot trainers based on STM32 for learning Robotic System Controllers?

2. LITERATURE REVIEW

2.1 Research and development

According to Sudjana and Ibrahim (2013), research essentially seeks answers to problems that require correct, or at least logically close, answers based on human reasoning supported by empirical facts. The essence of research is viewed as a systematic effort to address problems through specific methods that involve collecting empirical data and drawing conclusions. Based on this understanding, it can be concluded that research is a controlled study, as it involves two elements: (a) an explicitly stated logical thinking process, and (b) the systematic and empirical collection of in format. Branch (2009) developed a theory of ADDIE-based

development known as the ADDIE-Based Systems Development Model. This model consists of five stages of development: Analysis, Design, Development, Implementation, and Evaluation.

The Analysis stage involves gathering the necessary information and data to identify the problem and objectives to be achieved. This stage includes needs analysis, context analysis, and target analysis.

The Design stage involves designing a solution that fits the identified problem and objectives. This stage includes instructional design, media design, and technology design.

The Development stage involves developing a pre-designed solution. This stage includes the development of learning materials, media, and technology.

The Implementation stage involves implementing the previously developed solutions. This stage includes the implementation of learning materials, media, and technology.

The Evaluation stage involves evaluating the previously implemented solutions. This stage includes the evaluation of learning materials, media, and technology. This evaluation is used to assess the success of the solutions that have been implemented and determine corrective steps for future solutions.

2.2 Learning Media

The term "media" comes from the Latin word "medius", which means "middle" or "intermediate". In Arabic, media refers to an intermediary or message delivery system from the sender to the recipient of the message (Arsyad, 2011).

According to Arief & Sadiman (2011), media refers to all physical tools that are capable of presenting messages and stimulating students to learn. However, experts have put forward several limitations regarding media, including one from the Association of Education and Communication Technology (AECT) in America, which limits media to all forms and channels that people use to convey messages or information.

2.3 STM32 Based Line Follower Robot Trainer

The STM32-based Line Follower Robot Trainer is a practicum module that implements a simple mobile robotic system widely used in the manufacturing industry. The practicum trainers are composed of several electronic devices, as follows:

a. Input devices: Photodiode sensor module, push button, and linear potentiometer.

b. Output devices: LM293D Driver Module, DC Motor, and LCD.

c. Process devices: STM32 Microcontroller Module.

In addition to the mentioned devices, the trainer is equipped with a serial communication port with the STM32 microcontroller for programming.

3. METHODS

The research method that we use to develop the STM32-based line follower robot trainer learning media is the ADDIE model, Branch (2009). The development research procedure broadly adopts the ADDIE steps described by Branch in his book "Instructional Design: The ADDIE Approach." The steps aim to introduce the ADDIE approach as the basis for the process of creating effective learning resources (Branch, 2009).

3.1 Development stages

The development stages in this study used the ADDIE method. The stages are as follows: Stage (1) Analysis, which was carried out by observing the field. The series of observation activities included direct observation of the teaching and learning activities and observing the students' activities in class.

Stage (2) Media design is the process of designing learning media in the form of practicum trainers to help understand the concept of mobile robotic systems. The learning media is designed in the form of a trainer kit that contains several compact component modules for different control processes. The block design of the line follower robot trainer kit includes: (a) Sensor control system, (b) DC motor driver control system, (c) Robot mechanical design, and (d) Software design.

Stage (3) is Development, which involves creating or developing learning resources and validating them. This is the actual stage of working on learning resources, and researchers carry out three research steps as follows: (a) creating line follower robot trainer media to support learning strategies, (b) creating teaching modules using the line follower robot trainer media, and (c) performing formative revisions.

The (4th) stage is Implementation, which involves applying the line follower robot trainer media as a learning medium. The implementation of the line follower robot trainer media as a learning medium is applied to class XII in the field of industrial electronics engineering expertise at SMK Negeri 1 Tambelangan. At this stage of implementation, there are five steps taken, namely preparing teachers, preparing students, distributing operational trainer modules, conducting media training, and providing job sheets.

The last stage is the (5th) Evaluation stage. In this stage, the researchers carry out three evaluation steps, namely: determining the evaluation criteria, selecting evaluation tools, and conducting evaluations. The researcher chooses perception evaluation as the evaluation criterion. The second step is to select the evaluation tool, for which the researcher chooses a questionnaire with a four-choice Likert scale. The third step is to conduct the evaluation by giving questionnaires to students after using the line follower robot trainer for three sessions. The results of the questionnaire will be used for the final improvement of the trainer kit. After making improvements in the evaluation stage, the development process of the STM32-based line follower robot trainer learning media is complete.

3.2 Product trials

In this study, we used a pre-experimental research design with a one-shot case study, which is a research design used to investigate a line follower robot based on STM32. This design was chosen because only one study group was used and there was no comparison with other groups to determine the increase in student learning outcomes after using the trainer media and teaching modules (Emzir, 2015).

This research will be conducted at several Vocational High Schools in Sampang Regency from August 2022 to November 2022. The test subjects will be students from class XII in the field of industrial

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electronics engineering expertise, including SMK Negeri 1 Tambelangan, SMK Negeri 1 Sampang, and SMKS Darul Ijtihad.

3.3 Instrument

As suggested by Arikunto (2010), research instruments are tools or facilities used by researchers to collect data, making their work easier and resulting in better outcomes. This study requires measurements of the level of media feasibility and students' mastery of the material. The instruments used in our research on the development of line follower robots are as follows: (1) instruments for measuring the level of feasibility of learning media. These instruments consist of three aspects: usability, hardware and software engineering, and visual communication (Arsyad, 2011).

Regarding the instrument for learning material, it consists of two aspects: the relevance of the material and the technical aspect of the media. To measure students' mastery of the material, we use test instruments in the form of multiple-choice questions that students must answer. Tests are given before and after the implementation of learning with media in the form of product development results (pre-test and post-test) (Putro, 2009).

3.4 Data collection

The data collection techniques used to obtain the data needed for the research were observation and questionnaire methods. These data were then analyzed to answer the research problems. Susilana (2008) suggests the use of questionnaires as one of the methods for collecting data.

3.5 Data analysis method

The data analysis methods used in the research on the development of STM32-based line follower robot are as follows: analysis of feasibility data, analysis of pre-test and post-test, and analysis of learning outcomes (Sudjana and Ibrahim, 2013).

4. RESULTS & DISCUSSION

4.1 Development results

The development model used in the development of STM32-based line follower robot trainer learning media is the ADDIE development research approach. The ADDIE model's stages include analysis, design, development, implementation, and evaluation. In the analysis stage, researchers obtained data based on observations and interviews that were analyzed using a qualitative approach method. Several need analysis problems were identified, including the need for a reliable microcontroller to process analog data from the photodiode sensor, which later will be displayed on a 16x2 LCD display and for DC motor control. The researchers also identified the need for a program that is easily understood by Vocational High School students with competence in Industrial Electronics Engineering. Furthermore, there is still limited learning media in the form of teaching modules that use analog line follower robot teaching modules.

Design is the planning stage, which refers to the development of the Trainer design for teaching Robotic System Controllers at Vocational High Schools in Sampang Regency. The results of this design stage include hardware design, software design, and teaching module design. The hardware design consists of controllers, sensors, driver actuators, and robot mechanics. For the controller, we use the STM32 module with the Arm Cortex-M3 microcontroller, as shown in Figure 1.

Figure 1.
STM32 Module

The sensors utilized in the STM32-based line follower robot are photodiode sensors. Figure 2 shows the result of the sensor design using the STM32 module.

Figure 2
Sensor and STM32

The driver is used to activate the DC motor control. The DC motor driver system uses the H-Bridge system. The actuator driver with the H-Bridge system is found in the L298N driver module, which can be seen in Figure 3.

Figure 3
Driver and STM32

A 2D CAD program was used in the mechanical design of a line follower robot based on STM32. Mechanical design is necessary to plan the appearance of the robot in such a way as to produce a compact design. This can be seen in Figure 4.

Figure 4
Mechanic Robot

The software design for the line follower robot based on STM32 uses the C++ programming language, as shown in Figure 5.

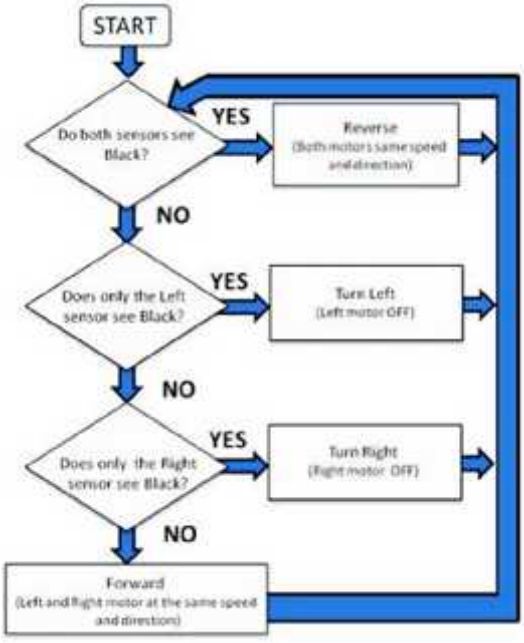


Figure 5
Flowchart

The design of teaching modules for students on line follower robot trainers based on STM32 includes: (1) Introduction to line follower robots, (2) Line follower robot design, (3) Installation and operation of line follower robot drivers, (4) Line follower robot worksheet, and (5) Pre-test and post-test questions.

Development, is the stage of creating a line follower robot trainer based on STM32. At this stage, three activities are carried out, namely (1) hardware installation, (2) programming, and (3) creation of teaching modules. Hardware installation involves assembling all robotic hardware according to the design specified in the robot's mechanical planning. In this line follower robot trainer, components such as the STM32 controller, I2C LCD 16x2 circuit, and battery are placed above the robot body with a height of 2 cm, while the DC motor and L298N module are placed directly above the robot body to make the robot appear compact. The line sensor module, which consists of 4 photodiode sensors, is placed under the robot body so that the sensors can detect the line to be followed. More details can be seen in Figure 6**.**

Figure 6.
Hardware installation results

Making a program for the STM32-based line follower robot trainer using C++ is done with the Arduino software. The choice to use Arduino software is because it is open source, which means designing the software will not be constrained by licenses. The programs embedded in the STM32-based line follower robot are as follows: (1) pin configuration, (2) sensor reading program, and (3) PID motor control program. When making teaching modules, students must comply with the syllabus for Robotic System Control subjects using the 2013 curriculum.

Implementation, involves an initial testing stage that is limited and carried out by students who are selected based on their sufficient level of competence, as indicated by their report card results. Large group trials are conducted to test the feasibility of the STM32-based line follower robot trainer. This is done to evaluate the trainer's performance in a real-life situation. The large group trial is conducted with the participation of Class XII students in the field of industrial electronics engineering at vocational high schools for the subject of robotic system control.

Evaluation, involves product evaluation after small group and large group trials (field trials). The data obtained comes in the form of suggestions to correct deficiencies in the STM32-based line follower robot trainer media. Some student responses regarding the media's shortcomings include the robot making sharp turns to the left or right, an unclear work system, and the need for a better explanation of the adjustment buttons for turning right, left, and straight.

4.2 Product evaluation results

The data obtained from the product evaluation can be used as material for revising the STM32-based line follower robot trainer media. The revisions were based on suggestions from media experts, subject matter experts, peer reviewers, and students.

Data validation, results show that the media expert's assessment was based on three aspects: utilization, engineering, and visual communication. From the assessment of these three aspects, it was determined that the average total score of the media expert feasibility test was 85.5 in the "Very Worthy" category. This was based on the evaluation of one teacher who was the chairman of the electronics MGMP in Sampang Regency and one subject teacher supporting robotic system control. The assessment of material experts was based on two aspects: material relevance and learning media techniques. From the assessment of these two aspects, it was obtained that the average total score of the media expert feasibility test was 65.5 in the "Very Worthy" category. This was based on the

evaluation of one teacher who was the chairperson of the electronics MGMP in Sampang Regency and one subject teacher supporting robotic system control. The peer viewer assessment was based on three aspects: usefulness, engineering, and visual communication. From the assessment of these three aspects, it was obtained that the average total score of the media expert feasibility test was 83 in the "Very Eligible" category. This was based on the evaluation of two teachers who were cross-subject tutors in the competence of Industrial Electronics Engineering expertise.

The Instrument Reliability and Validity Test, involved testing the feasibility of learning media with a total of 68 respondents. The obtained t-table was 0.2012 for a significance level of 0.05. In the reliability test, the split-half method was used and the coefficient obtained was 0.983, indicating a very high reliability. Meanwhile, for the validity test, the average coefficient score for the media type was 0.591 and for the material type was 0.63. All 16 statement items were found to be valid, indicating the validity of the instrument.

Student response data: The small group trials involved five students, comprising one student from Tambelangan 1 State Vocational School, three students from Sampang 1 State Vocational School, and one student from Darul Ijtihad Private Vocational School. All of them were in class XII Industrial Electronics Engineering and served as respondents conducting an assessment of the feasibility of the STM32-based line follower robot media trainer with two assessment aspects, namely media aspects and material aspects. In the small group test, they obtained an average score of 46.6 in the appropriate category. In the large group test, SMKN 1 Tambelangan obtained an average score of 50.8, SMKN 1 Sampang obtained an average of 51.8, and Darul Ijtihad SMKS obtained an average score of 50.6. All of these educational units were in the proper category.

4.3 Learning outcomes data

To determine the improvement in student learning outcomes after conducting learning using the trainer that has been developed, operational trials were conducted on the subjects of robotic system control, involving a total of 68 students comprising 15 students from SMK Negeri 1 Tambelangan, 33 students from SMK Negeri 1 Sampang, and 20 students from Darul Ijtihad Private Vocational School. The pre-test scores for SMKN 1 Tambelangan obtained an average score of 56, while SMKN 1 Sampang and SMKS Darul Ijtihad obtained average scores of 55.47 and 52.53, respectively. Meanwhile, the post-test scores obtained average scores of 89.1 for SMKN 1 Tambelangan, 89.6 for SMKN 1 Sampang, and 89.3 for SMKS Darul Ijtihad.

4.4 Product development analysis

The line follower robot learning media was developed based on the problem formulation and the learning media needs required by the Class XII Robotic System Controller subject, which is based on the basic competence of implementing a mobile robotic system. The development was produced based on these basic competencies and the results of observations at the Sampang District Vocational High School, serving as the foundation for the development of STM32-based line follower robot learning media in the subject of Robotic System Controllers. The development of STM32-based line follower robot learning media includes: (1) the development of sensor components from the LDR-Led sensor into a more practical and reliable photodiode sensor module, (2) the use of the Cortex ARM 32 microcontroller or better known as STM32 to replace analog controllers that require an op-amp component as a comparator so that the sensor detection process is faster, (3) the use of a microcontroller to control DC motor speed with Pulse Wide Modulation (PWM) when the track is straight, turns right and turns left with a PID control system (Proportional, Integral and Differential) with settings P = 12, integral = 0 D = 30, and (4) the use of the C++ programming language using open source Arduino Ide software. The source code for the STM32-based line follower robot system can be seen in Figure 7.

Figure 7.
Development of line follower robots

4.5 Product performance

The performance of the line follower robot product based on STM32 undergoes several blocks of testing. The first block is the **sensor test**, which measures the sensor voltage when the robot follows a straight track, turns right, and turns left with the program loaded onto the controller. The measurement results show that the interval voltage for logic 0 is 0-1.5 volts, while for logic 1, it is 1.6-5 volts. Based on these data, it is found that the straight track has logic 0110, the right-turning track is 0011, and the left-turning track is 1100. The second block is the DC motor driver test, which measures the voltage input to the DC motor when the robot follows a straight track, turns right, and turns left with the program loaded onto the controller. The measurement results are presented in Table 1.

Table 1
DC motor test results

No	Track	Motor Test Results (Volts)	
		Right	Left
1	Straigh t	4,9	5
2	Turn right	3,8	2,2
3	Turn left	2,3	3,5

The testing of DC motor control, shows that the PWM (Pulse Width Modulation) value generated to rotate the motor is a linear variable for the magnitude of the position error, calculated by the PID (Proportional, Integral, and Differential) control (Fatchurrohman, 2014). The results of the test can be seen in Table 2.

Table 2
PID Testing

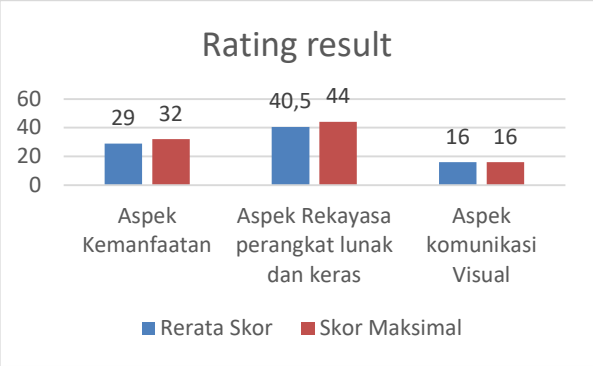
Error	P	I	D	Speed	Move	L	R	LPWM	RPWM
-11	12	0	30	110	-462	-352	572	-255	255
9	12	0	30	110	378	268	488	255	255
-7	12	0	30	110	-294	-184	404	-184	255
-5	12	0	30	110	-210	-100	320	-100	255
-3	12	0	30	110	-126	-16	236	-16	236
-2	12	0	30	110	-84	26	194	26	194
-1	12	0	30	110	-42	68	152	68	152
0	12	0	30	110	0	110	110	110	110
1	12	0	30	110	42	152	68	152	68
2	12	0	30	110	84	194	26	194	26
3	12	0	30	110	126	236	-16	236	-16
5	12	0	30	110	210	320	100	255	100
7	12	0	30	110	294	404	184	255	184
9	12	0	30	110	378	488	268	255	255
11	12	0	30	110	462	572	352	255	255

4.6 Analysis of student learning outcomes

Improving student learning outcomes in three schools with the same field of expertise in industrial electronics engineering, namely Tambelangan 1 State Vocational School, Sampang 1 Public Vocational School, and Darul Ijtihad Private Vocational School, through learning efforts using a line follower robot trainer based on STM32, resulted in a difference in the average score between the pretest and posttest. The average pre-test score was 55.41, while the post-test score was 89.71, indicating an increase of 76.88%. Therefore, it can be concluded that there is a difference in the learning outcomes before and after using the line follower robot media. The sig (2-tailed) value was .000, which is smaller than the significance level of 0.05, indicating that H0 is rejected and H1 is accepted. In other words, there are differences in the learning outcomes of vocational high school students in Sampang Regency before and after using the STM32-based line follower robot trainer.

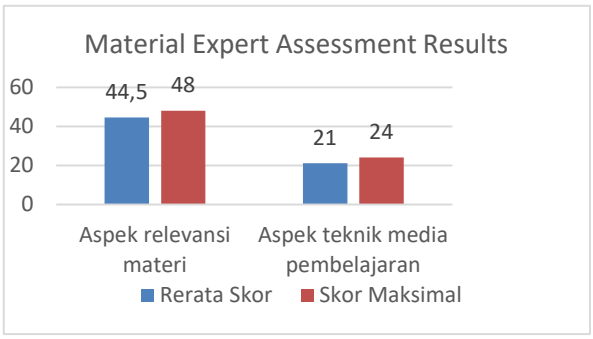
4.7 Product feasibility analysis

Based on the results of the media expert's feasibility test, it was found that the usability aspect received a score of 29 in the highly feasible category, the engineering aspect received a score of 40.5 in the highly feasible category, and the visual communication aspect received a score of 16 in the highly feasible category. These can be seen in Graph 1.



Graph 1
Media expert feasibility assessment graph

Based on the data from the material experts' feasibility test, the response results for the relevance aspect of the material received an average score of 44.5 in the very feasible category, and the technical aspects of the learning media received an average score of 21 in the very feasible category. These results can be seen in Graph 2.

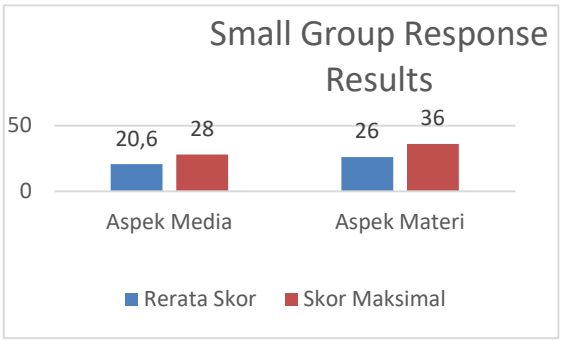


Graph 2
Material expert feasibility assessment graph

Based on the peer review data, the usability aspect received a score of 28 in the highly feasible category, the engineering aspect received a score of 40 in the highly feasible category, while the visual communication aspect received a score of 15. These scores can be seen in Graph 3.

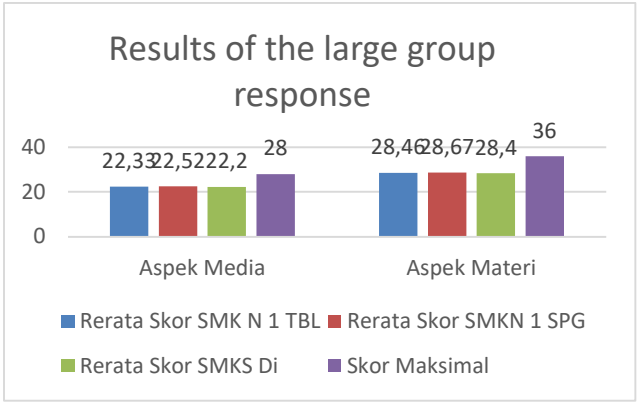
Graph 3
Peer viewer feasibility assessment graph

The small group trial involved 5 students from class XII of Industrial Electronics Engineering as respondents who conducted an assessment of the feasibility of the STM32-based line follower robot trainer media. The assessment consisted of 2 aspects, namely the media aspect and the material aspect. Based on the results of the assessment, the media aspect received a score of 20.6 in the feasible category, while the material aspect received a score of 26 in the feasible category. These results can be seen in Graph 4.



Graph 4
Small group response graph

Based on the data obtained from the large group responses, the media aspect obtained scores of 22.33, 22.52, and 22.2 for SMK Negeri 1 Tambelangan, SMK Negeri 1 Sampang, and Private Vocational High School Darul Ijtihad, respectively, with the appropriate category. Meanwhile, the material aspects obtained scores of 28.46, 28.67, and 28.4 for SMK Negeri 1 Tambelangan, SMK Negeri 1 Sampang, and Darul Ijtihad Private Vocational School, respectively, in the proper category. The results can be seen in Graph 5.



Graph 5
Large group response graph

5. CONCLUSIONS AND SUGGESTIONS

5.1 Conclusion

Based on the results of the research and discussion on the development of a line follower robotic arm media trainer based on STM32, the following conclusions can be drawn.

The development of STM32-based line follower robot trainer media was carried out using the ADDIE method, which includes analysis, design, development, implementation, and evaluation. The robot system comprises mechanical, electronic, and software systems. The mechanical system consists of the body of the line follower robot, while the electronic system comprises a Cortex ARM 32 controller, a photodiode line sensor, and a DC Motor Driver. The software system consists of PID control program code, Straight Track, and Turning Track. The line follower robot trainer is capable of making straight track movements and turning right and left where the track has been determined.

The performance of the line follower robot *trainer* media based on the test results of the sensor block, DC motor block, and DC motor control is as expected by the researchers. The voltage for the sensor block which detects black lines with straight tracks, turns right, and turns left is an average of 3.2 volts, while for the DC motor block, the output voltage is an average of 3.4 Volts for straight tracks, right turns, and left turns. The DC Motor control has a Proportional setting of 12, Integral setting of 0, and Differential setting of 30.

The use of line follower robot media has shown to increase student learning outcomes, with an average pretest score of 55.41 and an average posttest score of 89.71, resulting in an increase of 76.88%.

The feasibility of the line follower robot media trainer is based on assessments carried out by media experts, material experts, peer viewers, small group trials, and field trials. The assessment by media experts in terms of three aspects (usefulness aspect, engineering aspect, and visual communication aspect) obtained an average total score of 85.5 in the "Very feasible" category. The assessment by material experts in terms of two aspects (relevance of the material and technical aspects of learning media) obtained a mean total score of 65.5 in the "Very Eligible" category. The assessment by peer viewers in terms of three aspects (usefulness aspect, engineering aspect, and visual communication aspect) obtained an average total score of 83 in the "Very Eligible" category. The mean total score in the small group trials was 46.6 with the "Suitable" category, and the total score for the average number of field trials (large group) from three schools that had the same skill competency was 50.86 with the "Adequate" category. From the results of these trials, it can be concluded that the developed media is suitable for use as a learning medium.

5.2 Suggestion

Based on the conducted research, there are several suggestions related to the development of STM32-based line follower robot trainer media, such as:

There is a need for further development of this line follower robot trainer media so that it can be utilized in other school subjects, such as embedded systems and electronic circuit applications.

Conducting further research to improve the performance of the line follower robot trainer media, such as improving the sensor block

and DC motor control to increase accuracy and precision in following the line.

Further evaluation of the effectiveness of the line follower robot trainer media as a learning tool, including its impact on student learning outcomes and motivation.

Exploring the possibility of integrating the line follower robot trainer media into vocational and technical education programs to support the development of students' practical skills in the field of engineering and robotics.

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