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Arduino-Based Digital Line Follower Robot Trainer Design as Learning Media

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Abstract - This research aims to develop learning media in the form of an Arduino-based line follower robot trainer as a learning media in the subject of Robotic Systems at SMK. The research method used is Research and Development (R&D) with the 4D development model (Define, Design, Develop, Disseminate). The research subjects consisted of two material experts, two media experts, two SMK teachers, and ten SMK students. The research instrument used a questionnaire to measure the feasibility and practicality of the media. The results of validation by material experts obtained an average percentage of 93.33%, which is in the 'Very Feasible' category, while validation by media experts showed a percentage of 90%, also in the 'Very Feasible' category. Practicality trials by teachers scored 87.5%, and by students 85%, both of which were in the 'Very Practical' category. Based on these findings, the Arduino-based line follower robot trainer media is declared very feasible and very practical to use as learning media in supporting the learning process of Robotic Systems in SMK.

Keywords— **Line Follower Robot Trainer, Learning Media, Interactive Learning, Robotics.**

I. INTRODUCTION

The development of technology in the era of Industry 4.0 has led to significant changes in the world of education, especially in the fields of engineering and electronics. The utilization of technology-based learning media is one solution in improving student understanding, especially in the field of robotics. The industrial revolution 4.0 is marked by technological developments, one example of this technological development is the Internet of Things (IoT) [1]. The industrial revolution 4.0 is an era where the existence of machines is massively utilized to ease human work. From time to time these machines are then developed as needed so that they can cover various fields including in the field of information and communication technology [2].

Along with the rapid innovation and development of technology, people have now switched from various manual systems to more practical and flexible systems. The presence of several technological instruments makes modern society put a point of dependence on all components [3].

The utilization of digital technology in learning has proven to be effective in improving understanding. Therefore, the development of an Arduino-based line follower robot trainer is expected to be an innovative solution in increasing the effectiveness of learning robotic systems. A trainer is a set of equipment used in a laboratory as an educational medium that combines working models and mock-ups. Trainer is a series of learning media consisting of devices or tools teaching aids and practicum modules used to support practicum or training activities in the field of education [4].

This trainer helps students gain hands-on experience in understanding technical concepts, which cannot be obtained through conventional methods. The constructivist learning model applied in the development of this trainer. The line follower robot trainer allows students to design, assemble, as well as test their own robots, thus supporting the experiential learning process. Trainers have an important role in practice-based learning. Technology-based learning kits can increase student engagement in understanding engineering and science concepts. With interactive learning kits, students can conduct hands-on experiments and develop their technical skills.

With this robot trainer, students or pupils will not only learn the theory of sensors, logic control and programming, but also apply it in real form. It promotes active learning where students are directly involved in the process of exploration, problem solving and evaluation of work results.

In addition, the use of this trainer supports a project-based learning approach. Students are challenged to design, build and test digital lines that not only enhance cognitive and psychomotor skills, but also influence character traits such as teamwork, perseverance and critical thinking. The purpose of making trainers is to support student learning in applying the knowledge of concepts obtained in real situations [5].

A trainer is a collection of actual components and tools or a duplication of the actual ones that can provide direct experience. Trainer means objects that can train, teach and educate. The trainer is flexible and can be developed according to curriculum requirements to support customized learning processes based on competency services. Digital

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trainers are composed of several units and different circuits that cover the subject matter in the field of digital engineering. In addition, teaching aids have a function to facilitate understanding of learning materials, where abstract materials are usually difficult for students to understand without the help of teaching aids [6].

Using an Arduino-based digital line follower trainer as a learning medium greatly contributes to enhancing the quality of the teaching and learning process, particularly in engineering and technology fields. Learning motivation is a conscious effort to stimulate, direct, and sustain a person's behaviour toward achieving specific goals [7]. Arduino offers an open-source, low-cost platform that enables students to build and test embedded systems projects. These microcontrollers allow for rapid prototyping and experimentation, helping students grasp fundamental principles of automation and control. By integrating Arduino into the classroom, educators can create a bridge between theoretical knowledge and practical application, making complex and technical material more accessible and understandable for students.

Furthermore, Arduino has become a foundational platform in robotics development due to its user-friendly programming environment and compatibility with various sensors and actuators. From an educational standpoint, this kind of learning tool aligns with the demands of the industrial revolution era, where technological and programming competencies are increasingly vital. Technology-based educational innovations also promote more inclusive access to learning opportunities by overcoming geographic and economic limitations. As a result, students worldwide can engage with high-quality educational content without needing to be physically present, fostering a more equitable and modern educational landscape [8].

The learning media is everything that can turn the message through various means, such as turning the mind, the mind, and the mind of the student so that it can encourage the creation of an effective learning process to turn the informalization of the student's self so that the learning objectives of the learning media can be achieved by turning the message back [9].

Learning media are a means by which the achievement of learning objectives can be supported. Digital learning media improve student motivation, interactivity, and comprehension compared to static learning materials. In learning, this robot will be used as learning media. This robot works on the basic principle of detecting color differences between black and white lines. Robotics projects serve as an ideal medium for vocational students to learn programming, electronics, and mechanical integration. The photodiode sensor will provide a digital signal to the microcontroller which then processes the signal to drive the motor. Photodiode sensors are commonly used in line follower robots due to their reliability in detecting light contrast for line tracking [10].

II. Method

The type of research used is development research/R&D (Research and Development). The research and development method is a research method used to produce certain products and test the effectiveness of certain products.[10] This development model was developed by Sivasailam Thiagarajan, Dorothy S. Semmel, and Melvyn I. Semmel in 1974. The 4D model is a development model that can be used to develop various types of learning media [11].

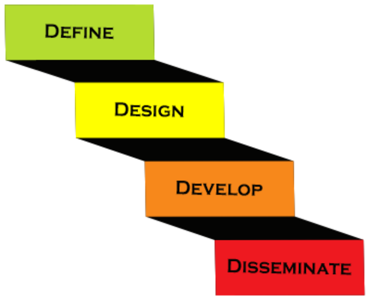

Fig 1. 4D development model

Based on figure 1 The development of the method that researchers will use is the Four D (4D) Model. This 4D model has 4 stages, namely, Define, Design, and Development and Dissemination.[12] This model was chosen because it has the advantages of being very suitable for the development of learning devices, expert validation, and the stages of implementation are divided in detail. The 4D model is considered systematic, suitable for technology-based learning media development, and has been widely used in various research and development in the field of education.

This research aims to produce a certain product, in this case in the form of [mention the product, for example: interactive learning media, learning modules, or digital-based student worksheet], and at the same time test the feasibility and effectiveness of the product in improving the quality of learning at the Define stage, observations were made to identify problems in learning robotic systems. The results of the observation showed that the previously available trainers were permanent and did not allow students to disassemble and reassemble, so they did not support their practical understanding.

Furthermore, at the Design stage, the trainer is designed using Arduino Nano as a microcontroller, photodiode sensor as an input system, and DC motor controlled by L293D motor driver as an output system. Product testing is done in two ways, namely product performance testing and product usage testing. Product performance testing is to test all components in the trainer whether they are running properly or not. Product usage testing is intended to determine the level of validity and practicality of the Arduino-based mobile robot line follower trainer that was developed. Validity testing is carried out in two parts, the first is content validity carried out by expert lecturers. In table 1 we can see the Validation Eligibility Criteria that will be used.

TABLE 1
VALIDATION ELIGIBILITY CRITERIA

Score	Criteria
5	Very Good
4	Good
3	Medium
2	Bad
1	Very Poor

A. Block Diagram

Block diagram is a part of the principle and performance of a system in making a tool design [13]. Block diagram also serves in determining the direction of the part to be made so that it can explain what will be designed and executed as in the following figure 2.

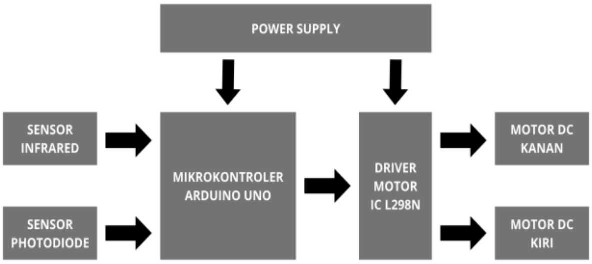

Fig 2. Block diagram drawing

The design and manufacture of the system begins with making a block diagram to clarify the overall system A block diagram is a graphical representation of a system, project, or scenario. It provides a functional view of a system and illustrates how the various elements of the system relate to each other. concept. The block diagram is shown in the following figure. Based on the block diagram that has been described, it can be explained that there are several that are divided including input, process and output.

We can see in figure 2 this is a block diagram of the Arduino-based Digital Line Follower Robot Trainer when the infrared sensor and photodiode are active, the sensor will send a signal to the Arduino which functions as a microcontroller, then after this the microcontroller sends a message to the motor driver to move the DC motor.

In the development of technology-based learning media, such as the Arduino-based Digital Line Follower Robot Trainer, block diagrams play an important role as a visual aid to understanding the overall workflow of the system. This block diagram illustrates the relationship between the main components in the system, starting from input, through process to output. The input component, in the form of a line sensor, is used to detect the color of the track, which then sends a digital signal to the microcontroller (Arduino).

The microcontroller acts as a control center, processing the data from the sensor based on specific programming logic. The processing results are sent to the motor driver, which is responsible for amplifying the signal before sending it to the DC motor as the main actuator. It is this motor that moves the robot wheel along the specified path.

The whole system is powered by a power source such as a battery or adapter. Through this block diagram, learners can understand the structure of the system in a modular and logical way, which greatly supports the understanding of complex technological concepts. The use of block diagrams in the learning process also makes it easier for students to see the function of each part in the system and its relationship to the automatic decision-making process, thus strengthening the integration between theory and practice in the classroom and laboratory.

B. Flowchart

The design and creation of the system is continued with a flow diagram to clarify the overall system concept. The flow diagram is shown in Figure 3 below. The flow of the system being designed will be displayed in the form of a flow chat or flow diagram. A flowchart is the flow of a program or system procedure being built which will be displayed in chart form [14].

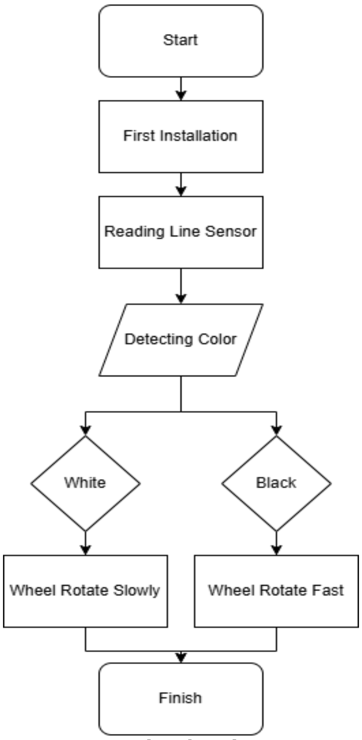

Fig 3. Flowchart design

Based on figure 3, it will be explained how the system works. In the design, it is explained how the NodeMCU ESP8266 can process data from the input of the working system to the output that appears in the database. To design a system, a flow diagram will first be created to describe the processes that occur in the system

C. Text Overall Circuit Design

Overall Circuit Design is a general description of how a system or device is designed as a whole following figure 4, including all components and how these components are interconnected to achieve the desired function.

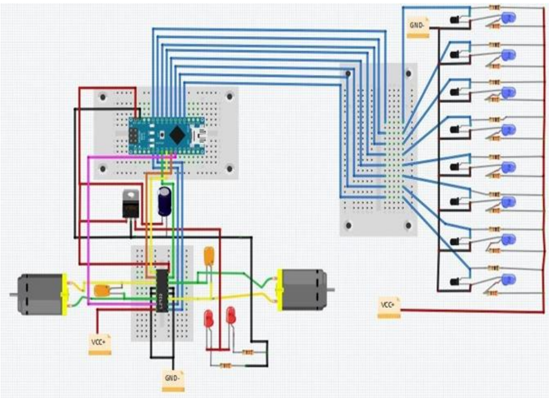

Fig 4. Overall Circuit Design

The principle of unity of design is one of the important design principles to create a complete and cohesive look. This principle unites all other design principles. Based on image 4, the infrared and photodiode are connected to the Arduino, then from the Arduino it is connected to the driver IC as a motor driver, after that from the driver IC it is connected to the DC motor so that the motor can rotate according to the commands of the Arduino as a microcontroller.

The design concept is the core idea that drives the design of a product. The design concept is described through a collection of sketches, drawings, and written statements. Design is an approach method that is used as a strategic innovation in the design process and approaches users through the process. Design is used as a method of analysis through the process of understanding user needs and focusing on form, relationships, behavior, interaction and human emotions to produce an optimal solution [15].

Circuit Design acts as a technical guide, showing in detail how all the electronic components are connected, from cable connections, to input/output pins on the Arduino, to connections to motor drivers, sensors and power supplies. By studying circuit design in depth, students not only understand the theoretical working concepts of the system, but also develop practical skills in assembling and analyzing electronic circuits. This process provides practical experience in reading schematics, recognizing electronic symbols and identifying current and signal flow paths. In the context of engineering learning, understanding circuit design is crucial as it forms the basis of electronics and troubleshooting skills. Students are also trained to be thorough, logical and systematic when constructing and testing circuits, which is in line with competency-based learning objectives. In other words, complete circuit design not only promotes technical understanding, but is also an effective means of introducing scientific thinking into the educational process.

III. Results And Discussion

A. *Development Result*

In this research, an Arduino-based digital line follower robot trainer that functions as a learning media has been successfully designed and built. This trainer was made with the aim of helping students understand the working principles and programming of line follower robots in a more practical and interactive way.

The designed line follower robot uses an optical sensor (infrared sensor) to detect the line, Arduino Uno microcontroller as the processing brain, and DC motor as the wheel drive. The infrared sensor will read the surface of the path (black/white) and send the data to the Arduino, which then processes the data to set the direction of motion of the DC motor through the motor driver. That way, the robot can follow the predetermined path.

The test results show that the robot can follow the path well, especially on straight trajectories and standard turns. However, on trajectories with sharp angles, it is necessary to make adjustments to the programme and sensor positions for optimal robot performance. In addition, sensor sensitivity also affects performance, so initial calibration is very important before use. In terms of learning, this trainer provides great benefits. Students can learn directly about Arduino programming, understand the function of sensors, motor drivers, and see the real implementation. This trainer also motivates students to be more active in experimenting and innovating, especially in the development of simple robotics. Overall Figure 5, the design of this trainer is considered successful and effective as a learning medium. However, for further development, it is recommended to add additional features such as Bluetooth control or ultrasonic sensors to avoid obstacles, so as to increase the complexity of learning and encourage students to think more creatively.

Sensor tests show that photodiode and infrared sensors can detect black and white lines with a high level of accuracy. This is one of the important factors in the success of the line follower robot navigation system. In the robot movement test, the robot can follow a predetermined path well based on input from the sensors, indicating that the sensor data processing algorithm and motor control work well.

Fig 5. The Whole Network

In the design stage, a trainer design was prepared using an Arduino Nano microcontroller as the main control system, a photodiode sensor to detect lines, a DC motor as an actuator, and an L298N driver IC as a motor controller. This trainer is designed to be disassembled, so that students can do independent assembly and understand the working principle of the robot more concretely. After the design is complete, the product is developed and tested through validity testing by material and learning media experts. The validation results show that the trainer is feasible to use with the category “very valid” both in terms of content, technique, and learning benefits.

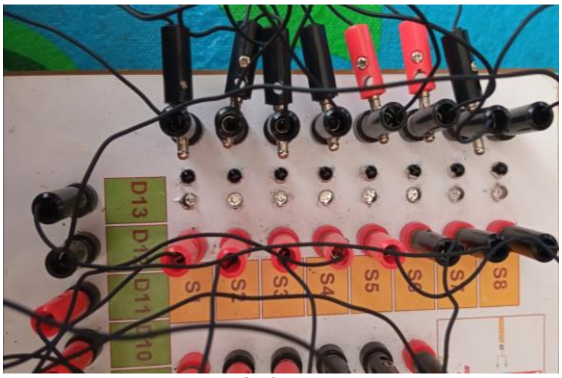

Fig 6. Sensors and other connectors position

The photodiode sensor has an important role in detecting the path that the robot must Figure 6. Explained that the photodiode sensor is able to distinguish black and white colors on the surface of the track, allowing the robot to move according to the predetermined path. In addition, this research also found that the integration of wireless communication in the line follower robot can increase the effectiveness of its use in IoT-based learning. That wireless communication enables remote control of robots, which has the potential to be further developed in educational robotics projects.

In this research, a photodiode sensor is installed at the bottom of the robot to read the trajectory line, and the data obtained from the sensor will be processed by Arduino to control the DC motor through the L298N motor driver. In this research, the main challenge was to design a system that could be disassembled without destabilizing the robot's electronics. The effectiveness of the trainer in learning shows significant results compared to previous learning media. This trainer has several advantages, such as the ability to be disassembled, which allows students to understand the components and how the robot works in more depth.

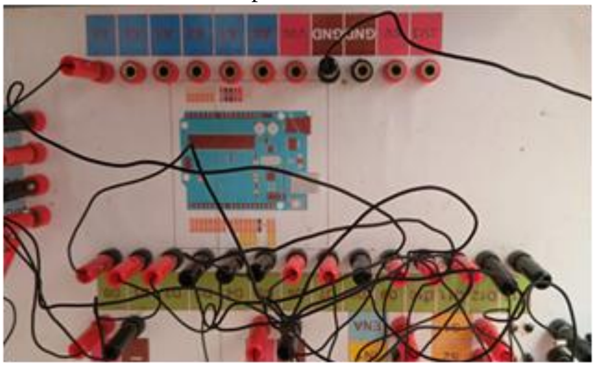

Fig 7. Deep schema

The previous trainer used in had limitations, including not being able to be disassembled and less flexible in modification. Follow Figure 7 with the new trainer that was developed, students can better understand the working principles of the robot by assembling it themselves, so that learning becomes more applicable and not just theory.

B. Validation Result

In this study, media trainer validation was carried out by two validators, namely material experts and learning media experts, to ensure that the resulting product meets the established standards.

TABLE 2
MATERIAL VALIDATOR

No	Statement	V1	V2
1	Suitability of the material with the curriculum and learning syllabus	4	4
2	Clarity of the concepts presented in the material	4	5
3	Depth of the material in supporting student understanding	4	4
4	Relevance of the material to the needs of industry and current technology	4	4
5	Ease of material for students to understand	5	5
6	Clarity of instructions and examples in the material	5	5
7	Suitability of the material in supporting student projects and practices	4	5
8	Breadth of material used at various levels of student understanding	5	4
9	Level of student involvement in understanding the material presented	4	4
10	Suitability of the material with learning objectives	4	4
11	Effectiveness of the material in improving understanding of robotics concepts	5	4
12	Attractiveness of the material in attracting students' interest in robotic systems	5	5
13	Clarity of the relationship between theory and practice in the material	4	4
14	Level of ease of material to be practiced in learning activities	5	4
15	Suitability of examples and case studies in the material with the real world	4	4
	Total Score	66	65
	Maximum Score	75	75
	Overall Percentage	88%	87%
	Description	**Valid**	

TABLE 3
MEDIA VALIDATOR

No	Statement	V1	V2
1	Suitability of the trainer with the curriculum and learning syllabus	4	4
2	Clarity of the material that can be delivered using the trainer	4	5
3	Quality of the trainer hardware	4	4
4	Ease of use of the trainer for students	4	4
5	Effectiveness of the trainer in improving student skills	4	4
6	Safety in using the trainer during practicum	4	5
7	Level of trainer interactivity in learning	4	4
8	Ease of understanding the material using the trainer	4	5
9	Effectiveness of the trainer in supporting the learning process of robotic systems	4	4
10	Suitability of the trainer with learning objectives	4	4
11	Clarity of instructions for using the trainer	4	5
12	Ability of the trainer in developing students' practicum skills	4	5
13	Suitability of the trainer in supporting students' robotic projects	4	4
14	Ease of operation of the trainer by students with various levels of expertise	4	5
15	Level of student involvement in using the trainer	5	5
	Total Score	61	67
	Maximum Score	75	75
	Overall Percentage	81%	87%
	Description	**Valid**	

Arduino-based line follower robot trainer has been tested through expert validation and practicality test. The validation results show that this trainer is in the "very valid" category both in terms of content, technique, and learning benefits.

The validation results show that the developed trainer meets the validity criteria with a Content Validity Index (CVI) value that is included in the very valid category. Several aspects that are assessed include content quality, clarity of instructions, ease of use, and effectiveness in learning. Based on the evaluation results from the validator, this trainer is considered to have a good structure, features that support learning, and components that allow students to explore in assembling and understanding the working system of the line follower robot. The validation results show that the trainer developed meets the validity criteria of several validators who have provided information.

Based on the evaluation results from the validators, this trainer is considered to have a good structure, features that support learning, and components that allow students to explore in assembling and understanding the working system of the line follower robot. In addition, the results of the practicality test conducted by subject teachers show that this trainer is easy to use and effective in improving students' understanding of the working principles of robotic systems.

C. Discussion

Based on the results of the discussion, the Arduino-based digital line follower robot trainer designed can work according to its function, namely following a predetermined path using an infrared sensor. The robot is able to move well on straight tracks and standard turns, although on trajectories with sharp angles improvements are still needed in terms of programmes and sensor calibration.

The results of validation conducted by media experts and users (students/teachers) show that this trainer is suitable for use as learning media. Based on the assessment of media experts, aspects such as tool design, component functions, and ease of use are considered good and according to standards. Meanwhile, from the user's perspective, this trainer is considered interesting, easy to understand, and helps them learn to understand the concept of robotics and programming practically.

When compared, the results of the discussion and validation support each other. The discussion results show that the trainer was successfully made and tested technically, while the validation results reinforce these findings by assessing that the tool is effective in the teaching-learning process. However, from both the test and validation results, notes for improvement were found, such as increasing sensor sensitivity, refining algorithms for extreme paths, and adding supporting features to optimise the learning media.

Overall, this trainer was not only successfully realised technically, but also well received from an educational perspective. This shows that the design of this Arduino-based line follower trainer has great potential to be used as an innovative learning medium in the field of robotics.

IV. Conclusions

Based on the results of research and validation, it can be concluded that this Arduino-based line follower robot trainer is valid and practical to use as learning media in schools. This trainer helps students understand the basic concepts of robotics, from assembly to programming, in an interesting and interactive way. The development of the trainer using the 4-D model (Define, Design, Develop, Disseminate) succeeded in producing products that meet the standards, as evidenced by the results of trials and expert validation. In addition, this trainer is also more economical than commercial tools, because it uses components that are easily available and open-source. Future development can focus on improving features, such as adding more sensitive sensors or integration with IoT technology. Additional training for teachers and students is also important to optimise the use of this trainer.

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