



Multisensor Fire Detection System Mobile Robot as a Learning Media in Firefighting Robotic Course

Direstu Amalia¹, Wildan Nugraha^{1*}, Sunardi¹, Rio Rizko¹, Jhellyananda Putri¹, Randa Agusta Pratama¹

¹Politeknik Penerbangan Palembang, Indonesia

*Correspondence to: wildan.nugraha@poltekbangplg.ac.id

Abstract: Firefighting Robotic technology has been used for a long time to achieve aviation safety and security goals. The research is deemed necessary because of some related issues: 1) A pressing need for lecturers and students to have access to learning media; 2) A lack of practical media that are pertinent to industries needs; and 3) Practical learning of Firefighting Robotics necessitates learning media that are by the needs of cadets. This research aims to create an innovative learning media for a firefighting robot course based on the Internet of Things (IoT) with a Proportional-Integrative-Derivative (PID) control system using a multisensor according to learning outcomes. The research method used the Plomp Model with initial data collection techniques using literature study and observations of Firefighting Robot designs and course outcomes. The research results are an automatic fire extinguishing Firefighting Robot that works in a labyrinth with a web-based main control system as a server connected to the client, namely the Firefighting Robot and fire alarm. The PID control system test result is $K_p = 100$, $K_d = 100$, and $K_i = 10$, which makes it stable in maneuvering the labyrinth. Validation results from material and media experts were conducted, and the learning media application successfully carried out system instructions. The material experts resulted in a quality aspect of the material content score of 4.8 with the category "Very Good". As a prototype, the researchers hope the firefighting robot concept can be developed on a large scale to support firefighting activities in real field situations in further research.

Keywords: firefighting robot, pid controller, multisensory, development

Recommended citation: Amalia, D., Nugraha, W., Sunardi., Rizko, R., Putri, J., & Pratama, R. A. (2023). Multisensor Fire Detection System Mobile Robot as a Learning Media in Firefighting Robotic Course. *Journal of Innovation in Educational and Cultural Research*, 4(4), 682-690.

INTRODUCTION

Mechatronics is an interdisciplinary science branch combining mechanical, electrical, and software engineering. Mechatronics science is applied to create Firefighting Robots, which are usually used to carry out work that requires high precision, requires much power, repetitive work, and dangerous work in the world of education (Laužikas et al., 2021). In aviation, Firefighting Robotics technology has been initiated for aircraft fuel-tank inspection activities in research by Maria Giorgia in 2021. Firefighting robots are being developed with designs for specific purposes, including a fire-extinguishing firefighting robot. As we know, fire extinguishing activities have a high risk and endanger the lives of both victims and firefighters (Aini, 2016). So, one thing that can be done is to use technology to extinguish fires. A study (Vijayalakshmi, 2017) shows the use of Internet of Things (IoT) technology in firefighting systems, fire monitoring, and safety management and is considered a critical application. Fire extinguishing Firefighting Robots with automatic control progress in accuracy and speed in handling fire and using various technologies. It was stated in research (Raj & Srivani, 2018; Kumar et al., 2021) that IoT technology was implemented in designing firefighting robots that provide fire information to firefighters. The android-based extinguishing Firefighting Robot is also equipped with a camera to monitor the Firefighting Robot moving around the room (Motade et al., 2020). Other research states that fire Firefighting Robots are equipped with machine learning technology to recognize fire classifications (classes) to protect firefighting personnel from safety threats during an incident (Bhattarai et al., 2020; Dhiman et al., 2022). A simulator in the form of a maze equipped with a fire extinguishing Firefighting Robot with Multi Independent Steering, which is waterproof and heat resistant to extinguish fires with the help of a fan even though it is not yet equipped with deep learning technology (Hartono & Firdaus, 2018) as well as a simulator with a fire extinguishing Firefighting Robot controlled by remote control (Prasetyo et al., 2018).

One of the successful strategies the government uses to raise the standard of its human resources, particularly in producing skilled workers, is adopting vocational education (Ariyani et al., 2021). As stated by Sudira (2014), vocational education in Indonesia is expected to meet the objectives of preparing a competent workforce in certain occupations as supporting industrial development and production services. As a vocational academy, in the sixth semester of the Diploma III-Penyelamatan dan Pemadam Kebakaran Penerbangan (DIII-

PPKP) at Politeknik Penerbangan Palembang, there is a course called Firefighting Robotics. In this course, cadets learn about mechanical analysis, degree of freedom structures in a Firefighting Robot application, servos, visual servoing, image processing, embedded systems for Firefighting Robotics, and basic Firefighting Robotics concepts. As a result, for this course, cadets must be able to explain the fundamentals of Firefighting Robotics, power supply systems, and Firefighting Robot drive systems, as well as the principles governing the operation of servos and power supplies, as well as the fundamentals of Firefighting Robot programming, cadets must also be able to demonstrate Firefighting Robot systems. Firefighting Robots typically have sensors and actuators that enable them to recognize and react to fire-related situations (Yunanto et al., 2021). The optical and infrared cameras, temperature sensors, and air quality sensors employed by Firefighting Robots are among their sensors. Meanwhile, until now, practical learning media has yet to be integrated with the course syllabus.

A grasp of robotics and technology is crucial when technology becomes increasingly important in every aspect of life and industry. According to (Indryani et al., 2022), students are better prepared for an increasingly digital and connected world. Research by (Nugraha et al., 2021) states that robotic-based educational tools may enhance students' critical-thinking abilities and learning outcomes. Chen and Chang (2008) state in their study that students can improve their problem-solving abilities while learning computer programming, arithmetic, and science with the help of robots. An animaloid robot that can promote robotics education and robot competition was developed by (Sendari et al., 2015) and has a positive evaluation from users. According to research by (Okyanida et al., 2020), student's interest in studying physics through media has increased due to using robot soccer as a teaching tool—conversely, the existence of robots as a practical learning media to implement project-based learning. Chen et al. (2022) state that students' creative thinking can be fostered via a project-based learning approach, particularly in fluency and flexibility.

This research aims to develop a firefighting robot, an Internet of Things-based fire extinguishing firefighting robot connected to a building's fire alarm system automatically, to provide practical learning activities and project-based learning implementation. The research is deemed necessary because of some related issues that the author can point out, including 1) A pressing need for lecturers and students to have access to learning media for Firefighting Robotics practice courses; 2) A lack of media for Firefighting Robotics practices that are pertinent to industries needs; and 3) Learning the practice of Firefighting Robotics necessitates learning media that are by the needs of cadets. Firefighting Robots and fire alarms are clients with the web, as the server will operate in a simulator like a labyrinth equipped with fire hotspot scenarios. Fire alarms placed in each room in the labyrinth will send information if there is a fire in one of the rooms. This Firefighting Robot has a camera to navigate the maze and a Firefighting Robotic arm to simulate human rescue. Apart from that, the main control system can simulate a fire; the server can also command a simulator device connected to a fire alarm to activate a fire scenario in the room.

METHODS

The researcher conducted this research for six months at Politeknik Penerbangan Palembang in Program Studi DIV TRBU and DIII PPKP. It uses Research and Development methods with the Plomp. This method consists of four main parts (Arianatasari & Hakim, 2018): the Preliminary Research Stage, the Prototyping Stage, the Assessment Stage, and the Systematic Documentation and Reflection Stage (Reflection and Documentation). The Plomp method combines instructional design principles, using a prototype methodology to create more helpful learning tools that align with user requirements. On this occasion, research was carried out up to the prototyping stage, namely prototype design (Haviz, 2016). The research began with Preliminary Research, a data collection technique carried out through literature studies and observations made of laboratory and practicum facilities as well as learning plans, namely Rencana Pembelajaran Semester (RPS) from the Mechatronics course in the Diploma IV Airport Engineering Study Program (DIV-TRBU Study Program) and the Fire Fighting Firefighting Robotic course in the Diploma III Aviation Rescue and Fire Fighting Study Program (Prodi DIII-PPKP) to see whether the technical and design needs are under the stages of Firefighting Robot design. As a course whose curriculum must contain 70% practice, this course also still needs adequate laboratories, simulators, or practice tools. In conclusion, the researcher recommends firefighting robots as a practical tool solution in firefighting robotic courses. The observation results show an opportunity to develop a Firefighting Robot, an IoT-based Firefighting Robot connected to the fire alarm in the labyrinth. This simulator represents the needs and learning outcome of the firefighting course, which demonstrates Firefighting Robot systems such as hardware recognition and control systems.

The Prototyping Stage, including design development and construction, begins with determining the design development construction of the Firefighting Robot, including a concept chosen based on the results of preliminary research through literature study and observation to the practical exercise; then, the construction starts with determining components, Proportional, Integrative, Derivative (PID) design, flowcharts diagram, and the required test scenarios define at this stage. The formative evaluation stage uses the Tessmer evaluation

(Nisa et al., 2020). In this case, it is technically a field trial or field test on product quality. Field tests were conducted on trial for the firefighting robot-motion control system (Ang et al., 2005) to see the robot's capabilities for conducting firefighting duties in the labyrinth. The testing conducted in Prodi DIII-PKPPK involves a media expert and a material expert.

A functionality test checks learning media's suitability, accuracy, and maintainability. Data analysis of the Firefighting Robot as learning media was discovered in two expert validation tests, and the experts are the one media expert in Firefighting Robotic, IoT, and system control and the one material expert, the lecturer in firefighting Firefighting Robotic course. The validation results are used for descriptive analysis in a rating divided into four categories: extremely valid, entirely valid, less valid, or invalid. Then, the value will be converted into qualitative data by referring the score to the value conversion table. This table is used to describe and display value conversions. Score Interval $X > Mi + 1.8 Sbi$, value A, with category Excellent; $Mi + 0.6 Sbi < X \leq Mi + 1.8 Sbi$, value B, with category Good, $Mi - 0.6 Sbi < X \leq Mi + 0.6 Sbi$, value C and category Average; $Mi - 1.8 Sbi < X \leq Mi - 0.6 Sbi$, value D and category Bad; $X \leq Mi - 1.8 Sbi$, with value E, category Very Bad. X = actual (empirical) score; Mi = ideal mean, calculated using the formula; $Mi = 1/2$ (ideal maximum score + ideal minimum score); Sbi = ideal standard deviation, determined by the formula; $SBI = 1/6$ (ideal maximum score minus ideal minimum score). The maximum ideal score for media experts is 1, so the Mi and SBI values are obtained as follows: $Mi = 1/2 (1+0) = 0.5$ and $SBI = 1/6 (1-0) = 0.167$. Based on the results of Mi and SBI calculations, the conversion table is obtained as follows:

Table 1. Media Expert Spec Values

Criterion	Score Account	Result
Excellent	$X > 0.5 + (1.8 \times 0.167)$	$X > 0.8$
Good	$0.5 + (0.6 \times 0.167) < X \leq 0.5 + (1.8 \times 0.167)$	$0.6 < X \leq 0.8$
Average	$0.5 - (0.6 \times 0.167) < X \leq 0.5 + (0.6 \times 0.167)$	$0.4 < X \leq 0.6$
Less	$0.5 - (1.8 \times 0.167) < X \leq 0.5 - (0.6 \times 0.167)$	$0.2 < X \leq 0.4$
Very Lacking	$X \leq 0.5 - (1.8 \times 0.167)$	$X \leq 0.2$

In the material aspect evaluated by material experts, we use a 1 to 5 rating scale. Calculation is as: $Mi = 1/2 (5+1) = 3$; $SBI = 1/6 (5-1) = 0.67$. A conversion table describes the results, as shown in the table below.

Table 2. Material Expert Criteria

Criterion	Account	Score	Percentage
Excellent	$X > 3 + (1.8 \times 0.67)$	$X > 4.2$	$X > 84\%$
Good	$3 + (0.6 \times 0.67) < X \leq 3 + (1.8 \times 0.67)$	$3.4 < X \leq 4.2$	$68\% < X \leq 84\%$
Average	$3 - (0.6 \times 0.67) < X \leq 3 + (0.6 \times 0.67)$	$2.6 < X \leq 3.4$	$52\% < X \leq 68\%$
Less	$3 - (1.8 \times 0.67) < X \leq 3 - (0.6 \times 0.67)$	$1.8 < X \leq 2.6$	$36\% < X \leq 52\%$
Very Lacking	$X \leq 3 - (1.8 \times 0.67)$	$X \leq 1.8$	$X \leq 36\%$

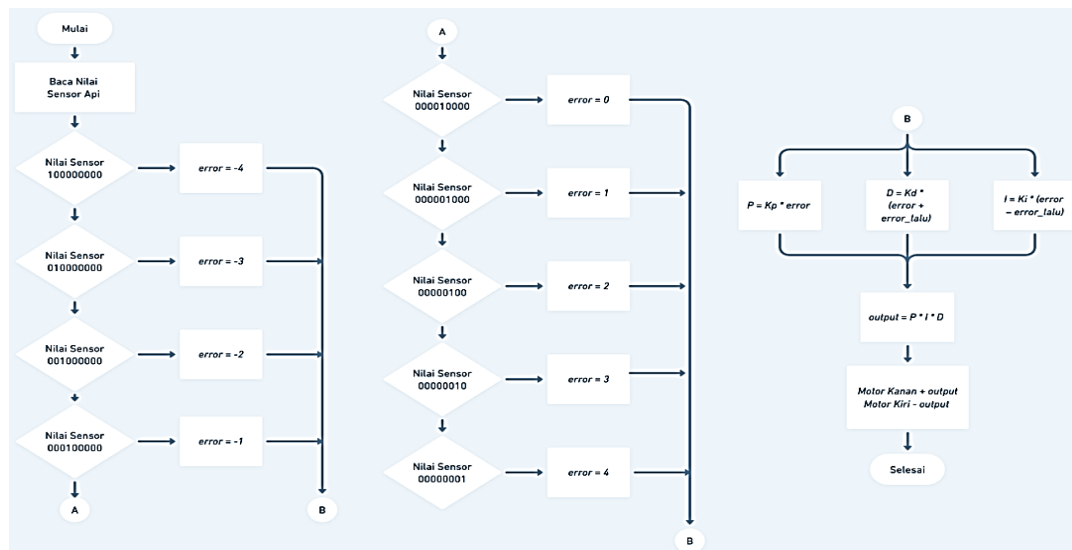
RESULT AND DISCUSSION

In the initial stages of Preliminary Research, the author carried out observation and many literature studies to obtain novelty value in this research. This prototype should represent the RPS course, and cadets must be able to explain the fundamentals of Firefighting Robotics, power supply systems, and Firefighting Robot drive systems, as well as the principles governing the operation of servos and power supplies, as well as the fundamentals of Firefighting Robot programming, the learning outcomes also want cadets to be able to demonstrate Firefighting Robot systems. We observe the Firefighting Robotics course planning document to determine the technical specifications needed to build a Firefighting Robot. Meanwhile, until now, no practical learning media has been integrated with the course syllabus to provide learning activities. The observation results show that providing practical equipment supporting learning outcomes, as stated in RPS, is necessary for practical technology development. The literature study results show many Firefighting Robot implementations, but our main aim is to create an IoT-based firefighting robot that functions as a practical learning tool. To simulate the situation in a building, we connect the firefighting robot to a labyrinth with fire alarms installed. This fire alarm will then call the Firefighting Robot to approach the room in the maze that simulates the source of the fire. In this research, the focus of the discussion is on the field testing of the Firefighting Robot prototype and starts with technical testing of the PID Firefighting Robot movement control. In the second stage, the Prototyping Stage, Firefighting Robot Simulator was designed as a fire extinguishing Firefighting Robot that can integrate with several systems. These systems are a web-based main control system and an Internet of things-based fire alarm system. Integration between these systems uses the internet network to connect systems. The following are the Firefighting Robot specifications.

Table 3. Firefighting Robot Specification

Input	Process	Output
Sensor Ultrasonic HCSR04	Mikrokontroller Arduino Mega 2560	Motor DC 450 RPM with elastic wheels
Pixycam Camera	Mikrokontroller ESP001 (connect the Firefighting Robot to the internet)	Servo Motor MGR955 as a Firefighting Robot hand
Flame Sensor Photodiode 9 Array		Driver motor MOSFET
Flame sensor UVtron		CO2 16g

As the learning outcome of the course to build a Firefighting Robot, we use a CO2 cylinder and a valve regulated by a motor servo. The servo motor will act as an opener or closer of the CO2 valve. It is equipped with several sensors that are used to support Firefighting Robot navigation. The Firefighting Robot uses ultrasonic sensors to navigate through labyrinth halls, fire sensors to navigate following the fire, and camera sensors to navigate to find victims. The fire sensor uses nine photodiodes made in a circle facing various directions. This sensor will perceive X-rays of light in the fire. The Firefighting Robot uses a PID (Proportional, Integrative, Derivative) motion control system to perform good maneuvers. Using the sensor as an input for controlling the robot and sensing the fire is also a part of implementing the firefighting robot, as stated in the RPS.

**Figure 1.** Flowchart Diagram

The diagram in [Figure 1](#) explains that the input is received from a sensor module that can read the direction of the fire point and the Firefighting Robot. If the binary value is 000010000, then the error value is 0. If the number 1 in the binary value is further to the right, then the error value is more than 0. If the number 1 is in the binary value, the sensor input value in the PID is called the error value. The error value is a 9-bit binary value obtained as input from the fire sensor value. The further to the left, the error value is less than 0. This error value then passes through a stage known as the processing stage. At this stage, the error value is then processed by the components, namely P (Proportional), I (Integral), and D (Derivative), to determine the speed and the direction of the rotating motor. This error value then goes through a stage called the processing stage. At this stage, the error value is then processed by the components, namely P (Proportional), I (Integral), and D (Derivative), to determine the speed of the motor and the direction of the rotating motor. The controller functions as an error data manager previously processed based on [Table 1](#). The controller functions as a filter to process error values to get an output that matches the range of DC motor values for fire navigation. The flowchart on the PID controller can be translated into the following equation.

$$\text{Output} = K_p * \text{error} + K_d * (\text{error} + \text{last error}) + K_i * (\text{error} - \text{last error}); \text{Right Motor} = \text{Initial Speed} + \text{Output}; \text{and Left Motor} = \text{Initial Speed} - \text{Output}$$

Calculating the error value with the PID components, they tested by setting the PID constant value according to the desired output value. They are determining the value of constants using the ultimate cycle reasoning (tuning) method—calculation of the error value done with the PID components. The final stage of this research is the Assessment Stage. It tests the control system using a simple PID type of control, but it is necessary to determine the constant value for each kind of control. It conducted a Test by setting the PID constant value according to the desired output value. Determining the constant value using the ultimate cycle reasoning (tuning) method and the Firefighting Robot product is according to the design.

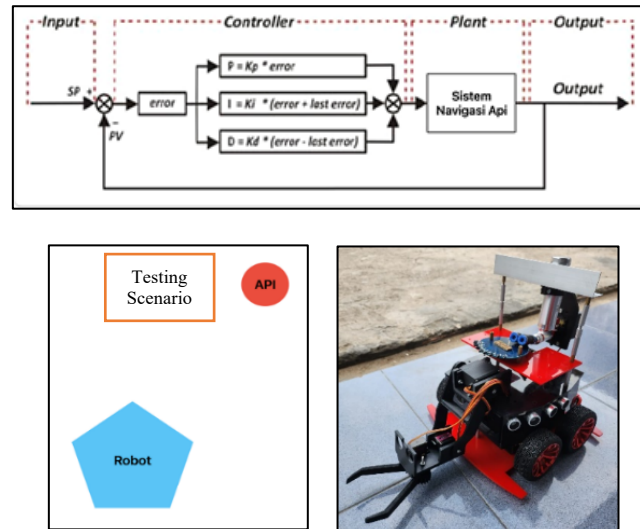


Figure 2. Firefighting Robot Product

The ultimate cycle method only calculates proportional constants and ignores integral and derivative constants (Borase et al., 2021). Navigate the fire and PID by placing the fire on the right front side of the Firefighting Robot as in the testing scenario illustration in Figure 2. This test was carried out in three stages. The first stage tests the proportional-derivative (PD) controller, the second stage tests the proportional-integral (PI) controller and the last tests the proportional-derivative-integral (PID) controller. The error value is read during Firefighting Robot oscillation until the Firefighting Robot is stable again. This value is then sent to the computer via USB to Serial TTL Converter and presented to the computer's Hyperterminal program. This error value is sent once every three loops (with sampling = 3). The data from the sampling results are then processed and presented in a graph in the Microsoft Excel application.

In order to make a knowledge level of skill, we developed a task by arranging three fire points in each room to extinguish, and the robot should overcome the task. The Technical testing included three tests; the first test of the Firefighting Robot uses proportional and derivative with a $K_p=100$ $K_d=100$. The first test uses PD by adjusting the values of $K_p = 100$ and $K_d = 100$. This test uses only proportional and derivative control components, while the integrative component is ignored first. PD testing showed a slight change in the Firefighting Robot's reaction to the direction of fire, but the speed of the Firefighting Robot turning towards the direction of the fire was still slow. However, the response results of this test are much better than if the Firefighting Robot did not use a proportional and derivative system. The second test uses proportional and integral with values $K_p=100$ and $K_i=10$. The second test is to use a PI controller by setting the K_p value = 100 and the K_i value = 10, which means using a PI-type controller, namely proportional (P) and integral (I) components. Unsynchronized movement is characterized by the Firefighting Robot turning to the right but then turning to the left, causing the Firefighting Robot to hit a hotspot. When a PI-type controller is implemented on a firefighting robot, the Firefighting Robot's movements become slower and more irregular. If we compare this analysis's results with the Firefighting Robot test results that do not use a control system. The third test uses proportional, derivative, and integral with values $K_p=100$, $K_d=100$, and $K_i=10$. The third test uses three components, namely PID testing, where this system is the most complex system of the three. Based on the test result, we use the PID system; it uses all the controller components (proportional, integral, and derivative) in carrying out its control actions because the trial results using a proportional-derivative controller can be considered satisfactory. The researchers set $K_p = 100$, $K_d = 100$, and $K_i = 10$ in the test. However, one small deviation still has the potential to be eliminated by adding components so that the gain value obtained is relatively small. The PID testing results are shown in Figure 3 below.

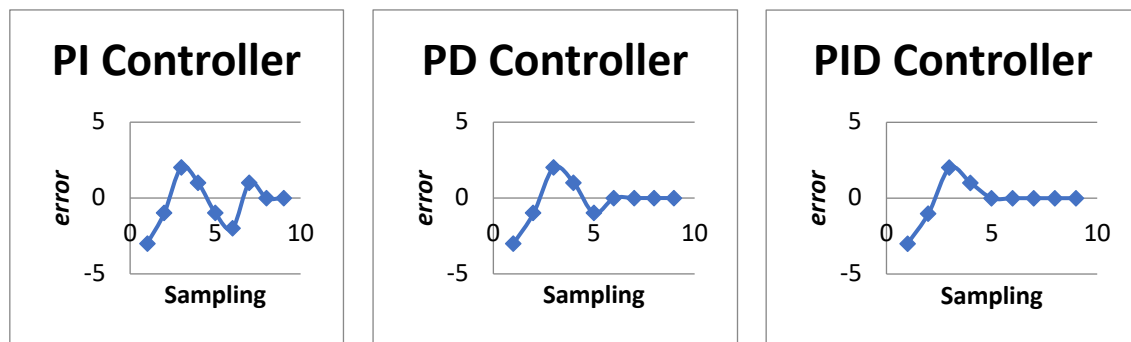


Figure 3. Graphic Response of PI, PD, and PID Controller Testing

For a firefighting robot to be a practical learning medium, we need a robot to be developed and perform technically to reach the learning outcomes, so we build robot tasks and abilities based on the learning outcomes of the firefighting robotic course. The development of this firefighting robot is also intended to support the implementation of project-based learning in this course, as advised, where cadets are given several cases to complete by being given challenging and meaningful assignments or projects (Treadwell, 2018). This project reflects an actual situation that requires problem-solving in firefighting jobs. This robot helps cadets reach the learning outcome that requires them to understand basic robotics theory concepts. The lecturer gives a project to directly observe the robot's movement, torque, and stability through this robot, and it helps cadets to understand concepts based on practical, as stated in (Gamage et al., 2022).

Daniah (2020) states that a nation's capacity for scientific literacy is directly correlated with its economic standing, making it a vital skill for all citizens. This firefighting robotic course uses a practicum-based learning environment or an inquiry model as a process skills method to provide scientific literacy skills. Our robot helps cadets understand and demonstrate arm and mobile robots, which are the forerunners of the development of firefighting robots (Rakib & Sarkar, 2016). Not only observing the robot hardware but cadets are given cases by carrying out programming language instructions to control the robot's movements and reactions in the labyrinth. Technical understanding needs are solved with the robot-machine interface provided by the labyrinth, which is made possible by IoT technology—an information-transmitting and -receiving robot controlled and monitored by a website. This kind of task should involve critical thinking skills and scientific literacy. To determine the result of technical testing, after conducting field testing, we conduct a product validation and a feasibility test on material experts and media experts (Taufiq et al., 2016). The validation process involves two validators: one is a media expert in electronics, microcontrollers, robotics, and artificial intelligence, and one is a learning material expert in firefighting. This testing involves questionnaires regarding the functionality of learning media and learning materials. The questionnaire was given to two media expert respondents and three material expert respondents. The accumulated assessment results get a score of 78. For calculating the functionality suitability aspect, the following formula is used: $X \text{ Value} = \text{Number of Score Obtained} / \text{Total Score} = 78 / 78 = 1$; The X value of 1 is obtained to check the element of suitability of the functionality of the media expert based on the calculations mentioned above. Based on these results, all functionality in the learning media application has successfully implemented system instructions.

Table 4. Material Expert Assessment Results

No.	Aspects	Average	
	Content	Learning	
1.	Sum		
	78	48	60
2.	Average		
	4,8	4,8	4,8
Category			
	Excellent	Excellent	Excellent
3.	Percentage		
	93%	93%	93%
Criterion			
	Excellent	Excellent	Excellent

In the table above, the results of the evaluation of learning media by material experts showed that the quality aspect of the material content obtained an average score of 4.8 with the category "Very Good". In previous research, several tests of Firefighting Robot controllers using PID showed a trial-and-error process in determining the P-I-D value (Ma'arif et al., 2021). As a fire extinguisher, Firefighting robots with multisensors are required to maneuver quickly and precisely. This robot requires these three control systems: P to rotate the motor, I as a clutch, and D as braking control. The Firefighting robot uses a Proportional, Integrative, and Derivative (PID) control system at the same time as suggested in several studies. Sibuea et al. (2021) use a microcontroller-based sonar sensor, meanwhile, Yunanto et al. (2021) conduct speed tests of fire extinguishing Firefighting Robots by using three components of PID, and Rakib and Sarkar (2016) use multisensors on its extinguishing Firefighting Robot with a type of PID testing. Research by Ang et al. (2005) states that using the P-I-D control system is more to the intent and purpose of making a tool because each control test has its function. Furthermore, Luo et al. (1998) state that for systems that do not require significant movement, a proportional (P) control system is sufficient because it reduces rise-time and steady-state error, increasing overshoot. The Integral control system (I) can reduce rise time, increase overshoot, and eliminate steady-state errors. The Derivative control system (D) functions to minimize overshoot and set time as researched. In general, the Firefighting Robot prototype that operates in the simulator does not use the three PID control systems because, as mentioned earlier, the proportional control function alone is sufficient. Still, we added all three to support better maneuverability performance in the firefighting robot. When this prototype is used as a product for the application, it is expected to pass basic testing.

CONCLUSION

This research has made a Fire Fighting Robot product that can maneuver well in a labyrinth. It is equipped with a PID control system and can connect to fire alarms via a web-based server. A fire alarm that detects a fire in the room will notify the Firefighting Robot via the web server. A firefighting robot is equipped with multisensors, a PID control system, a CO₂ extinguisher, and a Firefighting Robot arm for evacuating casualties. The performance of the firefighting robot was evaluated by testing its PID control system. The researchers set constant values in the test with $K_p = 100$, $K_d = 100$, and $K_i = 10$. The results of the trial using a proportional-derivative controller can be considered satisfactory. However, one small deviation still has the potential to be eliminated by the addition of integral components so that the gain value obtained is relatively small. This robot uses these three control systems due to the need for maneuvering, which is the main function of this firefighting robot because each P-I-D component has its controller function. The development of this firefighting robot is also intended to support the implementation of project-based learning in this course, as advised, where cadets are given several cases to complete by being given challenging and meaningful assignments or projects. This project reflects an actual situation that requires problem-solving in firefighting jobs. This robot helps cadets reach the learning outcome that requires them to understand basic robotics theory concepts. The lecturer gives a project to directly observe the robot's movement, torque, and stability through this robot, and it helps cadets to understand concepts based on practicals. The firefighting robot still requires extensive implementation and testing to determine user usability. In the future, researchers hope a firefighting robot can be developed as a fire-resistant Firefighting Robot capable of recognizing fire classes with the addition of a conventional neural network system. As a prototype, the researcher hopes the firefighting robot concept can be developed on a large scale to support firefighting activities in real field situations in further research.

REFERENCES

- Aini, A. N. (2016). Analisis Risiko Kerja Dan Upaya Pengendalian Bahaya Pada Petugas Pemadam Kebakaran Di Dinas Pemadam Kebakaran Kota Semarang. *Jurnal Kesehatan Masyarakat*, 4(1), 277-283.
- Ang, K. H., Chong, G., & Li, Y. (2005). PID control system analysis, design, and technology. *IEEE Transactions on Control Systems Technology*, 13(4). <https://doi.org/10.1109/TCST.2005.847331>
- Arianatasari, A., & Hakim, L. (2018). Penerapan Desain Model Plomp Pada Pengembangan Buku Teks Berbasis Guided Inquiry. *Jurnal Pendidikan Akuntansi*, 6(1).
- Ariyani, L. F., Widjaja, S. U. M., Wahyono, H., Haryono, A., Rusdi, J. F., & Pratama, C. B. A. (2021). Vocational education phenomena research method. *MethodsX*, 8. <https://doi.org/10.1016/j.mex.2021.101537>
- Bhattarai, M., & Martinez-Ramon, M. (2020). A Deep Learning Framework for Detection of Targets in Thermal Images to Improve Firefighting. *IEEE Access*, 8. <https://doi.org/10.1109/ACCESS.2020.2993767>
- Borase, R. P., Maghade, D. K., Sondkar, S. Y., & Pawar, S. N. (2021). A review of PID control, tuning methods, and applications. *International Journal of Dynamics and Control*, 9(2).

- Chen, G. D., & Chang, C. W. (2008). Using humanoid robots as instructional media in elementary language education. 2008 Second IEEE International Conference on Digital Game and Intelligent Toy Enhanced Learning, 201-202. IEEE.
- Chen, S. Y., Lai, C. F., Lai, Y. H., & Su, Y. S. (2022). Effect of project-based learning on development of students' creative thinking. *International Journal of Electrical Engineering and Education*, 59(3). <https://doi.org/10.1177/0020720919846808>
- Daniah, D. (2020). Pentingnya Inkuiri Ilmiah Pada Praktikum dalam Pembelajaran IPA untuk Peningkatan Literasi Sains Mahasiswa. *Pionir: Jurnal Pendidikan*, 9(1). <https://doi.org/10.22373/pjp.v9i1.7178>
- Dhiman, A., Shah, N., Adhikari, P., Kumbhar, S., Dhanjal, I. S., & Mehendale, N. (2022). Firefighting robot with deep learning and machine vision. *Neural Computing and Applications*, 34(4), 2831-2839. <https://doi.org/10.1007/S00521-021-06537-Y/METRICS>
- Gamage, A. A., Valls Pou, A., Canaleta, X., & Fonseca, D. (2022). Computational Thinking and Educational Robotics Integrated into Project-Based Learning. *Sensors*, 22(10). <https://doi.org/10.3390/S22103746>
- Hartono, R., & Firdaus, G. A. (2018). Implementation of Intelligent Fire Extinguisher Robots with Multi-independent Steering. *Telekontran: Jurnal Ilmiah Telekomunikasi, Kendali Dan Elektronika Terapan*, 6(2). <https://doi.org/10.34010/telekontran.v6i2.3798>
- Haviz, M. (2016). Research And Development; Penelitian di Bidang Kependidikan yang Inovatif, Produktif dan Bermakna. *Ta'dib*, 16(1). <https://doi.org/10.31958/jt.v16i1.235>
- Indryani, L., Saputra, H., & Azro, I. (2022). Pembuatan Media Pembelajaran Berbasis Virtual Reality Tentang Robot Lengan 6-Sumbu Pada Mata Kuliah Robotika di Jurusan Teknik Komputer. *Jurnal Laporan Akhir Teknik Komputer*, 2(1).
- Kumar, R. S., Hariharan, J., Revanth, R. S., Prasanth, K. R., & Lokesh, J. (2021, October). Automatic Fire Fighting Robot using RPI. 2021 2nd International Conference on Smart Electronics and Communication (ICOSEC), 136-139. IEEE. <https://doi.org/10.1109/ICOSEC51865.2021.9591689>
- Laužikas, M., Miliūtė, A., Morozovaitė, V., & Karpičius, D. (2021). Effectiveness and efficiency criteria for strategic application of mechatronics in business processes. *Insights into Regional Development*, 3(3). [https://doi.org/10.9770/ird.2021.3.3\(5\)](https://doi.org/10.9770/ird.2021.3.3(5))
- Luo, R., Joe Qin, S., & Chen, D. (1998). A new approach to closed-loop autotuning for proportional-integral-derivative controllers. *Industrial and Engineering Chemistry Research*, 37(6). <https://doi.org/10.1021/ie970675j>
- Ma'arif, A., Istiarno, R., & Sunardi, S. (2021). Kontrol Proporsional Integral Derivatif (PID) pada Kecepatan Sudut Motor DC dengan Pemodelan Identifikasi Sistem dan Tuning. *ELKOMIKA: Jurnal Teknik Energi Elektrik, Teknik Telekomunikasi, & Teknik Elektronika*, 9(2). <https://doi.org/10.26760/elkomika.v9i2.374>
- Motade, S., Bidwai, A. S., Kale, K. J., & Mahajan, A. M. (2020). Fire Fighting Robot Using Android Application. *International Journal Of Advance Scientific Research And Engineering Trends*, 4(11).
- Nisa, W. L., Ismet, I., & Andriani, N. (2020). Development of E-Modules Based on Multi-representations in Solid-State Physics Introductory Subject. *Berkala Ilmiah Pendidikan Fisika*, 8(2). <https://doi.org/10.20527/bipf.v8i1.7690>
- Nugraha, W. S., Pujiasti, D., Nurjamaludin, M., & Suryaningrat, E. F. (2021). The development of robotic-based learning media in improving critical thinking abilities and learning outcomes of primary students. *Journal of Physics: Conference Series*, 1987(1). <https://doi.org/10.1088/1742-6596/1987/1/012047>
- Okyranida, I. Y., Saraswati, D. L., & Mulyaningsih, N. N. (2020). Ability Media Robotics (Robot Soccer) in Fostering the Learning Interest of Students in the Subjects of Physics. *Kasuari: Physics Education Journal (KPEJ)*, 3(1). <https://doi.org/10.37891/kpej.v3i1.116>
- Prasetyo, T. F., Nurhidayat, Y., & Rohmanudin, W. (2018). Rancang Bangun Prototipe Simulator Robot Pemadam Api. *Seminar Nasional Teknologi Informasi 1*, 724-732.
- Raj, P. A., & Srivani, M. (2018, December). Internet of robotic things based autonomous fire fighting mobile robot. 2018 IEEE international conference on computational intelligence and computing research (ICIC), 1-4. IEEE.

- Rakib, T., & Sarkar, M. A. R. (2016). Design and fabrication of an autonomous fire fighting robot with multisensor fire detection using PID controller. 2016 5th International Conference on Informatics, Electronics, and Vision. <https://doi.org/10.1109/ICIEV.2016.7760132>
- Sendari, S., Elmunsyah, H., & Mahandi, Y. D. (2015). Six-Legged Animaloid Robot as a Trainer for Robotic Course. *Proceedings of the 3rd UPI International Conference on Technical and Vocational Education and Training*, 14. <https://doi.org/10.2991/ictvet-14.2015.44>
- Sibuea, S., Rahmaddoni, A., & Widodo, B. (2021). Perancangan Robot Pemadam Api Dengan Pengontrolan Gerak Metode Proportional Integral Derivative (Pid) Menggunakan Sensor Sonar Berbasis Mikrokontroler. *Jurnal Informatika Dan Teknologi Komputer*, 1(3).
- Sudira, P. (2014). Indonesia Vocational Education Praxis Between Mazab John Dewey And Charles Prosser. *3rd International Conference on Vocational Education and Training*.
- Taufiq, M., Amalia, A. V., Parmin, P., & Leviana, A. (2016). Design Of Science Mobile Learning Of Eclipse Phenomena With Conservation Insight Android-Based App Inventor 2. *Jurnal Pendidikan IPA Indonesia*, 5(2), 291–298. <https://doi.org/10.15294/JPII.V5I2.7375>
- Treadwell, S. M. (2018). Making the Case for Project-based Learning (PBL) in Physical Education. In *Journal of Physical Education, Recreation and Dance*, 89(1). <https://doi.org/10.1080/07303084.2018.1393225>
- Vijayalakshmi, S. R., & Muruganand, S. (2017). Internet of Things technology for fire monitoring system. *International Research Journal of Engineering and Technology (IRJET)*, 4(6).
- Yunanto, R. H., Desriyanti, D., & Vidyastari, R. I. (2021). Analysis Of Response Speed Settings Flame Sensor Fire Fighting Robots Using Pid. *Journal of Electrical and Electronic Engineering-UMSIDA*, 5(2), 175-185.