CHAPTER V
CONCLUSIONS AND RECOMMENDATIONS

This chapter presents the conclusions obtained from the results of the design, implementation, and testing of the ESP32-based Multifunctional Educational Mobile Robot that have been conducted in the previous chapters. The conclusions are formulated to address all problem formulations and research objectives established in Chapter I. Furthermore, this chapter also conveys development suggestions that can serve as references for future researchers in developing more advanced and comprehensive educational robot systems.

5.1 Conclusions

Based on the results of the design, implementation, and testing conducted in the research "Design and Construction of a Multifunctional Educational Mobile Robot for STEM Learning Based on Visual Programming Using ESP32," the following conclusions can be drawn:

1. The ESP32-based multifunctional educational mobile robot has been successfully designed and developed with the capability to operate in three operation modes, namely line follower, obstacle avoidance, and smartphone control. The robot utilizes an aluminum chassis with four mecanum wheels that enable omnidirectional movement, equipped with an HC-SR04 ultrasonic sensor, three TCRT5000 line sensors, an L293D motor driver, and internal ESP32 Bluetooth communication. The modular design and the use of affordable components make this robot an interactive and economical STEM learning medium.
2. The Finite State Machine (FSM) method of the Moore Machine type has been successfully implemented as the decision-making mechanism for each robot operation mode. The line follower mode FSM defines 4 states (FORWARD, TURN_LEFT, TURN_RIGHT, STOP) with inputs from 3 line sensors. The obstacle avoidance mode FSM defines 4 states (FORWARD, BACKWARD, TURN_LEFT, STOP) with input from the ultrasonic sensor. The smartphone control mode FSM defines 9 movement states with inputs from the Dabble application. The conformity of robot

behavior with the FSM transition table reached 90% in line follower mode, 90% in obstacle avoidance mode, and 100% in smartphone control mode, proving that the implementation of FSM successfully models robot behavior in a structured, deterministic, and documented manner.

3. Scratch/PictoBlox-based visual programming has been successfully implemented on the educational mobile robot. The PictoBlox platform provides a drag-and-drop interface that allows students to create robot control programs using visual command blocks without having to write text-based programming code. The designed FSM logic can be directly translated into if-else blocks in PictoBlox. The Upload Mode feature enables programs to be executed in standalone mode on the ESP32, allowing the robot to be operated independently by students.

5.2 Recommendations

Based on the research results and system limitations that have been identified, there are several recommendations for further development in subsequent research:

1. Addition of Internet of Things (IoT) Features. The system can be further developed by utilizing the WiFi connectivity of the ESP32 so that the robot can be controlled and monitored via the internet using IoT platforms such as MQTT, Blynk, ThingsBoard, or web-based applications.
2. Development of an Omnidirectional Robot. The use of mecanum wheels or omni wheels can be implemented to enable the robot to move in all directions, thereby providing a more modern robotics learning experience that aligns with current industrial technology developments.
3. Addition of Sensors and Actuators. The system can be further developed by adding various sensors such as color sensors, gas sensors, temperature and humidity sensors, light sensors, ESP32-CAM cameras, as well as additional actuators such as servo motors and robot grippers to expand the variety of learning projects.
4. Implementation Across Various Educational Levels. Future research can test the use of this robot across various educational levels such as junior high school, senior high school, vocational high school, and higher

education institutions to determine its effectiveness in enhancing students' STEM skills, computational thinking, problem-solving, and creativity.

5. Development of STEM Robotics Modules and Curriculum. The developed mobile robot can be complemented with practical modules, job sheets, and a structured STEM-based robotics learning curriculum so that it can be widely used in extracurricular activities, school laboratories, and teacher training programs.

Through these various developments, the ESP32-based Multifunctional Educational Mobile Robot is expected to serve not only as a robotics learning medium but also as a smart technology learning platform capable of supporting the development of STEM, AI, IoT competencies, and 21st-century skills for students.