CHAPTER V
CONCLUSION

5.1 Conclusion

Based on the results of the design, implementation, and testing of the system that has been carried out, the following conclusions can be drawn.

First, the ESP32-based wearable system is designed and built to detect sitting posture using the MPU-6500 gyroscope sensor with Fuzzy Type-2 logic-based data processing. The sensor is able to read pitch and roll angles consistently with standard deviations ranging from 0.1595° to 0.2342° per posture class. The use of Fuzzy Type-2 as a preprocessing stage produces more stable sensor data through a confidence-based adaptive weighting mechanism, resulting in cleaner data before entering the classification process.

Second, a Support Vector Machine (SVM) algorithm with a Radial Base Function (RBF) kernel and a multi-class One-vs-One approach was applied to classify the sitting posture into three categories (upright, slightly hunched, and hunched) by training the model using 720 data (80%) and testing it on 180 data (20%). The model achieved a test accuracy of 100% as well as an average 5-fold cross-validation accuracy of 99.72%, which confirmed that the model did not overfit and had good generalization capabilities. The implementation of the model on ESP32 was carried out by converting SVM parameters into hardcoded C arrays, with consistent classification results between MATLAB and ESP32. The deployment process is going well.

Third, posture correction feedback is provided through a vibrating motor that is activated in real-time when the user is in an unergonomic posture. Vibration patterns are designed differently according to severity: periodic vibrations (1-second intervals) for slightly hunched postures, and continuous vibrations for hunchback postures. A 3-second validation mechanism is applied so that the vibrating motor is only activated when an unergonomic posture is detected consistently, avoiding activation due to momentary movement.

Fourth, the integration of the system with the Blynk IoT platform is carried out through the ESP32 Wi-Fi connection using the Blynk Cloud protocol. The data is connected to Blynk's IoT platform so that user posture data can be monitored and analyzed in real-time or within a certain period of time. The information displayed includes pitch and roll angle values, posture classification status, posture quality graphs, and posture distribution percentage reports at the end of each usage session.

Fifth, tests on two subjects showed changes in posture distribution after vibration feedback was activated. The percentage of upright posture increased from 77.3% to 92.3% in the first subject, and from 85.1% to 95.4% in the second subject. The data shows that the developed system is not only able to monitor posture in real-time, but also has a measurable impact on the distribution of the user's sitting posture during the usage session.

5.2 Suggestions

Based on the results of the research that has been conducted and the limitations identified during the development and testing process of the system, there are several suggestions that can be considered for further research and development.

First, related to datasets and data collection. The dataset used in this study was collected using a holder to ensure controlled ground truth. In subsequent research, it is recommended to collect datasets directly from sensors attached to the user's body with a consistent position according to real usage conditions. This will reduce the potential domain gap between the training and deployment stages, and result in a more representative model of actual human posture variations.

Second, related to the number and diversity of test subjects. The system testing in this study involved two subjects with relatively similar characteristics, so that the results obtained were descriptive as an initial functional validation. Further research is recommended to involve more subjects with more diverse variations including differences in gender, age, sitting habits, and type of work so that the effectiveness of the system can be statistically inferentially proven.

Third, related to the implementation of Fuzzy Type-2 on embedded systems. In this study, the implementation of Fuzzy Type-2 in ESP32 is an adaptation of the full scheme used in the analysis stage in MATLAB, with simplification of the type reduction process to meet real-time computing needs. Further research can explore a more complete implementation of Fuzzy Type-2 with a type reduction algorithm optimized for embedded devices that is more computationally efficient than the full Karnik-Mendel iteration.

Fourth, related to long-term testing. The testing in this study was carried out in one session per condition with a duration of ±2.5 hours. It is recommended to conduct longitudinal testing over a longer period of time, such as a few weeks to months to evaluate whether the system is able to induce permanent changes in posture habits, rather than just a temporary change during the period of use of the tool.

Fifth, related to hardware development. The system can be developed by adding an automatic calibration mechanism that does not depend entirely on the user's protocol, for example by adding sensors or visual indicators that validate the upright position before baseline calibration is performed. In addition, the integration of the direct charging module on the device will improve the practicality of daily use.

Sixth, related to the development of system features. To increase long-term benefits, the system can be developed by adding features of historical postural analysis, ergonomic recommendations based on user habit patterns, and rest reminder notifications. Integration with digital health platforms or occupational safety management systems can also extend the impact of using these systems in a broader context.