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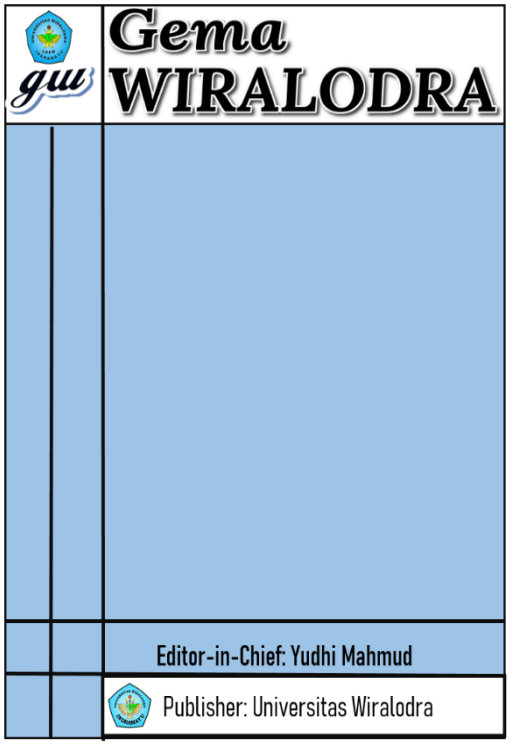

Development of a Website-Based Wind Speed and Wind Direction Warning System in Pao-Pao Village, Maros Regency

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Development of a Website-Based Wind Speed and Wind Direction Warning System in Pao-Pao Village, Maros Regency

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Abstract
This study aims to develop a website-based early warning system for wind speed and wind direction as an effort to mitigate strong-wind disasters in Pao-Pao Village, Maros Regency. The background of this study is the absence of an early warning system capable of providing fast, accurate, and real-time information on wind conditions to the community, so that residents still rely on manual observation. The study employed the Research and Development (R&D) method with a System Development Life Cycle (SDLC) approach using the Waterfall model, covering the stages of requirement analysis, design, implementation, testing, and system evaluation. The system was developed using an anemometer sensor to measure wind speed, a wind vane sensor to detect wind direction, an ESP32 microcontroller for data processing, a website as the monitoring medium, and Telegram notifications as the medium for delivering early warnings. System testing was carried out using the Black Box Testing method, sensor testing, and user evaluation through a questionnaire administered to 15 respondents from the Pao-Pao Village community. The results show that all system functions operated properly, with a functional testing success rate of 100%. The wind direction sensor was able to detect eight cardinal and intercardinal directions with identical readings across five repetitions, except at four boundary angles, while the wind speed sensor showed a linear relationship between changes in wind speed and the sensor's output voltage. The user evaluation results obtained an average score of 4.4, categorized as "Very Good". Thus, the developed system has met the aspects of validity, functionality, and practicality, making it feasible to be used as a medium for monitoring wind conditions and as a website-based early warning system in Pao-Pao Village, Maros Regency.
Keywords: Early Warning System, Internet of Things (IoT), Wind Speed, Wind Direction, ESP32, Website, Disaster Mitigation.

1. Introduction

Wind is the movement of air masses caused by pressure differences between regions, with its direction and speed capable of changing dynamically (Kartasapoetra, 2012). In Indonesia, this weather dynamic frequently triggers tornado (puting beliung) disasters, the number of which continues to increase every year, with the highest distribution of cases occurring on Java, Sumatra, and South Sulawesi (Suhardi et al., 2020), a pattern corroborated by more recent national meteorological data showing Sumatra and Java as the two islands with the highest tornado incidence recorded in 2023 (BMKG, 2024).

Maros Regency, South Sulawesi, is one of the regions repeatedly affected by strong winds. In June 2022, a tornado struck Maros Baru Sub-district in Maros Regency and damaged 161 residential houses, 53 of them heavily (ASEAN Coordinating Centre for Humanitarian Assistance on disaster management (AHA Centre, 2022). One area with the potential to be affected is Pao-Pao Village, which to date has no early detection device for strong-wind

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disasters, so that residents rely solely on intuition and manual observation whenever the sky begins to darken and the wind starts to blow hard.

The absence of an early warning system places the community in a vulnerable position, as they do not have sufficient time to protect their homes and families, particularly children and the elderly. In fact, the negative impacts of tornadoes range from ecosystem damage and material losses to psychological trauma among affected communities, impacts that could be reduced if the potential hazard could be identified and communicated to local residents at an earlier stage.

The development of Internet of Things (IoT) technology opens opportunities to build low-cost, real-time, and easily accessible weather monitoring systems through everyday devices such as smartphones. Previous studies have demonstrated this potential, for instance an IoT-based wind speed and wind direction monitoring system using a Raspberry Pi that sends data to a web server (Fernando et al., 2022), a flood and windstorm detection and weather monitoring system based on Arduino Mega with a buzzer, an Android application, and a web application (Pradirta et al., 2022), and a lidar-based wind-hazard detection system deployed at a major airport for aviation safety (Yuan et al., 2022). More recently, a portable IoT-based digital instrument combining an anemometer with a Hall-effect wind vane achieved over 97% measurement accuracy for both wind speed and wind direction (Soehartanto & Setiantoro, 2023), confirming the continued feasibility of low-cost, microcontroller-based wind instrumentation. National disaster records further indicate a consistent upward trend in hydrometeorological hazards, including strong winds, across Indonesian regions in recent years (Badan Nasional Penanggulangan Bencana [BNPB], 2022), reinforcing the urgency of localized early warning solutions such as the one proposed for Pao-Pao Village, while a recent GIS-based risk assessment has likewise been used to classify tornado-prone zones and prioritize mitigation actions in other Indonesian regions (Khairiyah et al., 2025). However, the previous studies above are limited in several respects: some focus on measurement accuracy or data display without any threshold-based warning mechanism (Fernando et al., 2022; Soehartanto & Setiantoro, 2023), while others combine wind sensing with other hazards and rely on local buzzers and applications (Pradirta et al., 2022), without an automatic threshold-triggered push warning dedicated to strong winds for residents of a rural village. Telegram-based early warning systems, in turn, have mostly been developed for flood monitoring (Sari & Christanto, 2023; Waluyo & Putra, 2024; Wijaya & Rino, 2024) rather than strong winds. Accordingly, the novelty of this study lies in integrating wind speed and wind direction sensing, a publicly accessible real-time website, and automatic threshold-triggered Telegram notifications in a single low-cost ESP32-based system, which is developed and evaluated specifically with the community of a rural village prone to strong winds, Pao-Pao Village. This combination has not been widely studied and constitutes the research gap underlying this study.

Based on the description above, this research is formulated into four problems, namely: (1) what are the results of developing a wind speed and wind direction warning system integrated with a website in Pao-Pao Village; (2) how valid is the developed system; (3) how practical is the system according to the Pao-Pao Village community; and (4) how effective is the system in increasing community awareness, as indicated by the community's perceived alertness (kewaspadaan), the effectiveness of the warnings received, and the system's contribution to reducing disaster risk. This study aims to produce, validate, and analyze the practicality and effectiveness of a website-based wind speed and wind direction warning system for the community of Pao-Pao Village, Maros Regency.

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2. Methods

This study employed the Research and Development (R&D) method (Sugiyono, 2018) with a System Development Life Cycle (SDLC) approach using the Waterfall model, covering the stages of requirement analysis, design, implementation, testing, and system evaluation. The product developed was a website-based wind speed and wind direction early warning system, which was then tested for validity (functional and sensor testing), practicality (user evaluation), and effectiveness (community awareness). The user evaluation involved 15 respondents from the Pao-Pao Village community.

The research was conducted over two months in Pao-Pao Village, Maros Regency. The research subjects included village officials and community members of Pao-Pao Village residing in areas prone to strong winds, as well as wind speed and direction data obtained from sensor measurements.

System Design and Implementation

The system was designed using a JL-FS2 type anemometer sensor to measure wind speed and a wind vane sensor based on an LED-photodiode array to detect eight wind directions. Cup- and vane-type anemometers of this kind remain the operational standard for wind-speed measurement in meteorological practice owing to their mechanical simplicity and favorable linearity of response (Pirooz et al., 2021). The analog signal from the anemometer was converted through a current-to-voltage converter module before being processed by the ESP32 microcontroller, while the digital signal from the wind vane was received directly by the microcontroller's digital pin. The ESP32 was selected for its integrated Wi-Fi and Bluetooth Low Energy connectivity within a single chip, characteristics that continue to make it a favored platform for low-cost IoT-based monitoring systems (El-Khozondar et al., 2024), consistent with recent cost-effective IoT weather-monitoring implementations that rely on Wi-Fi-connected microcontrollers for continuous data transmission to a remote server (Mohapatra & Subudhi, 2022). The processed data was then transmitted to a server via an internet connection, stored in a database, and displayed on a website interface in real time. The system was also equipped with Telegram notifications and an emergency alarm that activated automatically whenever wind speed exceeded the predetermined safety threshold; this automatic, threshold-triggered alarm mechanism follows the same sensor-activated warning logic used in other emergency notification systems designed for rapid hazard response (Santoso et al., 2025), and mirrors the design rationale of recent Telegram-integrated IoT early-warning systems that combine microcontroller-based sensing with instant messaging alerts for time-critical hazard communication (Wijaya & Rino, 2024; Waluyo & Putra, 2024). The software used included Arduino IDE for microcontroller programming, as well as Visual Studio Code and XAMPP for developing the PHP, HTML, and JavaScript-based website application.

Data Collection Techniques

Data were collected through semi-structured interviews with officials and community members of Pao-Pao Village to explore system requirements, as well as questionnaires referring to the ISO 25010 quality standard for black box testing and user evaluation. The research instruments were validated by two expert validators on the aspects of instructions, instrument content, and language, obtaining an average validity score of 96.82% (very valid category) and a Percentage of Agreement value of 96.82% (very reliable category).

Data Analysis Techniques

Qualitative data from interviews and observations were analyzed descriptively to describe user needs and environmental conditions. Quantitative data from sensor measurements were

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analyzed by comparing sensor output values against standard measuring instruments. Black box testing used a Guttman scale (Yes/No) with the success percentage formula P = (F/N) x 100%, while user satisfaction evaluation used a 5-point Likert scale, analyzed descriptively (Sugiyono, 2017) to obtain a category interpretation of the system's acceptance level. The 30-item questionnaire covered six aspects: ease of use (items 1–5), system performance (6–10), information accuracy (11–15), system benefits (16–20), warning system (21–25), and user satisfaction (26–30). The effectiveness of the system in improving community awareness was measured through three indicators drawn from this instrument: (1) perceived alertness of the community (item 22), (2) the effectiveness and comprehensibility of the early warnings (items 21 and 25), and (3) the contribution of the system to reducing disaster risk (items 16 and 18). Mean scores were interpreted using the criteria: >4.2 Very Good, >3.4–4.2 Good, >2.6–3.4 Fairly Good, >1.8–2.6 Poor, and ≤1.8 Very Poor.

3. Results and Discussion

This section presents the results of the development and testing of the website-based wind speed and wind direction warning system, namely black box testing, sensor testing, and user evaluation, followed by a discussion of the results in relation to previous studies on IoT-based early warning systems.

Table 1.
Results of Black Box Testing and Sensor Testing

Testing Aspect	Number of Items/Respondents	Result	Category
Black Box Testing	8 items	100%	Accepted
Wind direction sensor (8 directions)	5 test repetitions	Consistent*	Good
Wind speed sensor	Linearity test	Linear relationship	Good
User evaluation	15 respondents, 30 items	Average 4.4	Very Good

*Source: Processed data (2026). *Misreadings at the boundary angles 70°, 160°, 250°, and 340°*

As summarized in Table 1, all four testing aspects — black box testing, wind direction sensor consistency, wind speed sensor linearity, and user evaluation — fall into the "Accepted", "Good", or "Very Good" categories, confirming that the system met its functional and practical design targets across every testing dimension. User evaluation was conducted through a 30-item questionnaire distributed to 15 respondents from the Pao-Pao Village community, covering aspects of ease of use, system performance, information accuracy, system benefits, and warning effectiveness. The analysis results showed an average score of 4.4 on a 5-point Likert scale, which falls into the "Very Good" category, indicating a high level of user acceptance of the developed system.

Overall, these results are consistent with the findings of Fernando et al. (2022) and Pradirta et al. (2022), which showed that the integration of anemometer sensors, microcontrollers, and an IoT platform can reliably transmit wind data to web and mobile applications. The system developed in this study reinforces those findings by adding a website interface as a public monitoring medium and Telegram notifications as a warning channel that is more easily accessible to rural communities without requiring them to continuously open the website. Within this architecture, the ESP32 microcontroller functions as the central link between the hardware sensors, the communication network, and the web-based application, a role consistent with recent analyses of IoT-based natural-disaster management architectures

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more broadly (Krichen et al., 2024). Comparable Telegram-integrated early warning designs have also been reported for other hazard types, including flood monitoring based on river-height and water-level sensing (Fauzi & Suharjo, 2026; Sari & Christanto, 2023; Sumardiono et al., 2022), cloud-based earthquake alert systems (Rosca & Stancu, 2024), and rural disaster-logistics classification frameworks in the Indonesian context (Yahya et al., 2021), indicating that the website-and-Telegram notification approach adopted in this study aligns with a broader, actively developing trend in low-cost IoT-based disaster early warning research. The application of IoT technology in this system allows the process of data acquisition, processing, and dissemination to occur automatically, so that information on environmental conditions can be received by users within a short time (Atzori et al., 2010; Gubbi et al., 2013), a cloud-centered data flow that remains the dominant pattern among current IoT application architectures more broadly (Dauda et al., 2024).

Regarding effectiveness, the mean scores per aspect were 4.40 for ease of use, 4.32 for system performance, 4.40 for information accuracy, 4.48 for system benefits, 4.42 for the warning system, and 4.48 for user satisfaction, all in the "Very Good" category, and all 15 respondents (100%) fell into this category. On the awareness indicators, item 22 (the system increases community alertness) obtained the highest score in the warning-system aspect (4.6), followed by the comprehensibility of the warning notification (item 21, 4.5), the effectiveness of the early warning (item 25, 4.4), the speed of obtaining wind information (item 16, 4.4), and the reduction of disaster risk (item 18, 4.4). These results suggest that the community perceived the system as effective in raising awareness of strong winds. However, this finding reflects perceived awareness only; awareness was not measured with a pre-test/post-test or a field warning-response simulation, so the effectiveness claim should be interpreted cautiously and examined further in future research. With a functional success rate of 100%, wind direction detection that is consistent except at boundary angles, linearity of the wind speed sensor output, and user acceptance in the very good category, this system is considered to have met the aspects of validity, functionality, and practicality as a monitoring medium as well as a website-based early warning system for the community of Pao-Pao Village, Maros Regency.

4. Conclusion

This study successfully developed a website-based early warning system for wind speed and wind direction utilizing Internet of Things (IoT) technology, consisting of an anemometer sensor, a wind vane sensor, an ESP32 microcontroller, a website as the monitoring medium, and Telegram notifications as the medium for early warnings. Black box testing showed a functional success rate of 100%, the wind direction sensor detected eight cardinal and intercardinal directions with identical readings across five repetitions except at four boundary angles (70°, 160°, 250°, and 340°), and the wind speed sensor showed a linear relationship between wind speed and output voltage. Evaluation involving 15 respondents from the Pao-Pao Village community obtained an average score of 4.4 (Very Good category). Based on the questionnaire indicators of system benefits and warning effectiveness, the system was perceived as effective in supporting community awareness of strong winds, although this has yet to be verified through a pre-test/post-test measurement. Thus, the developed system has met the aspects of validity, functionality, and practicality, making it feasible to be used as an early warning system for wind speed and wind direction in Pao-Pao Village, Maros Regency, with the potential to be applied in other regions with similar wind disaster risk characteristics. Future research is recommended to add other meteorological sensors, prediction features based on

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machine learning, and a mobile application to further improve the coverage and speed of information delivery.

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