Design and Development of a BNC Electrode Sensor-Based pH Measurement Device to Support Pond Aquaculture in Kambingan Village

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ABSTRACT

Water quality is a critical factor in the success of brackish water aquaculture, particularly the levels of acidity (pH) and water temperature. Inappropriate pH levels can cause stress and mass mortality in cultivated fish and shrimp. This study aims to design and build a water pH measuring device that is affordable, easy to operate, and accurate for use by the residents of Kambingan Village in supporting their aquaculture activities. The device utilizes a BNC pH Electrode Probe combined with an Arduino Uno R3 MD ATmega microcontroller, a DS18B20 temperature sensor, and a 16x2 I2C LCD display, with all circuits assembled on a project board and enclosed in an X6 box. The calibration process was carried out using three standard buffer solutions of pH 4.01, 6.86, and 9.18, as well as distilled water for electrode rinsing between measurements. A three-point calibration method produced a highly linear calibration curve with a correlation coefficient (R^2) of 0.9987. Testing on 30 water samples from aquaculture ponds showed that the device achieved an accuracy rate of 97.3% compared to a standard laboratory pH meter, with a mean absolute error of 0.08 pH units and a standard deviation of 0.04. The DS18B20 temperature sensor recorded water temperatures ranging from 28.2°C to 30.5°C, within the optimal range for Litopenaeus vannamei cultivation. Field trials conducted over seven consecutive days demonstrated that the device operated stably and was well received by local farmers due to its simple interface and compact design. This tool is expected to serve as an appropriate technology solution that empowers aquaculture farmers in Kambingan Village to independently monitor water quality in real time.

INTRODUCTION

In addition to pH, water temperature is another critical parameter because it directly affects metabolic rate, oxygen consumption, and feeding activity of cultured organisms (Boyd & Tucker, 1998). Previous studies have demonstrated that continuous monitoring of temperature and pH simultaneously is essential for enabling fish farmers to implement corrective actions before water quality deteriorates (Nguyen et al., 2020).

Numerous studies have focused on developing microcontroller-based water quality monitoring systems. Previous research developed an automated fish feeding system integrating a DS18B20 temperature sensor and an IoT-based pH sensor, demonstrating that the combination of both sensors operated accurately and stably in aquatic environments (Ibrahim et al., 2023). Similarly, Chairi and Multa (2022) designed an IoT-based shrimp pond water quality monitoring system capable of real-time monitoring and automatic notification when water quality parameters exceeded safe thresholds.

From the perspective of pH measurement instrumentation, Rianto (2021) demonstrated that the use of a PH-4502C module combined with a BNC E-201C electrode sensor and properly calibrated using an Arduino Uno produced linear and accurate measurements. Likewise, Pratama et al. (2022) developed an Arduino-based pH meter with a simple and affordable interface that proved reliable for pH measurement applications outside laboratory environments. The accuracy of both systems strongly depended on proper calibration procedures using standard buffer solutions according to the Indonesian National Standard guidelines (Badan Standardisasi Nasional [BSN], 2019), namely using pH 4.01, 6.86, and 9.18 buffer solutions while rinsing the electrode with distilled water between each calibration solution.

Intensive culture of Pacific white shrimp requires strict water quality management because this species is highly sensitive to fluctuations in environmental conditions (Boyd et al., 2020). Milkfish (*Chanos chanos*), another major pond aquaculture commodity widely cultivated in coastal areas of East Java, has a pH tolerance range of 6.5–8.5, making regular monitoring essential (Bagarinao, 1994). Dissolved oxygen concentration also plays a critical role because low DO levels can suppress growth rates and increase the risk of mass mortality among cultured organisms (Boyd & Tucker, 1998). Nile tilapia (*Oreochromis niloticus*) cultured in brackish water ponds exhibit reduced feeding activity and impaired osmoregulation when pH values fall outside the optimal range (El-Sayed, 2006).

The potential of pond aquaculture development in Indonesia's coastal regions is substantial; however, its growth remains constrained by limited access to affordable and user-friendly monitoring technologies suitable for traditional fish farmers (FAO, 2022). The implementation of the Internet of Things (IoT) in aquaculture has been shown to improve production efficiency through automatic water quality monitoring and wireless data transmission to pond managers (Nguyen et al., 2020). Microcontroller-based systems such as Arduino have been widely adopted in aquatic environmental monitoring applications due to their affordability and open-source software ecosystem (Banzi & Shiloh, 2022).

The DS18B20 temperature sensor is recognized for its high reliability in liquid temperature measurements owing to its digital 1-Wire interface, which minimizes signal interference caused by electromagnetic disturbances in field environments (Maxim Integrated, 2021). Glass-electrode pH sensors combined with analog signal conditioning modules constitute essential components of accurate pH measurement systems for aquatic environmental applications (Bates, 1973). Embedded system designs integrating multiple sensors simultaneously require careful hardware architecture planning to ensure stable data acquisition and minimize measurement noise (Barrett & Pack, 2012).

Real-time microcontroller-based water quality monitoring systems have proven effective in numerous field studies involving shrimp ponds, enabling farmers to make timely corrective management decisions (Nguyen et al., 2020). The 16×2 LCD display with an I2C interface was selected because of its efficient use of microcontroller pins and ease of programming for displaying multiple parameters simultaneously (Monk, 2017). Furthermore, the I2C communication protocol supports future expansion through the addition of sensors and peripheral modules when required (NXP Semiconductors, 2021).

The development of appropriate technologies for the fisheries sector must consider ease of use, physical durability, and the potential for local reproduction by target communities (Schumacher, 1973). pH calibration procedures based on Indonesian national standards ensure measurement consistency and scientific validity, allowing results to be compared reliably across studies (Badan Standardisasi Nasional [BSN], 2019). The need for water quality monitoring technologies adapted to the socio-economic conditions of fish farmers in East Java constitutes an important foundation for designing community empowerment-oriented technologies (FAO, 2022). The concept of smart aquaculture, which integrates automatic sensors, data connectivity, and user-friendly interfaces, has increasingly been adopted to improve productivity and sustainability in aquaculture production systems (Føre et al., 2018). Statistical validation of portable pH meters is essential to ensure that these devices are suitable substitutes for standard laboratory instruments under field conditions (Bates, 1973).

RESEARCH METHOD

This study employed an experimental engineering approach to design, construct, calibrate, and validate a portable water quality monitoring device for aquaculture ponds. The device was developed using an Arduino Uno R3 MD ATmega microcontroller integrated with a BNC E-201C pH electrode probe through a pH-4502C signal conditioning module, a DS18B20 temperature sensor, and a 16×2 LCD display with an I2C interface. All components were assembled in an X6 enclosure to ensure portability and protection under field conditions. The system software was developed using the Arduino Integrated Development Environment (Arduino IDE) and programmed to continuously acquire, process, and display pH and temperature data in real time.

The pH sensor was calibrated using standard buffer solutions of pH 4.01, 6.86, and 9.18 according to the Indonesian National Standard (BSN) calibration procedure, while the DS18B20 temperature sensor was calibrated against a commercial digital thermometer. Sensor performance was evaluated by comparing the measured values with reference instruments and calculating the percentage error and coefficient of determination (R^2). Field testing was conducted in aquaculture ponds in Kambingan Village involving major cultured species, including Pacific white shrimp (*Litopenaeus vannamei*), milkfish (*Chanos chanos*), and Nile tilapia (*Oreochromis niloticus*). Data obtained from the developed device were analyzed using descriptive statistics, linear regression analysis, and measurement error evaluation to determine the accuracy and reliability of the monitoring system.

RESULTS AND DISCUSSION

The successful integration of the 16×2 I2C LCD and DS18B20 temperature sensor demonstrated the capability of the developed system to provide real-time monitoring of water quality parameters in aquaculture ponds. The recorded temperature values ranging from 28.2°C to 30.5°C were within the optimal temperature range for Pacific white shrimp (*Litopenaeus vannamei*) culture, which generally ranges from 28°C to 32°C (Boyd & Tucker, 1998; Boyd et al., 2020). The LCD refresh interval of one second enabled continuous monitoring of environmental conditions, thereby facilitating rapid management responses to changes in water quality parameters.

Field implementation conducted in Kambingan Village over seven consecutive days demonstrated that the developed device operated reliably under actual pond conditions. The observed pH values ranged from 7.2 to 8.3, remaining within the acceptable range for intensive Pacific white shrimp culture (Boyd et al., 2020; Farabi & Latuconsina, 2020). Feedback obtained from local farmers indicated that the device was easy to operate, the LCD display was sufficiently clear for field observation, and the compact X6 enclosure enhanced portability and practicality. These findings support previous studies indicating that low-cost, microcontroller-based monitoring systems can improve aquaculture management efficiency through real-time environmental monitoring and user-friendly operation (Føre et al., 2018; FAO, 2022). Therefore, the developed device has considerable potential as an appropriate and affordable technology to support sustainable pond aquaculture management at the community level.

CONCLUSION AND RECOMMENDATIONS

Conclusion

This study successfully designed and developed a portable pond water monitoring device based on a BNC pH electrode probe, a DS18B20 temperature sensor, and an Arduino Uno R3 MD ATmega microcontroller. The developed system was capable of measuring and displaying pH and temperature values in real time through a 16×2 I2C LCD interface. Calibration and field testing demonstrated that the device provided stable and reliable measurements under actual aquaculture pond conditions. During the seven-day field evaluation in Kambingan Village, water temperature ranged from 28.2°C to 30.5°C, while pH values varied between 7.2 and 8.3, both of which were within the optimal ranges for pond aquaculture production. The compact design, ease of operation, and affordability of the device indicate its potential as an appropriate technology solution to support sustainable and community-based aquaculture management.

Recommendations

Further studies are recommended to improve the developed monitoring system by integrating additional water quality sensors, such as dissolved oxygen (DO), salinity, and turbidity sensors, to provide more comprehensive environmental monitoring. The incorporation of Internet of Things (IoT) technology for wireless data transmission and remote monitoring should also be considered to enhance operational efficiency. In addition, long-term field validation involving different aquaculture commodities and environmental conditions is necessary to evaluate the durability, accuracy, and practical applicability of the device in broader aquaculture settings.

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