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Implementation of Kalman Filter With Pi-Controller for Temperature Sensor in Fish Pond Monitoring System

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ABSTRACT

The research aims to determine monitoring the temperature in fish ponds is crucial for successful cultivation, especially in tropical climates that often experience hot weather. This study proposes an approach using the Kalman Filter method and PI (Proportional-Integral-Derivative). Aside from that, to controller to improve the accuracy of monitoring the temperature in fish ponds. Integration with the Firebase Realtime Database allows for real-time data monitoring. Testing was conducted by comparing the DS18B20 temperature sensor without a filter with three variations of the Kalman Filter and PI controller. The results show that using Kalman Filter 3 with the PI controller resulted in a significant reduction in error and noise compared to using Kalman Filter alone. In conclusion, the integration of the Kalman Filter and PI controller with the Firebase Realtime Database can improve the accuracy of monitoring the temperature in fish ponds and has positive implications for increasing efficiency and fish welfare.

Tujuan penelitian adalah mengetahui pemantauan suhu dalam kolam ikan menjadi krusial untuk keberhasilan budidaya, terutama dalam iklim tropis yang seringkali mengalami cuaca panas. Penelitian ini mengusulkan pendekatan menggunakan metode Kalman Filter dan pengontrol PI (Proportional-Integral-Derivative). Selain itu juga untuk meningkatkan akurasi pemantauan suhu kolam ikan. Integrasi dengan Firebase Realtime Database memu- ngkinkan pemantauan data secara real-time. Pengujian dilakukan dengan membandingkan sensor suhu DS18B20 tanpa filter dengan tiga variasi Kalman Filter dan pengontrol PI. Hasilnya menunjukkan bahwa penggunaan Kalman Filter 3 dengan pengontrol PI menghasilkan penurunan error dan noise yang signifikan dibandingkan dengan penggunaan Kalman Filter saja. Kesimpulannya, integrasi Kalman Filter dan pengontrol PID dengan Firebase Realtime Database dapat meningkatkan akurasi pemantauan suhu kolam ikan dan memiliki implikasi positif dalam meningkatkan efisiensi dan kesejahteraan ikan.

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1. Introduction

Nowadays, the growth of technology creates an increasing demand for devices that can support various human activities. Technological advancements are expected to provide many positive benefits in daily life. The presence of technology not only opens up opportunities for more innovations but can also enhance better performance in the fish farming sector. Especially in very large industrial-scale fish farms. From the graph above, based on data from KKP Statistics, aquaculture production from 2019-2021 has decreased. This has resulted in fish farmers experiencing big enough losses [1].

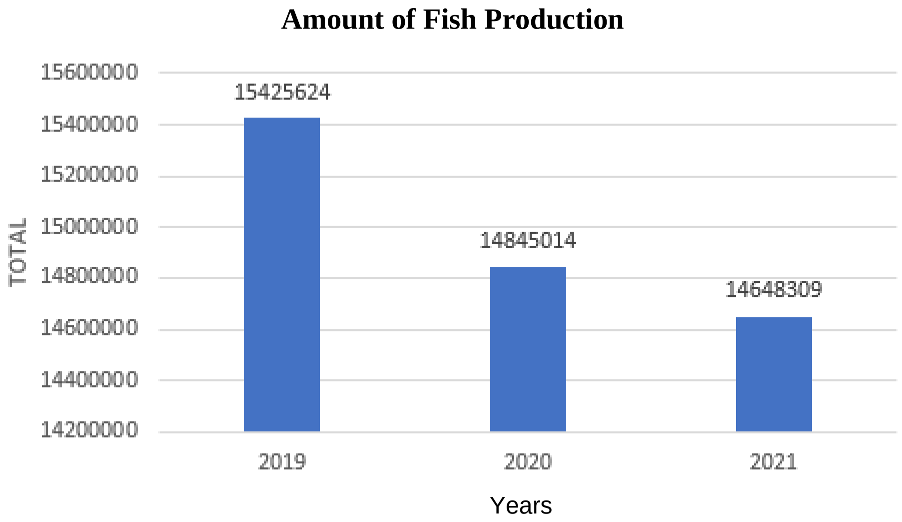

Fig. 1. Data on the amount of fish production

It was reported by liputan6.com that extreme weather caused Sawohan's ponds to fail in their harvest. In the life of the fish, this interaction will have a significant impact on the conditions for success in the fish cultivation sector, becoming a determining factor in achieving the goals of the Ministry of Education and Culture.

According to information obtained from the Central Bureau of Statistics in 2021 regarding the instability of temperature weather in Indonesia, this is a serious challenge for the fish farming sector. Therefore, to overcome this problem, water measurement parameters, including water quality parameters, that can be monitored in fish farming are regulated following the provisions contained in Government Regulation No. 82 of 2001. This regulation aims to establish class two and three water quality standards applicable to fish farming.

In facing this challenge, the importance of continuously monitoring the temperature in the fish pond becomes very important [2][3]. One effective method for carrying out this monitoring is to apply the Kalman filter method to the temperature sensor. Kalman filter is a signal processing technique that can improve estimates of measured data, overcome interference, and increase the accuracy of temperature measurements [4][5]. By applying the Kalman filter, data obtained from temperature sensors can be analyzed and refined to produce more precise temperature estimates related to the conditions of the fish pond cultivation industry sector.

The main advantage of the Kalman filter method lies in its capacity to estimate the state of the system and make predictions of the system state, even in conditions where data is limited or there is interference with sensor readings [6]. In the context of monitoring temperature in fish ponds during long periods of dry season, the Kalman filter plays a role in reducing the effects of unwanted temperature fluctuations, ensuring more accurate temperature estimation, and providing more effective control over possible temperature changes. Thus, the application of the Kalman filter is essential in maintaining environmental conditions in fish ponds to meet the needs of fish and support their well-being in the face of extreme weather changes, such as those that occur during prolonged dry seasons.

Therefore, this project emphasizes the important aspect of maintaining fish welfare in fish ponds through efficient monitoring and regulation of water temperature using the Firebase Realtime Database enabling temperature and humidity data from sensors to be stored directly. Firebase provides fast and structured data access through mobile or web applications, enabling the user to monitor fish pond conditions in real time and respond quickly to changes [7]. Thus, the integration of Firebase in a fish pond monitoring system not only improves monitoring efficiency, but also allows users to take appropriate actions based on available information, to support fish welfare, and to improve the overall optimization of the fish pond environment.

This method can be achieved by utilizing high technology, such as applying the Kalman filter method to the DS18B20 temperature sensor and integrating it with the ESP32 microcontroller. The main advantage of using the Kalman filter method is its ability to predict system status by estimating the state of the system, which has the effect of increasing the precision and accuracy of the temperature sensor measurements. Even in situations with limited data, the use of these filters allows the sensor to achieve balance more quickly than conventional methods that only take sensor measurements. Through the implementation of the Kalman filter and PI control, our efforts are aimed at increasing the accuracy of temperature estimation, achieving more stable temperature control, and maintaining the water temperature to always suit the needs of the fish within the framework of the fish pond monitoring system [8].

2. Research Method

This research utilizes an experimental approach that involves direct testing of the Kalman Filter method and PI controller in the context of fish pond temperature monitoring. The experimental approach was chosen because it allows the researcher to control certain variables that affect the results of the experiment, thereby allowing a more accurate analysis of the effectiveness of the method being tested.

In the initial stage of the research, an experimental design was carried out which included selecting a representative type of fish pond, selecting an appropriate temperature sensor, and setting the hardware configuration. The fish ponds were selected concerning adequate size for accurate temperature monitoring as well as environmental conditions suitable for the needs of the fish [9][10].

The Kalman Filter method was chosen because of its ability to process sensor data to produce more accurate temperature estimation, especially in the face of noise or interference in sensor readings [11]. Meanwhile, the PI controller was chosen to optimize the system response to temperature changes that occur in the fish pond [12][13].

During the testing process, the data collected from the temperature sensor is processed using the Kalman Filter method and a PI controller. The processed data is then compared with the actual temperature data measured directly to evaluate its accuracy. The tests are conducted under controlled conditions to ensure the validity of the results obtained. Using this experimental approach, it is expected that this research can make a significant contribution in improving fish pond temperature monitoring and ultimately, supporting the success of fish farming.

2.1 Materials and Tools

- **ESP-32**, The ESP-32 microcontroller is used to read and process data from the sensors used in this project. In addition, it is also used to send data to the Firebase real-time database.
- **DS18B20 Sensor**, The DS18B20 sensor is used to read the water temperature in fish ponds. This sensor can be accessed using the ESP-32 microcontroller.
- **DHT22 Sensor**, The DHT22 sensor is used to read the air temperature around the fish pond. This sensor can also be accessed using the ESP-32 microcontroller.
- **Resistors**, Resistors are used to limit current and control voltage levels in a circuit, providing resistance to electric current.
- **18650 battery**, An 18650 battery is used as the power source in this project, with a nominal voltage of about 3.7 volts and a capacity measured in milliampere-hours (mAh), ranging from 2000mAh to over 3500mAh.

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- **TP4056 Module**, The TP4056 module is used to charge the battery to keep it safe and efficient in this project.
- **Jumper Cables**, Jumper cables are used as a link between two points in this project circuit.
- **Solder**, Solder is used to connect two or more components in this project.
- **Tin**, Tin is used as a process for connecting tool components in this project.

2.2 Data Collection Procedure

- **Installation of DS18B20 Temperature Sensor**: The DS18B20 temperature sensor is installed outside the fish pond keeping in mind the optimal distance to ensure accurate temperature monitoring.
- **Integration with ESP32 Microcontroller**: The temperature sensor is interfaced with the ESP32 microcontroller. A WiFi connection is configured to transmit the temperature data detected by the sensor to the Firebase Realtime Database. This allows direct and real-time access to data remotely over the internet.
- **Initial Testing**: Before the actual data collection begins, initial testing is conducted to ensure that the sensors are functioning properly and the data can be sent appropriately to the Firebase Realtime database. This testing aims to identify and fix potential technical issues before the actual data collection process begins.
- **Testing the Kalman Filter Method and PI Controller**: After the initial setup is complete, testing of the Kalman Filter method and PI controller on the data received from the temperature sensor is carried out. This test aims to evaluate the effectiveness of these methods in improving the accuracy of fish pond temperature monitoring. These steps are carefully performed to ensure the validity and reliability of the results obtained.

2.3 Data Analysis

- **Data Processing**: The temperature data received from the sensors will be processed using the Kalman Filter method and a PI controller. The Kalman Filter is used to remove noise and produce a more accurate temperature estimation, while the PI controller is used to correct the desired temperature set point.
- **Comparison of Results**: After the data has been processed with and without the filter, a comparison is made between the results. This comparison aims to evaluate the accuracy improvement provided by the Kalman Filter and PI controller in improving the temperature estimation.
- **Change Analysis**: In addition, analyses were also conducted to understand the change in temperature estimation before and after the use of the filter. This helps in determining the effectiveness of the filter in improving the accuracy of fish pond temperature monitoring.
- **Interpretation of Results**: The analyzed results will be interpreted to conclude the effectiveness of the Kalman Filter method and PI controller in improving the accuracy of fish pond temperature monitoring. These findings will form the basis for recommendations regarding the use of these methods in practical applications.

3. Sensor Calibration

DS18B20 Temperature Sensor Calibration: The DS18B20 temperature sensor is calibrated through a series of tests involving three different conditions: plain water, ice cubes, and hot water. Each test is carried out sequentially by inserting a temperature sensor probe into the media, while the measurement value is displayed on the Arduino IDE serial monitor. The purpose of this calibration is to ensure that the DS18B20 sensor can provide accurate measurements according to actual conditions. DHT22 Temperature Sensor Calibration: Calibration of the DHT22 sensor is carried out using an accurate comparison tool, namely the HTC-2 Temperature Clock. Temperature measurements are carried out in environments with different temperature variations, ensuring that both devices (Temperature Clock HTC-2 and DHT22 sensor) are in stable condition. Measurement data from both devices is displayed on the Arduino IDE serial monitor for comparison. This process aims to verify the measurement accuracy of the DHT22 sensor and ensure that the sensor can provide accurate values according to actual environmental conditions. With this approach, the accuracy of the DS18B20 and DHT22 temperature sensors is verified through a systematic and controlled calibration process. The results of this calibration will be an important basis for ensuring the accuracy of sensor measurements before being implemented in fish pond temperature monitoring applications.

4. Result and Discussion

4.1 DS18B20 Temperature Sensor Calibration

The calibration process is carried out to ensure that the DS18B20 temperature sensor provides accurate measurement results. The test results show variations in temperature results in some test samples. In 30 tests, the average error of the DS18B20 sensor was 0.33°C. Although this level of accuracy is slightly below the datasheet specification which mentions an accuracy level of 0.33°C, the average error is 0.33°C. ±0.5°C within the temperature range of -10°C to 85°C, but the sensor is still reliable for temperature measurements within that range.

Table 1. Calibration of DS18B20 temperature sensor

No	DHT Temp. Sensor	Temp. Clock HTC-2	Error
1	20.31	20.8	0.11
2	20.61	20.9	0.29
:	:	:	:
30	38.75	38.8	0.05
average = 0.33			

4.2 DHT22 Sensor Calibration

The calibration process of the DHT22xsensor involves comparing the measurement results with a comparison tool that has high accuracy. The calibration results show that the DHT22 sensor provides fairly accurate results, with an average error of about 0.49°C. This value is below the 0.5°C limit which is an acceptable level of accuracy for the temperature sensor in this application.

Table 2. DHT22 Sensor Calibration

No	DHT Temp. Sensor	Temp. Clock HTC-2	Error
1	23.9	24.0	0.1
2	23.8	24.1	0.3
:	:	:	:
30	29.7	30.9	1.2
average = 0.49			

In conclusion, the calibration results show that both temperature sensors, DS18B20 and DHT22, provide fairly accurate and reliable measurement results for use in monitoring fish pond temperatures. Although there is a slight variation in the measurement results, the accuracy of the sensors is still within the acceptable range for this application. Thus, the calibration results ensure that the data generated by both sensors is reliable and accurate for use in the fish pond temperature monitoring system [14][15].

4.3 Determination of The Best Kalman Filter

This test aims to evaluate the effectiveness of the Kalman filter in reducing noise in DS18B20 temperature sensor data. The testing process is done by taking data for 5 minutes with an estimation per second. The test results show that Kalman filter 3 with Q=10 and R=10 values gives the best results in reducing noise in temperature sensor data. The use of Kalman filter 3+PI can improve the

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accuracy of temperature estimation and reduce noise significantly. The integration of Kalman filter 3 with the PI controller can be an effective solution to improve the performance of the fish pond temperature monitoring system.

Table 3. Absolute Error of The Best Kalman Filter

KF1	KF2	KF3
0.28	0.19	0.1

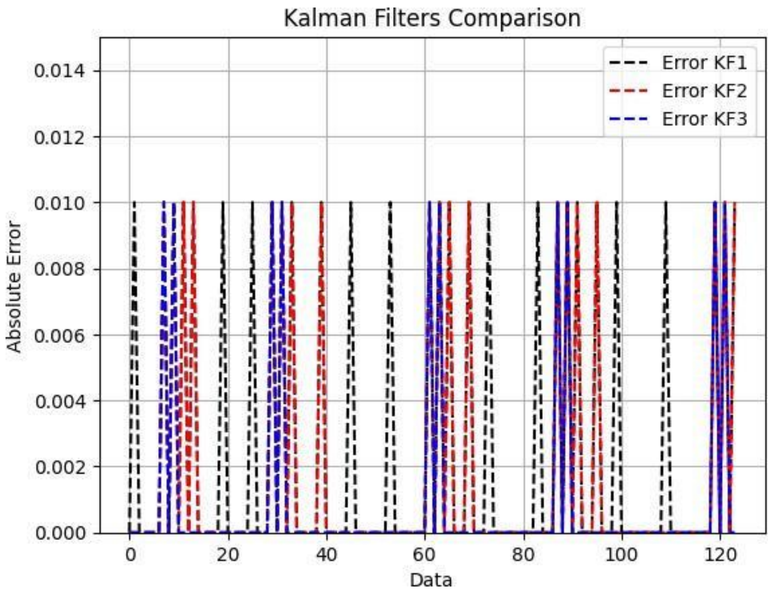

Fig. 2. Best Kalman filter

4.4 Testing Kalman Filter with PI Kalman Filter

The integration of Kalman filter 3 with the PI controller shows better performance in overcoming noise and improving the accuracy of temperature estimation. This test has the potential to provide great benefits in fish pond temperature monitoring, where accurate estimation is critical for fish welfare and overall production performance.

4.5 Kalman Filter Testing with The Best PI Kalman Filter Against Noise and Without Noise

This test aims to evaluate the performance of the Kalman Filter with the best Kalman Filter PI in overcoming noise interference and improving the accuracy of fish pond temperature estimation. The testing process is carried out by taking DS18B20 temperature sensor data for 5 minutes with an estimation per second. This aims to simulate the condition of temperature sensor measurements in an actual fish pond environment, where temperature fluctuations and noise interference can occur unexpectedly [17].

The test results show that the integration of Kalman Filter 3 with the PI controller can reduce the measurement error due to noise. Kalman Filter 3+PI produces an error value of 13.88, while Kalman Filter 3 without PI controller produces a value of 14.18. This shows that the integration of PI in Kalman Filter 3 has a positive impact on reducing noise and increasing the accuracy of temperature estimation [18].

Analyses were also carried out in conditions without noise. Kalman Filter 3+PI without noise produces an error value of 3.68, while Kalman Filter 3 without noise produces a value of 7.91. This result shows that Kalman Filter 3+PI is also better at reducing measurement errors on the sensor when conditions are without noise.

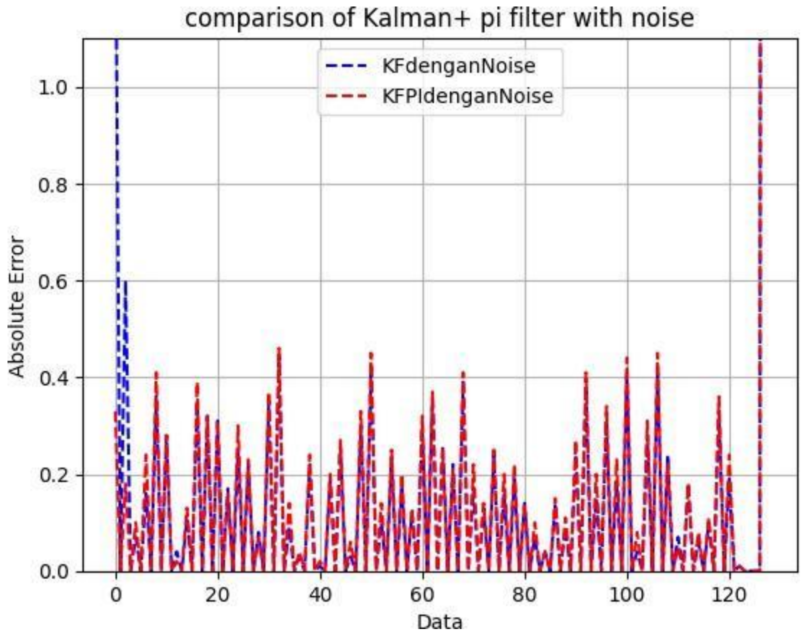

Fig. 3. KFPI graph with noise

Table 4. Absolute Error of Kalman Filter With Noise

KF1	**KF2**
14.18	13.88

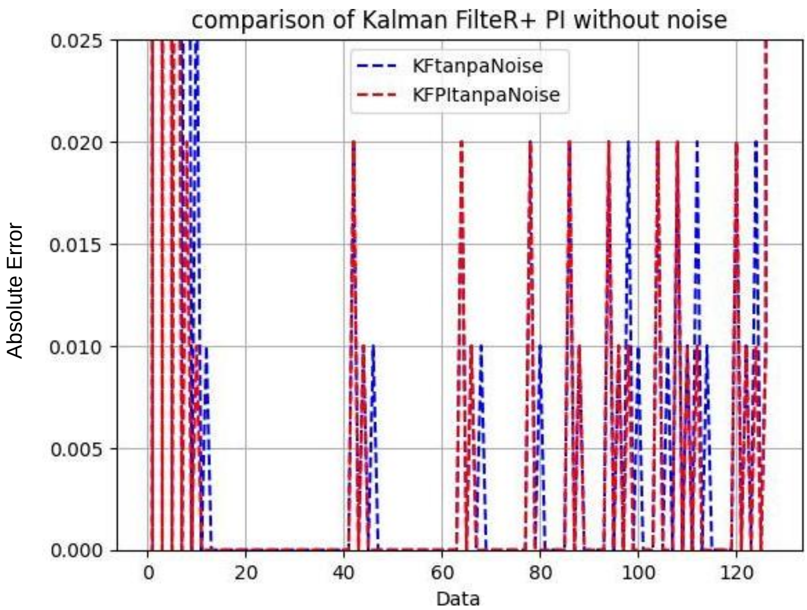

Fig. 4. KFPI graph without noise

From these test results, it can be concluded that the integration between Kalman Filter 3 and PI controller has better performance in overcoming noise and improving temperature estimation accuracy. This has great potential in monitoring the temperature of fish ponds, where accurate estimation is critical to fish welfare and overall production performance [16].

Table 5. Absolute Error of Kalman Filter Without Noise

KF1	**KF2**
7.91	3.68

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4.6 Firebase Realtime Data Testing

Realtime Firebase data testing is an important stage in the development of applications that use the Firebase platform. The main goal is to ensure that the connection between the application and the database runs smoothly and that the data displayed in the application is accurate and matches what is stored in the database. This test ensures that the Firebase Realtime Database function operates as expected.

The first step in this test is to populate data into the database and ensure that the data is immediately reflected in the application interface using the Real-time Database. This was done to verify that the data synchronization process was automatic and that data changes were immediately visible to the application user.

In addition, these tests emphasize security and performance aspects. Developers need to ensure that data retrieval from the database follows predefined access rules and that the system remains responsive and optimized, especially when there is an increase in the number of users or data volume.

Conducting thorough Firebase Realtime data testing is critical to improving application quality, ensuring system reliability, and providing a seamless user experience. By conducting rigorous testing, developers can identify and fix potential issues before the app is released to end users, thereby increasing user confidence in the developed app.

4.7 Overall System Testing

The overall system test is carried out to validate operational consistency and effective integration by previously prepared design plans. This testing process involves verifying the function of each component involved in the system, from hardware to servers, as well as evaluating the availability of sensor readings and real-time data transmission that can be accessed via the user's cellphone.

The main purpose of system testing is to ensure that each element in the system can operate according to the desired standards and can interact with each other effectively. This is very important to ensure that the system can function properly in a real operational environment.

The system testing process was carried out thoroughly, starting from testing individual components to testing the integration between components. Each stage of testing was meticulously carried out to ensure that every aspect of the system was working properly and in line with expectations.

5. Conclusion

Implementation of Kalman filter in water temperature monitoring system in a fish pond using DS18B20 and DHT22 temperature sensors has been successfully carried out. This system is designed to monitor water temperature quality in the fishing industry. Data from both sensors can be displayed in real time, enabling automatic and instant data synchronization between connected devices. Communication between devices uses the HTTP protocol. Component testing has verified that the DS18B20 and DHT22 sensors function according to datasheet specifications. The DS18B20 sensor has an accuracy level of around ±0.33°C, while the DHT22 sensor has an accuracy of around 29.7°C with an average error of around 0.49°C. Both sensors meet established accuracy standards, with error rates lower than the 0.5°C limit. The use of Kalman filters, especially Kalman filter 3, has been proven to increase the accuracy of temperature estimates on the DS18B20 sensor. With the Kalman filter, fluctuations in temperature sensor values can be suppressed, producing more consistent and accurate estimates. The use of the PI Controller together with the Kalman filter also improves the system's response to changes in temperature estimates, by adjusting the KP and KI values accordingly. The system has functioned according to the planned design. Sensors can take readings and send data directly to a real-time database using the HTTP protocol. Data can be monitored directly via the Firebase web platform, which can be accessed in real-time via the user's mobile device.

The results of this study show that the implementation of the Kalman filter in a fish pond temperature monitoring system can improve the accuracy of temperature estimation and system response to temperature changes. This system can be an effective solution to monitor the quality of water temperature in fish ponds in real time.

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