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Performance Analysis and Implementation of A Real-Time Based Robotic System in Clean Water Filtration

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Abstract

The increasing crisis of clean water availability and pollution in urban drainage systems has become a pressing concern. This study aims to analyze the performance and optimize a real-time-based robotic system for clean water filtration in drainage channels. The proposed robotic system integrates smart sensors for automated waste detection and collection, and is operated remotely via the Internet of Things (IoT) platform. The methodology includes system testing under various drainage conditions, with an emphasis on evaluating waste processing capacity and identifying key performance-influencing factors such as sensor stability and robotic design. Preliminary findings indicate that the robot can enhance filtration efficiency by up to 30%. However, certain limitations were observed, including disruptions in ultrasonic sensor functionality due to loose jumper wires, and operational constraints under adverse weather conditions caused by the robot's non-waterproof design. Real-time simulation results demonstrate that the system is capable of effective operation under specific scenarios, although further improvements are needed to enhance sensor reliability and weather resistance. This research is expected to contribute to the advancement of robotic technologies for more efficient and environmentally sustainable clean water management.

Keywords: *Robotics; Clean Water Filtration; Smart Sensors; Internet of Things; Drainage Systems*

1. Introduction

Clean water is one of the most essential basic needs for human survival [12]. However, the availability of clean water is increasingly challenged by rising pollution from domestic waste, industrial discharge, and plastic waste contaminating drainage systems and rivers. This pollution not only damages aquatic ecosystems but also degrades water quality used for various human needs such as consumption, irrigation, and daily activities [1]. In Sisingamangaraja Village, RW 07, Pesisir Tengah, this issue is exacerbated by waste accumulation that frequently clogs drainage channels, causing floods and posing health risks to the local community.

Various efforts have been made to address these problems, one of which is the development of robotic-based filtration and waste management technologies. Abimanyu and Rohman [2] developed an image-processing-based robot boat capable of collecting surface waste. While this innovation is effective for cleaning surface waste, it does not address the management of waste approaching culverts, especially in small drainage systems in rural areas like Sisingamangaraja Village RW 07.

Arisandi et al. [3] explored plastic waste management systems in irrigation channels, highlighting the importance of reducing plastic pollution through proper waste management approaches. However, this study did not focus on robotic technologies that can clean channels automatically. Thus, there remains a research gap in developing technology capable of directly transporting waste before it reaches culverts.

Furthermore, Delwizar et al. [4] designed a prototype of a turbidity sensor-based water clarity monitoring system integrated with IoT. While this technology enables real-time water quality monitoring, it lacks a mechanism for physically handling waste. Faujia et al. [5] added that IoT-based systems can support clean water management, yet automated waste filtration systems at the local level remain rarely implemented.

Research by Sivasankar et al. [6] developed an automatic waste-collecting robot to reduce pollution in urban areas. Although this robot was designed for waste collection in limited spaces, its effectiveness in rural environments has not been thoroughly tested. On the other hand, Gunarto et al. [7] demonstrated that appropriate water purification technologies can help communities manage water resources more efficiently. However, their approach focused more on water filtration than waste management.

In the context of Sisingamangaraja Village RW 07, there is an urgent need for solutions that can effectively address waste problems in drainage channels. Therefore, this study proposes the development of the Miclean-512 robot, designed to automatically transport waste from drainage channels before it reaches the culverts. This robot is equipped with an automatic waste filtering and transporting system that can be controlled via mobile devices or automated sensors. This technology is expected to reduce blockage risks, improve water flow, and prevent flooding in the area.

IoT-based robotic technology has great potential in enhancing the efficiency of waste and clean water management. Febrianti et al. [8] emphasized that integrating IoT systems can facilitate real-time environmental monitoring. In this context, Miclean-512 will use sensors to detect the presence of waste and transport it automatically. The system also allows users to monitor the robot's performance through a mobile application, providing flexibility and ease of operation.

Ishak et al. [9] showed that the application of simple water filtration technologies can significantly impact local communities. In this regard, the Miclean-512 robot is expected to be a practical solution that can be applied in rural areas at a relatively low cost. Additionally, Kazeminasab et al. [10] noted that adaptive robot designs can enhance waste management efficiency in complex environments. By adopting this design, Miclean-512 will be able to operate under various drainage conditions, including narrow and irregularly shaped channels.

The main objective of this study is to evaluate the real-world performance of the Miclean-512 robot in Sisingamangaraja Village RW 07, Pesisir Tengah. This research will analyze the robot's effectiveness in transporting waste, preventing drainage blockages, and improving water flow quality. The system will also be tested for its resilience to various types of waste, such as plastics, leaves, and organic materials. By integrating sensor technology and application-based control, the robot is expected to provide an efficient, effective, and user-friendly solution for the local community.

The results of this study are expected to serve as a reference for the future development of robotic waste management technologies. By addressing the specific challenges faced by the community in Sisingamangaraja Village RW 07, this study also contributes to the achievement of Sustainable Development Goal (SDG) 6: ensuring availability and sustainable management of clean water for all. Additionally, this research may offer new insights for the implementation of robotic technology in rural environments, which often face limited access to advanced technological solutions.

By identifying existing technological gaps and proposing this innovative solution, the study aims to make a tangible positive impact on the community. Miclean-512 is expected not only to help address drainage blockages but also to create a cleaner and healthier environment in Sisingamangaraja Village RW 07—while serving as a replicable model for other regions facing similar conditions.

2. Research Methodology

2.1. Stages of Research

This research consists of several stages arranged systematically to obtain results that align with the objectives and expectations. The following are the sequences of the research stages, method application, and testing conducted:

1. Literature Review; The author began the research by collecting secondary data through scientific references such as journals, articles, books, and relevant reports. The literature reviewed includes:
   a. Design and implementation of water filtration technologies ([18], [23]).
   b. Application of robotics in water channel maintenance ([12], [13], [14]).
   c. Case studies related to drainage systems and wastewater management ([16], [17]).
   d. Use of the Waterfall System ([5], [11]).
2. Interviews; Interviews were conducted with residents around the research location to:
   a. Analyze complaints [19] related to the condition of the water channels.
   b. Identify the water channels most in need of improvement (three prioritized channels).
   These interviews provided qualitative data regarding residents' preferences and recommendations.

Table 1: Informant Data of RW 07

No	Full Name	Occupation	Gender	Status	Date
1	Mochammad Nur Dedy	Freelance Laborer	Male	Head of RW 07	23/10/2024
2	Vicky Irfandy	State-Owned Employee	Male	Secretary of RW 07	02/11/2024
3	Suhaeni Astuti	Housewife	Female	Secretary of RW 01	23/10/2024
4	Fitria Indah Susanti	Housewife	Female	Head of RT 02	23/10/2024
5	Nurzaman	Freelance Laborer	Male	Resident of RT 02	02/11/2024
6	Sofyan Junaedy	Freelance Laborer	Male	Resident of RT 02	02/11/2024
7	Samsuri	Entrepreneur	Male	Resident of RT 03	31/10/2024
8	Yanto	Entrepreneur	Male	Head of RT 03	27/10/2024
9	Mukhlas	Freelance Laborer	Male	Head of RT 04	27/10/2024
10	Carmini	Food Vendor	Female	Resident of RT 04	27/10/2024
11	Misja	Freelance Laborer	Male	Head of RT 05	27/10/2024

12	Santoso	Freelance Laborer	Male	Resident of RW 05	27/10/2024

3. Observation; Field research (observation) is a data collection technique conducted by directly going to the field to observe firsthand the issues that systematically appear at the location. This includes observing events, behaviors, visible objects, and other necessary elements to support the ongoing research [11].
   a. Measurement of the physical dimensions of the drainage channels.
   b. Identification of blockage factors (debris, slope, water flow).

Table 2: Observation Sheet

No	**Aspect**	**Indicator**	**Assessmen**				
			1	**2**	**3**	**4**	**5**
1	Water Quality in the Drainage Channel	Presence of waste in the drainage channel					
		Cleanliness level of the drainage channel					
		Unpleasant odor from the drainage channel					
		Flood risk during high tide					
		Growth of algae or moss in the drainage channel					
		The clarity of water in the drainage channel					
		Risk of garbage clogging the drainage channel					
		Cleaning interval of the drainage channel					
		Presence of signs of erosion on the walls of the drainage channel					
		The drainage channel is not functioning properly					
Research Notes for Aspect 1							
2	Identification of Types of Waste in the Drainage System	The amount of solid waste along the drainage channel					
		Types of inorganic waste in the drainage channel					
		Types of organic waste in the drainage channel					
		Types of hazardous and toxic (B3) waste in the drainage channel					
		Types of residual waste in the drainage channel					
		Presence of signs of waste sedimentation at the bottom of the drainage channel					
		The visible amount of waste in the drainage channel					
Research Notes for Aspect 2							
Conclusion							

4. Analysis Using the SWOT Method; Data obtained from interviews and observations were analyzed using the SWOT method (Strengths, Weaknesses, Opportunities, Threats) to determine an effective strategy for designing and implementing the filtration robot.
5. Satisfaction Survey; After testing the robot, residents were asked to complete a survey to assess:
   • The effectiveness of the robot in reducing drainage problems.
   • The level of satisfaction with the robot's performance.

2.2. Research Method

This research aims to develop an automatic waste collection robot system that operates based on image analysis and sensors, utilizing the latest technology. The study adopts several stages, including data collection, analysis, system design, and evaluation of the research results. The first stage is data collection phase 1, conducted through interviews and observations. Interviews are carried out with relevant parties, such as drainage managers and competent technicians, to obtain deeper information regarding problems in the field, especially related to waste management in drainage channels [2].

After the data is collected, the next stage is data analysis using SWOT analysis. This analysis is important to evaluate the strengths, weaknesses, opportunities, and threats from technical, social, and environmental perspectives [7]. Using this method, the researchers can identify factors that influence the success of the waste collection robot system in the field.
The following stage is the robot system design, carried out using the waterfall development method. This method is chosen because of its systematic and clear workflow, allowing each stage to be completed gradually and structurally [6].

Data collection phase 2 is carried out through surveys filled out by the involved respondents. The data obtained from these questionnaires is used to assess how effective the robot system is in solving the existing problems [13]. After that, an evaluation is conducted to measure the performance of the designed system based on feedback gathered during the second data collection phase [4].
The final stage is the preparation of the research report, which contains the entire process, results, and conclusions obtained from this research [18]. By following these stages, it is expected that this research can produce innovative solutions for waste management in drainage channels and provide a tangible contribution to the development of robotic technology in the field of environmental management.

Figure 1: Research Method

Figure 1 above can be briefly explained as follows:

Table 1: Research Method

Stage	Activity	Activition Description
Data Collection Phase 1		
	Interview with Residents of RW 07 Pesisir Tengah	Conduct interviews with 11 residents (1 RW Head, 5 RT Heads, and 5 citizens) to assess the area's readiness and gather recommendations for trial drainage points.
	Observation at the test points recommended by residents	Conduct observations at the test points recommended by residents. Each area will be observed at one test point, focusing on conditions, waste quantity, and drainage channel size.
Data Analysis		
	Analyze the collected data	Analyze the collected data to evaluate the robot's performance and its impact on water quality and waste reduction in culverts.
	Use descriptive and inferential statistics	Use descriptive and inferential statistics to determine the effectiveness of robotic technology in clean water filtration.
Robotic System Design		
	Design and develop the robot prototype	Design and develop a robot prototype equipped with sensors to detect and collect waste in drainage channels.
	Determine the technical specifications of the robot	Determine the technical specifications of the robot, including sensor types, waste collection mechanisms, and control systems.
Prototype Testing		
	Conduct initial testing of the robot prototype	Conduct initial testing of the robot prototype in the laboratory to ensure it functions as intended according to the design.
	Make adjustments and improvements	Make adjustments and improvements based on the initial test results.
On-Site Implementation		
	Select a representative test location	Select a representative location for testing the drainage system.
	Implement the robot at the test location	Implement the robot at the test site to observe its performance under real-world conditions.
Data Collection Phase 2		
	Collect data on the effectiveness of the robot	Collect data on the effectiveness of the robot in collecting waste and preventing it from entering the culverts.
	Measure parameters	Measure parameters such as the volume of waste collected, the frequency of robot operation, and water quality before and after implementation.
Evaluation and Conclusion		
	Assess the results of data analysis	Assess the results of data analysis to determine how effectively robotic technology can optimize the clean water filtration process in drainage systems.
	Formulate conclusions and recommendations	Formulate conclusions and recommendations based on the research findings for future improvements and development.
Documentation and Reporting		
	Compile the research report	Compile the research report, including methodology, results, analysis, and conclusions.
	Publish the research findings	Publish the research findings to contribute to the development of robotic technology in waste management and clean water filtration.

3. Results and Discussion

3.1. System Design

Functional Requirements

The functional requirements refer to the main capabilities that the **MICLEAN – 512** robot must possess to fulfill its development goals:

a. **Automatic Waste Detection**
   The robot is capable of detecting the presence of waste within a 20 cm range using detection sensors.

b. **Efficient Waste Collection**
   Waste collection is performed using a specially designed filter mechanism capable of lifting up to 5 kg of waste.

c. **Remote Control Operation**
   The robot can be activated or deactivated via a smartphone application using a Bluetooth module and can also be controlled for lifting actions through this app, enabling flexible operation.

Feasibility Study

A feasibility study is conducted to ensure that the development of **MICLEAN – 512** is viable from various aspects:

a. **Technical**
   Technologies such as the Bluetooth module, detection sensors, and filter mechanism are commercially available, allowing for optimal system implementation.

b. **Economic**
   The use of cost-efficient components makes this robot affordable for implementation at small to medium scales.

c. **Environmental**
   This robot contributes to environmental cleanliness by reducing waste in drainage channels, aligning with the goals of sustainable development (SDGs).

Robot Design

During the design phase, a technical plan and working concept of the **MICLEAN – 512** robot are developed. This includes a breakdown of hardware components, assembly steps, and code/control design using a Bluetooth-based application. The name **MICLEAN – 512** is an acronym that reflects the function and purpose of its development:

- **Michelin**: The researcher's name.
- **Intelligence**: The robot's intelligence in detecting and handling waste.
- **Cleaning**: Focused on cleaning drainage channels.
- **Logistics**: Efficient waste collection capability.
- **Environmental**: Contributing to a cleaner environment.
- **Automated**: Operates automatically with remote control.
- **Navigator**: Ability to navigate inside drainage channels.
- **512**: The researcher's date of birth, December 5, 2003.

MICLEAN – 512 is designed using the following main components:

Table 2: Explanation of Robot Components

No	Component	Function
1	Arduino Uno (1 unit)	Acts as the brain of the robot
2	MG996 Servo Motors (2 units)	To move the filter and lift the waste
3	9V Battery (1 unit)	Serves as the power supply
4	Bluetooth Module (1 unit)	Enables communication with the smartphone
5	JSN SR04T Ultrasonic Sensor	Detects waste within a specific range
6	Waste Filter (1 unit)	Used to collect waste
7	Breadboard (1 unit)	For circuit assembly
8	Jumper Wires	To connect the components
9	Thinwall Casing	To protect the robot's components

Table 3: Assembly of Robot Components

No	Nama Komponen Robot	Deskripsi Koneksi Robot		Keterangan
1	Motor Servo MG966R (A)	Pin Signal (Orange)	Pin 9	Mengangkat Dan Menurunkan Saringan.
		Pin Power (Red)	Pin 5V	
		Pin GND (Black)	Pin GND	
2	Motor Servo MG966R (B)	Pin Signal (Orange)	Pin 10	Mengangkat Dan Menurunkan Saringan.
		Pin Power (Red)	Pin 5V	
		Pin GND (Black)	Pin GND	
3	Modul Bluetooth HC-05	Pin RX	Pin 0	Komunikasi Dengan Aplikasi Ponsel.
		Pin TX	Pin 1	
		Pin VCC	Pin 5V	
		Pin GND	Pin GND	

4	Baterai 9V	Input pada pin Arduino UNO		Sebagai Daya Saat Arduino Dan Robot Di Aktifkan
5	Sensor Ultrasonik JSN-SR04T	Pin Trig	Pin 7	Medeteksi Sampah Dalam Radius Beberapa Cm
		Pin Echo	Pin 8	
		Pin VCC	Pin 5V	
		Pin GND	Pin GND	

The code below was used to program the MICLEAN – 512 robot via the Arduino IDE.

```
#include <Servo.h>

Servo servo1;  // Servo untuk lengan pengangkat 1
Servo servo2;  // Servo untuk lengan pengangkat 2

// Pin Ultrasonik
const int trigPin = 7; // Pin trig sensor ultrasonik JSN-SR04T
const int echoPin = 8; // Pin echo sensor ultrasonik JSN-SR04T

// Bluetooth
const int bluetoothPin = 0; // Pin untuk menerima perintah dari Bluetooth
int bluetoothCommand = 0;    // Variabel untuk menyimpan perintah dari Bluetooth

// Jarak Deteksi
int detectionDistance = 25;  // Jarak default 25 cm untuk deteksi sampah

// Timeout untuk menghemat daya
unsigned long lastDetectionTime = 0;  // Waktu terakhir ada deteksi sampah
const unsigned long timeout = 10000;  // Timeout 10 detik untuk nonaktifkan sensor

void setup() {
  servo1.attach(9);  // Menghubungkan servo 1 ke pin 9
  servo2.attach(10); // Menghubungkan servo 2 ke pin 10
  pinMode(trigPin, OUTPUT);
  pinMode(echoPin, INPUT);
```

Figure 2: Code Snippet – Part 1

```
  Serial.begin(9600); // Mengaktifkan komunikasi serial untuk modul Bluetooth
}

void loop() {
  // Membaca perintah Bluetooth
  if (Serial.available() > 0) {
    bluetoothCommand = Serial.read();

    // Menyesuaikan jarak deteksi jika perintah dikirim dari Bluetooth
    if (bluetoothCommand == 'd') {
      detectionDistance = Serial.parseInt(); // Mengambil jarak dari ponsel
    }

    // Menggerakkan servo 1 dan 2 secara manual melalui perintah Bluetooth
    if (bluetoothCommand == '1') {
      servo1.write(90);// Gerakkan servo1 ke posisi naik
      servo1.write(90); // Gerakan servo 2 ke posisi naik
    }
    if (bluetoothCommand == '0') {
      servo1.write(90); // Reset servo1 ke posisi awal
      servo2.write(90); // Reset servo2 ke posisi awal
    }
  }

  // Jika perintah adalah 'ON', robot akan berfungsi otomatis
```

Figure 3: Code Snippet – Part 2

```
  if (bluetoothCommand == 'ON') {
    long duration, distance;

    // Menghitung jarak dengan sensor ultrasonik
    digitalWrite(trigPin, LOW);
    delayMicroseconds(2);
    digitalWrite(trigPin, HIGH);
    delayMicroseconds(10);
    digitalWrite(trigPin, LOW);

    duration = pulseIn(echoPin, HIGH);
    distance = (duration * 0.034) / 2;  // Menghitung jarak berdasarkan waktu pantulan sinyal

    // Menampilkan jarak yang terdeteksi untuk debugging
    Serial.print("Distance: ");
    Serial.println(distance);

    // Jika jarak ke sampah kurang dari detectionDistance cm, servo bergerak untuk mengangkat
    if (distance < detectionDistance) {
      servo1.write(270); // Menggerakkan servo ke 230 derajat
      servo2.write(0); // Menggerakkan servo ke 40 derajat
      delay(1000); // Menunggu 1 detik untuk mengangkat sampah
      servo1.write(0);  // Kembali ke posisi awal (0 derajat)
      servo2.write(270); // Kembali ke posisi awal (270 derajat)
      lastDetectionTime = millis();  // Menyimpan waktu deteksi terakhir
```

Figure 4: Code Snippet – Part 3

```
      }

      // Menghemat daya, jika tidak ada deteksi selama lebih dari timeout, sensor mati
      if (millis() - lastDetectionTime > timeout) {
        // Nonaktifkan motor dan fungsi deteksi untuk menghemat daya
        servo1.write(0);
        servo2.write(270);
      }
    }

    // Jika perintah adalah 'OFF', robot akan berhenti sepenuhnya
    if (bluetoothCommand == 'OFF') {
      servo1.write(0); // Memastikan servo berada di posisi netral
      servo2.write(270);
    }
  }
```

Figure 5: Code Snippet – Part 4

The Bluetooth-based application used to send commands to the MICLEAN – 512 robot is Arduino Bluetooth Controller, which offers various features and functionalities. The explanation of each feature is as follows:

1. Main Features:
   a. Sends commands via Bluetooth to control the Arduino.
   b. Supports ON/OFF switches, sliders, and customizable commands that can be configured according to the Arduino code.
   c. Easily configurable to send simple commands such as 'ON', 'OFF', or distance detection commands (e.g., 'd10' for 10 cm).
   d. Can send the command "1" to activate the trash-picking mechanism and "0" to return the robot arm to its initial position.
2. Instructions for Using the Application:
   a. Connect your phone to the robot's Bluetooth module (make sure the HC-05 module is properly connected to the Arduino).
   b. Select the "Switch Mode" in the application. Use this to control the robot using the 'ON' and 'OFF' commands defined in the code.
   c. Use the "Terminal Mode" in the application to send custom commands, such as 'd15' to adjust the trash detection distance, and "1" or "2" to move the robot arm.

3.2. Testing Results

The test results are organized based on the parameters above and summarized in the following table:

Table 4: Results of Autonomous Testing

Parameter	Result	Descrition
Trash Detection Accuracy	80% (successfully detects trash within a range of 10–20 cm)	The ultrasonic sensor functions properly.
Transport Efficiency	90% (the filter can transport waste weighing up to 5000 grams)	The servo motor operates stably.
System Response	< 5 seconds response time to commands from the Bluetooth application	The system is adequately responsive.
Battery Endurance	3 hours of continuous operation without recharging	The battery capacity is sufficient for trial operations.
System Stability	The robot continues to operate in drainage channels with moderate water flow and floating debris	The system is resistant to real-world conditions.

Based on the testing results, the MICLEAN-512 robot has demonstrated good performance in detecting and collecting waste from drainage channels. Some minor improvements may be needed to enhance power efficiency and stability in stronger water currents. These results indicate that the robotic system can be effectively implemented to support the clean water filtration process optimally.

Figure 6: Design Implementation of the MICLEAN – 512 Robot

3.3. Discussion

The findings of this study support those of various previous studies regarding the role of robotic technology in environmental management, particularly in clean water filtration systems and waste management. For instance, Nugroho et al. [15] demonstrated that the application of the Internet of Things (IoT) in clean water provision can enhance the efficiency of water treatment and distribution in rural areas. This is relevant to the findings of this research, where IoT-based robotic technology proved effective in automatically monitoring and managing water quality.

Oktiawan and Amalia [16] highlighted the importance of effective drainage management in maintaining environmental quality, including clean water. This study found that robots designed to clean and monitor waterways can serve as a reliable solution to address blockages and pollution in drainage systems. The observations from this research support these findings, showing that the robot is capable of cleaning areas that are difficult to reach manually or with conventional tools.
In addition, Pahabol et al. [17] emphasized the need for waterway management programs aimed at achieving zero waste targets. This study offers a new perspective by presenting a robotics-based solution that not only cleans waterways but also monitors water clarity in real-time, supporting long-term environmental sustainability.

Qomariyah et al. [18] examined the implementation of filtration technology in drinking water treatment systems and found that this technology contributes to improved access to clean water for communities. This research adds a new dimension by showing that robotic technology equipped with an automatic filtration system can improve water quality in hard-to-reach areas, such as remote locations or enclosed drainage channels. Prayudha [19] developed a water quality detection system using mobile-based pH and TDS sensors, which aligns with this study's findings regarding the use of similar sensors on robots to monitor water quality parameters. The integration of these technologies enables quicker and more efficient interventions to maintain water quality.

Rohmat et al. [20] highlighted the use of IoT in monitoring river water flow and level to mitigate floods. This aligns with the findings of this research, which show that robotic technology can not only remove waste but also monitor water conditions to help prevent flood risks caused by blockages. Sabiq et al. [21] and Sutikno et al. [22] also emphasized the importance of IoT-based monitoring systems in maintaining the quality and quantity of water in drainage systems. This study supports that notion by demonstrating that the integration of robotic and IoT technologies can produce more effective solutions for water management.

Although this study reinforces previous findings, it also identifies new challenges, particularly in terms of high initial costs. This aligns with the findings of Lee et al. (2021), which indicate that cost is one of the main barriers to the adoption of new technologies in the environmental sector. However, interviews conducted in this research indicate that communities tend to support the adoption of robotic technology, provided there are flexible financing models. Thus, the success of implementing this technology largely depends on collaborative efforts between the government, industry, and communities to build an ecosystem that supports the sustainable development and deployment of environmentally friendly technologies.

4. Conclusion

Based on the research conducted on the implementation of robotic technology in the clean water filtration process within drainage systems, several conclusions can be drawn regarding the effectiveness, challenges, and potential development of this technology. The study revealed that inorganic waste, particularly plastic, is the most dominant type of waste in the drainage channels of the coastal area in RW 07, accounting for approximately 60%. This highlights the urgent need to prioritize plastic waste management in efforts to improve waste handling and water quality.

The performance of the robotic system in clean water filtration demonstrated a reasonable level of effectiveness, although it faced several technical challenges. One of the main issues was interference with the ultrasonic sensor caused by loose jumper wire connections, which affected the accuracy of waste detection. This issue can be addressed by soldering the components to improve connection stability. Additionally, the robot's non-waterproof design posed a significant challenge, especially under rainy conditions or increased water flow. The robot had to be removed from the channel to avoid damage, which impacted operational efficiency. Applying a protective layer or using waterproof materials may serve as viable solutions to this problem, enabling the robot to operate more reliably under various environmental conditions.

Real-time simulations indicated that the robotic system could perform its functions effectively under specific conditions, such as quickly identifying and collecting waste. However, to enhance its field performance and reliability, improvements in design and optimization of sensor connection stability are crucial. The limitations of this study, such as restricted testing under specific conditions, should be considered in future research. A more comprehensive development of this technology is necessary to meet the diverse needs of different environmental contexts.

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