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Development Of Pipeline Robots to Clean Clogged Sewagens For Palm Oil Factories

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ABSTRAK

Pabrik minyak sawit sering menghadapi inefisiensi operasional yang signifikan akibat penyumbatan saluran pembuangan limbah yang disebabkan oleh residu minyak, serat, dan puing-puing. Penyumbatan ini tidak hanya mengurangi efisiensi aliran sistem pembuangan limbah tetapi juga memerlukan intervensi perawatan yang sering sehingga menyebabkan waktu henti produksi. Metode manual saat ini padat karya, tidak aman, dan memakan waktu, seringkali melibatkan paparan lingkungan berbahaya. Untuk mengatasi tantangan ini, proyek ini mengusulkan desain dan pengembangan sistem robot otonom yang mampu mendeteksi dan menghilangkan penyumbatan di dalam ruang terbatas pipa pembuangan industri. Robot yang diusulkan mengintegrasikan pengikis mekanis dan sistem jet air bertekanan tinggi yang dikendalikan oleh unit mikrokontroler (ESP32) yang memungkinkannya untuk membersihkan secara efektif sambil menavigasi jaringan pipa internal. Robot ini dirancang dengan bodi akrilik yang ringkas, roda traksi bergaya tangki, dan sistem deteksi rintangan cerdas menggunakan sensor inframerah. Robot ini dapat beroperasi secara otonom di dalam pipa pembuangan limbah pabrik minyak sawit, secara signifikan mengurangi tenaga kerja manusia dan risiko keselamatan. Integrasi fungsi IoT juga memungkinkan pemantauan waktu nyata dan pengoperasian jarak jauh, memastikan pengawasan yang efisien terhadap proses pembersihan. Pengujian awal dalam kondisi pipa simulasi menunjukkan efektivitas robot dalam membersihkan penyumbatan standar dalam waktu singkat, dengan tingkat keberhasilan yang tinggi. Perkembangan ini merupakan langkah signifikan menuju pengelolaan limbah industri yang berkelanjutan dan peningkatan efisiensi operasional di industri minyak sawit.

ABSTRACT

Palm oil factories often face significant operational inefficiencies due to the clogging of Waste drainage channels caused by oil residues, fibers, and debris. These clogs not only reduce the flow efficiency of waste disposal systems but also require frequent maintenance interventions that lead to production downtime. Current manual methods are labor-intensive, unsafe, and time-consuming, often involving exposure to hazardous environments. Addressing these challenges, this project proposes the design and development of an autonomous robotic system capable of detecting and eliminating clogs within the confined spaces of industrial drainage pipelines. The proposed robot integrates mechanical scrapers and a high-pressure water jet system controlled by a microcontroller unit (ESP32) that allows it to clean effectively while navigating the internal pipeline network. The robot is designed with a compact acrylic body, tank-style traction wheels, and a smart obstacle detection system using infrared sensors. It can operate autonomously within the waste drainage pipelines of palm oil factories, significantly reducing human labor and safety risks. The integration of IoT functionalities also allows real-time monitoring and *remote operation, ensuring efficient oversight of the cleaning process. Initial testing in simulated pipeline conditions demonstrates the robot's effectiveness in clearing standard blockages within a short time frame, with a high success rate. This development represents a significant step toward sustainable industrial waste management and improved operational efficiency in the palm oil industry.*

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1. INTRODUCTION

Palm oil production generates considerable waste by-products that can accumulate within factory drainage systems [6], [7]. Blockages in these pipelines not only slow down operations but also result in costly downtimes and maintenance. Traditional cleaning methods require manual intervention, posing risks to workers and interrupting the continuous processing of materials [5], [8]. The solution is an autonomous robot specifically designed to navigate and clean the drainage channels, ensuring consistent and safe waste flow. [1], [2], [10].

The buildup of organic residues, fibrous waste, and oil sludge in palm oil processing lines often leads to frequent system interruptions and high labor costs associated with routine maintenance [6], [7]. Manual cleaning methods not only require the shutdown of production lines but also expose workers to hazardous conditions inside narrow and contaminated pipe networks. An automated robotic system tailored for this environment will reduce these risks significantly by allowing regular and efficient cleaning without halting operations [2], [5], [10]. This project focuses on developing a reliable robotic solution to address these recurring industrial challenges in a sustainable and cost-effective manner. that can accumulate within factory drainage systems. Blockages in these pipelines not only slow down operations but also result in costly downtimes and maintenance. Traditional cleaning methods require manual intervention, posing risks to workers and interrupting the continuous processing of materials. The solution is an autonomous robot specifically designed to navigate and clean the drainage channels, ensuring consistent and safe waste flow.

The robot offers a safer, more efficient alternative to manual cleaning, reduces operational downtime, and supports sustainable manufacturing practices. The integration of automation enhances productivity and minimizes exposure to harmful environments. This is particularly significant in palm oil factories, where workers often face dangerous conditions due to confined spaces, toxic residues, and high temperatures within drainage systems. By automating the cleaning process, the robot minimizes the risk of injury and reduces dependence on manual labor, thereby improving overall workplace safety.As palm oil remains a major global commodity, innovations like this robotic system can help improve the industry's long-term viability and social responsibility.

Palm oil factories often encounter significant disruptions due to the clogging of waste drainage pipelines, which are primarily caused by the accumulation of oil residues, fibrous materials, and solid waste by-products. These clogs not only impede the continuous flow of waste materials but also necessitate frequent and labor-intensive manual interventions that interrupt factory operations. Moreover, workers are exposed to health and safety risks during cleaning tasks conducted in confined

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and contaminated spaces. The current methods used to address these blockages are inefficient and pose operational, environmental, and safety challenges. Therefore, there is an urgent need for an autonomous and efficient solution that can perform cleaning operations without halting production and compromising worker safety

2. METHOD

The Motor Driver System consists of two BTS7960 motor drivers, each of which controls a set of wheel motors on either side of the robot. The ESP32 sends directional signals to these drivers, which then move the robot forward, backward, and around curves in the pipeline. The ESP32 ensures precise navigation through the tight and possibly twisting pipeline system by controlling the two sets of wheel motors (left and right). Because these motors are so powerful, they require BTS7960 drivers that can tolerate larger current levels without overheating, allowing the robot to go consistently over the pipeline's obstructions. [10]

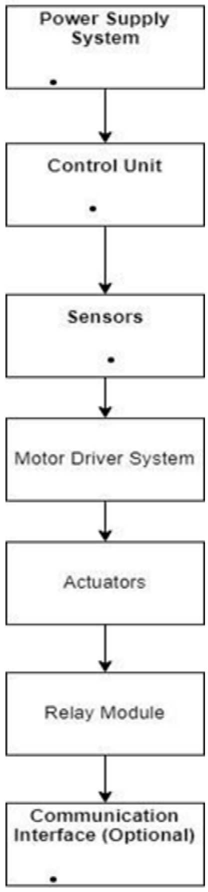

Figure 1.Block diagram pipeline

The block diagram for the pipeline robot developed for leakage inspection and blockage clearing is organized around many main components that work together to perform autonomous cleaning duties in the pipeline [3], [4], [10].. At the heart of the system is the ESP32 microcontroller, which acts as the control unit. A 12V LiPo battery powers the ESP32 and all other components. A 12V to 5V DC converter is used to reduce the voltage for the ESP32 and other 5V components. The ESP32 analyzes data from the IR Sharp Distance Sensors and controls both the robot's movement and the cleaning mechanism [3], [4].

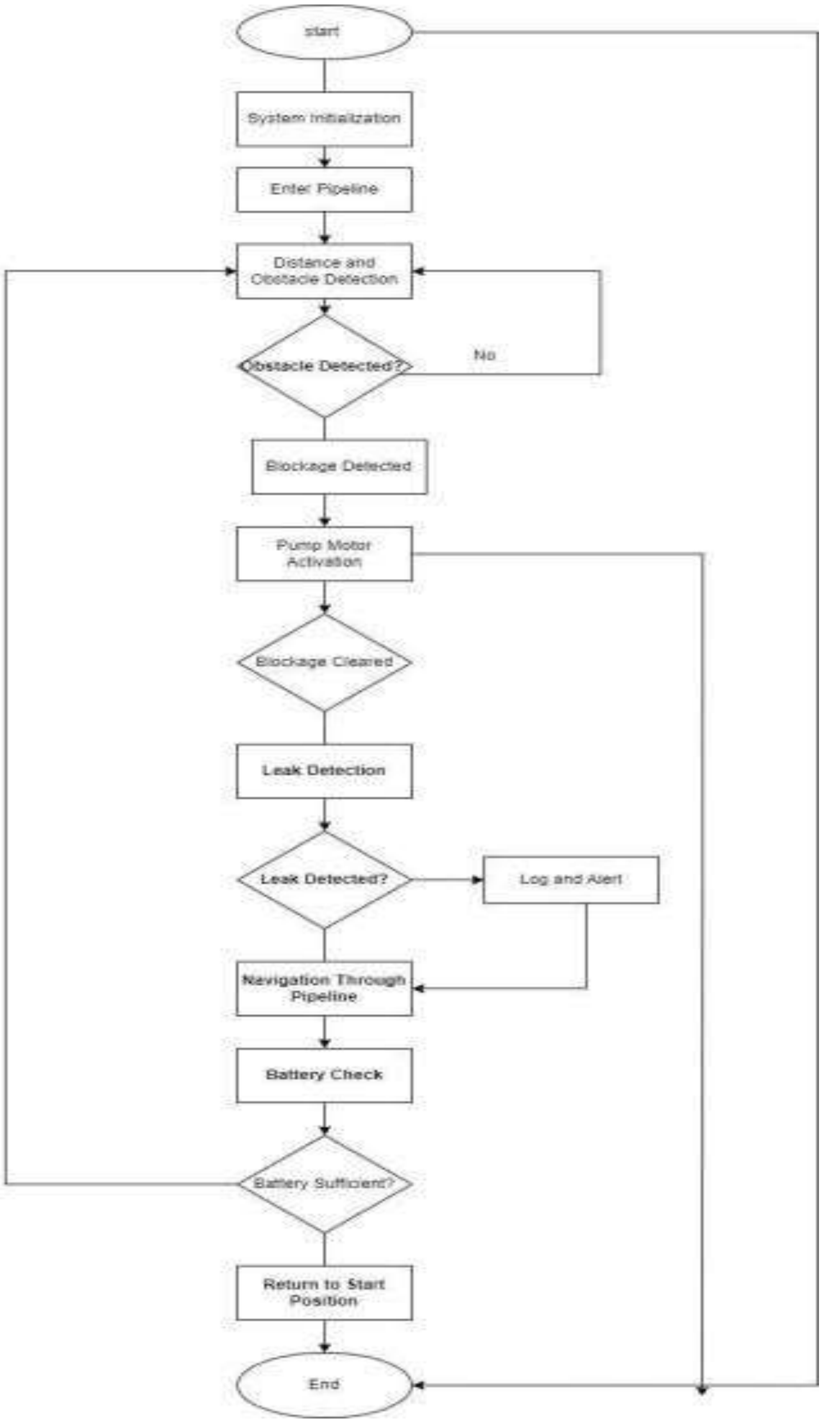

Figure 2. Flowchart System

The pipeline robot project flowchart begins with the System Initialization stage, which turns on all components, including sensors, motor drivers, and the microcontroller, and tests their functionality [5]. This initial phase guarantees that each component is prepared to carry out its specialized function inside the pipeline, such as identifying obstructions or inspecting for leaks. If any component fails to initialize, the system promptly cancels the operation to ensure the robot's performance and safety. Following successful initialization, the robot proceeds to Enter Pipeline, where it begins its journey through the pipeline to inspect for blockages and potential leaks

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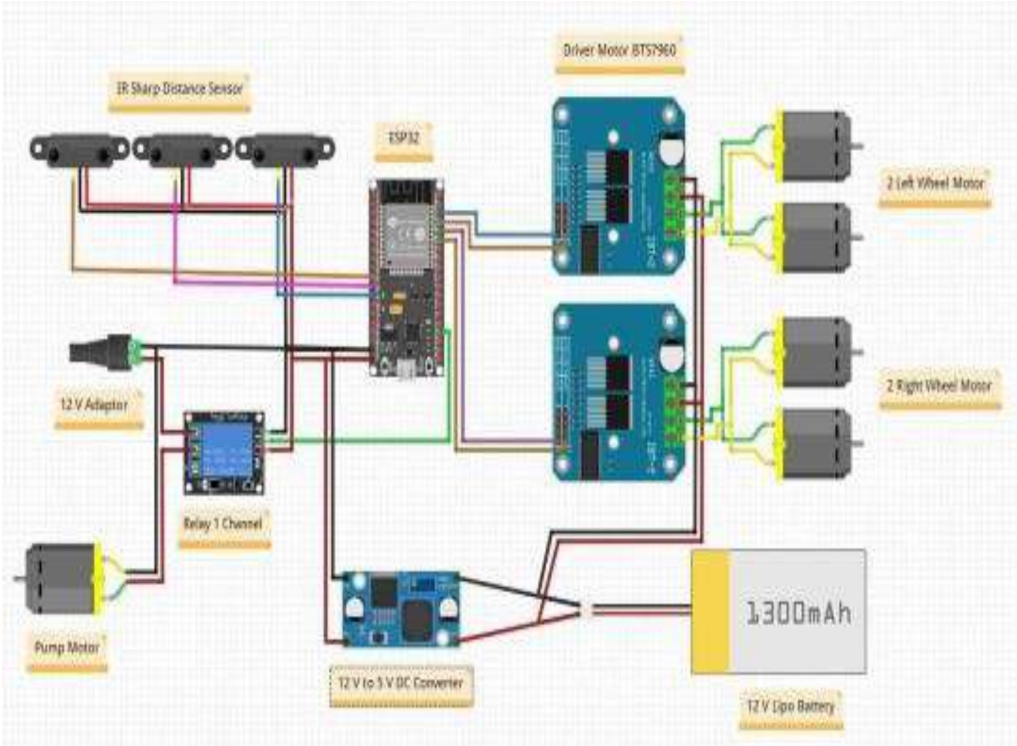

Figure 3. Wiring Diagram

Creating an autonomous robotic pipeline inspection and cleaning system for clogged drains in a palm oil industry entails combining modern sensor technologies, strong mobility, and intelligent control systems. The foundation of the design is an ESP32 microcontroller, which acts as the robot's brain, combining sensor data, motor controls, and relay signals. The robot is outfitted with several infrared distance sensors, which allow it to identify obstructions, measure distances, and navigate through limited regions within the pipeline. With precise real-time data, the robot can avoid collisions and operate more effectively through the pipeline environment.

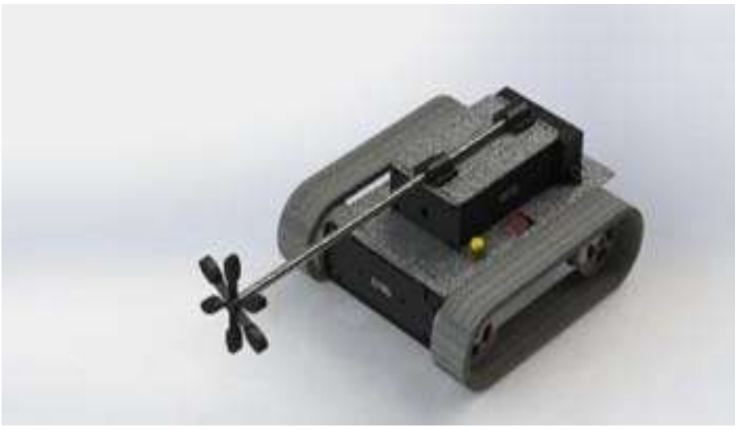

Figure 4. 32V of LiFePo4 batteries with PCM installed

The overall assembly of the pipeline cleaning robot, as shown in Fig 3.7, demonstrates a compact and integrated mechanical layout optimized for navigating and cleaning industrial drainage pipelines. The robot features a tank-style tracked system, providing superior mobility on slippery and debris-filled surfaces commonly found in palm oil factory pipelines. [9], [10].

The body is constructed from lightweight yet durable materials (such as acrylic or metal) to ensure structural integrity while allowing easy movement through narrow pipeline sections. All core components—including motors, sensors, pump systems, and control electronics—are strategically arranged to maintain balance and operational efficiency.

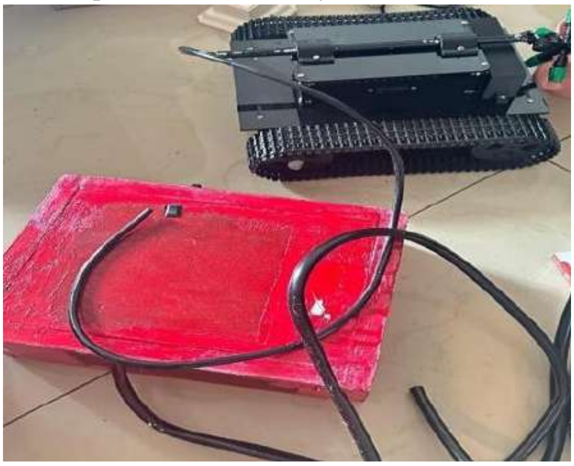

Figure 5. 32V of LiFePo4 batteries with PCM installed

The combination process involves assembling the core functional modules into a cohesive cleaning system. At this stage, the tank, compressor, hose, and nozzle are strategically positioned and connected to ensure smooth operational flow. The tank, painted red, serves as a water storage unit and is securely placed near the robot. The compressor, fixed to the robot's body, is connected via a flexible hose to the tank. This connection enables the compressor to extract water directly from the tank and pressurize it.

Once the pressurized water exits the compressor, it travels through an upper pipe system mounted above the tank and is directed to a nozzle at the front end of the robot. The nozzle is responsible for spraying high-pressure water into clogged areas during operation. The precise alignment and fitting of these components are critical to avoid leaks and ensure consistent water delivery. This careful combination of mechanical parts ensures that the robot functions as an integrated cleaning unit, ready for autonomous deployment inside drainage pipelines.

3. RESULT AND DISCUSSION

The analysis is grounded in experimental tests involving three distinct types of blockages: oil sludge, fiber clumps, and mixed debris. Performance was measured in terms of the time taken to remove each type of blockage, across multiple trials, under consistent robot operating parameters: 138 PSI water pressure and a movement speed of 0.60 m/s.

Table 1. Testing Parameters and Conditions

Parameter	Value
Water Pressure	138 PSI
Robot movement speed	0.60 m/s
Test Pipeline Length	3 meters
Number of Trials Blockage Type	5 trials each

To ensure consistent and reliable performance evaluation, the tests were conducted in a controlled simulated pipeline environment that mimicked actual drainage systems found in palm oil factories. The robot was tested in a 3-meter-long pipeline section with a diameter of 150mm [5], representing common pipeline dimensions. Each test involved inserting the robot into the pipeline, where it autonomously navigated, detected blockages, and activated its cleaning mechanism using a water jet system operating at 138 PSI. The robot's constant movement speed of 0.60 m/s was maintained throughout all trials to eliminate speed as a variable and ensure that differences in cleaning time could be attributed solely to the type and severity of the blockage.

Table 2. Cleaning Time Results For Each Blockage Type Across Five trials

Trial	Soapy Water(A)	Fiber Clumps(B)	Mixed Debris(C)
1	5.2 min	6.1 min	7.4 min
2	4.9 min	6.0 min	7.2 min
3	5.1 min	5.8 min	7.3 min
4	5.3 min	6.3 min	7.1 min
5	5.0 min	5.9 min	7.5 min
Average	**5.1 min**	**6.2 min**	**7.3 min**

The cleaning trials were conducted to evaluate how efficiently the robot could remove different types of blockages: soapy water, fiber clumps, and mixed debris. Each type of blockage was tested over five separate runs, and the time taken to clear each was recorded to calculate an average cleaning duration. The results showed a clear trend—soapy water blockages were removed the fastest, averaging 5.1 minutes, due to their low viscosity and loose adherence to the pipe walls. Fiber clumps took slightly longer, averaging 6.02 minutes, as their fibrous structure required more focused spraying to break apart and flush through. Mixed debris, the most complex and compact of the three, required the longest average time of 7.3 minutes, as it combined sticky and solid elements that resisted initial cleaning efforts.

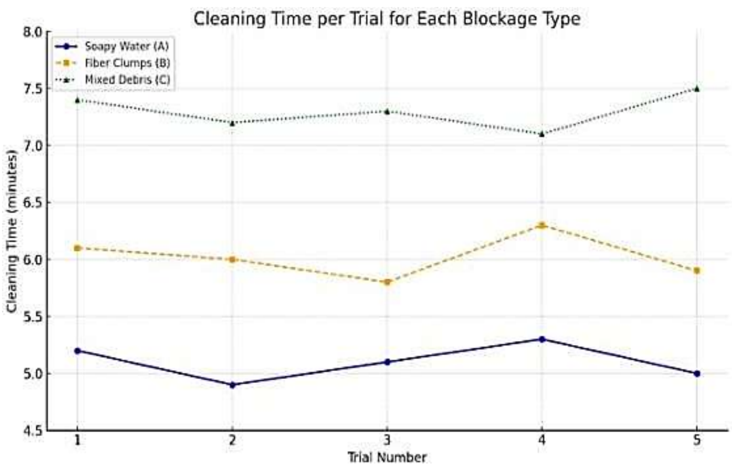

Figure 6. Cleaning Time Trends for Different Blockage types

The line chart in Section 4.4 visually illustrates the cleaning time trends for each type of blockage across five trials. It clearly shows that soapy water (Type A) had the shortest and most consistent cleaning times, typically remaining just above or below 5 minutes. Fiber clumps (Type B) displayed moderate variability, with times ranging from 5.8 to 6.3 minutes, indicating slightly more resistance during removal. Mixed debris (Type C) consistently took the longest to clean, hovering above 7 minutes in all trials due to its complex composition. The chart effectively highlights the robot's reliable performance and how blockage type directly impacts cleaning duration, validating the robot's efficiency in real-world simulated conditions.

4. CONCLUSION

The development of an autonomous pipeline cleaning robot for palm oil factory drainage systems has proven to be a significant advancement in addressing the recurring challenges of waste blockage and maintenance inefficiencies. Through mechanical, electrical, and software integration, the proposed robot successfully demonstrated its ability to detect, navigate, and clean various types of blockages including soapy residues, fiber clumps, and mixed debris—within simulated pipeline conditions.The robot was equipped with essential components such as an ESP32 microcontroller, infrared distance sensors, tank-track mobility, and a high-pressure water spray system.

REFERENSI

[1] Y. Tong, H. Liu, and Z. Zhang, "Advancements in Humanoid Robots: A Comprehensive Review and Future Prospects," *IEEE/CAA J. Autom. Sin.*, vol. 11, no. 2, pp. 301–328, 2024, doi: 10.1109/JAS.2023.124140.

[2] L. S. Grigore, I. Priescu, D. Joita, and I. Oncioiu, "The Integration of Collaborative Robot Systems and Their Environmental Impacts," *Processes*, vol. 8, no. 4, p. 494, Apr. 2020, doi: 10.3390/pr8040494.

[3] N. A. Mohd Yussof and H. W. Ho, "Review of Water Leak Detection Methods in Smart Building Applications," *Buildings*, vol. 12, no. 10, p. 1535, Sep. 2022, doi: 10.3390/buildings12101535.

[4] J.-C. Krapez *et al.*, "Multispectral Optical Remote Sensing for Water-Leak Detection," *Sensors*, vol. 22, no. 3, 2022, doi: 10.3390/s22031057.

[5] B. Khaled, "Impact of Robotic Cleaning Technologies on Labor Dynamics and Productivity in the Facility Management Sector Impact of Robotic Cleaning Technologies on Labor Dynamics and Productivity in the Facility Management Sector Main Findings."

[6] P. C. Nath *et al.*, "Recent advances in artificial intelligence towards the sustainable future of agri food industry," *Food Chem.*, vol. 447, p. 138945, Jul. 2024, doi: 10.1016/j.foodchem.2024.138945.

[7] P. Kumar *et al.*, "Environmental and human health implications of metal(loid) Source identification, contamination, toxicity, and sustainable clean-up technologies," Aug. 26, 2022, *Frontiers Media S.A.* doi: 10.3389/fenvs.2022.949581.

[8] B. Khaled and L. Nasser, "Impact of Robotic Cleaning Technologies on Labor Dynamics and Productivity in the Facility Management Sector," *AI, IoT Fourth Ind. Revolut. Rev.*, vol. 13, no. 11, pp. 9–17, Nov. 2023.

[9] C. Hao Wei and N. Jafferi, "Development of Drainage Cleaning Machine with Virtual Simulation," *Res. Prog. Mech. Manuf. Eng.*, vol. 2, no. 2, pp. 11–20, 2021, doi: 10.30880/rpmme.2021.02.02.002.

[10] D. Lattanzi and G. Miller, "Review of Robotic Infrastructure Inspection Systems," *J. Infrastruct. Syst.*, vol. 23, no. 3, Sep. 2017, doi: 10.1061/(ASCE)IS.1943-555X.0000353.