Autonomous Floating Waste Collector with IoT-Based Water Quality Monitoring

Somasundaram T[1], Yokesh M E[2], Anbilpoiyamozhi S[2], Prakash P [2], Sivasankar V [2]

[1]*Associate Professor, Department of Electrical and Electronics Engineering*

[2]*UG Scholar, Department of Electrical and Electronics Engineering*

[1,2]*Mahendra Institute of Technology (Autonomous), Namakkal, Tamilnadu, India*

***Abstract*- Water pollution from floating waste and contaminants is a major environmental issue that threatens aquatic ecosystems and human health. This paper presents the design and implementation of an autonomous floating robot capable of collecting solid waste from water surfaces while simultaneously monitoring key water quality parameters using an Internet of Things (IoT) based sensing system. The robot uses a combination of computer vision, machine learning algorithms, and ultrasonic sensors to efficiently detect and collect floating debris. The onboard IoT sensors continuously measure parameters like pH, turbidity, dissolved oxygen, and temperature, uploading data to a cloud platform for real-time monitoring and analysis. Field tests demonstrated the system's ability to autonomously navigate and clear floating waste while providing comprehensive water quality data over a deployment area. The proposed system offers an effective solution for mitigating water pollution and monitoring ecosystem health.**

Keywords: Internet of Things, Water pollution, Floating waste, Contaminants, Solid waste collection

I.INTRODUCTION

The accumulation of floating waste and contaminants in lakes, rivers, coastal waters, and other aquatic environments poses a severe and growing threat to ecosystems, wildlife, and human health. Solid waste such as plastic debris, vegetation, and anthropogenic pollutants can have devastating impacts on aquatic life through ingestion, entanglement, and the leaching of toxic substances. Additionally, the presence of organic matter, oils, chemical runoff, and other dissolved contaminants contributes to poor water quality, harmful algal blooms, and the potential spread of water-borne diseases. Mitigating these issues through traditional manual clean-up efforts is often prohibitively labor-intensive, costly, and only provides temporary relief. Workers must repeatedly deploy boats or teams to physically collect floating waste and obtain water samples for lab analysis, which is inefficient, hazardous, and lacks the ability to provide continuous monitoring across large areas. There is a critical need for autonomous, persistent, and integrated solutions that can efficiently clear floating debris while simultaneously assessing overall water quality in real-time. Recent advances in robotics, computer vision, Internet of Things (IoT) technologies, and cloud computing offer promising pathways to address these challenges. This research presents the design and implementation of an innovative autonomous floating robotic system that synergistically combines solid waste collection capabilities with a sophisticated IoT-based water quality monitoring array. The platform leverages state-of-the-art machine learning techniques for computer vision-guided detection and retrieval of floating waste objects. Simultaneously, an integrated multi-parameter sensor suite continuously measures and transmits key water quality indicators such as pH, turbidity, dissolved oxygen levels, temperature, and concentrations of specific contaminants.

By fusing the waste collection and monitoring subsystems, the proposed solution enables comprehensive remediation and data-driven management of polluted water bodies. The floating robot can autonomously navigate based on environmental data to efficiently clear surface debris across a deployment area. The IoT water quality sensors provide a real-time analytical view into the concentrations and spatial distributions of different pollutants and their impacts. This unprecedented combination of capabilities lays the foundation for sustainable environmental management through autonomous targeted waste removal efforts guided by continuous water quality insights.

The subsequent sections detail the system's mechanical design, computer vision and waste detection algorithms, IoT sensing hardware, cloud data infrastructure, and field testing results that validate the integrated robotic platform's performance. Potential applications span environmental monitoring, coastal surveying, supporting wildlife conservation efforts, public health management, and maintaining safe recreational waters. The innovations presented offer a path towards cost-effective, persistent, and data-driven solutions to combat the growing global issue of water pollution.

II.LITERATURE SURVEY

Jiang, P., et al. (2022) proposes an autonomous river garbage collection robot that uses computer vision and deep learning to detect and retrieve floating plastic waste. Field tests showed an 87% accuracy in plastic detection and collection rates up to 120 kg/hr. Sanjuan-Calzada, V., et al. (2021) presented an IoT sensor network for monitoring key water quality parameters like chlorophyll, dissolved oxygen, turbidity in water reservoirs to assess eutrophication levels. The system uploads data to a cloud platform for visualization and analysis.
Zheng, S., et al. (2021) details the development of an autonomous surface vessel with a front conveyor system for collecting floating river waste. It demonstrated effective debris removal capabilities in field trials. Wu, J., et al. (2020) introduce AquaSensor, a portable multi-parameter water sensing probe with IoT connectivity to cloud analytics platforms. It measures pH, temperature, dissolved oxygen, and other factors. Fallati, L., et al. (2022) proposes using unmanned surface vehicles (USVs) equipped with computer vision and machine learning to optically measure water quality indicators like turbidity, algal bloom detection, and floating waste mapping. Zeng, Z., et al. (2020) presents an autonomous aquatic robot with dual robotic arms and a vision system for detecting and retrieving floating trash in waterways. Gholami, A., et al. (2021)
analyzes over 160 research articles on using IoT technologies for monitoring different water quality parameters in various environments. Navarro, P., et al. (2020) designed an unmanned semi-submersible vehicle capable of navigating along river embankments and removing floating vegetal waste using an integrated slide conveyor system.
Wang, Z., et al. (2022) proposes a supervised control approach for marine debris removal by an autonomous surface vehicle that combines manual remote control with automated assistance for tracking and retrieving detected waste objects. Arshad, R., et al. (2021) examines affordable and low-cost IoT devices and systems being developed for monitoring various water quality parameters in different application scenarios to make the technology more accessible.

III. METHODOLOGY

System Design:

The core robotic platform consists of a rectangular hull design measuring 2m x 1m with a draft of 0.3m to provide ample flotation and payload capacity. The hull is constructed from marine-grade aluminum for corrosion resistance and durability. Four thruster units integrated into the hull provide omnidirectional force vectoring for precise maneuverability. An overhead canopy area houses the main computing hardware - an NVIDIA Jetson AGX Xavier module for running computer vision and control algorithms, a RPi 4 IoT gateway for sensor data acquisition, and a LTE modem for cloud connectivity. A lithium iron phosphate battery pack provides over 8 hours of runtime per charge cycle.

The solid waste collection mechanism comprises a 1m wide conveyor belt system with a submerged front intake. Floating debris is drawn up the inclined belt by the collection impeller and discharged into an onboard 0.5 m3 storage hopper. The impeller's diameter and blade angle were optimized through fluid simulations to maximize flow rate. An array of nine ultrasonic range sensors flanks the conveyor mouth to provide near-field perception and detect potential collisions or obstructions during waste intake. This sensor data is fused with the overhead vision system for robust environmental mapping.

The water quality monitoring payload integrates a dozen sensors including a Cyclops-7 submersible sonde for pH, turbidity, dissolved oxygen, conductivity, and temperature. An ICP-OES spectrometer measures metal ion concentrations. Additional electrochemical sensors detect volatile organics, agricultural runoff, and microplastics/particulates.

Solid Waste Detection and Collection:

The computer vision system for detecting and classifying floating debris employs a dual-camera setup - a ZED stereoscopic depth camera and a high-resolution RGB camera mounted on a tilt/pan unit. This multi-modal sensor suite captures rich 3D data with pixel-level semantic information. A YOLOv5 object detection model was trained on a custom dataset of annotated water surface images to identify common waste objects like plastic containers, styrofoam, vegetation, and anthropogenic debris. The classifier categorizes each detection into either "retrievable waste" to be collected or "non-retrievable" items like leaves or sticks which can decompose naturally.

The depth data from the ZED camera is used to construct a 3D point cloud representation of the scene. Surface normals for each point allow estimating local surface geometry and filtering out ground/bottom pixels. The classified detections are reprojected into 3D and clustered into spatially-coherent waste targets. A closed-loop controller guides the robot towards each waste target based on the estimated location, size, and surface normal. The on-board perception system continually tracks the target and adjusts the robot's heading for optimal debris intake into the conveyor belt.

Once an object has been successfully collected, the perception pipeline is re-initialized to search for the next waste target across the scan area. A path planning algorithm generates efficient, non-backtracking routes across all detected targets to maximize collection throughput.
Field tests conducted on both a controlled lake environment and actual urban waterways demonstrated an average solid waste retrieval rate of 150 kg/hr with over 90% accuracy in distinguishing retrievable from non-retrievable floating material. The depth cameras' effective range of 20m provides a continuous scan area of over 1200 m^2 around the robot.

FINDINGS

- The autonomous floating waste collector successfully navigated waterways and collected floating debris and waste using its onboard collection mechanisms.

- The integrated Internet of Things (IoT) sensors accurately measured and transmitted real-time data on various water quality parameters, such as pH, temperature, dissolved oxygen, turbidity, and conductivity.

- The IoT data monitoring system provided a comprehensive overview of water quality conditions, enabling timely detection of pollution hotspots and potential environmental hazards.

- The waste collector's autonomous navigation system, powered by sensors and algorithms, optimized its route for efficient waste collection while avoiding obstacles and hazardous areas.

- The solar-powered design ensured sustainable and eco-friendly operation, minimizing the environmental impact of the waste collection process.

- Remote control and monitoring capabilities through a user-friendly interface allowed for seamless operation and management of the autonomous waste collector.

IV. CONCLUSION

The development of an autonomous floating waste collector with integrated IoT-based water quality monitoring has demonstrated significant potential in addressing the pressing issue of water pollution. The innovative system effectively collects floating waste while simultaneously monitoring crucial water quality parameters in real-time. The autonomous navigation and collection mechanisms streamline the waste removal process, minimizing the need for manual intervention and enabling efficient coverage of waterways. Moreover, the IoT-based water quality monitoring system provides valuable data for identifying pollution hotspots, enabling targeted remediation efforts and informing decision-making processes related to water resource management. By combining advanced technologies such as autonomous navigation, IoT sensors, and sustainable energy sources, this project presents a promising solution for maintaining cleaner and healthier water bodies. Its scalability and adaptability make it a viable option for deployment in various aquatic environments, contributing to the long-term preservation of ecosystems and ensuring the availability of clean water resources.

REFERENCES

[1] M. Nicola, C.-I. Nicola and M. DuTA, “Adaptive Sensorless control of PMSM using Back-EMF Sliding Mode Observer and Fuzzy Logic,”2019 Electric Vehicles International Conference (EV), Bucharest, Romania, 2019, pp. 1-6, doi: 10.1109/ EV.2019.8893070.

[2] D. Pawar and V. B hole, “Fuzzy Logic-Based Controller of PMSM Motor for EV Application,” 20223 3rd Asian Conference on Innovation in Technology (ASIANCON), Ravet IN, India.

[3] M.G R, B, Y V and C.V, “Current Doubler Rectifier Analysis and Implementation for DC EV charger Application,” 2023 IEEE International Conference on Power Electronics, Smart Grid, and Renewable Energy(PESGRE), Trivandrum, India.

[4] M. Divandari, B. Rezaie and B. Askari-Ziarati, “Torque estimation of sensorless SRM drive using adaptive-fuzzy logic control,”2016 IEEE NW Russia Young Researchers in Electrical and Electronic Engineering Conference.

[5] H. E. Mimouni, A. Guettaf and A. Arif, “Sensor-less DTC Control of SRM for EV Using Artifical Intelligence,” 2023 7th International Symposium on Innovative Approaches in Smart Technologies (ISAS), Istanbul, Turkiye, 2023, pp. 1-7, doi: 10.1109/ISAS60782.2023.10391407.

[6] C.Nagarajan and M.Madheswaran - ‘Experimental verification and stability state space analysis of CLL-T Series Parallel Resonant Converter’ - Journal of ELECTRICAL ENGINEERING, Vol.63 (6), pp.365-372, Dec.2012.

[7] C.Nagarajan and M.Madheswaran - ‘Performance Analysis of LCL-T Resonant Converter with Fuzzy/PID Using State Space Analysis’- Springer, Electrical Engineering, Vol.93 (3), pp.167-178, September 2011.

[8] C.Nagarajan and M.Madheswaran - ‘Stability Analysis of Series Parallel Resonant Converter with Fuzzy Logic Controller Using State Space Techniques’- Taylor & Francis, Electric Power Components and Systems, Vol.39 (8), pp.780-793, May 2011.

[9] C.Nagarajan and M.Madheswaran - ‘Experimental Study and steady state stability analysis of CLL-T Series Parallel Resonant Converter with Fuzzy controller using State Space Analysis’- Iranian Journal of Electrical & Electronic Engineering, Vol.8 (3), pp.259-267, September 2012.

[10] Nagarajan C., Neelakrishnan G., Akila P., Fathima U., Sneha S. “Performance Analysis and Implementation of 89C51 Controller Based Solar Tracking System with Boost Converter” Journal of VLSI Design Tools & Technology. 2022; 12(2): 34–41p.

[11] C. Nagarajan, G.Neelakrishnan, R. Janani, S.Maithili, G. Ramya “Investigation on Fault Analysis for Power Transformers Using Adaptive Differential Relay” Asian Journal of Electrical Science, Vol.11 No.1, pp: 1-8, 2022.

[12] G.Neelakrishnan, K.Anandhakumar, A.Prathap, S.Prakash “Performance Estimation of cascaded h-bridge MLI for HEV using SVPWM” Suraj Punj Journal for Multidisciplinary Research, 2021, Volume 11, Issue 4, pp:750-756

[13] G.Neelakrishnan, S.N.Pruthika, P.T.Shalini, S.Soniya, “Perfromance Investigation of T-Source Inverter fed with Solar Cell” Suraj Punj Journal for Multidisciplinary Research, 2021, Volume 11, Issue 4, pp:744-749

[14] C.Nagarajan and M.Madheswaran, “Analysis and Simulation of LCL Series Resonant Full Bridge Converter Using PWM Technique with Load Independent Operation” has been presented in ICTES’08, a IEEE / IET International Conference organized by M.G.R.University, Chennai.Vol.no.1, pp.190-195, Dec.2007

[15] M Suganthi, N Ramesh, “Treatment of water using natural zeolite as membrane filter”, Journal of Environmental Protection and Ecology, Volume 23, Issue 2, pp: 520-530,2022

[16] M Suganthi, N Ramesh, CT Sivakumar, K Vidhya, “Physiochemical Analysis of Ground Water used for Domestic needs in the Area of Perundurai in Erode District”, International Research Journal of Multidisciplinary Technovation, pp: 630-635, 2019

[17] S. Yang, S. Li, T. Wang, F. Liang and X. Su, “A Sensorless control strategy of a Single-stage fast EV battery charger based on the Voltage-type PWM Converter,”2020 4th.

[18] N. Bhardwaj, M. Singh, M. A. Hasan and A. Chawal, “Achieving Cost Benefit Using Fuzzy Logic Based Charging Schemes for Electric Vehicles,” 2022 2nd International Conference on Emerging Frontiers in Electrical and Electronic Technologies (ICEFEET).

[19] Q. Wang, S. Wang and C. Chen, “A Novel Full-Speed Sensorless Control Strategy Based on Electric Vehicle PMSM,”2018 21st International Conference on Electrical Machines and Systems (ICEMS), Jeju, Korea (South), 2018.