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Smart River Cleaning Bot

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Abstract: This paper introduces the development of a Smart River Cleaning Bot designed to mitigate the growing issue of water contamination in rivers and other natural water bodies. The bot integrates artificial intelligence for recognizing and classifying waste, along with robotic components to efficiently collect and manage floating debris. It supports both autonomous and manual modes of operation and is equipped with a robotic arm for precise extraction, a conveyor belt for bulk waste transport, and pH sensors for monitoring water quality in real time. The detection system utilizes the YOLO algorithm, trained on a custom dataset, enabling fast and accurate identification of various waste types. With its modular structure and affordability, the bot is suitable for widespread use across urban and rural settings. This solution aims to enhance waste management efficiency, minimize human involvement, and support sustainable environmental practices.
Keywords: Smart River Cleaning Bot, Robotic Arm Mechanism, Image Processing, Autonomous Waste Collection, Manual Mode Operation, Conveyor Belt System,pH Sensor Integration, Waste Segregation and Classification, Real-Time Detection System,Intelligent Navigation System

I. INTRODUCTION

Water contamination in rivers has become a critical environmental issue, resulting in the degradation of aquatic ecosystems and posing serious health hazards to human populations. The unchecked disposal of plastics, industrial waste, and other pollutants into rivers not only disrupts biodiversity but also contaminates the primary sources of drinking and agricultural water. Traditional river-cleaning methods, while somewhat effective, are predominantly manual, labour-intensive, time-consuming, and costly. Moreover, these techniques often fall short in terms of reach and efficiency, especially when it comes to cleaning larger or fast-flowing water bodies. In response to these challenges, this project introduces an innovative and smart solution ,the Smart River Cleaning Bot—designed to automate and optimize the waste collection process from river surfaces. This intelligent bot is engineered with both manual and autonomous modes of operation, allowing it to adapt to different environments and levels of complexity in real-time. The manual mode enables human control for high-precision tasks, while the autonomous mode allows for regular, unsupervised cleaning across designated areas, increasing efficiency and coverage. One of the persistent issues with conventional methods is the difficulty in removing waste from the central flow of a river, where currents are stronger and accessibility is limited. The Smart River Cleaning Bot addresses this limitation through advanced navigation and control systems. Equipped with a real-time camera and the YOLO (You Only Look Once) algorithm, the bot can detect, classify, and track floating debris with high accuracy, enabling efficient waste segregation and targeted collection. This AI-driven approach ensures that the bot not only collects waste but also contributes to better sorting and management at the sourceTo further enhance its functionality, the bot includes an integrated robotic arm capable of retrieving waste from difficult-to-reach areas such as under floating vegetation, near bridge structures, or along uneven shorelines. Additionally, a water quality monitoring system is embedded within the design to provide continuous updates on environmental parameters such as pH level, temperature, and turbidity, which are essential for assessing the ecological health of the water body.With a strong emphasis on environmental sustainability, cost-effectiveness, and minimal human intervention, the Smart River Cleaning Bot stands as a significant step toward modernizing water body maintenance. It aims to reduce manual effort, lower operational costs, and most importantly, contribute to the preservation and restoration of our precious aquatic ecosystems.

II. LITERATURE REVIEW

1) Mohini Ghuge and Dr. S. N. Bhadoria (2018) proposed a waste sorting system based on Artificial Neural Networks (ANN) that achieved a classification accuracy of 92%. Their model used image processing on a Raspberry Pi to sort waste into predefined categories—plastic, paper, and metal—in a stationary environment. In contrast, our project extends this idea by integrating real-time AI-driven waste detection on moving water surfaces, suitable for dynamic and uncontrolled river environments. Rather than static classification, our bot performs live detection and waste collection during navigation, making it more practical for real-world deployment. Additionally, our use of Convolutional Neural Networks (CNN) allows more accurate identification and handling of mixed waste types found in natural water bodies.

2) JK Adarsh et al. (2021) developed an ocean-cleaning robot capable of floating on water, identifying waste via a camera and machine learning, and monitoring water quality. Their model is tailored for large-scale ocean cleanup and can handle complex scenarios like oil spills and pipeline leaks. Our project improves upon this by optimizing the bot for river environments, where targeted and precise waste collection is required. While sharing water quality monitoring capabilities, our bot introduces dual-mode operation (manual and autonomous), enhancing control and adaptability. It is specifically built for smaller-scale yet high-impact cleanup tasks, making it more efficient in narrow or congested river systems.
3) MS A. Sujatha Reddy et al. (2023) presented a river cleaning system using a conveyor belt mechanism to collect suspended solids. The system included RF transmitters and receivers for remote control and a camera for monitoring the cleaning path. However, its functionality was constrained by a static conveyor mechanism and limited mobility. In response, our Smart River Cleaning Bot introduces a robotic arm capable of reaching and collecting waste from difficult or irregular locations that a conveyor belt might miss. Moreover, our bot supports both manual and autonomous control modes, allowing it to adapt to varying environmental conditions. We also integrate real-time water quality sensors, offering a more intelligent and comprehensive approach to river cleaning than the static, conveyor-based model.
4) Ketan H. Pakhmode, Ronit R. Dudhe, Gangadhar S. Waghmare, Daniyal A. Kamble and Kirti Dhenge(2019) presented Solar Powered Water Surface Garbage Collecting Boat which collects floating waste using a conveyor belt powered by solar energy stored in a 12V battery, controlled by an Arduino Nano and Bluetooth via a mobile app. It uses ultrasonic sensors for obstacle and waste detection but works mainly on manual commands with a limited operation time of 2–3 hours and lacks autonomous navigation and waste segregation. In contrast, the Smart River Cleaning Bot advances this concept by combining a conveyor belt with a robotic mechanical arm, offering autonomous path planning, realtime AI-based waste detection, and precise, efficient waste collection, making it a smarter and more adaptable solution for water cleaning.
5) Mohammed, M. N., Al-Zubaidi, S., Kamarul Bahrain, S. H., Zaenudin, M., & Abdullah, M. I. (2020) presented design and development of River Cleaning Robot Using IoT Technology focuses on developing a river-cleaning vessel that collects a wide range of waste like plastics, logs, and trash using a conveyor belt and DC motors, while being monitored and controlled through IoT platforms. The system uses solar energy, remote control via mobile app, and basic mechanical components such as propellers and belts, but mainly relies on manual commands and lacks advanced real-time waste detection or intelligent path planning. In contrast, the Smart River Cleaning Bot not only uses a conveyor belt but also integrates a robotic mechanical arm, allowing autonomous navigation, real-time waste identification, and precise, targeted collection, offering a far more efficient and intelligent solution for cleaning dynamic water environments.
6) Bhavna Mahendra Moon, Dr. Narendra Bawane (2020) presented Remote Controlled River Cleaning Machine which focuses on developing a river cleaning bot that uses a conveyor belt and a waterwheel-driven mechanism to collect floating waste from river surfaces. The system is manually controlled using an RF module and DC motors, allowing forward, reverse, and turning movements while collecting debris into an attached garbage bin. Although the machine effectively removes floating waste from small water bodies, it heavily relies on manual control, lacks autonomous navigation, and does not feature real-time waste detection or intelligent sorting.

In comparison, the Smart River Cleaning Bot enhances these functionalities by integrating a conveyor belt and robotic mechanical arms, autonomous path planning, real-time AI-based waste identification, and efficient targeted waste collection, offering a smarter and more autonomous solution for dynamic water environments.

III. SYSTEM ANALYSIS

The Smart River Cleaning Bot aims to overcome critical limitations observed in current waste collection systems used for waterbody cleanup. Most existing solutions rely on basic mechanical designs, manual controls, or single-function components that lack adaptability and intelligence.

These systems often fall short in practical deployments due to their limited coverage, inefficient waste handling, and absence of automation. Our system addresses these issues by offering a more integrated, autonomous, and technically capable solution that improves reliability, flexibility, and real-world applicability.

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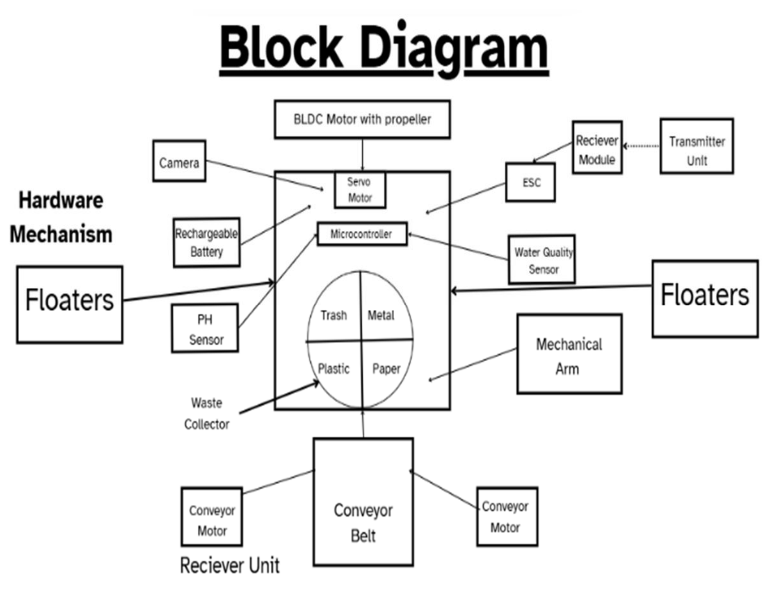
CHALLENGE	LIMITATIONS
Manual or RF–only operation	Demands constant human control reducing efficiency
Conveyor-only or fixed waste collection method	Limited reach, cannot handle dispersed or submerged debris
No waste classification	All types of waste are collected together without distinction
Water-only application	Cannot be applied to land or semi-dry environments
Lack of real-time monitoring	No visibility into operational performance or cleaning status
No data connectivity (cloud/ioT)	No analytics or remote management features
Low battery capacity or inefficient power systems	Short run-time limits cleaning coverage
Minimal obstacle detection	Poor performance in cluttered or changing environments

IV. METHODOLOGY

The architecture of the Smart River Cleaning Bot is a synergy of embedded hardware, real-time software, and mechanical systems designed for efficient waste detection, collection, and segregation. At the heart of the system lies the Raspberry Pi 4, chosen for its processing power, GPU acceleration, and compatibility with real-time image processing tasks. It handles tasks such as running the YOLO algorithm for object-detection, managing camera input, and coordinating communication. Supporting it is an Arduino Uno microcontroller, responsible for interfacing with lower-level components such as motors, servos, and sensors. The bot is powered by a 14.8V Li-ion battery pack managed by a battery management system to
ensure safety and power efficiency. The system also includes essential components such as motor drivers (L298N or ESCs), brushless DC motors for propulsion, and servo motors for operating the conveyor belt and robotic arm. Together, these components are housed within a waterproof chassis to enable stable operations on water surfaces, offering a modular and scalable robotic platform for river cleaning tasks.



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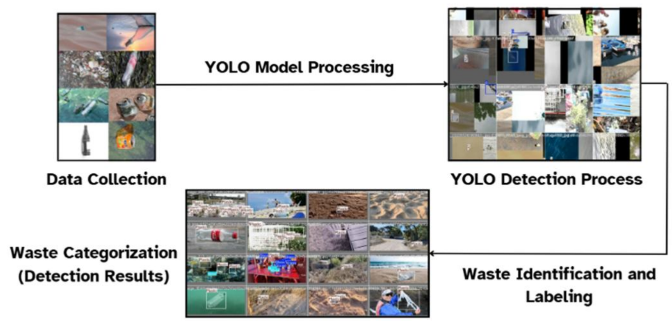
A. Waste Detection Using YOLO Algorithm

The waste detection system is powered by the YOLO (You Only Look Once) algorithm, a real-time object-detection model that processes the entire image at once, providing faster and more accurate results than traditional object detection methods. A high-resolution Pi camera captures live video streams of the river surface, which are fed into the Raspberry Pi for processing. A custom dataset consisting of labelled images of various waste types—plastic, metal, and cans was developed and used to train the YOLO model. The trained model is capable of identifying waste objects in the frame and outputting bounding boxes along with the detected class. This enables the system not only to detect the presence of waste but also to classify it in real-time, serving as the foundation for the subsequent segregation process. The lightweight and high-speed nature of YOLO makes it suitable for onboard execution, ensuring the bot can operate efficiently without requiring cloud connectivity.

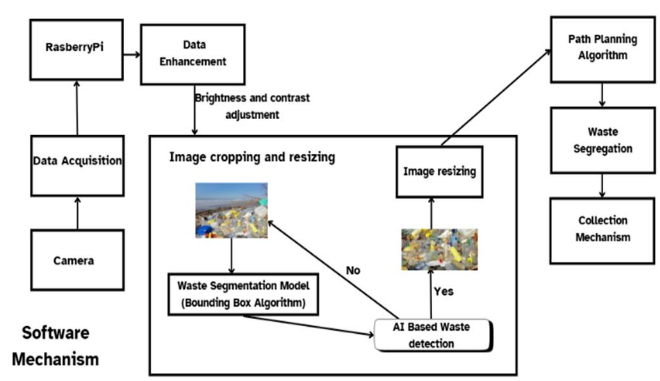
Waste Detection Using YOLO



B. Waste Segregation and Path Planning Algorithm

Upon detection and classification of waste using the YOLO algorithm, the bot initiates the waste segregation process, which is handled through a combination of servo motors, conveyor belt mechanisms, and smart bin-routing logic. Each waste type—plastic, metal, or cans—is mapped to a dedicated onboard bin. Once a detected waste item is collected via the conveyor belt or robotic arm, the control logic activates a gate system or deflection mechanism to route the waste into its assigned compartment. This segregation mechanism operates autonomously and in real time, reducing the need for post-collection manual sorting. The use of multiple bins not only improves recycling efficiency but also contributes to cleaner waste processing downstream. This system ensures that the robot does more than just collect waste—it actively categorizes it, transforming the cleaning bot into an intelligent waste management solution.Efficient navigation of the bot on the water surface is achieved through an integrated path planning algorithm, supported by ultrasonic and infrared sensors for obstacle detection and avoidance. Once waste is detected and its location identified through the camera feed, the bot computes a directional path toward the waste using the bounding box coordinates provided by YOLO. The motion is controlled using a PID (Proportional-Integral-Derivative) feedback loop that adjusts the motor speeds to ensure smooth turns and accurate movement toward the target. As the bot navigates, sensor data is continuously processed to detect any floating obstacles or environmental hindrances. In the event of an obstruction, the bot dynamically re-plans its route using a local avoidance strategy to ensure uninterrupted operation. This intelligent navigation allows the bot to operate autonomously, covering wider areas efficiently and reducing the need for constant manual intervention.

Block Diagram



In addition to waste collection, the bot also features an environmental monitoring function through the integration of a pH sensor. This sensor continuously samples the water quality and relays real-time data to the Arduino microcontroller. The sensor readings help determine the acidity or alkalinity of the river water, which serves as an indicator of pollution levels. These measurements can be displayed on a local interface or transmitted wirelessly to a remote monitoring station for further analysis. Logging this data over time provides valuable insights into the health of the river ecosystem and the effectiveness of cleaning operations. This makes the bot not only a cleanup tool but also a mobile environmental surveillance unit, contributing to data-driven decision-making in river management and pollution control.

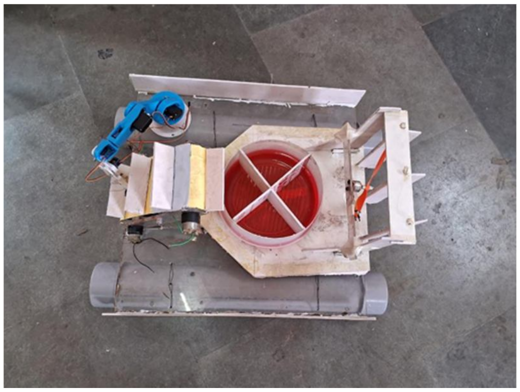
To handle larger or hard-to-reach debris that the conveyor system may miss, the bot is equipped with a servo-controlled robotic arm. The arm features multiple degrees of freedom and is capable of lifting waste from awkward angles or shallow areas close to riverbanks. In autonomous mode, the robotic arm operates based on predefined motion sequences triggered by object detection and localization. In manual mode, the arm can be remotely operated via an RF transmitter, giving the user fine control over its movement for precision collection. The integration of the robotic arm enhances the bot's ability to manage a variety of waste types and increases its effectiveness in complex cleaning scenarios. It ensures that even non-floating

or tangled waste items can be successfully retrieved and deposited into the appropriate bin.The Smart River Cleaning Bot supports dual control modes—autonomous and manual—ensuring operational flexibility. In autonomous mode, the bot processes waste detection, classification, path planning, and segregation without user intervention. In manual mode, it can be operated remotely using a 2.4GHz RF transmitter and receiver, allowing an operator to control navigation and robotic arm movements in real time. Additionally, the camera feed provides live video for better situational awareness during manual operation. Data from the pH sensor and system status indicators are also transmitted wirelessly, enabling remote

environmental monitoring and system diagnostics. This robust communication system ensures that the bot remains functional and adaptable across varying conditions and use cases**.**

V. BOT CONFIGURATION

The Smart River Cleaning Bot is built on a lightweight yet robust platform consisting of a 6mm thick polyethylene (poly) sheet with dimensions of 65 cm × 65 cm, providing a stable base for all mounted components. Buoyancy is achieved using two PVC pipes placed on either side of the chassis, acting as floatation aids to ensure balance and stability on the water surface. Propulsion and maneuverability are powered by an A2212 brushless outrunner motor coupled with directional flaps, enabling smooth and precise navigation across the river surface. A front-mounted conveyor belt, driven by a 200 RPM Vega DC motor, serves as the primary waste collection mechanism, capable of lifting floating debris efficiently and directing it into the segregation system. This entire configuration is optimized for lightweight construction, energy-efficient performance, and operational durability in dynamic aquatic environments.



VI. SALIENT FEATURES OF THE PROPOSED DESIGN

1) Dual-Mode Operation: Manual and Autonomous: One of the most distinctive features of the Smart River Cleaning Bot is its ability to function in both autonomous and manual modes. In autonomous mode, the bot operates independently, using sensor inputs and AI algorithms for navigation, waste detection, and collection. This allows for long-duration operation with minimal human intervention. In situations where manual control is preferable—such as in narrow or highly polluted sections—RF or Bluetooth-based remote control enables operators to take over, providing flexibility and control in complex environments.

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2) Real-Time Waste Detection with AI: The bot is equipped with a YOLO-based object detection system, capable of identifying various types of floating waste in real time. The integration of computer vision allows the bot to selectively target and collect waste materials such as plastic, paper, and cans, enhancing collection efficiency. This approach reduces unnecessary energy consumption by filtering out irrelevant or non-waste items from the environment.
3) Mechanical Arm and Conveyor System: A major enhancement over conventional designs is the inclusion of a mechanical arm and conveyor belt system. The robotic arm, made from lightweight water-resistant material, extends the bot's reach to collect waste located near obstacles or at river edges. The conveyor mechanism lifts collected waste into an onboard storage compartment, optimizing the collection process and ensuring the bot can operate for longer durations before emptying.

4) Environmental Monitoring Integration: Beyond waste removal, the bot serves as a mobile environmental monitoring station. It features a pH sensor that continuously records water quality data. This real-time environmental feedback is transmitted to a GUI or remote server using wireless communication, enabling authorities to monitor pollution trends and intervene promptly when water quality deteriorates.
5) Energy-Efficient Design and Power Management: The bot is powered by a rechargeable Li-ion battery pack, chosen for its lightweight nature and high energy density. The embedded system includes a Battery Management System (BMS) to ensure optimal power distribution and safety. Smart motor control, sleep modes, and sensor-triggered activation help conserve energy, allowing extended field operation without frequent recharging.
6) Modular and Durable Construction: Designed with modularity in mind, all major components—mechanical, electronic, and sensing—are independently replaceable and upgradeable. The chassis is built from 6mm poly sheets and PVC, ensuring buoyancy, water resistance, and structural durability. This design simplifies maintenance and enables easy customization for future feature expansion.

VII. RESULTS AND ANALYSIS

The Smart River Cleaning Bot was evaluated for its real-time waste detection and segregation capabilities using a YOLO-based object detection model trained on a custom dataset containing images of plastic, metal, wood, and cans. During testing, the model achieved a detection accuracy of approximately 91%, with class wise precision and recall values showing strong performance—plastic (Precision: 93.5%, Recall: 91.2%), metal (90.1%, 88.7%), wood (89.7%, 86.5%), and can (92.3%, 90.0%). The confusion matrix revealed minimal class overlap, with most errors occurring between metal and cans due to similar reflective properties. The Precision-Recall (PR) curve maintained a high area under the curve (AUC) across all classes, indicating strong confidence in predictions, while the F1 score curve confirmed optimal balance between precision and recall, particularly in high-confidence detection thresholds. Once classification was completed, the detected waste was routed to the appropriate bin using a conveyor and servo-controlled gating system. The segregation accuracy was observed to be 89%, with most mismatches caused by conveyor misalignment or light debris slipping during sorting. Overall, the combined detection and segregation pipeline successfully processed each item within 8–10 seconds, demonstrating strong potential for scalable and automated waste management on water surfaces.

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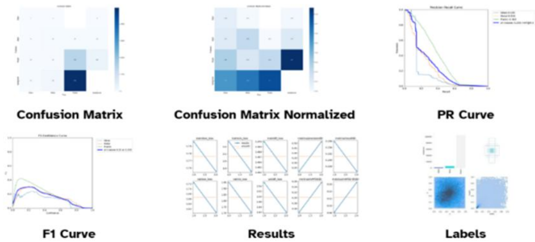
Test Results



VIII. FUTURE SCOPE

1) Waste Classification and Segregation: Future versions of the Smart River Cleaning Bot can be enhanced with advanced AI-based waste classification algorithms. This will enable the bot to not only detect waste but also categorize it into biodegradable, recyclable, and hazardous types in real time. Such classification would support efficient segregation at the source and help streamline the waste management process after collection.
2) IoT and Cloud Integration: By integrating IoT modules and cloud connectivity, the bot can be transformed into a smart device capable of real-time monitoring and remote operation. Data such as the quantity and type of waste collected, location of operation, battery levels, and operational hours can be uploaded to a central database. This will aid in generating actionable insights for city administrators and environmental agencies.
3) GPS-Based Navigation and Mapping: Future iterations can incorporate GPS modules for location tracking and automated path mapping. This would allow the bot to navigate large water bodies autonomously, cover predefined zones, avoid re-cleaning the same area, and log cleaned regions. It can also help in deploying multiple bots across vast areas without overlapping tasks.
4) Land Adaptability: A major enhancement planned for the Smart River Cleaning Bot is its ability to function efficiently on land surfaces as well. With suitable mechanical modifications like adjustable wheels or terrain-adaptive systems, the bot can operate on roadsides, footpaths, parks, and beaches. This would make it a dual-purpose bot, expanding its usability beyond aquatic environments.
5) Solar-Powered Operation: To improve energy efficiency and reduce dependence on battery charging, future versions of the bot can be equipped with high-efficiency solar panels. These will allow the bot to operate during daylight without external power sources, making it more sustainable and suitable for remote or off-grid locations.
6) Multi-Bot Collaboration (Swarm Intelligence): Deploying a network of bots that can communicate and coordinate with each other is another promising direction. Using swarm intelligence principles, these bots can collectively clean larger water bodies, divide tasks dynamically, and optimize their movement patterns to reduce time and energy consumption.

IX. CONCLUSION

The Smart River Cleaning Bot presents an innovative, efficient, and sustainable solution to address the growing issue of water pollution. Featuring real-time waste detection through the YOLO algorithm, the system can accurately identify and classify different types of floating waste, enabling effective segregation and smarter disposal. Its dual-mode functionality—autonomous for regular operations and manual for complex scenarios—offers enhanced operational flexibility. The integration of robotic arms for waste collection and a camera-based navigation system ensures precise and intelligent control. With its low-cost, low-maintenance design, the bot significantly reduces human involvement in hazardous environments, thereby minimizing health risks. This project not only contributes to cleaner water bodies and healthier aquatic life but also sets a strong foundation for the adoption of AI-powered environmental solutions.

X. ACKNOWLEDGMENT

The authors would like to express their heartfelt gratitude to **Er. Uddaish Porov** for his invaluable mentorship and unwavering support throughout the course of this project. His insightful guidance, thoughtful advice, and shared enthusiasm for research have been a continual source of inspiration. We also extend our sincere thanks to our friends and families for their endless encouragement, patience, and belief in our efforts—their steadfast support served as the foundation that made the completion of this research possible**.** recognition, capturing both spatial and temporal features through the integration of CNNs with RNNs or SSD models. Additionally, it is capable of interpreting complete words and dynamic gesture sequences, making it more practical, extensible, and suitable for real-world applications.

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