MANUAL GUIDE

LABI BOT

INNOVATING THE FUTURE OF ROBOTICS AND ENVIRONMENTAL PROTECTION

CHEITH CHOUK

About this book

This book is a comprehensive guide and technical manual for Labi-Bot — the autonomous beach-cleaning robot developed to combine robotics and AI in environmental conservation.
Here you will find the complete project story, technical specifications, design insights, AI model explanations, hardware details, and future upgrade ideas.
Whether you're a developer, engineer, or environmental enthusiast, this guide will help you understand and build upon Labi-Bot's innovative approach.

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Introduction & Project Overview

“ why Labi-bot ? “

1. The Plastic Crisis: Why It Matters

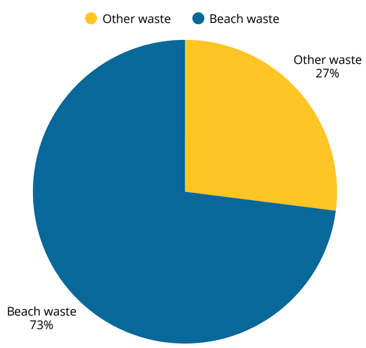
Plastic pollution is one of the biggest environmental challenges of our time. damaging coastal ecosystems, and polluting beaches.
Beaches are the frontline of this crisis:

The impact? It harms tourism, wildlife, and even human health.

The Threat

- Marine Life: Animals mistake plastic for food, leading to injuries and death.
- Microplastics: Break down into tiny particles that enter the food chain.
- Scale of the Crisis: Over 12 million tons of plastic end up in oceans each year.
- On Our Beaches: More than 73% of beach waste is plastic, making cleanup urgent.

Manual cleanup is slow, expensive, and unsustainable.
That’s why we asked:
“Can robotics and AI change the game?”
The answer is **Labi-Bot** — an autonomous beach-cleaning robot designed to fight plastic pollution and protect our oceans.



2. Why we created Labi-Bot ?

We love **technology**. We love **nature**. But every summer, we saw the same thing: beaches covered in **plastic waste**. Volunteers worked hard to clean up, but the problem kept coming back, bigger every year.

We asked ourselves:
"**What if a robot could do the boring cleanup — so humans can enjoy the beach?**"

That question started our journey.
We wanted a **smart, autonomous robot** that combines:

- Robotics (to move and collect waste),
- AI (to detect and sort plastics), and
- Purpose (to protect our oceans).

3.Our Mission

To create smart, autonomous technology that cleans beaches, protects marine life, and inspires innovation for a cleaner planet.

Why It Matters

Every piece of plastic we remove is a life saved.
Every clean beach is a step toward a sustainable future.
Labi-Bot isn’t just a robot—it’s a commitment to the planet.

Core Values

- Sustainability – Technology should help nature, not harm it.
- Innovation – Robotics and AI can solve real-world problems.
- Creativity – We think outside the box to make a difference.
- Community – Together, we can make change scalable.

Our Vision

A world where every coastline is plastic-free, and robots work alongside humans to protect what matters most: our oceans.

Clean Beaches. Smarter Future

4.Meet Our Team

Junior ROBOTICS

"Empowering Future Innovators"

Cheith Chouk

- Littering Detection Algorithm
- 3D Design (SolidWorks)
- Power Distribution System
- Local Web Interface Development
- Parts Assembly

Jasser Riahi

- Bottle Collection Algorithm
- Mobile App Development
- Autonomous Navigation System
- Motor & Sensor Electronics
- Communication

Part 2: Labi-Bot Development Journey

“ Great ideas don’t happen overnight — they grow, evolve, and transform ”

6.Forum DSI - 2024

What is Forum DSI?

Forum DSI is a national conference and exhibition where young innovators present robotics and embedded systems solutions. We participated in the 10^{th} edition, showcasing our very first bottle-collecting robot. It was our first real public test, where we received great feedback and earned a trophy—an achievement that gave us confidence to push the project further.

Concept & Mechanism

The robot's main idea was simple: detect a plastic bottle and pick it up using a robotic arm with a gripper (pince).

- **Arm mechanism:**

3 servo motors (shoulder, elbow, and gripper open/close)
Designed to lower, grab the bottle, and lift it into a container

- **Drive base:**

2 × 6 V DC motors with wheel drive
Supported by PID motor control for smooth and accurate movement

- **Collection process:**

Robot aligns with a bottle
Arm lowers toward the bottle
Gripper closes and lifts
Bottle is stored in the basket

Forum DSI - 2024

Hardware Components Used

Control & Actuation:
Arduino Mega — motor + actuator control
PCA9685 — 12-channel servo driver (precise PWM for the arm)
IBT-2 H-bridges (×2) — high-current drivers for the DC motors
3 Servo motors — arm + gripper
2 × 6 V DC motors — drive base
Power:
6 × 18650 Li-ion batteries (with regulators for servos & logic)
Sensing:
Camera (for detecting bottles)

What We Achieved

- Demonstrated a working prototype capable of detecting and collecting bottles.
- Learned how to integrate multiple hardware modules in one robot.
- Won a trophy at Forum DSI 10^{th} edition, proving that our concept had real potential.

Limitations We Noticed

- Precision issues on sand (arm required perfect alignment).
- Slow collection cycle (pick-and-place is time consuming).
- Delicate mechanism that was not robust outdoors.

Forum DSI - 2024

Vision System

To detect plastic bottles, we used a pre-trained YOLOv5 model (You Only Look Once, version 5). This model was chosen because:

- It is fast and lightweight, ideal for real-time detection.
- It is trained on general objects and can recognize bottles with good accuracy.
- It integrates easily with Python and Raspberry Pi.

How the Detection Worked

1.Frame Division:

Each video frame from the camera was divided into 3 virtual zones:

- Left | Center | Right

This helped the robot "decide" where the bottle is located in its field of view.

2.**Bottle Detection:**

YOLOv5 detected if a plastic bottle existed in the frame.

If yes, its bounding box coordinates determined which zone (L, C, R) it was in.

3.**Communication with Arduino (UART):**

The Raspberry Pi processed YOLOv5 outputs.

It then sent a simple message via UART serial to the Arduino Mega:

`"L"` → Rotate left

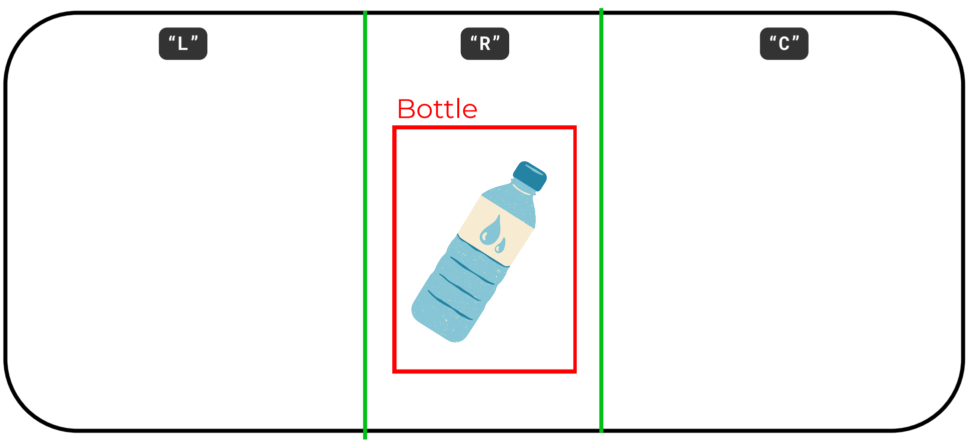
`"R"` → Rotate right

`"C"` → Move forward

4.**Action Execution:**

Arduino controlled the DC motors accordingly.

Once the bottle was centered and close enough → the robotic arm (gripper) was activated.



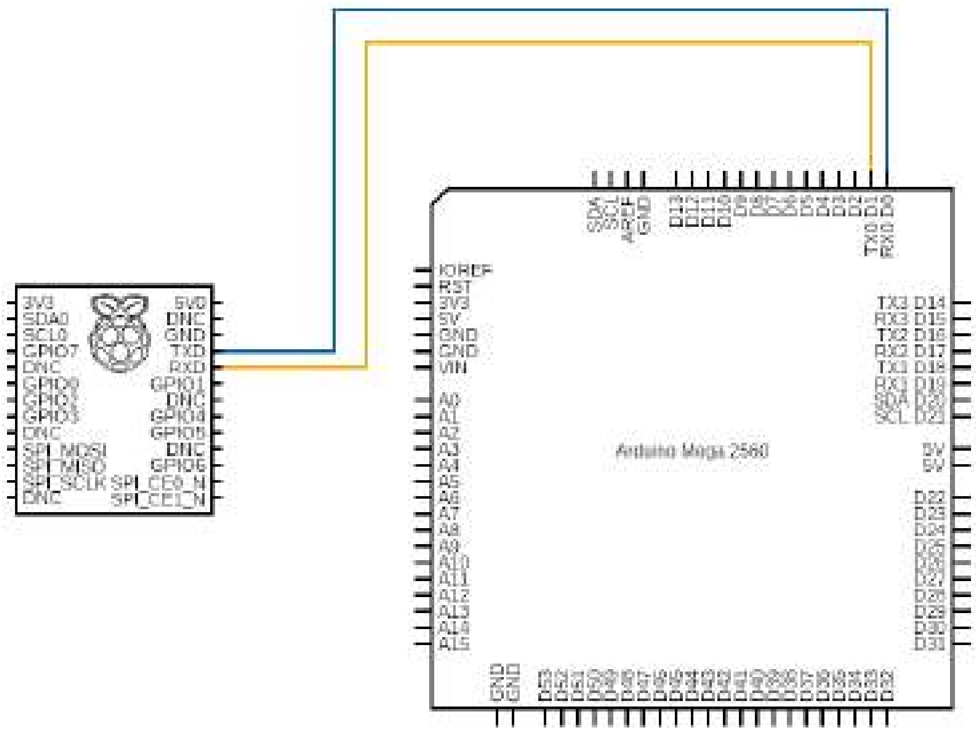
Forum DSI - 2024

Key Achievements

- Achieved real-time detection of bottles with Raspberry Pi.
  Implemented communication bridge (Raspberry → Arduino) for decision-making.
- Robot successfully located and collected bottles at Forum DSI.

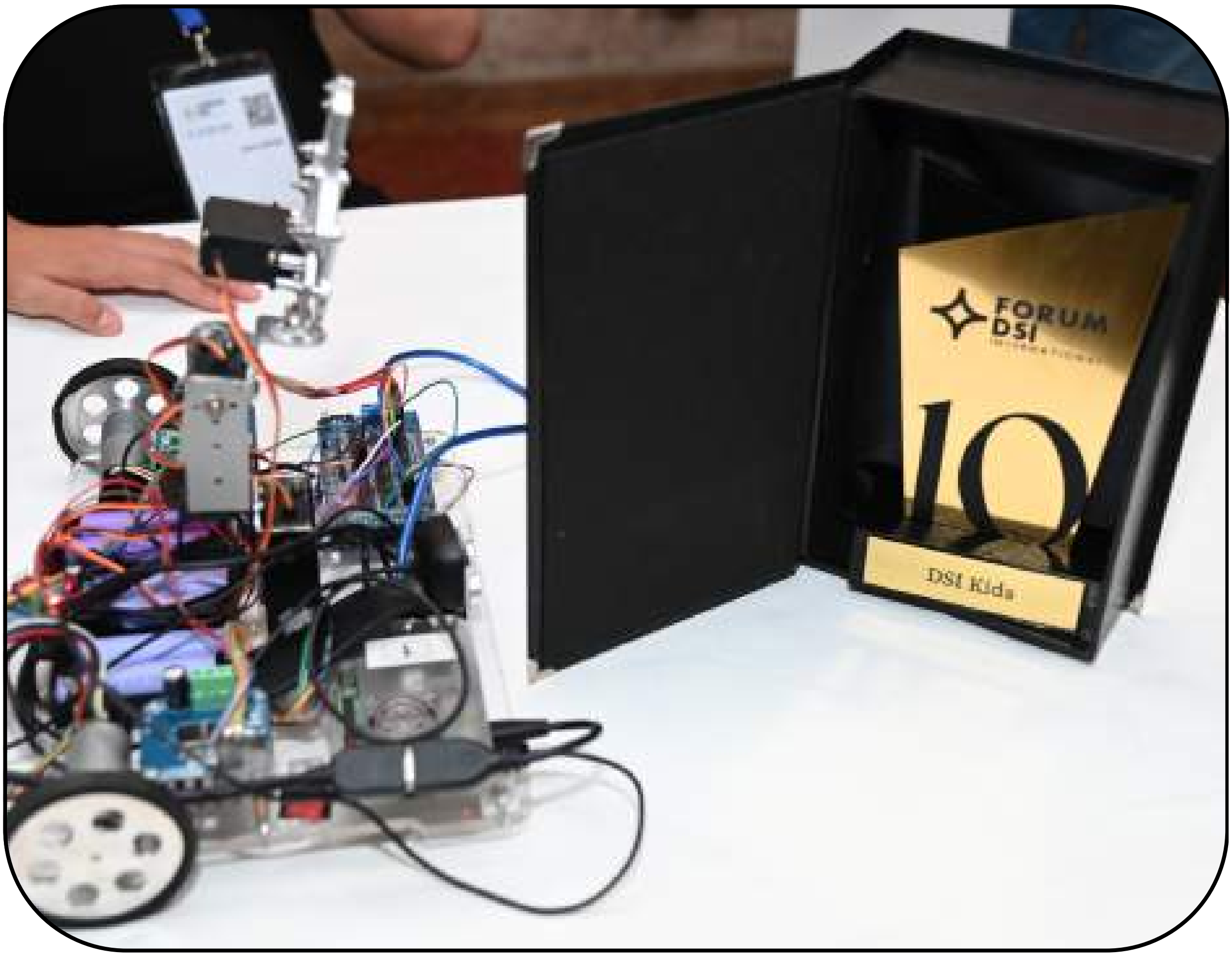
Limitations

- YOLOv5 model was pre-trained, not custom-trained on our dataset (reduced accuracy on unusual bottles)..
- High computational demand on Raspberry Pi → caused lag in detection outdoors.



Forum DSI - 2024

The Forum DSI experience was truly our doorway into the world of AI and robotics. It was more than just building a robot — it was about learning how to understand an environmental problem, design a practical solution, and communicate its value to an audience. This first step taught us how to transform an idea into a real project, while sharpening our technical and communication skills. It was the spark that pushed us to dream bigger with labi-Bot



7.RoboFest Tunisia – Labi-Bot V1

What is RoboFest?

RoboFest is a national exhibition where young innovators present their robotics projects in front of three judges. Each team must not only demonstrate their robot's technical performance but also explain the design process, goals, and impact of their project. Winning first place grants the opportunity to represent Tunisia in the International RoboFest Exhibition in the United States.

Concept & Mechanism

For labi-Bot V1, we improved both the collection system and the perception hardware:

- **Collection Mechanism:**

We replaced the robotic arm with a lifting door system, capable of opening and closing to collect bottles more efficiently.

- **Drive Base:**

We introduced a chain-based drive system powered by a V12 motor, which increased traction and control.

- **Obstacle Detection:**

An ultrasonic sensor was added to detect obstacles and prevent collisions.

- **Vision System:**

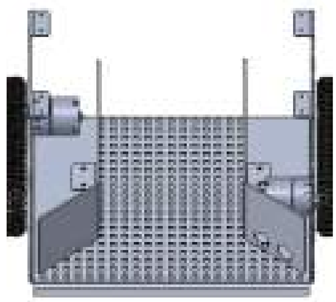
We upgraded to two cameras for better perception and accuracy.

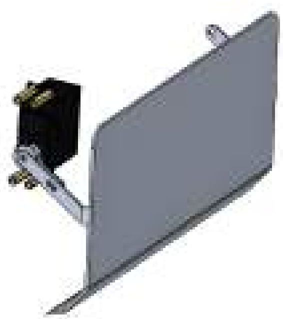
- **Control Units:**

Still based on Raspberry Pi (vision + AI) and Arduino (motion + sensors) working together.

- **Mechanism Control:**

A servo motor was added to precisely manage the lifting door system.





RoboFest Tunisia – labi-Bot V1

Hardware Components Used

Control & Actuation:
Arduino Mega — motion & sensor management
Raspberry Pi — vision + AI processing
V12 DC Motor — drive base (chain mechanism)
Servo Motor — lifting door control
Power:
Power bank 5000 Mah
Sensing:
2 × Cameras — improved bottle detection & tracking
Ultrasonic Sensor — obstacle detection & avoidance

What We Achieved

- The robot could detect plastic bottles more precisely and collect them using the improved door mechanism.
- The AI algorithm was more advanced compared to the Forum DSI prototype, providing more reliable bottle detection.
- The addition of two cameras increased accuracy in identifying and localizing objects.

Limitations We Noticed

- The chain drive system was unstable — it often slipped on smooth surfaces.
- The low ground clearance caused the robot's base to grip or drag on the floor.
- Dead angle Sensor , detection only left side

RoboFest Tunisia – labi-Bot V1

What We Gained from This Stage

Participating in RoboFest Tunisia not only pushed us to improve Labi-Bot technically but also gave us the chance to present in front of experts and be selected to represent Tunisia internationally. It was both a validation of our work and a motivation to push the project to the next level.

Vision & AI System — Labi-Bot V1

Bottle Detection Upgrade

Switched from YOLOv5 → YOLOv8n for better accuracy and speed.
Still lightweight, optimized for Raspberry Pi.

Same navigation principle:

Camera frame divided into 3 zones: Left | Center | Right.
Raspberry Pi sends simple UART messages to Arduino Mega:

`“L”` → Rotate left
`“R”` → Rotate right
`“C”` → Move forward

Arduino executes motor commands, keeping bottle centered for collection.

Human Behavior Detection (NEW FEATURE) ⚠️

Second camera connected to an external PC (not Raspberry Pi).
Custom-trained YOLOv8-Pose model to detect littering actions:

- Arm swing motion.
- Palm release gesture.

If littering behavior detected → Audio alert triggered from the robot.

Navigation & Control

Autonomous movement remained the same as V0.
Arduino + sensors managed movement decisions.
Camera(s) provided AI-powered vision for both bottles & humans.

ultralytics YOLO

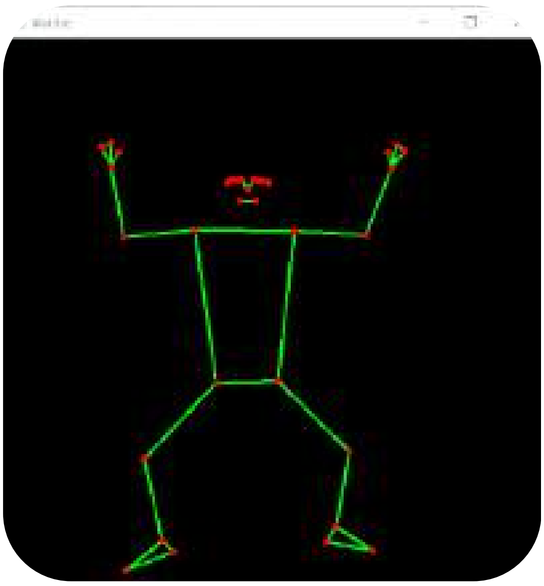
RoboFest Tunisia – labi-Bot V1

Key Achievements

- Upgraded YOLOv8n for bottle detection → faster & more accurate than YOLOv5.
- Successfully integrated dual vision system:
- Raspberry Pi for bottle detection.
- External PC + YOLOv8-Pose for human behavior detection.
- First time implementing AI-based human action recognition (detecting littering gestures).
- Robot collected bottles more precisely compared to the Forum DSI version.
- Won first place at Robofest Tunisia 2024, earning qualification for the USA international exhibition.

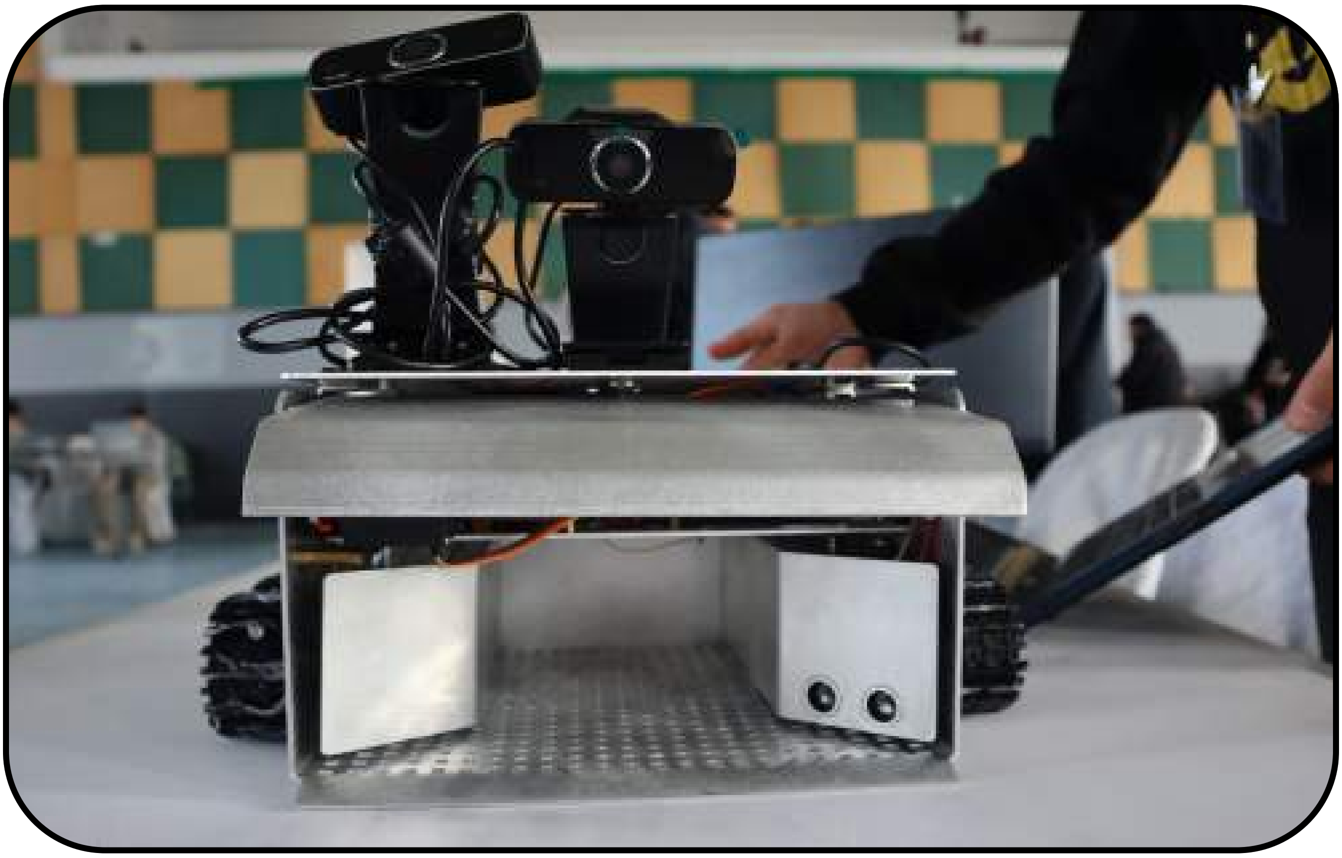
Limitations

- External PC dependency for human detection (not yet fully embedded).
- Chain drive base slipped on smooth surfaces → reduced mobility.
- Low ground clearance → robot sometimes scraped the floor.
- Littering detection accuracy still limited to clear arm gestures (subtle behaviors missed).



RoboFest Tunisia – labi-Bot V1

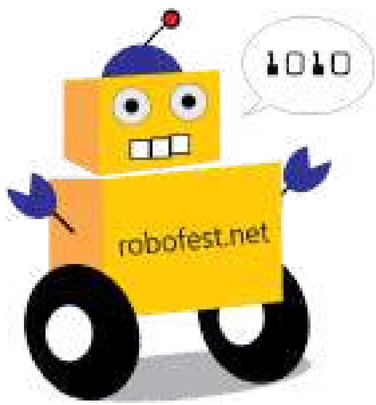
The Robofest Tunisia experience was a turning point in our journey. Unlike the Forum DSI, where we were simply introducing our first steps into AI and robotics, this time we were competing at a higher level, with judges carefully evaluating every technical and practical detail. It was here that Labib-Bot evolved into more than just a bottle collector — it became a robot that could also understand human behavior through AI. When the announcement came that we had not only won first place but also qualified to represent Tunisia in the United States, it was an unforgettable moment. The excitement, pride, and sense of responsibility pushed us to raise our ambitions higher. Robofest was not just a competition — it was the bridge that carried us from a local idea to the international stage.

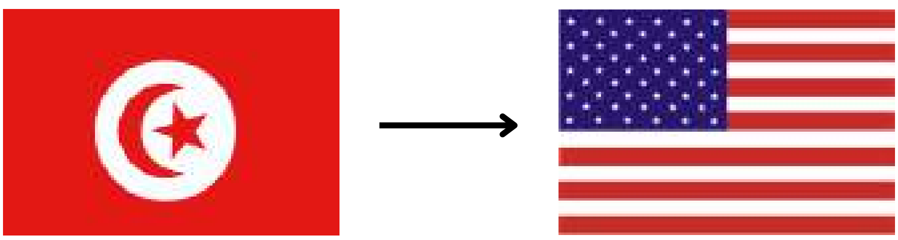


7.Labi-Bot for international competition

The International Exhibition – USA

After winning at Robofest Tunisia, we earned the chance to represent our country on the global stage. The International Exhibition gathers teams from over 80 countries, where the world's brightest young minds present their robotics projects in front of international judges.
But this was more than just another robotics event. The stakes were incredibly high: the top 3 teams are awarded scholarships to study in one of the best universities in the United States.
For us, standing there among so many talented innovators was both humbling and motivating. Labib-Bot, which started as a small idea back home, had now grown into a project with global recognition — a symbol of how passion and teamwork can turn a local environmental challenge into an international success story.

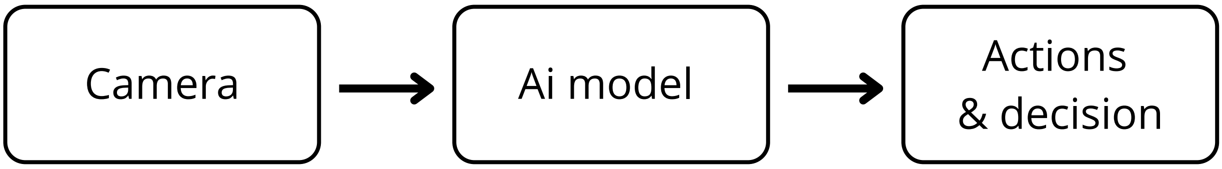




Labi-Bot for international competition

Advanced Mechanism

The final version of Labi-Bot was engineered with real-world deployment in mind. Unlike earlier prototypes, this design emphasized robustness, autonomy, and reliability. Equipped with a 4-wheel all-terrain drive system and large off-road tires, the robot could smoothly navigate beaches, dunes, and uneven surfaces without getting stuck. The dual-door comb-style collection mechanism allowed precise capture of bottles and litter without disturbing the surrounding environment. Once an item was collected, it was automatically funneled into the storage compartment, making the process seamless and fully autonomous. Combined with its high ground clearance and durable aluminum frame, this mechanism ensured that Labi-Bot could operate for extended periods in outdoor, sandy conditions without frequent intervention.



Labi-Bot for international competition

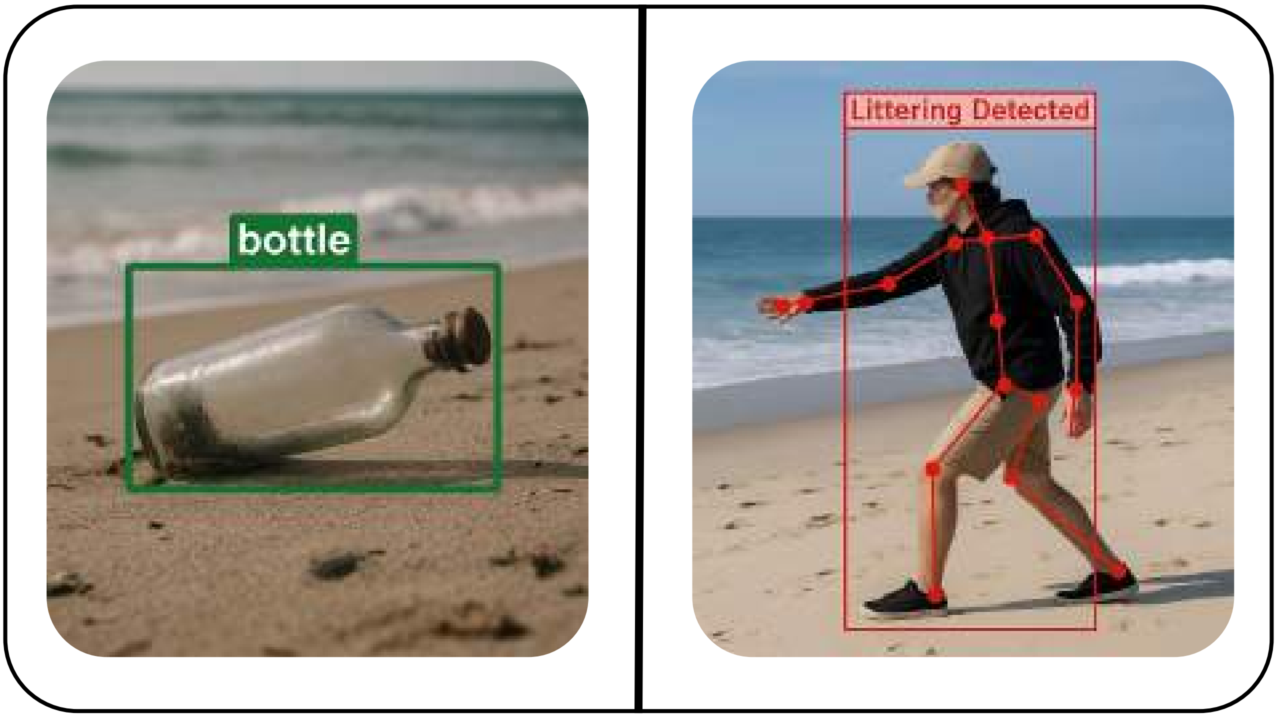
AI Integration and Features

At this stage, Labi-Bot evolved beyond being just a collection robot — it became a smart environmental assistant. Powered by the NVIDIA Jetson AGX Xavier (32 GB), the robot gained the ability to perform advanced real-time AI processing directly on board.

Two integrated cameras handled its dual vision system:

- One camera dedicated to bottle detection using YOLOv11n.
- A second camera for human littering detection, powered by a custom-trained YOLOv11n-pose model.

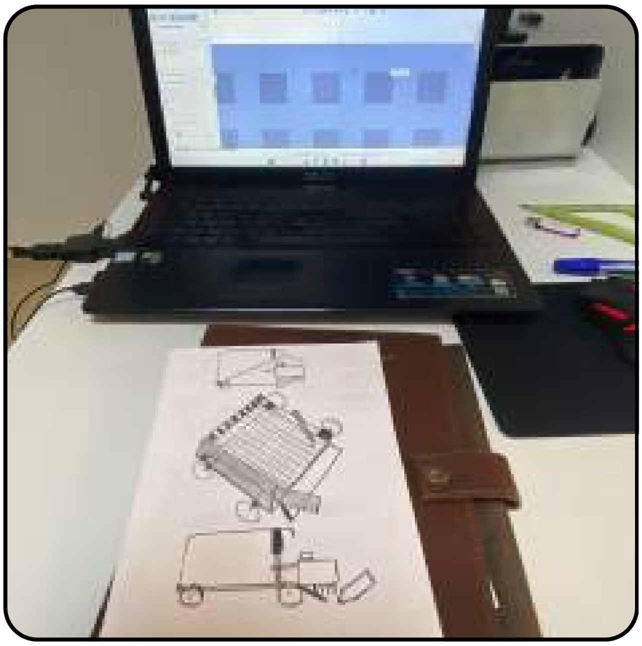
This integration meant that Labi-Bot not only removed waste but also actively raised awareness about responsible behavior. When it detected someone discarding waste improperly, it could trigger audio alerts through its built-in speakers, encouraging people to stop littering. This feature transformed Labi-Bot from a cleanup tool into an educational and preventive solution.



Labi-Bot for international competition

Storage and Operation Enhancements

A major leap in this version was the development of a large-capacity storage system. Labi-Bot featured a 70 L storage bin with sand-filtering perforations, allowing it to separate collected litter from residual sand. The bin was supported by two actuators that could tilt it upward, while a servo-controlled back door enabled quick discharge of waste. This design allowed operators to empty the bin in seconds, ensuring uninterrupted operation during long cleanup sessions.
Powering the robot were dual 4S 5200 mAh LiPo batteries — one dedicated to driving and actuators, the other to the NVIDIA Xavier and AI systems. This smart distribution extended runtime to nearly 3 hours of continuous work, while recharging both packs took just 1 hour with a standard LiPo charger.
These storage and power upgrades made Labi-Bot not just more powerful, but also practical and sustainable for repeated real-world use.



Labi-Bot for international competition

Hardware Overview

Frame & Dimensions

- Dimensions: 72 × 50 × 50 cm
- Material: CNC-machined aluminum (thicknesses: 4 / 3 / 2 / 1 mm)
- Ground clearance: 60 mm

Mobility System

- 4 × 230 mm off-road wheels
- 2 × 12 V, 500 RPM DC motors (drive)
- Motor drivers: 2 × IBT-2 H-bridge

Collection & Storage

- Dual comb-style bottom doors (servo-driven)
- Main storage bin (~72 × 40 cm, ~70 L capacity)
- 2 × Linear actuators (L298 driver) — tilt mechanism for bin
- Rear discharge door (servo motor)
- Sand-filtering perforations in bin

Computing & Control

- NVIDIA Jetson AGX Xavier (32 GB) — AI processing
- Arduino Mega 2560 — low-level motor and actuator control
- Serial communication link (Jetson ↔ Arduino)

Sensing & Perception

- 2 × Redragon cameras (5 m range)
- 2 × side motor sensors (positioning/feedback)
- Ultrasonic sensor (obstacle detection)

Audio & Awareness System

- 2 × speakers with dedicated control card
- Pre-programmed audio alerts (e.g., littering detection)
- **Connectivity & Communication**
- Wi-Fi 2.4 & 5.0 GHz (with local AP mode, 80 m range)
- Bluetooth 5.0 module
- Mobile app interface with status LEDs

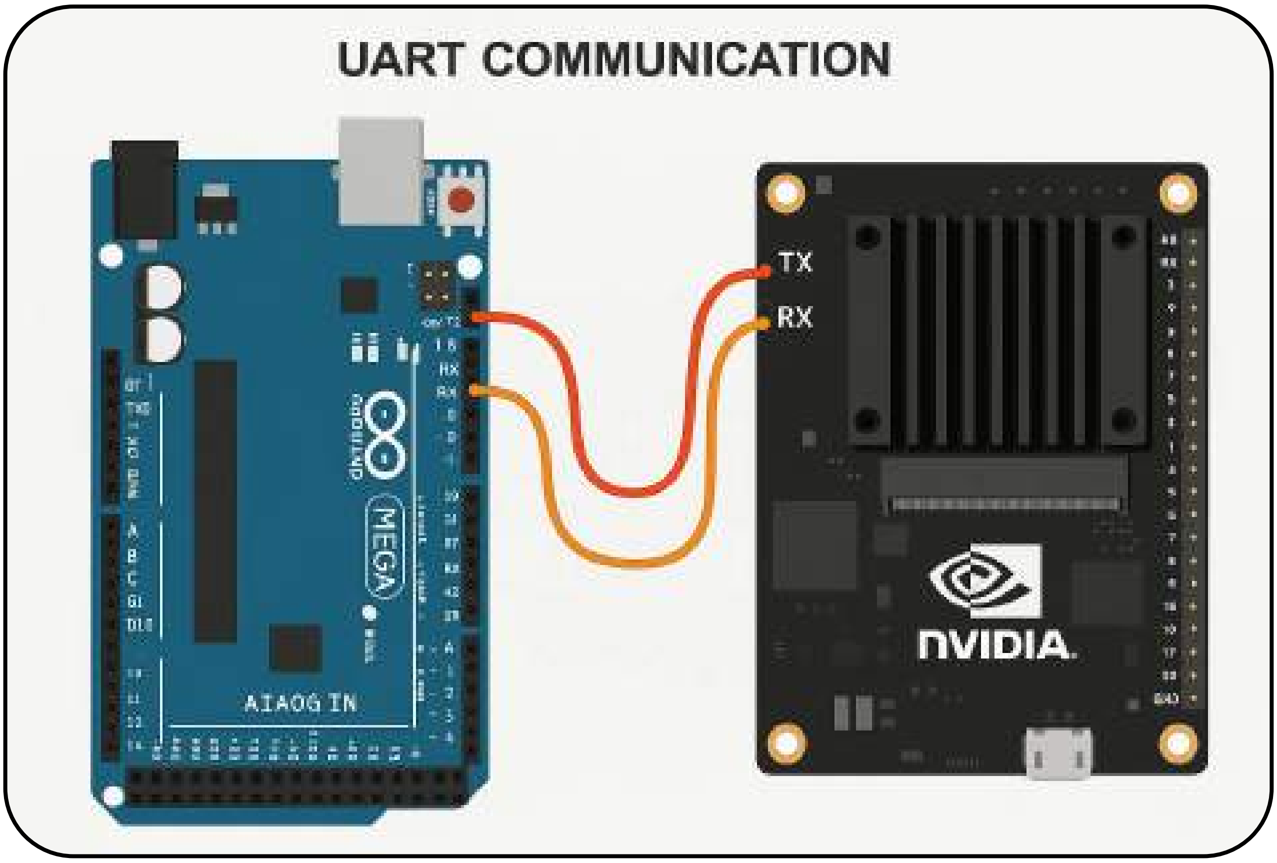
Labi-Bot for international competition

Electronics and Power Systems

The electronic architecture of the final version of Labi-Bot was carefully designed to balance high performance, reliability, and efficiency. Every component was chosen to handle demanding outdoor conditions while ensuring uninterrupted operation for several hours

Motor Control & Drivers

The robot's powerful 12V DC motors were driven by 2 × IBT-2 H-bridge drivers, capable of handling high currents and providing precise speed and torque control.
The collection system actuators were managed by an L298 driver, ensuring smooth lifting and tilting operations for the storage bin.
Servo motors, used for the collection doors and back discharge gate, were controlled directly through the Arduino Mega's integrated PWM outputs, allowing accurate and responsive actuation.



Labi-Bot for international competition

Power Distribution & Stabilization

To coordinate all systems, Labi-Bot employed a custom-designed power distribution PCB. This board regulated energy flow between the motors, actuators, and AI computer while preventing overloads.
A DC-to-DC stabilizer ensured clean and stable power delivery to the NVIDIA Jetson AGX Xavier, protecting sensitive electronics from voltage drops caused by motor activity.
Separate circuits isolated the compute unit from the high-current loads of the drive system, reducing noise and ensuring reliable operation.

Battery System & Autonomy

Labi-Bot was powered by two independent LiPo 4-cell 5200 mAh batteries:
Battery A: Dedicated to actuators, motors, and servos.
Battery B: Dedicated to the Jetson Xavier and vision system.
This dual-battery architecture optimized performance and prevented sudden brownouts during peak load. With this setup, the robot could run for up to 3 continuous hours on a single cycle.

Charging & Safety

Recharging the system was streamlined with a dual-pack LiPo smart charging system, allowing both batteries to be recharged in parallel in just one hour. Standard XT60 connectors provided secure high-current connections, minimizing risks of disconnection in the field. Safety features such as overcharge protection and balanced charging extended the lifespan of the batteries.

Labi-Bot for international competition

Mechanical Design & Manufacturing

Frame & Structure

- Built from CNC-machined aluminum sheets of varying thickness (4 / 3 / 2 / 1 mm) for an optimal balance between rigidity and weight reduction.
- Modular frame design allowed easier maintenance and future upgrades.

Mobility System

- 4 × 230 mm off-road wheels designed for high traction on sandy and uneven terrain.
- Ground clearance of 60 mm ensured smooth traversal without dragging or clogging.
- Robust wheel hubs and motor mounts CNC-machined for precision alignment and durability.

Collection Mechanism

- Dual comb-style doors fabricated from 3 mm aluminum, operated by high-torque servo motors.
- Designed for smooth opening/closing to minimize jamming during collection.
- Integrated with sensors to synchronize with bottle detection system.

Storage & Filtration

- Large storage bin (~72 × 40 cm), fitted with perforated aluminum base to filter sand while retaining plastic waste.
- Bin mounted on dual linear actuators, enabling controlled tilt discharge.
- Rear discharge door (servo-controlled) for efficient emptying of collected waste.

Labi-Bot for international competition

Factory Visit: Laser Cutting & Assembly Process

CNC Machining

- Key functional components, such as the perforated bin floor and servo mounting brackets, were CNC-machined for durability and accuracy.
- High-load areas (wheel hubs, actuator mounts) were reinforced through this process.

Assembly & Integration

- After manufacturing, the team conducted the mechanical assembly in-house.
- The electronics (NVIDIA Jetson AGX Xavier, Arduino Mega, drivers, sensors) were carefully integrated with the frame.
- This phase was not only technical but also educational, as it allowed the team to bridge the gap between design on paper and real-world engineering.

"From digital design to real metal — this was the moment Labi-Bot became real"

Labi-Bot for international competition

Factory Visit: Laser Cutting & Assembly Process

Bringing the final prototype of Labi-Bot to life required precision manufacturing and collaboration with industry experts. To achieve the required quality and robustness, our team worked closely with a professional fabrication workshop.

Laser Cutting

- The aluminum sheets of varying thickness (4 / 3 / 2 / 1 mm) were laser cut with millimeter precision, ensuring exact dimensions for the frame, storage bin, and comb-style collection doors.
- This process guaranteed smooth edges and minimized post-processing, making the parts ready for assembly.

Bending & Pliage

- Structural parts were then folded and shaped using industrial bending machines.
- This step gave strength and rigidity to the aluminum frame while keeping the design lightweight and modular.

PART 3: AI & SOFTWARE ARCHITECTURE

"Teaching a robot to see is easy — teaching it to understand is the real challenge"

12. AI Models Used in Labi-Bot

The intelligence of Labi-Bot relies on two state-of-the-art YOLOv11n models running in real time:

1.YOLOv11n (object detection

- Detects plastic bottles in diverse environments (sand, grass, pavement).
- Trained to operate efficiently on NVIDIA Jetson AGX Xavier, balancing speed and accuracy.

2.YOLOv11n-pose (gesture recognition)

- Identifies human keypoints and tracks gestures related to throwing litter.
- Works alongside object detection to not just recognize trash, but also understand human behavior.

These models make Labi-Bot both an autonomous collector and an educational awareness tool, encouraging responsible environmental habits.

Model	**Size** (pixels)	**mAP** 50-95	**speed cpu onnx**	**speed** tensorRT	**params** (M)	**FLOPs (B)**
yolov11n	640	39.5	~56.1	~1.5	2.6	6.5
yolov11n-pose	640	50	~52.4	~1.7	2.9	7.6

13. Training the AI: Dataset & Techniques

To reach competition-level performance, we built a large custom dataset tailored to our problem:

1. Bottle Detection Dataset
   - Thousands of images of bottles in varied conditions: half-buried in sand, lying flat on grass, partially covered, or in motion.
   - Augmentations (rotation, scaling, brightness, blur) ensured the model was robust to outdoor conditions.

2. Human Littering Dataset
   - Over 10,000 annotated images of people throwing bottles or similar objects.
   - Captured in different angles, distances, and lighting for higher generalization.
   - Labeled with pose keypoints (arms, elbows, wrists, hands).

Training Techniques:
- Transfer learning from pretrained YOLOv11n weights.
- Fine-tuning with our dataset until achieving 86% accuracy on the test set.
- Hyperparameter tuning (confidence thresholds, NMS) for real-world optimization.

14. Contextual Vision: Understanding Human Behavior

Labi-Bot goes beyond object detection to truly understand context:

Detection Pipeline

- YOLOv11n checks if a bottle is present.
- YOLOv11n-pose checks for a throwing action.
- If both occur → system enters “monitoring mode.”

Validation Rule (Bottle Disappearance Logic):

- If the detected bottle disappears from the frame for more than 2 seconds,
- And this disappearance followed a throwing gesture,
- Then Labi-Bot confirms the event as littering.

This three-step reasoning makes the system more reliable, avoiding false alarms from normal movements (like stretching or waving).

littering is not about an object leaving hand

It s about human pattern

15. Pose Estimation & Gesture Recognition

The YOLOv11n-pose model extracted skeletal keypoints of humans in the scene.

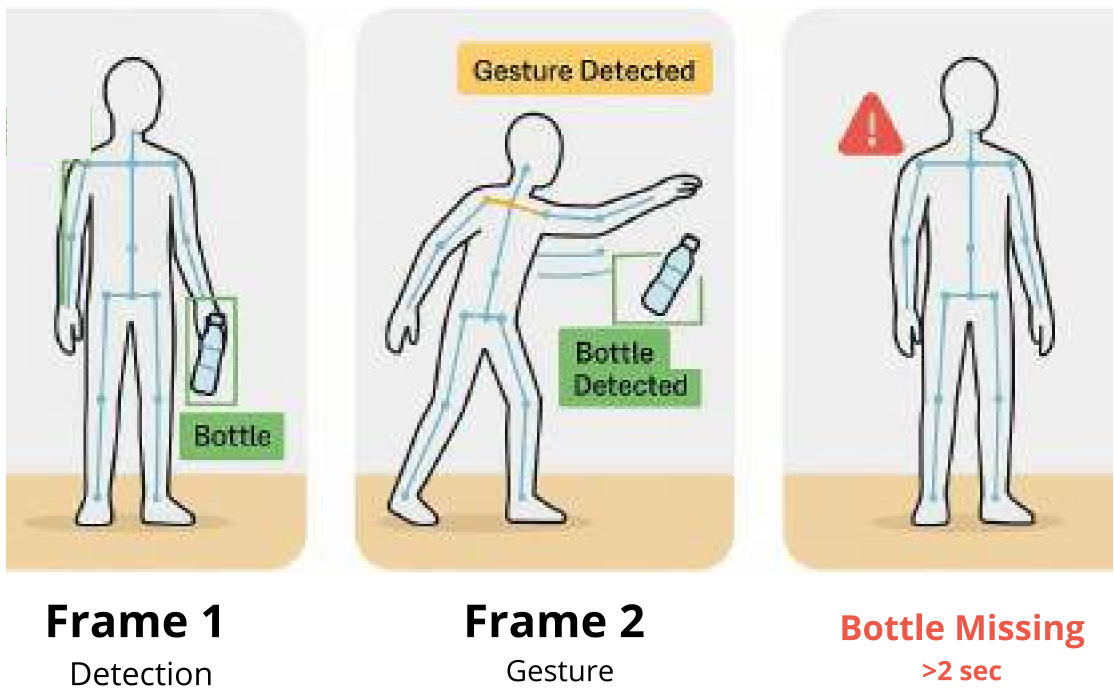
We defined gesture rules for throwing:

- Arm raised and extended forward.
- Wrist release detected.
- Object trajectory aligned with bottle detection.

Hybrid AI + Logic Approach:

- YOLOv11n-pose detects gestures.
- YOLOv11n verifies bottle presence.
- Disappearance rule confirms littering.

This layered method significantly improved reliability, reducing false positives in crowded environments.



16. Real-Time Processing & Edge AI

Parallel Execution

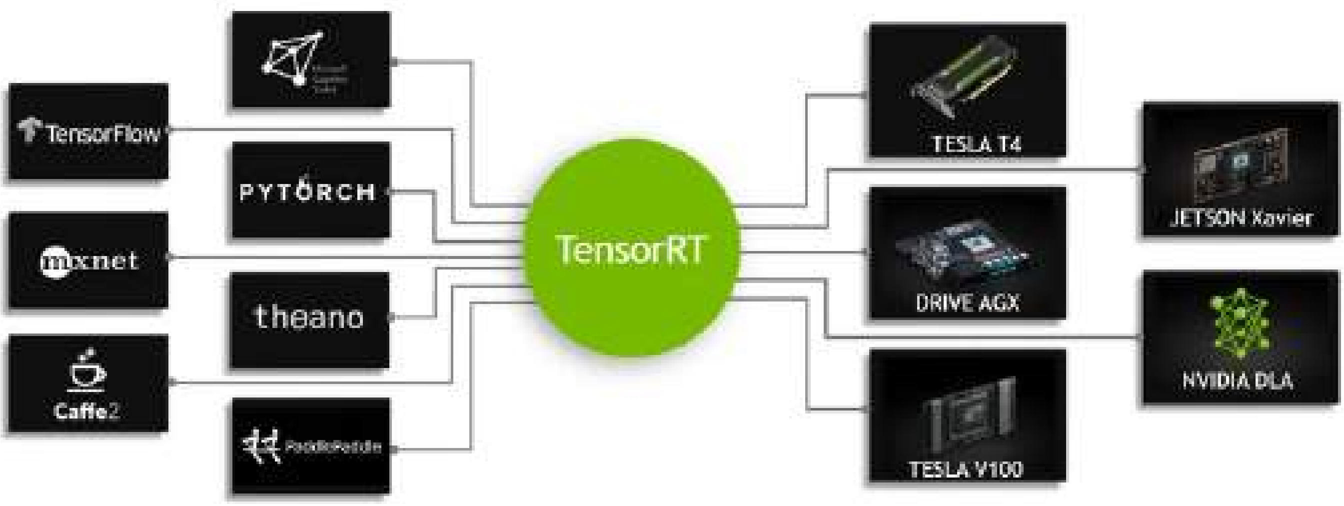
- Bottle detection and gesture recognition run on separate threads.
- Latency reduced to < 50 ms per frame.

Optimization

- TensorRT acceleration used for YOLOv11n models.
- Frame resizing and adaptive batching to maintain 15–20 FPS consistently outdoors.

Performance

- Smooth bottle tracking and gesture recognition.
- Fully offline operation, crucial for environments without internet.



17. Software Workflow & System Integration

The final integration combined AI models, decision-making, and robot actuation into a clear workflow:

1.**Input Layer**

- Dual cameras capture video streams (bottle detection + human monitoring).
- AI Inference
- YOLOv11n detects bottles in real time.
- YOLOv11n-pose tracks human poses for throwing gestures.

2.Decision Logic

- If throwing gesture detected → monitor bottle.
- If bottle disappears for > 2 sec → confirm littering event.

3.Action Layer

- Arduino Mega receives commands:
- Navigation toward detected bottles.
- Servo activation to collect waste.
- Audio system issues awareness messages when littering detected.

4.User Monitoring

- Events (detections, littering, storage status) streamed live to the mobile/web app.
- Operators can remotely command discharge or monitor robot health.
- This modular AI-driven workflow made Labi-Bot an autonomous, interactive, and reliable cleanup robot.

PART 4: USER INTERFACE & OPERATIONS

“The interface is the bridge between Labi-Bot’s intelligence and the user’s control.”

18. Mobile and Local Web App Overview

To ensure that Labi-Bot was not only autonomous but also easy to operate, we developed a dedicated mobile application, available on both iOS and Android. The app connects directly to the robot via two secure modes:

- **Bluetooth**: Used during the first-time setup or when configuring the robot in close range.
- **Wi-Fi Local Access Point (AP):** Once configured, the robot broadcasts its own local network, allowing smartphones to connect from up to 80 meters away.

The app was designed for monitoring and control toggles rather than full manual driving. The key features included:

Robot Connection & Configuration (via Bluetooth during setup).

- **Mode Selection**: Enable Bottle Collection Mode, Human Behavior Detection Mode, or activate both simultaneously.
- **Status Monitoring**: Real-time battery percentage, operational state, and sensor status.
- **Live Camera Feed**: A direct video stream from the robot's cameras, showing what Labi-Bot sees in the field.
- **Lighting Control:** Switch the robot's LED lights on or off for visibility in dark conditions.
- **Discharge Mode:** Enable the automatic rear-door discharge mechanism when the storage bin is full.

This mobile app gave operators a simple, field-ready interface that allowed them to set the robot into action within seconds.

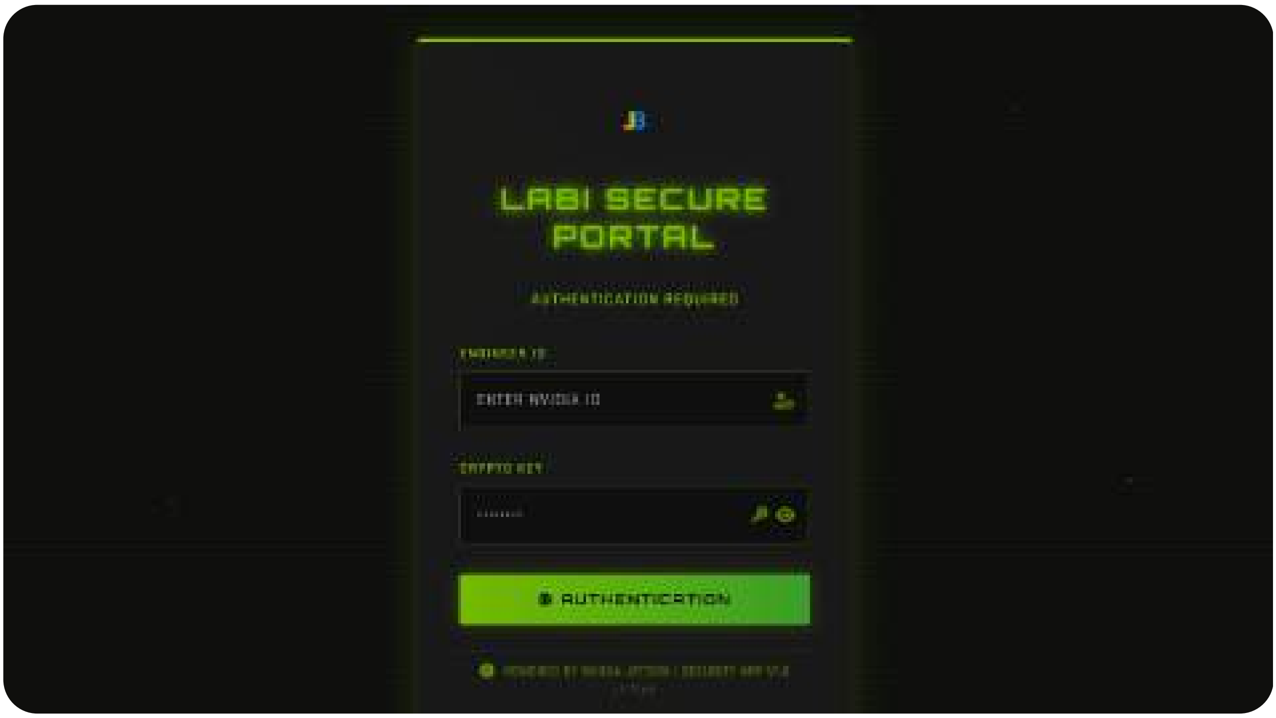
19. Dashboard Features and Data Management

Beyond the mobile app, we designed a web dashboard for deeper monitoring and accountability. Unlike the app, which focused on robot operations, the dashboard was dedicated to data, alerts, and evidence collection.

Hosted locally on the NVIDIA Jetson AGX Xavier, the dashboard ensured security and independence from the cloud. Access was password-protected with a unique operator ID.

Key features included:

- **Evidence Capture:** Each time a person littered, the dashboard logged an image of the litterer with a timestamp.
- **Authority Integration:** These logs could be forwarded to beach patrol or municipal authorities to enforce fines for littering.
- **Operational Status:** Displayed whether the AI models were running online or offline.



19. Dashboard Features and Data Management

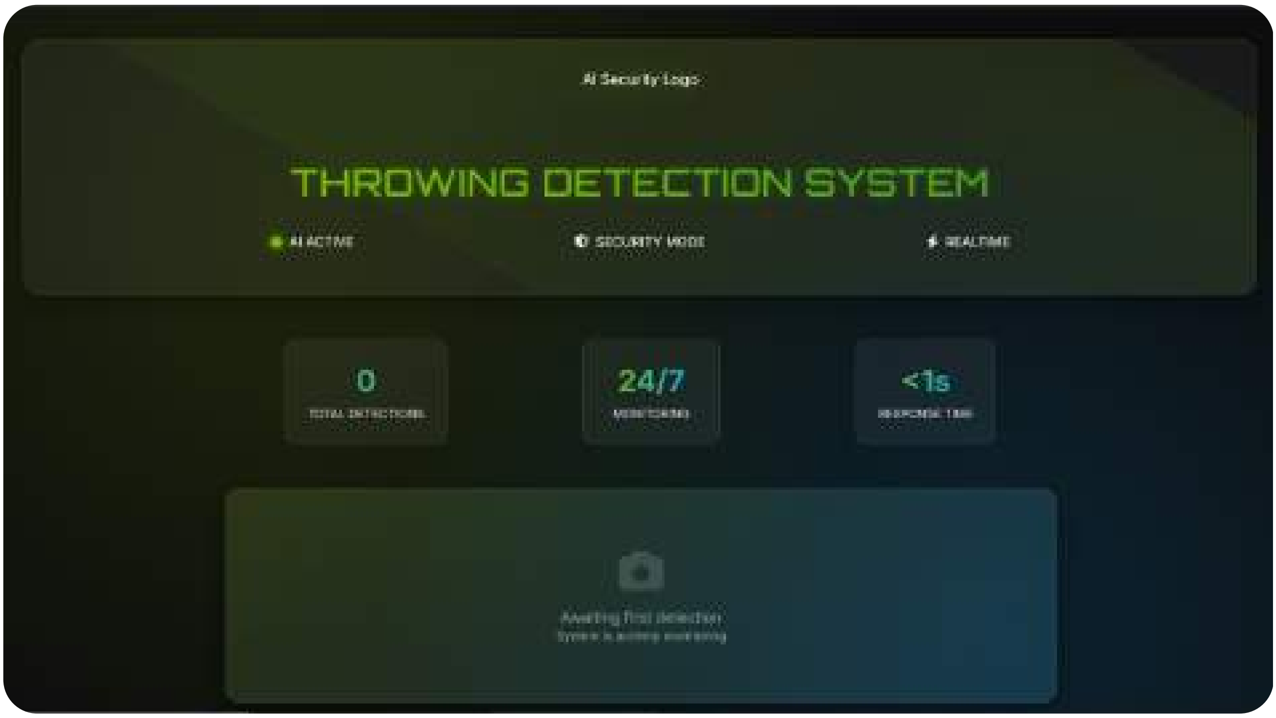
Statistics Panel:

- Number of littering events detected.
- Number of bottles collected.
- Active runtime logs.

Local Storage System:

- All pictures and logs were saved directly to the Jetson module. This ensured that even if the web dashboard was compromised or a technical error occurred, the data remained safe locally.

The dashboard served as the accountability layer of Labi-Bot, transforming the robot from just a cleaner into an environmental enforcement assistant.



20. Alert System & Littering Detection Response

To make the system responsive and educational, we integrated a dual alert mechanism that combined robot-side feedback with operator-side notifications.

1.Robot Audio Alerts

When the robot detected a person throwing waste, it played a pre-recorded message through its speakers:

“Please throw your bottle into the trash bin. The environment is our responsibility, and we need to keep it clean.”

This immediate feedback not only discouraged littering but also helped raise awareness in real time.

2.Mobile App Notifications

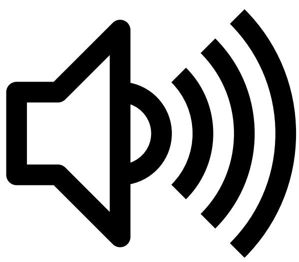
At the same moment, the operator received a push notification on the mobile app, alerting them of the incident. This allowed them to cross-check the dashboard logs and take further action if needed.

Logging for Enforcement

Every littering event was automatically recorded with:

- A photo of the litterer.
- Timestamp.
- Confirmation of the detection sequence (object presence + gesture + disappearance).

This combined approach made Labi-Bot not only a cleaning tool but also an active deterrent against irresponsible behavior on beaches



PART 5: TESTING, RESULTS & FEEDBACK

"Every test is not an end, but a lesson—each challenge pushes the robot, and us, to evolve."

21. PERFORMANCE METRICS & ACCURACY

To evaluate the effectiveness of Labi-Bot, both AI and hardware performance were tested in controlled and real-world environments.

- **Bottle Detection (YOLOv11n):** Pre-trained model downloaded from YOLO's official repository, providing reliable detection of plastic bottles in various lighting conditions.
- **Gesture Detection (YOLOv11n-pose):** Custom-trained on 10,000 images of littering behavior, achieving 86% accuracy. This accuracy was sufficient for live demonstrations, though still improvable.
- **Inference Speed:** The Jetson AGX Xavier achieved 15–50 ms per frame depending on scene complexity, ensuring real-time responsiveness.
- **Collection Rate:** On average, Labi-Bot could pick up around 30 bottles per hour during field testing, though performance varied based on terrain and clutter.
- **Runtime:** The dual LiPo battery system successfully delivered 3 hours of continuous operation per cycle, as designed.

These metrics confirmed that Labi-Bot's AI + hardware integration was stable, although gesture accuracy and nighttime detection remained areas for further development.

22. FIELD TESTING & LESSONS LEARNED

Labi-Bot was tested in two main environments: beaches and public parks. These settings provided a realistic mix of sand, uneven terrain, and pedestrian activity.

- **Terrain Performance:** On flat surfaces such as park pathways, the robot operated smoothly. On beaches, however, sand clogging occasionally affected the wheels and bin mechanism. Additional clearance and sealed housings will be required in future versions.
- **Mechanical Challenges:** While stability on sand was generally good, some slipping occurred on steep or soft dunes.
- **Key Lesson:** The team realized that robotics is a constant cycle of iteration. From the first version to the third prototype, improvements never truly ended. The main insight was that there is no “final product”—only evolving versions that adapt to new challenges.

23. FEEDBACK FROM COMPETITIONS

The most valuable feedback came during international competition in the United States.

- **Jury Response:** The judges were highly impressed by the evolution of Labi-Bot. Having seen only the first version previously, they were shocked at the drastic improvements in AI integration, mechanical design, and operational capabilities.
- **Focus of Feedback:** All aspects—mechanical engineering, AI software, and sustainability—received recognition. Judges encouraged the team to continue enhancing AI detection and scalability for larger deployments.
- **Public Reaction:** During demonstrations, the public was enthusiastic. Many visitors wanted to test the robot themselves by throwing bottles. They were especially amused when their faces appeared on the dashboard with a timestamp, followed by the playful remark: "Now you have a fine to pay—the police will contact you soon!" This interaction created awareness in a fun, engaging way.
- **Recognition:** Labi-Bot won 2nd place internationally, securing a $64,000 scholarship, validating both the technical quality and social impact of the project

24. CHALLENGES & LIMITATIONS

Despite its successes, Labi-Bot faced several significant challenges:

- **AI Training:** Custom training YOLOv11n-pose for throwing gestures proved difficult since throwing movements vary greatly between individuals.
- **Overheating:** The NVIDIA Jetson AGX Xavier frequently overheated during long sessions. This was mitigated by adding ventilation holes in the base structure.
- **Actuator Strength:** The original design with a single actuator was insufficient for lifting the storage bin. A second actuator was added for reliable discharge.
- **Mechanical Assembly:** The aluminum frame made the robot heavy, complicating manual handling during assembly and transport.
- **Night Detection**: AI struggled to detect people in low-light conditions. LED headlights were integrated to partially address this issue.
- **Open Questions:** While the system is functional, there is still room for enhancement in gesture accuracy, thermal management, and autonomy—challenges addressed in the next section (Part 6)

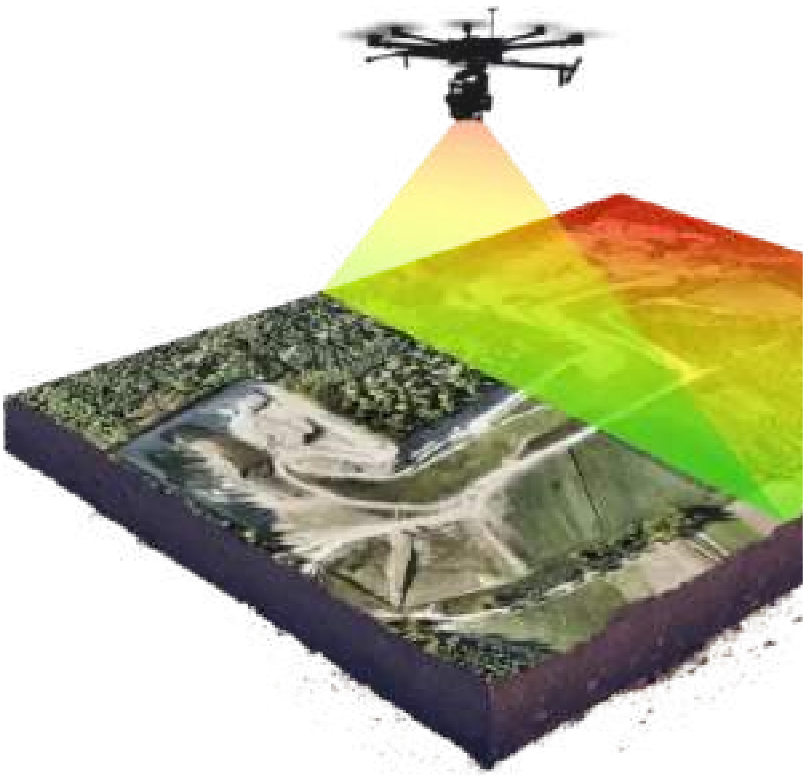
PART 6: FUTURE ENHANCEMENTS & INNOVATIONS

"Innovation never ends; each version of Labi-Bot is just the beginning of what it can become."

25. Proposed Hardware Upgrades

Future iterations of Labi-Bot will focus on improving both mobility and durability. The integration of a 360° LIDAR sensor will allow precise environmental mapping, enabling real-time navigation and obstacle avoidance. To better handle challenging terrain such as sand and uneven ground, the robot will be equipped with shock absorbers and larger off-road tires, reducing mechanical stress and ensuring smoother operation

The waste collection system will also see major upgrades. A larger-capacity storage bin with an internal sorting mechanism (triage method) will allow Labi-Bot to separate recyclables, organics, and paper waste directly during collection. This will transform the robot from a simple collector into a smart recycling assistant.



26. AI Model Improvements

The AI architecture of Labi-Bot will continue to evolve. Upcoming improvements include:

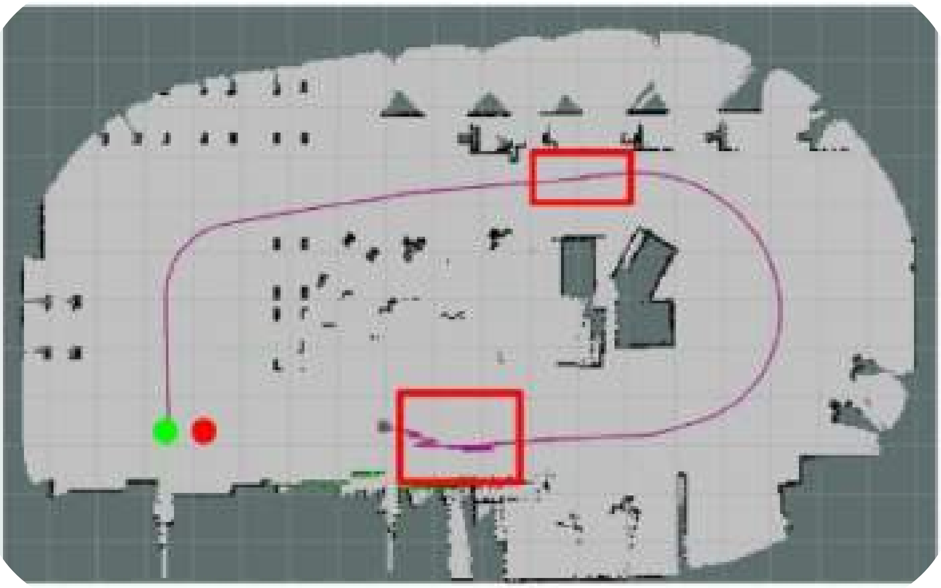
- **Expanded Detection Capabilities:** Training YOLOv11 models to recognize additional types of waste such as cups, cans, bags, and paper.
- **Night Vision & 360°** Awareness: Integrating low-light cameras and potentially a thermal/infrared module for detection in poor visibility. A 360° panoramic camera system will ensure no blind spots.
- **Larger & Richer Datasets:** Expanding beyond the initial 10,000 images to tens of thousands of annotated frames to boost detection accuracy.
- **Automated Sorting AI**: Coupled with the triage bin, AI models will not only detect trash but also classify it into recyclable categories in real time.

These upgrades will make Labi-Bot a multi-purpose waste management robot, capable of adapting to diverse urban and natural environments.

27. Autonomous Navigation Advances

One of the most ambitious goals for Labi-Bot is transitioning from semi-autonomous to fully autonomous navigation. With the integration of **LIDAR and SLAM (Simultaneous Localization and Mapping)**, the robot will build its own maps and operate independently across beaches, parks, or city areas.

Future versions will combine GPS guidance for large outdoor areas with local obstacle avoidance sensors (ultrasonic or depth cameras). This will allow Labi-Bot to perform patrol-style cleanups, covering entire zones without human intervention, and returning to its docking station when batteries are low

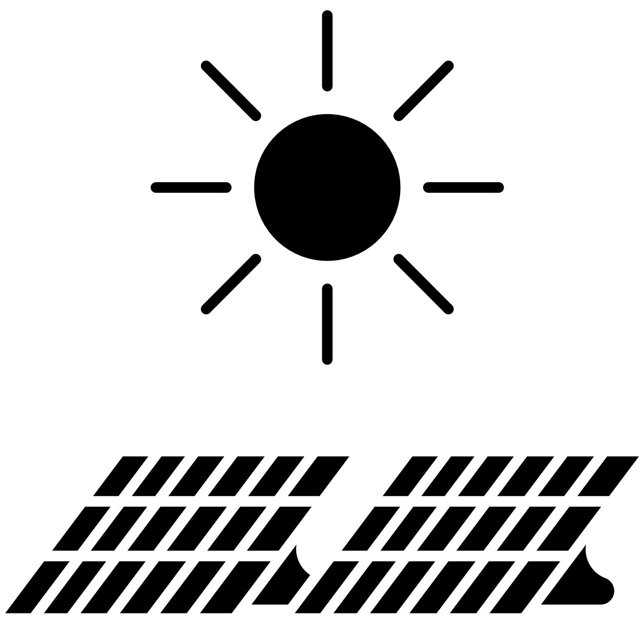


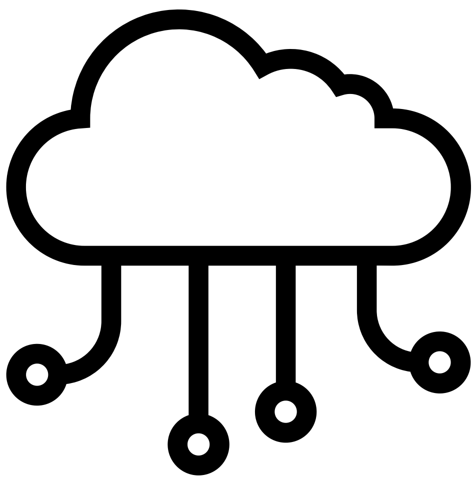
28. Sustainability and Scalability Plans

Sustainability is at the core of Labi-Bot’s roadmap. Plans include:

- **Solar-Powered Charging:** Integration of solar charging systems to reduce dependency on external power and extend runtime.
- **Cloud-Based Version:** A cloud platform will allow authorities to monitor multiple Labi-Bots simultaneously, with centralized data storage and analytics.
- **Scaled Versions:** Smaller, affordable models for schools, municipalities, and NGOs; larger industrial versions for coastal cleanup and public events.
- **Fleet Collaboration:** Future Labi-Bots could operate as a swarm of robots, coordinating through a central system to divide tasks and maximize efficiency.
- **Community Engagement:** Partnerships with local governments, universities, and environmental organizations to ensure the technology is deployed where it can have the most impact.

Through these future enhancements, Labi-Bot will not only become more powerful and autonomous but also scalable and accessible, ensuring that its mission of cleaning and protecting the environment can reach a global level.





PART 7: APPENDICES

"Details matter: the appendices ensure future builders and researchers can replicate, improve, and scale Labi-Bot."

29. Technical Specifications Summary

1. **Dimensions & Weight**

- Size: 72 × 50 × 50 cm
- Weight: ~18 kg (including batteries)
- Frame & Mechanical
- CNC-machined aluminum (thickness 1–4 mm)
- Dual comb-style doors (servo-driven, 3 mm aluminum)
- Storage bin: 72 × 40 cm, perforated bottom, actuator tilt + servo discharge
- Ground clearance: 60 mm

2. **Mobility**

- 4 × off-road wheels (230 mm)
- Motors: 12 V, 500 RPM DC motors
- Motor drivers: 2 × IBT-2
- Actuator driver: 1 × L298

3. **Electronics & Power**

- Main controllers: NVIDIA Jetson AGX Xavier (32 GB), Arduino Mega 2560
- Power: 2 × LiPo 4S 5200 mAh (separate for compute & actuation)
- Runtime: ~3 hours
- Charging: ~1 hour with dual LiPo smart charger
- Power distribution: custom PCB with DC-to-DC stabilizers
- Connectors: XT60 standard

4. **Sensors & Peripherals**

- Cameras: 2 × Redragon USB (5 m range)
- Audio: 2 × speakers + control card
- Connectivity: Wi-Fi 2.4/5 GHz, Bluetooth 5.0, Local AP (80 m range)
- Cooling: base ventilation slots

5. **AI & Software**

- YOLOv11n (bottle detection)
- YOLOv11n-pose (littering gesture detection)
- Dataset: 10,000+ images of littering behaviors
- Accuracy: ~86% on gesture detection
- Processing speed: 15–50 ms per frame (avg. ~30 ms)

30. Code Snippets & Configuration Examples

Arduino Motor Control (simplified):

cpp

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```cpp
int motor1PWM = 5;
int motor2PWM = 6;

void setup() {
  pinMode(motor1PWM, OUTPUT);
  pinMode(motor2PWM, OUTPUT);
}

void loop() {
  analogWrite(motor1PWM, 180); // Forward
  analogWrite(motor2PWM, 180);
  delay(2000);
  analogWrite(motor1PWM, 0);   // Stop
  analogWrite(motor2PWM, 0);
  delay(1000);
}
```

YOLOv11n Inference (Python, simplified):

python

Copy Edit

```python
from ultralytics import YOLO

model = YOLO("yolov11n-pose.pt")
results = model("frame.jpg")

for person in results:
    keypoints = person.keypoints
    if detect_throwing_gesture(keypoints):
        print("Littering detected!")
```

31. List of Components & Suppliers

- Frame & Mechanical: CNC Aluminum sheets (local factory)
- Motors: 12 V, 500 RPM DC Motors
- Motor Drivers: IBT-2, L298
- Actuators: Linear Actuators (10–15 cm stroke)
- Controllers: NVIDIA Jetson AGX Xavier
- Microcontroller: Arduino Mega 2560
- Cameras: Redragon USB
- Speakers & Audio Card: Generic USB module
- Batteries: LiPo 4S 5200 mAh
- Connectors: XT60
- PCB & Power Modules: Custom-made, DC-to-DC stabilizer

32. References & Resources

- YOLOv11 Models – https://github.com/ultralytics
- Arduino Documentation – https://www.arduino.cc
- NVIDIA Jetson Platform – https://developer.nvidia.com/embedded-computing
- Field Robotics Research Papers – Journal of Field Robotics, IEEE Robotics & Automation Letters
- Environmental Studies on Marine Litter – UNEP Reports, Ocean Conservancy Data

33. ACKNOWLEDGMENTS

Through our journey with Labi-Bot, we gained far more than technical achievements.
We learned how to transform ideas into practical solutions, how to communicate complex concepts to different audiences, and how to adapt quickly when challenges arose.
The competitions sharpened our teamwork, problem-solving, and project management skills, while also teaching us resilience, creativity, and the importance of continuous improvement.
These experiences prepared us not just as engineers, but as innovators ready to tackle real-world problems.
Most importantly, to everyone who believes that technology can serve the planet—thank you.

About the Author

With more than 8 years of experience in robotics, I have worked across the full spectrum of the field—mechanical design, electrical conception, assembly, wiring, computer vision, IoT, and AI training.
My passion for robotics has led me to win the title of Tunisian National Champion in tele-guided robots and to become Vice Champion at the American International Robotics Exhibition, where I proudly represented my country on a global stage.
Through every challenge and project, I've learned that robotics is not just about machinesit's about solving problems, pushing boundaries, and shaping a better future

"Every circuit wired, every line of code written, is a step toward a smarter and cleaner world."
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