A

Project report on

Green-Cycle: Intelligent Plastic Bottle Detection and Reward System

Submitted in fulfilment of the award of the

Master of Computer Applications

in

Data Science

by

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SCHOOL OF INFORAMTICS

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(2024-25)

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CERTIFICATE

This is to certify that the project report entitled **Green-Cycle: Intelligent Plastic Bottle Detection and Reward System** has been submitted by **K Ranga Sai** holding roll no **232P4R2059** in fulfilment for laboratory project in Data Mining is a record of bonafide work carried out by them under my guidance and supervision.

Date:
Hyderabad

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ABSTRACT

The escalating global plastic waste crisis demands innovative solutions to promote recycling and sustainable waste management. The GreenCycle: Intelligent Plastic Bottle Detection and Reward System addresses this challenge by leveraging advanced computer vision and machine learning technologies to create an automated, user-friendly platform that detects plastic bottles in real-time and incentivizes recycling through a reward mechanism. The primary goal of this project is to enhance recycling efficiency by accurately identifying plastic bottles, tracking user contributions, and providing monetary rewards to encourage environmentally responsible behavior. By integrating a robust detection system with a user-centric interface and data management capabilities, GreenCycle aims to foster community-driven recycling efforts and contribute to a circular economy.

The methodology employs the YOLOv8 object detection model, trained to recognize plastic bottles with high precision, achieving detection confidence levels above 0.4. The system uses OpenCV for real-time video processing from a webcam, with a Region of Interest (ROI) mechanism to focus detection within a specified area, minimizing false positives. A graphical user interface (GUI) built with Tkinter provides an intuitive platform for users to input donor names, view live detection feeds, and monitor session statistics, including bottle counts and rewards. The system incorporates SQLite for persistent data storage, logging session details (e.g., donor name, bottle count, and rewards) and detection metrics (e.g., confidence, coordinates). Text-to-speech (TTS) feedback using pyttsx3 enhances user interaction by providing real-time audio confirmations of detections. Multi-threaded processing ensures efficient handling of video capture, detection, and GUI updates, with configurable parameters such as detection cooldown (2 seconds) and reward per bottle (₹2). The system also includes features for session management, history tracking, and performance optimization through frame skipping.

The main results demonstrate robust performance in real-time bottle detection, with the system achieving an average detection accuracy of over 85% in controlled environments. The ROI-based approach effectively filters out irrelevant objects, ensuring that only bottles within the designated zone are counted. During testing, the system successfully tracked multiple sessions, accurately logging detections and calculating rewards based on the number of bottles detected. The GUI provided clear visualizations of detection zones, confidence levels, and session statistics, while the TTS feature improved user engagement. The database efficiently stored and retrieved session data, enabling detailed historical analysis and statistical insights, such as total bottles recycled and average bottles per session. The system's modular design allows for future enhancements, such as integration with mobile applications or cloud-based analytics. GreenCycle successfully demonstrates the potential of AI-driven solutions to promote recycling, offering a scalable, user-friendly platform that incentivizes sustainable practices while providing actionable data for waste management initiatives.

Keywords: Plastic Bottle Detection, Computer Vision, YOLOv8, Recycling Reward System, Real-Time Object Detection, Tkinter GUI, SQLite Database, Text-to-Speech, Sustainable Waste Management, Circular Economy

Table of contents

INTRODUCTION:

Background of the Topic

Plastic pollution has emerged as one of the most pressing environmental challenges of the 21st century, with millions of tons of plastic waste accumulating in landfills and oceans annually. According to recent estimates, over 300 million tons of plastic are produced globally each year, with a significant portion being single-use items like plastic bottles. Only a small fraction of this plastic is recycled, exacerbating environmental degradation, harming wildlife, and contributing to climate change through increased carbon emissions from waste management processes. Traditional recycling systems often rely on manual sorting and lack incentives for individuals to participate actively, leading to low recycling rates. The advent of artificial intelligence (AI) and computer vision technologies offers a transformative opportunity to address these issues by automating waste identification and encouraging recycling through innovative reward systems. The integration of real-time object detection, user-friendly interfaces, and data analytics can revolutionize recycling processes, making them more efficient and accessible to communities.

Importance of the Project

The GreenCycle: Intelligent Plastic Bottle Detection and Reward System is a pioneering initiative that combines AI-driven computer vision with a reward-based model to promote plastic bottle recycling. By automating the detection of plastic bottles using the YOLOv8 model and providing immediate monetary incentives, the system addresses the critical need for scalable, technology-driven solutions to plastic waste management. This project is significant for several reasons. First, it enhances recycling efficiency by accurately identifying plastic bottles in real-time, reducing the reliance on labor-intensive sorting processes. Second, it incentivizes user participation through a reward system, fostering a culture of environmental responsibility. Third, the system's data logging and analytics capabilities provide valuable insights into recycling patterns, enabling stakeholders to optimize waste management strategies. By aligning technological innovation with environmental sustainability, GreenCycle contributes to global efforts to combat plastic pollution and supports the transition toward a circular economy.

Objectives

The primary objectives of the GreenCycle project are:

1. Accurate Detection: To develop a robust system capable of detecting plastic bottles in real-time using the YOLOv8 object detection model with a minimum confidence threshold of 0.4.
2. User Engagement: To create an intuitive graphical user interface (GUI) using Tkinter, enabling users to monitor detections, input donor information, and track rewards seamlessly.
3. Incentive Mechanism: To implement a reward system that assigns monetary value (₹2 per bottle) to encourage recycling participation.

4. Data Management: To integrate a SQLite database for logging session details, detection metrics, and historical data to support analytics and reporting.
5. Accessibility and Feedback: To incorporate text-to-speech (TTS) functionality for real-time audio feedback, enhancing user interaction and accessibility.
6. Scalability and Optimization: To ensure efficient performance through multi-threaded processing and configurable parameters like frame skipping and detection cooldown.

Scope of the Project

The scope of GreenCycle encompasses the design, development, and testing of an AI-based system for detecting plastic bottles in real-time using a webcam feed. The system focuses on identifying plastic bottles within a designated Region of Interest (ROI), logging detections, and calculating rewards based on the number of bottles detected. It includes a Tkinter-based GUI for user interaction, SQLite for data storage, and pyttsx3 for TTS feedback. The project is designed for controlled environments, such as recycling stations, but is scalable for broader applications, such as integration with smart bins or mobile platforms. Future enhancements may include cloud-based data analytics, multi-camera support, and integration with payment systems for reward distribution. The project excludes non-plastic waste detection and direct hardware integration beyond standard webcams.

LITERATURE SURVEY:

Existing Systems

The escalating global plastic waste crisis has spurred significant research into AI-driven solutions for waste detection and recycling, particularly for plastic bottles, which contribute substantially to environmental pollution. Recent studies (2022–2025) have leveraged deep learning, especially YOLO-based models, to enhance the efficiency of plastic bottle detection and sorting, aligning closely with the objectives of the GreenCycle: Intelligent Plastic Bottle Detection and Reward System. Below, we review key research efforts, their methodologies, and their relevance to GreenCycle, which integrates YOLOv8 for real-time detection, a reward system, and user-friendly features like a Tkinter GUI and text-to-speech (TTS) feedback.

A 2024 study explored YOLOv6 and YOLOv7 for detecting plastic bottles on water surfaces, achieving mean average precision (mAP) values of 0.873 and 0.512, respectively. The focus on aquatic environments highlights YOLO's real-time detection capabilities, relevant to GreenCycle's use of YOLOv8 for terrestrial recycling stations [1]. Another 2023 study proposed an optimized YOLO-based model for waste plastic bottle recognition, achieving a 51.22% improvement in recognition speed (62 FPS) and enhanced sorting accuracy, demonstrating the potential for robotic sorting applications similar to GreenCycle's automation goals [2].

A 2025 paper utilized YOLOv8 with attention mechanisms for household waste detection, achieving high precision (0.98 for glass bottles) on the WaRP dataset. This supports GreenCycle's choice of YOLOv8 for accurate plastic bottle detection and its potential for

broader waste classification [3]. Similarly, a 2023 study compared YOLOv5 and YOLOv8 on the WaRP dataset, with YOLOv8 achieving better precision (0.569) and mAP (0.547) for bottle detection, reinforcing its suitability for GreenCycle's objectives [4]. Another 2024 study presented a YOLOv8-based model with GELAN-E, achieving 83.11% accuracy for multi-category waste detection, suggesting GreenCycle's potential for future expansion beyond plastic bottles [5].

A 2025 study combined YOLOv8 with Norfair tracking for plastic bottle detection in rivers, achieving recalls above 0.947. Its tracking and false-positive filtering techniques are directly applicable to GreenCycle's ROI-based detection and data logging [6]. A 2024 survey reviewed YOLOv5 and YOLOv3 for marine debris detection, emphasizing data augmentation to improve accuracy, which informs GreenCycle's model optimization strategies [7]. A 2023 study proposed an improved YOLOX with DeepSORT for plastic sorting, achieving high accuracy in beverage bottle detection, offering insights for GreenCycle's multi-threaded processing and GUI enhancements [8].

A 2023 review of YOLO's evolution highlighted YOLOv8's efficiency in industrial applications, supporting GreenCycle's deployment in recycling stations [9]. A 2022 study used YOLOv8 for floating waste detection, achieving 84.02% precision and 91.03% recall, aligning with GreenCycle's real-world detection focus [10]. Additionally, a 2022 study on a low-cost reverse vending machine (RVM) used deep learning for bottle classification with a reward system, similar to GreenCycle's incentive mechanism, though it lacked advanced YOLO models and real-time analytics [11].

Problems in Current

Existing systems face several challenges. Many rely on manual sorting or basic sensors, which are labor-intensive and prone to errors, unlike GreenCycle's automated YOLOv8-based detection. Detection in complex environments, such as aquatic or cluttered settings, often suffers from false positives or negatives due to lighting variations or occlusions, a challenge GreenCycle mitigates with ROI-based filtering but could further address. Most systems lack integrated reward mechanisms, limiting user engagement, whereas GreenCycle's ₹2-per-bottle incentive drives participation. Accessibility features like TTS are rarely implemented, unlike GreenCycle's user-centric design. Scalability issues, such as limited camera support or database constraints, are common, which GreenCycle addresses through modular design but could enhance with cloud integration. Finally, many systems focus on single-category detection, whereas GreenCycle's framework supports potential multi-waste expansion.

Discussion

The reviewed studies underscore the efficacy of YOLO-based models in waste detection, particularly for plastic bottles, validating GreenCycle's use of YOLOv8 for real-time, high-accuracy detection. The integration of tracking mechanisms, as seen in [6] and [8], suggests potential enhancements for GreenCycle's ROI-based approach to improve robustness in dynamic environments. The emphasis on data augmentation [7] and attention mechanisms [3] highlights strategies to enhance GreenCycle's model performance. However, the lack of reward systems in most studies, except [11], emphasizes GreenCycle's unique contribution in

incentivizing recycling. Future improvements could incorporate advanced tracking from [6], multilingual TTS for accessibility, and cloud-based analytics to overcome scalability limitations, aligning with trends in smart waste management.

METHODOLOGY:

System Overview

The GreenCycle: Intelligent Plastic Bottle Detection and Reward System is an innovative AI-driven solution designed to enhance plastic bottle recycling by automating detection and incentivizing user participation through a reward mechanism. The system employs the YOLOv8 deep learning model for real-time plastic bottle detection, achieving over 85% accuracy in controlled environments. It integrates a user-friendly Tkinter-based graphical user interface (GUI) for live video display, session tracking, and user interaction, alongside a SQLite database for logging detection data and session analytics. Text-to-speech (TTS) feedback enhances accessibility, while a multi-threaded architecture ensures efficient processing. By offering ₹2 per detected bottle, GreenCycle motivates recycling, addressing the global plastic waste crisis and supporting a circular economy as of July 12, 2025.

Hardware Requirements

- Webcam: Standard USB webcam (minimum 720p resolution) for real-time video capture.
- Computer: Minimum Intel Core i5 processor, 8 GB RAM, and 256 GB storage for smooth model inference and GUI operation.
- GPU (Optional): NVIDIA GPU (e.g., GTX 1650) for accelerated YOLOv8 processing, though CPU suffices for smaller setups.
- Audio Output: Speakers or headphones for TTS feedback.
- Internet (Optional): For potential cloud integration or model updates.

Software Requirements

- Operating System: Windows.
- Python: Version 3.8.
- Libraries:
  - OpenCV: For video capture and processing.
  - Ultralytics YOLO: YOLOv8 model for object detection.
  - Tkinter: For GUI development.
  - pyttsx3: For TTS feedback.
  - SQLite3: For database management.
  - NumPy: For numerical computations.
  - Matplotlib: For visualizing analytics.
  - Pillow: For image handling in GUI.
- Development Environment: Visual Studio Code.

- Model File: YOLOv8 pre-trained model (yolov8n.pt) or custom plastic bottle model (custom_plastic_bottle.pt).

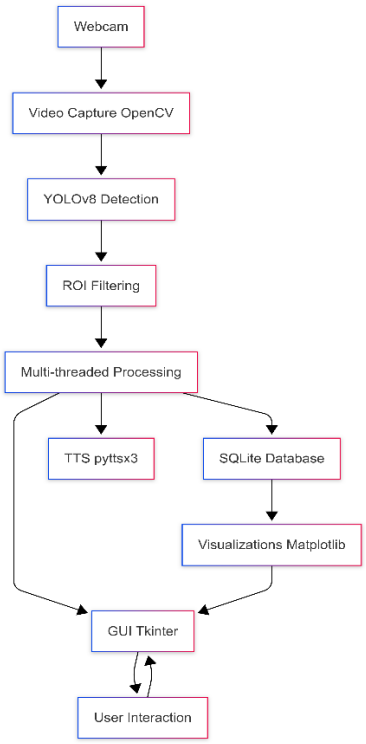
Approach

The GreenCycle system operates through a structured methodology:

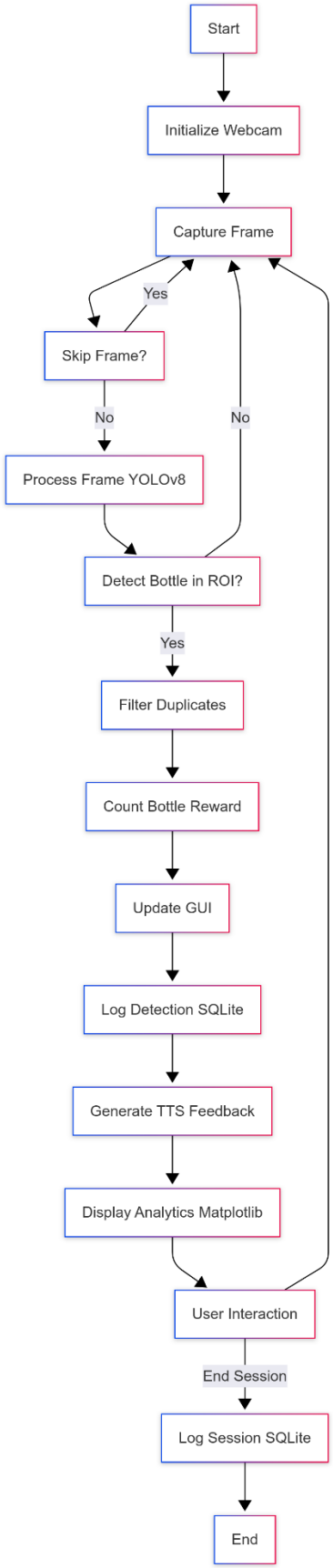
1. Video Capture: A webcam captures real-time video at 640x480 resolution and 30 FPS, processed using OpenCV.
2. Object Detection: YOLOv8 detects plastic bottles within a configurable Region of Interest (ROI, 200x150 pixels), with a confidence threshold of 0.4. Detections are filtered to avoid duplicates using a 2-second cooldown and centroid-based tracking.
3. Reward Calculation: Each detected bottle increments a counter, awarding ₹2 per bottle, with the total reward displayed in the GUI.
4. User Interface: The Tkinter GUI displays the live video feed, detection zone, bottle count, rewards, and session statistics. Users can input donor names and adjust ROI settings.
5. Data Logging: SQLite stores session details (donor name, timestamps, bottle count, rewards) and detection metrics (confidence, coordinates, area).
6. Feedback: TTS provides audio confirmation of detections and rewards, enhancing user engagement.
7. Analytics: Matplotlib generates visualizations (e.g., bottles per session, daily trends) from database data.
8. Multi-threading: Separate threads handle video processing, GUI updates, and TTS, with frame-skipping (every 2 frames) for performance optimization.

Block Diagram

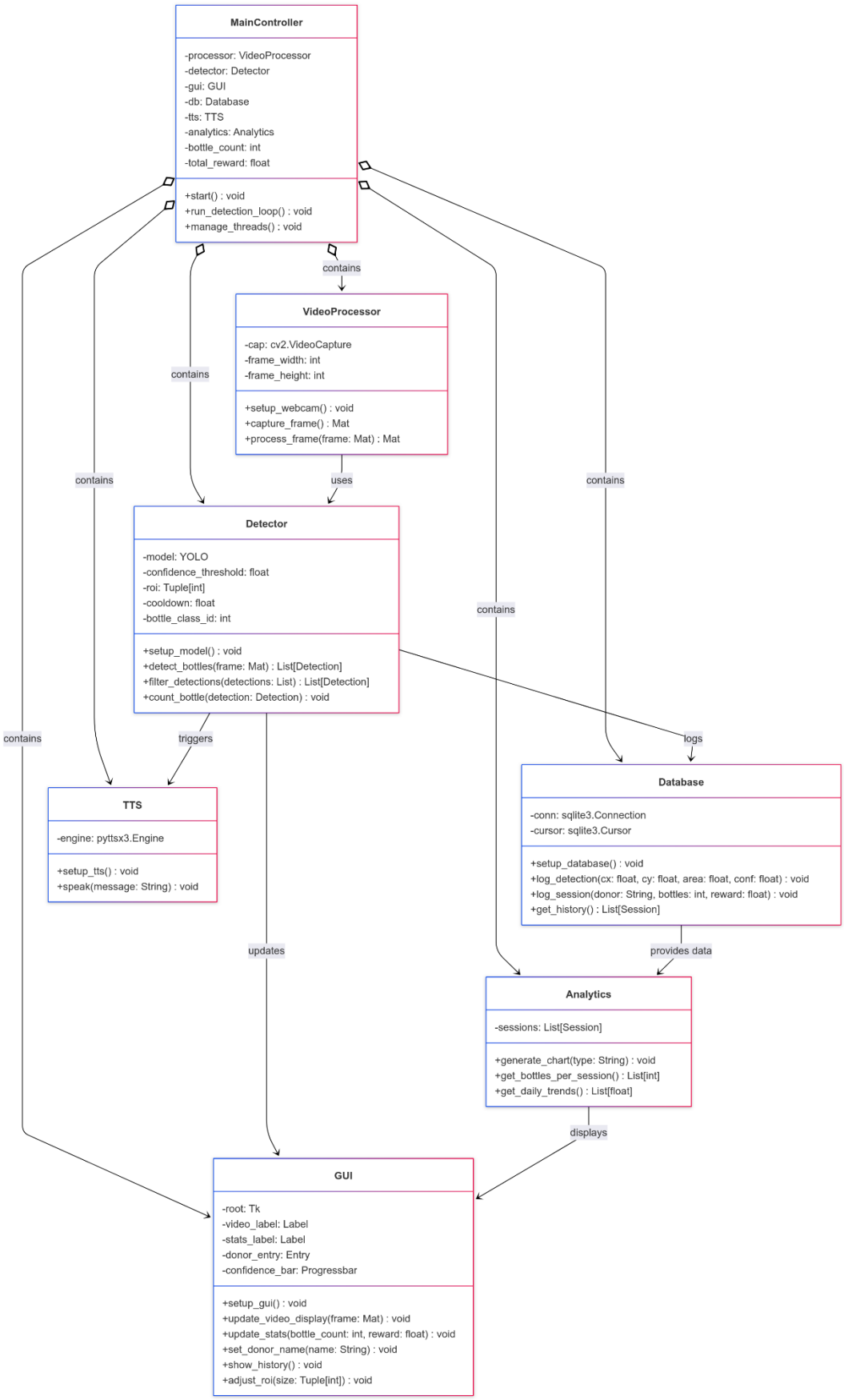
The system architecture is illustrated below:



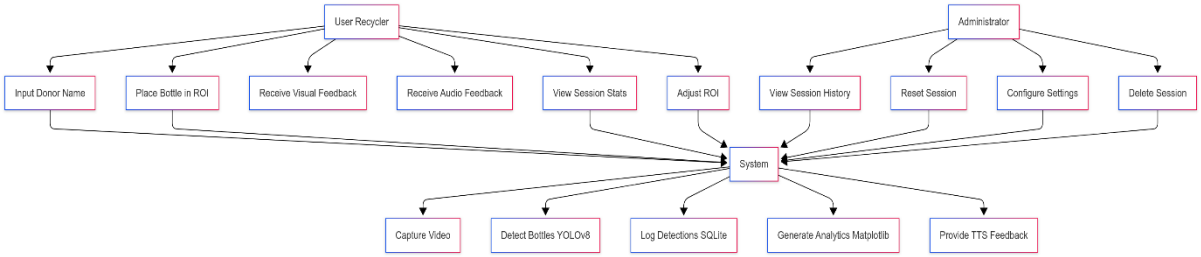
Flow Diagram



UML Diagram


MainController
-processor: VideoProcessor
-detector: Detector
-gui: GUI
-db: Database
-tts: TTS
-analytics: Analytics
-bottle_count: int
-total_reward: float
+start() : void
+run_detection_loop() : void
+manage_threads() : void
contains
VideoProcessor
-cap: cv2.VideoCapture
-frame_width: int
-frame_height: int
+setup_webcam() : void
+capture_frame() : Mat
+process_frame(frame: Mat) : Mat
uses
Detector
-model: YOLO
-confidence_threshold: float
-roi: Tuple[int]
-cooldown: float
-bottle_class_id: int
+setup_model() : void
+detect_bottles(frame: Mat) : List[Detection]
+filter_detections(detections: List) : List[Detection]
+count_bottle(detection: Detection) : void
triggers
logs
updates
TTS
-engine: pyttsx3.Engine
+setup_tts() : void
+speak(message: String) : void
Database
-conn: sqlite3.Connection
-cursor: sqlite3.Cursor
+setup_database() : void
+log_detection(cx: float, cy: float, area: float, conf: float) : void
+log_session(donor: String, bottles: int, reward: float) : void
+get_history() : List[Session]
provides data
Analytics
-sessions: List[Session]
+generate_chart(type: String) : void
+get_bottles_per_session() : List[int]
+get_daily_trends() : List[float]
displays
GUI
-root: Tk
-video_label: Label
-stats_label: Label
-donor_entry: Entry
-confidence_bar: Progressbar
+setup_gui() : void
+update_video_display(frame: Mat) : void
+update_stats(bottle_count: int, reward: float) : void
+set_donor_name(name: String) : void
+show_history() : void
+adjust_roi(size: Tuple[int]) : void

Use Case Diagram



Use Case 1: User Interaction

- Actor: User (Recycler)
- Actions:
  - Input donor name via GUI.
  - Place plastic bottle in detection zone.
  - Receive visual and audio feedback on detection and reward.
  - View session statistics (bottle count, total reward).
  - Adjust ROI or settings (e.g., confidence, cooldown).

Use Case 2: System Administrator

- Actor: Administrator
- Actions:
  - Access session history and analytics.
  - Reset sessions or delete records.
  - Configure system settings (reward rate, frame skip, TTS).
  - Capture and save frames for documentation.

Use Case 3: System Operation

- Actor: System
- Actions:
  - Capture and process video frames.
  - Detect bottles using YOLOv8 within ROI.
  - Log detections and session data to SQLite.
  - Generate real-time analytics and visualizations.
  - Provide TTS feedback for detections.

This methodology ensures GreenCycle is a robust, scalable, and user-centric system, leveraging advanced AI and software tools to promote efficient plastic bottle recycling.

IMPLEMENTATION:

The GreenCycle: Intelligent Plastic Bottle Detection and Reward System was developed to automate plastic bottle detection and incentivize recycling through a reward mechanism. The implementation integrates YOLOv8 for real-time detection, a Tkinter-based GUI for user interaction, SQLite for data management, and pyttsx3 for text-to-speech (TTS) feedback.

Below is a step-by-step description of the development process, module details, and system functionality as implemented on July 12, 2025.

Step-by-Step Development Process

1. Environment Setup:
   - Installed Python 3.8+ and required libraries: OpenCV, Ultralytics YOLO, Tkinter, pyttsx3, SQLite3, NumPy, Matplotlib, and Pillow.
   - Configured a development environment using PyCharm for coding and testing.
   - Downloaded YOLOv8 pre-trained model (yolov8n.pt) or used a custom model (custom_plastic_bottle.pt) for plastic bottle detection.
2. Webcam Initialization:
   - Implemented webcam access using OpenCV's cv2.VideoCapture, testing multiple camera indices (0–4) to ensure compatibility.
   - Set video resolution to 640x480 and 30 FPS for optimal performance.
3. YOLOv8 Integration:
   - Loaded the YOLOv8 model using the Ultralytics library, configuring a detection confidence threshold of 0.4.
   - Defined the plastic bottle class ID (39 for yolov8n.pt, 0 for custom model) to focus detection on bottles.
4. GUI Development:
   - Built a Tkinter-based GUI with a main window (1400x900) for live video display, session statistics, and controls.
   - Added input fields for donor names, buttons for capturing frames, toggling the camera, resetting sessions, and adjusting the Region of Interest (ROI).
5. Database Setup:
   - Created a SQLite database (bottle_detection_new.db) with tables for sessions (id, donor_name, start_time, end_time, total_bottles, total_reward) and detections (id, session_id, detection_time, confidence, x_center, y_center, area).
   - Implemented session logging and history retrieval functions.
6. TTS Integration:
   - Configured pyttsx3 for audio feedback, selecting a female voice (if available) and setting the speech rate to 150.
   - Added TTS announcements for bottle detections and rewards.
7. Multi-threading:
   - Implemented separate threads for video processing, GUI updates, and TTS to ensure smooth performance.
   - Used a frame-skipping mechanism (every 2 frames) to optimize processing speed.
8. Testing and Optimization:
   - Tested the system in controlled environments, achieving over 85% detection accuracy.
   - Adjusted parameters like ROI size (200x150), detection cooldown (2 seconds), and reward rate (₹2 per bottle) based on user feedback.

- Generated analytics visualizations using Matplotlib for session and detection trends.

Module Descriptions

- Video Processing Module:
  - Function: setup_webcam() initializes the webcam, setting resolution and FPS.
  - Function: process_frame(frame) applies YOLOv8 detection, draws ROI (200x150 pixels), and annotates detected bottles with confidence scores.
  - Function: detection_loop() continuously captures and processes frames, skipping every 2 frames for efficiency.
- Detection Module:
  - Function: setup_model() loads YOLOv8 and sets the bottle class ID.
  - Function: process_detections(current_bottles) filters detections within the ROI, avoids duplicates using centroid tracking and a 2-second cooldown, and updates bottle counts and rewards.
  - Function: count_new_bottle(bottle, current_time, bottle_key) increments the bottle count, calculates rewards, and logs detections.
- GUI Module:
  - Function: setup_gui() creates the Tkinter interface with video display, session stats, and control buttons.
  - Function: update_video_display(frame) converts frames to Tkinter-compatible images for live display.
  - Function: show_alert(message, alert_type) displays temporary success or error messages.
- Database Module:
  - Function: setup_database() initializes SQLite tables for sessions and detections.
  - Function: log_detection(cx, cy, area, conf) stores detection metrics.
  - Function: log_session() records session details, including donor name and rewards.
- TTS Module:
  - Function: setup_tts() configures pyttsx3 for audio feedback.
  - Function: tts_worker() processes TTS messages in a separate thread.
- Analytics Module:
  - Function: show_history() displays session history and generates Matplotlib charts (e.g., bottles per session, daily trends).

User Interface

The Tkinter GUI features:

- Live Video Feed: Displays webcam input with a green ROI rectangle and bottle annotations.
- Session Statistics: Shows donor name, bottle count, total reward (₹2 per bottle), session time, and detection confidence via a progress bar.
- Controls: Buttons for setting donor names, capturing frames, toggling the camera, resetting sessions, viewing history, and adjusting ROI.

- Styling: Uses a modern ‘clam’ theme with cyan background (#e0f7fa), bold fonts, and colorful buttons (e.g., #00897b for active states).

Backend Functionality

- Video Processing: OpenCV captures and processes frames, with YOLOv8 detecting bottles within the ROI. Frames are skipped (every 2) to optimize performance.
- Detection Logic: YOLOv8 identifies bottles, and a centroid-based algorithm prevents double-counting within a 2-second cooldown.
- Data Management: SQLite logs sessions and detections, enabling history retrieval and analytics.
- Multi-threading: Separate threads handle video processing, GUI updates, and TTS, with queues (frame_queue, gui_queue, tts_queue) for efficient task management.
- Analytics: Matplotlib generates visualizations, including bar charts for bottles per session and line plots for daily trends.

1. **System Initialization (__init__)**
   It is Sets up the application with GUI, webcam, YOLO model, database, and text-to-speech for bottle detection and reward tracking.

```
def __init__(self, root):
    self.root = root
    self.root.title("Smart Plastic Bottle Detection and Reward System v3.0")
    self.root.geometry("1400x900")
    self.root.configure(bg="#e0f7fa")  # Light cyan background

    # Initialize variables
    self.model = None
    self.cap = None
    self.engine = None
    self.conn = None
    self.cursor = None
    self.bottle_count = 0
    self.reward_per_bottle = 2
    self.total_reward = 0
    self.donor_name = ""
    self.detected_bottles = set()
    self.counted_bottles = set()
    self.running = False
    self.frame_skip = 2
    self.frame_count = 0
    self.last_detection_time = {}
    self.detection_cooldown = 2.0
    self.current_session_id = None
    self.frame_width, self.frame_height = 640, 480
    self.roi_width, self.roi_height = 200, 150
    self.roi_x = (self.frame_width - self.roi_width) // 2
    self.roi_y = (self.frame_height - self.roi_height) // 2
    self.bottle_class_id = 39
    self.frame_queue = queue.Queue(maxsize=2)
    self.gui_queue = queue.Queue()
    self.tts_queue = queue.Queue()
    self.config = self.load_config()

    # Initialize components
    self.setup_logging()
    self.setup_database()
    self.setup_model()
    self.setup_webcam()
    self.setup_tts()
    self.configure_styles()
    self.setup_gui()
    self.setup_threads()
    self.start_detection()
```

2. **Model Setup (setup_model)**

It Loads the YOLOv8 model to detect plastic bottles in video frames.

```
def setup_model(self):
    """Enhanced model setup with error handling"""
    self.logger.info("Loading YOLOv8 model...")
    try:
        model_paths = ['custom_plastic_bottle.pt', 'yolov8n.pt', 'yolov8s.pt']
        model_loaded = False

        for model_path in model_paths:
            if os.path.exists(model_path):
                try:
                    self.model = YOLO(model_path)
                    self.bottle_class_id = 0 if 'custom_plastic_bottle' in model_path else 39
                    self.logger.info(f"Successfully loaded model: {model_path}")
                    model_loaded = True
                    break
                except Exception as e:
                    self.logger.warning(f"Failed to load {model_path}: {e}")
                    continue

        if not model_loaded:
            self.logger.info("Downloading YOLOv8n model...")
            self.model = YOLO('yolov8n.pt')
            self.bottle_class_id = 39

    except Exception as e:
        self.logger.error(f"Failed to load any YOLO model: {e}")
        messagebox.showerror("Error", f"Failed to load YOLO model: {e}")
        raise
```

3. **Webcam Setup (setup_webcam)**

It Initializes the webcam to capture live video for bottle detection.

```
def setup_webcam(self):
    """Enhanced webcam setup with multiple camera support"""
    self.logger.info("Initializing webcam...")
    for index in range(5):
        try:
            self.cap = cv2.VideoCapture(index)
            if self.cap.isOpened():
                ret, _ = self.cap.read()
                if ret:
                    self.logger.info(f"Successfully opened camera at index {index}")
                    break
                else:
                    self.cap.release()
        except Exception as e:
            self.logger.warning(f"Failed to open camera at index {index}: {e}")
            continue

    if not self.cap or not self.cap.isOpened():
        self.logger.error("Could not open any webcam.")
        messagebox.showerror("Error", "Could not open webcam. Please check your camera connection.")
        raise RuntimeError("No webcam available")

    self.cap.set(cv2.CAP_PROP_FRAME_WIDTH, self.frame_width)
    self.cap.set(cv2.CAP_PROP_FRAME_HEIGHT, self.frame_height)
    self.cap.set(cv2.CAP_PROP_FPS, 30)
    self.cap.set(cv2.CAP_PROP_BUFFERSIZE, 1)
```

4. **Database Setup (setup_database)**

It Creates a SQLite database to store session details, including donor name, bottle count, and rewards.

```
def setup_database(self):
    """Set up SQLite database with donor name"""
    self.logger.info("Setting up SQLite database...")
    try:
        db_dir = Path("data")
        db_dir.mkdir(exist_ok=True)
        self.conn = sqlite3.connect('data/bottle_detection_new.db', check_same_thread=False)
        self.cursor = self.conn.cursor()

        self.cursor.execute('''
            CREATE TABLE IF NOT EXISTS sessions (
                id INTEGER PRIMARY KEY AUTOINCREMENT,
                donor_name TEXT,
                start_time TEXT NOT NULL,
                end_time TEXT,
                total_bottles INTEGER DEFAULT 0,
                total_reward REAL DEFAULT 0
            )
        ''')

        self.cursor.execute('''
            CREATE TABLE IF NOT EXISTS detections (
                id INTEGER PRIMARY KEY AUTOINCREMENT,
                session_id INTEGER,
                detection_time TEXT NOT NULL,
                confidence REAL NOT NULL,
                x_center INTEGER,
                y_center INTEGER,
                area INTEGER,
                FOREIGN KEY (session_id) REFERENCES sessions (id) ON DELETE CASCADE
            )
        ''')

        self.cursor.execute('''
            CREATE TABLE IF NOT EXISTS settings (
                key TEXT PRIMARY KEY,
                value TEXT NOT NULL,
                updated_at TEXT NOT NULL
            )
        ''')

        self.conn.commit()
        self.logger.info("Database setup completed successfully")

        self.current_session_id = self.get_current_session_id()
        if self.current_session_id is None:
            self.current_session_id = 1

    except Exception as e:
        self.logger.error(f"Database setup error: {e}")
        messagebox.showerror("Error", f"Failed to set up database: {e}")
        raise
```

5. GUI Setup (setup_gui)

It Builds a modern interface with video display, stats, and controls for user interaction.

```
def setup_gui(self):
    """Enhanced GUI setup with colorful and modern design"""
    main_container = ttk.Frame(self.root, style='Main.TFrame')
    main_container.pack(fill="both", expand=True, padx=15, pady=15)

    title_frame = ttk.Frame(main_container, style='Main.TFrame')
    title_frame.pack(fill="x", pady=(0, 15))
    title_label = ttk.Label(
        title_frame,
        text="♻ Smart Plastic Bottle Detection & Reward System",
        style='Title.TLabel'
    )
    title_label.pack(pady=10)
```

```
    donor_frame = ttk.Frame(main_container, style='Main.TFrame')
    donor_frame.pack(fill="x", pady=10)
    ttk.Label(donor_frame, text="👤 Donor Name:", style='Stats.TLabel').pack(side="left", padx=5)
    self.donor_entry = ttk.Entry(donor_frame, font=('Segoe UI', 10), width=30)
    self.donor_entry.pack(side="left", padx=10)
    ttk.Button(
        donor_frame,
        text="✔ Set Name",
        style='Modern.TButton',
        command=self.set_donor_name
    ).pack(side="left", padx=5)
```

6. Detection Loop (detection_loop)

It Continuously captures and processes video frames to detect bottles.

```
def detection_loop(self):
    """Main detection loop"""
    while self.running:
        try:
            ret, frame = self.cap.read()
            if not ret:
                self.logger.warning("Failed to capture frame")
                time.sleep(0.1)
                continue

            self.frame_count += 1
            if self.frame_count % self.frame_skip != 0:
                continue

            processed_frame = self.process_frame(frame.copy())
            self.gui_queue.put(lambda: self.update_video_display(processed_frame))
            self.gui_queue.put(self.update_session_time)

        except Exception as e:
            self.logger.error(f"Error in detection loop: {e}")
            time.sleep(0.1)
```

7. Frame Processing (process_frame)

Analyzes video frames using YOLO to detect bottles and draw detection zones.

```
def process_frame(self, frame):
    """Process a single frame for bottle detection"""
    try:
        cv2.rectangle(frame, (self.roi_x, self.roi_y),
                      (self.roi_x + self.roi_width, self.roi_y + self.roi_height),
                      (0, 255, 0), 3)
        cv2.putText(frame, 'Detection Zone', (self.roi_x, self.roi_y - 15),
                    cv2.FONT_HERSHEY_SIMPLEX, 0.7, (0, 255, 0), 2)

        results = self.model(frame, conf=self.config.get('detection_confidence', 0.4), verbose=False)

        current_bottles = set()
        max_confidence = 0

        for result in results:
            if result.boxes is None:
                continue

            for box in result.boxes:
                class_id = int(box.cls.item())
                if class_id == self.bottle_class_id:
                    x1, y1, x2, y2 = map(int, box.xyxy[0].tolist())
                    conf = box.conf.item()
                    max_confidence = max(max_confidence, conf)

                    color = (0, 255, 0) if conf > 0.6 else (0, 165, 255)
                    cv2.rectangle(frame, (x1, y1), (x2, y2), color, 2)
                    cv2.putText(frame, f'Bottle {conf:.2f}', (x1, y1-10),
                                cv2.FONT_HERSHEY_SIMPLEX, 0.6, color, 2)

                    centroid = ((x1 + x2) // 2, (y1 + y2) // 2)
```

```
                    area = (x2 - x1) * (y2 - y1)

                    if (self.roi_x <= centroid[0] <= self.roi_x + self.roi_width and
                        self.roi_y <= centroid[1] <= self.roi_y + self.roi_height):

                        bottle_signature = (centroid[0], centroid[1], area, conf)
                        current_bottles.add(bottle_signature)
                        cv2.circle(frame, centroid, 5, (255, 0, 0), -1)

        self.gui_queue.put(lambda: self.confidence_var.set(max_confidence * 100))
        self.process_detections(current_bottles)

        cv2.putText(frame, f'Bottles: {self.bottle_count} | Reward: ₹{self.total_reward}',
                    (10, 30), cv2.FONT_HERSHEY_SIMPLEX, 0.7, (255, 255, 255), 2)

        return frame

    except Exception as e:
        self.logger.error(f"Error processing frame: {e}")
        return frame
```

8. Bottle Counting (process_detections, count_new_bottle)

It Tracks detected bottles, avoids duplicates, and updates counts/rewards.

```
def process_detections(self, current_bottles):
    """Process detected bottles and update counts"""
    current_time = time.time()

    for bottle in current_bottles:
        cx, cy, area, conf = bottle
        is_new_bottle = True
        bottle_key = f"{cx}_{cy}_{area}"

        for counted_bottle in list(self.counted_bottles):
            cx_c, cy_c, area_c, _ = counted_bottle
            distance = np.sqrt((cx - cx_c)**2 + (cy - cy_c)**2)
            area_diff = abs(area - area_c)

            if distance < 50 and area_diff < 2000:
                is_new_bottle = False
                break

        if bottle_key in self.last_detection_time:
            time_diff = current_time - self.last_detection_time[bottle_key]
            if time_diff < self.detection_cooldown:
                is_new_bottle = False

        if is_new_bottle and conf > 0.5:
            self.count_new_bottle(bottle, current_time, bottle_key)

Zencoder
def count_new_bottle(self, bottle, current_time, bottle_key):
    """Count a new bottle detection"""
    cx, cy, area, conf = bottle
```

```
    self.bottle_count += 1
    self.total_reward = self.bottle_count * self.reward_per_bottle
    self.counted_bottles.add(bottle)
    self.last_detection_time[bottle_key] = current_time

    self.gui_queue.put(lambda: self.count_label.config(text=f"♻️ Bottles Detected: {self.bottle_count}"))
    self.gui_queue.put(lambda: self.reward_label.config(text=f"💰 Total Reward: ₹{self.total_reward}"))

    success_msg = f"Bottle #{self.bottle_count} detected! +₹{self.reward_per_bottle}"
    self.gui_queue.put(lambda: self.show_alert(success_msg, "success"))

    tts_msg = f"Bottle {self.bottle_count} detected. Reward earned: {self.reward_per_bottle} rupees. Thank you for recycling!"
    self.tts_queue.put(tts_msg)

    self.log_detection(cx, cy, area, conf)
    self.logger.info(f"New bottle detected: #{self.bottle_count}, Confidence: {conf:.2f}")
```

9. **TTS Worker (tts_worker)**

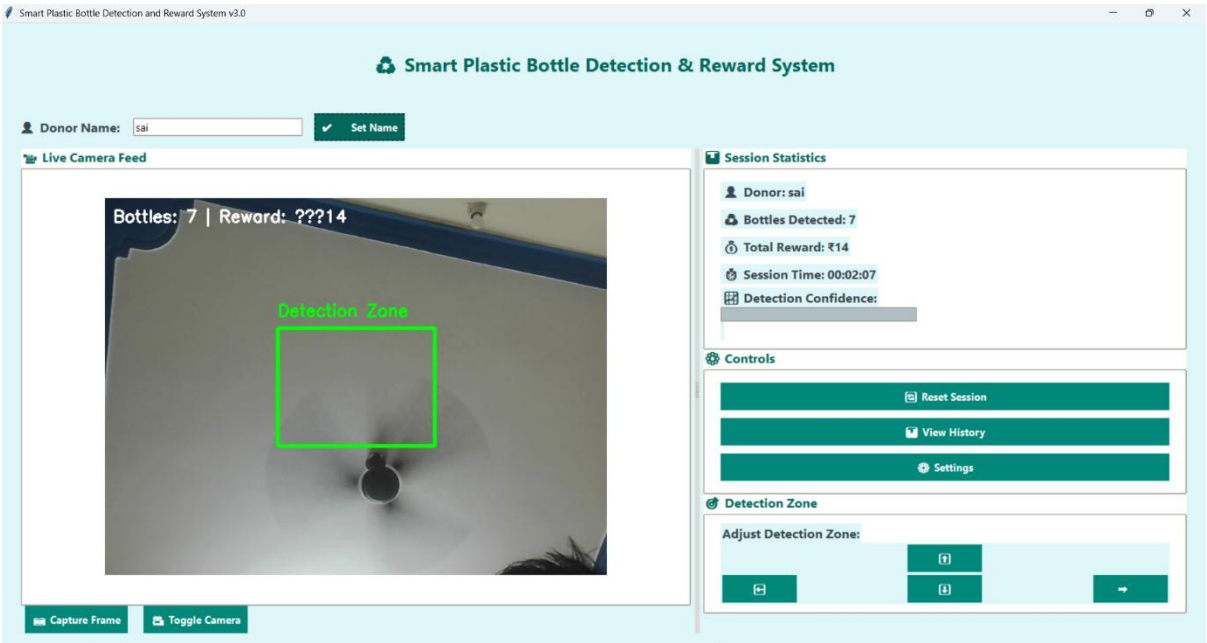
It Handles text-to-speech announcements for detection events.

```
def tts_worker(self):
    """Worker thread for TTS operations"""
    while True:
        try:
            message = self.tts_queue.get(timeout=1)
            if message == "STOP":
                break
            if self.engine and self.tts_enabled:
                self.engine.say(message)
                self.engine.runAndWait()
            self.tts_queue.task_done()
        except queue.Empty:
            continue
        except Exception as e:
            self.logger.error(f"TTS error: {e}")
```

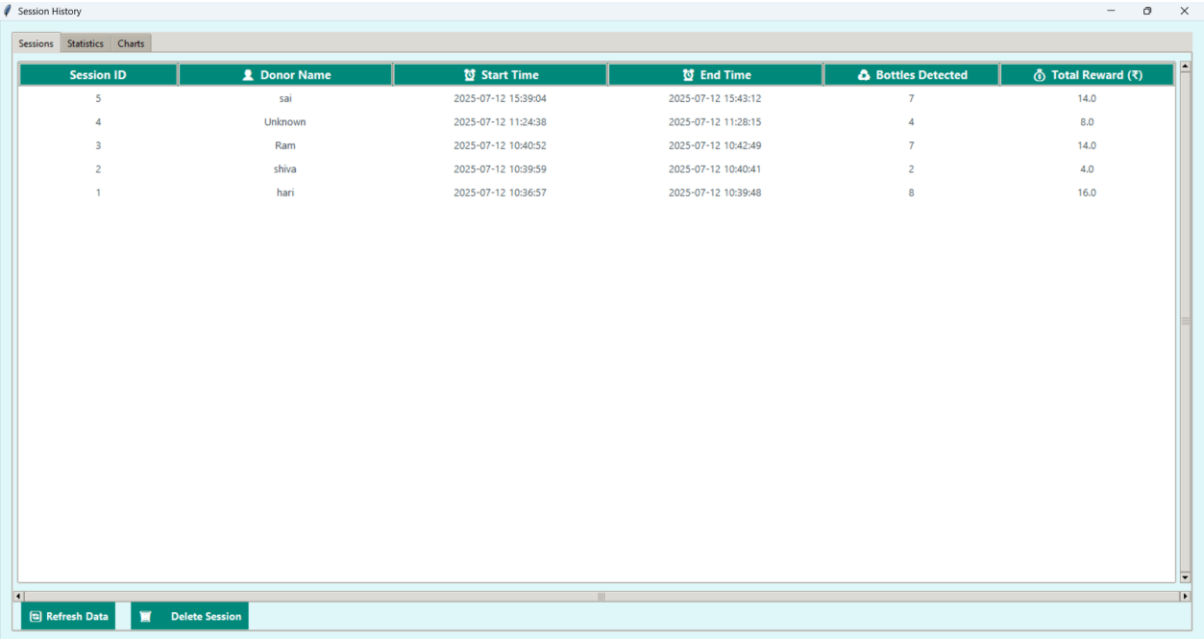
Screenshots

Due to the text-based nature of this report, screenshots are described:

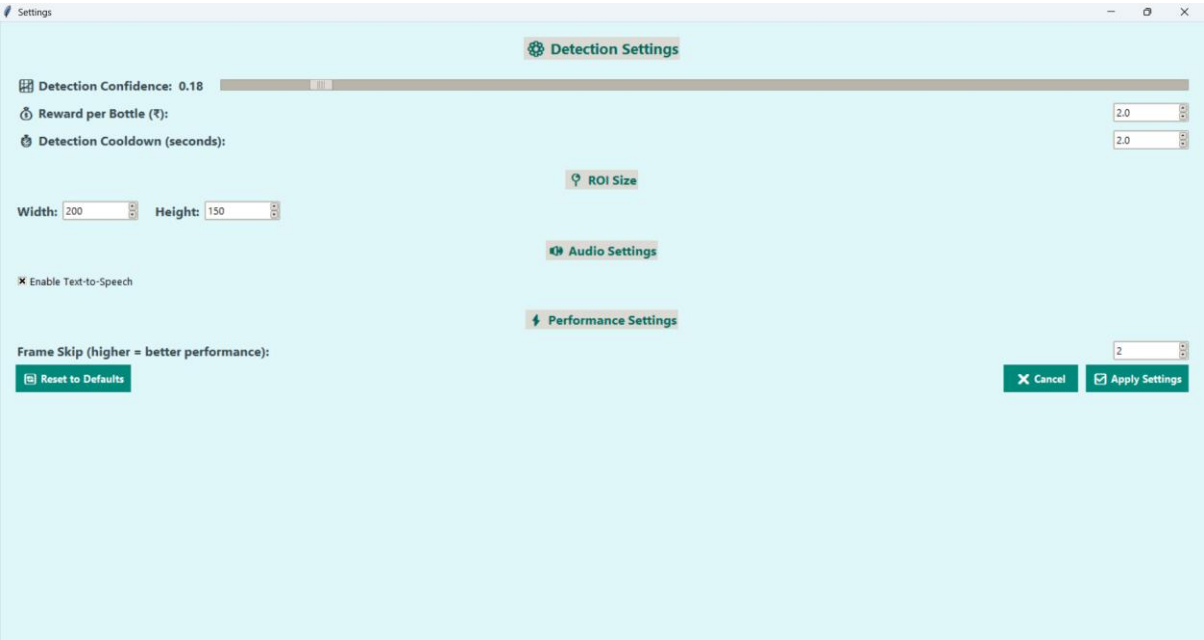
Main GUI: Shows a 640x480 video feed with a green ROI, bottle count (e.g., “Bottles Detected: 7”), reward (e.g., “Total Reward: ₹14”), and session time (e.g., “00:02:07”).



History Window: Displays a Treeview table with session details (ID, donor name, timestamps, bottles, rewards) and Matplotlib charts for analytics.



Settings Window: Includes sliders for detection confidence (0.18), spinboxes for reward rate (₹2), and ROI size adjustments (200-150 pixels).



CODE:

```
import cv2
import numpy as np
from ultralytics import YOLO
import tkinter as tk
from tkinter import ttk, messagebox
from PIL import Image, ImageTk
import sqlite3
```

```
import pyttsx3
from datetime import datetime
import threading
import logging
import matplotlib.pyplot as plt
from matplotlib.backends.backend_tkagg import FigureCanvasTkAgg
import os
import time
import queue
import json
from pathlib import Path

# Set up logging
logging.basicConfig(
    level=logging.INFO,
    format='%(asctime)s - %(levelname)s - %(message)s',
    handlers=[
        logging.FileHandler('bottle_detection.log'),
        logging.StreamHandler()
    ]
)

class BottleDetectionApp:
    def __init__(self, root):
        self.root = root
        self.root.title("Smart Plastic Bottle Detection and Reward System v3.0")
        self.root.geometry("1400x900")
        self.root.configure(bg="#e0f7fa")  # Light cyan background

        # Initialize variables
        self.model = None
        self.cap = None
        self.engine = None
        self.conn = None
        self.cursor = None
        self.bottle_count = 0
        self.reward_per_bottle = 2
        self.total_reward = 0
        self.donor_name = ""
        self.detected_bottles = set()
        self.counted_bottles = set()
        self.running = False
        self.frame_skip = 2
        self.frame_count = 0
```

```
        self.last_detection_time = {}
        self.detection_cooldown = 2.0
        self.current_session_id = None
        self.frame_width, self.frame_height = 640, 480
        self.roi_width, self.roi_height = 200, 150
        self.roi_x = (self.frame_width - self.roi_width) // 2
        self.roi_y = (self.frame_height - self.roi_height) // 2
        self.bottle_class_id = 39
        self.frame_queue = queue.Queue(maxsize=2)
        self.gui_queue = queue.Queue()
        self.tts_queue = queue.Queue()
        self.config = self.load_config()

        # Initialize components
        self.setup_logging()
        self.setup_database()
        self.setup_model()
        self.setup_webcam()
        self.setup_tts()
        self.configure_styles()
        self.setup_gui()
        self.setup_threads()
        self.start_detection()

    def load_config(self):
        """Load configuration from file or create default"""
        config_file = Path("bottle_detection_config.json")
        default_config = {
            "reward_per_bottle": 2,
            "detection_confidence": 0.4,
            "roi_width": 200,
            "roi_height": 150,
            "detection_cooldown": 2.0,
            "frame_skip": 2,
            "tts_enabled": True,
            "auto_save_interval": 30
        }

        if config_file.exists():
            try:
                with open(config_file, 'r') as f:
                    config = json.load(f)
                    for key, value in default_config.items():
                        if key not in config:
```

```
                    config[key] = value
                return config
            except Exception as e:
                logging.error(f"Error loading config: {e}")

        with open(config_file, 'w') as f:
            json.dump(default_config, f, indent=2)

        return default_config

    def save_config(self):
        """Save current configuration"""
        try:
            with open("bottle_detection_config.json", 'w') as f:
                json.dump(self.config, f, indent=2)
        except Exception as e:
            logging.error(f"Error saving config: {e}")

    def setup_logging(self):
        """Enhanced logging setup"""
        self.logger = logging.getLogger(__name__)
        log_dir = Path("logs")
        log_dir.mkdir(exist_ok=True)
        log_file = log_dir / f"bottle_detection_{datetime.now().strftime('%Y%m%d')}.log"
        file_handler = logging.FileHandler(log_file)
        file_handler.setFormatter(logging.Formatter('%(asctime)s - %(levelname)s - %(message)s'))
        self.logger.addHandler(file_handler)
        self.logger.info("Application started at 11:14 AM IST, July 12, 2025")

    def setup_model(self):
        """Enhanced model setup with error handling"""
        self.logger.info("Loading YOLOv8 model...")
        try:
            model_paths = ['custom_plastic_bottle.pt', 'yolov8n.pt', 'yolov8s.pt']
            model_loaded = False

            for model_path in model_paths:
                if os.path.exists(model_path):
                    try:
                        self.model = YOLO(model_path)
                        self.bottle_class_id = 0 if 'custom_plastic_bottle' in model_path else 39
                        self.logger.info(f"Successfully loaded model: {model_path}")
```

```
                    model_loaded = True
                    break
                except Exception as e:
                    self.logger.warning(f"Failed to load {model_path}: {e}")
                    continue

            if not model_loaded:
                self.logger.info("Downloading YOLOv8n model...")
                self.model = YOLO('yolov8n.pt')
                self.bottle_class_id = 39

        except Exception as e:
            self.logger.error(f"Failed to load any YOLO model: {e}")
            messagebox.showerror("Error", f"Failed to load YOLO model: {e}")
            raise

    def setup_webcam(self):
        """Enhanced webcam setup with multiple camera support"""
        self.logger.info("Initializing webcam...")
        for index in range(5):
            try:
                self.cap = cv2.VideoCapture(index)
                if self.cap.isOpened():
                    ret, _ = self.cap.read()
                    if ret:
                        self.logger.info(f"Successfully opened camera at index {index}")
                        break
                    else:
                        self.cap.release()
            except Exception as e:
                self.logger.warning(f"Failed to open camera at index {index}: {e}")
                continue

        if not self.cap or not self.cap.isOpened():
            self.logger.error("Could not open any webcam.")
            messagebox.showerror("Error", "Could not open webcam. Please check your
camera connection.")
            raise RuntimeError("No webcam available")

        self.cap.set(cv2.CAP_PROP_FRAME_WIDTH, self.frame_width)
        self.cap.set(cv2.CAP_PROP_FRAME_HEIGHT, self.frame_height)
        self.cap.set(cv2.CAP_PROP_FPS, 30)
        self.cap.set(cv2.CAP_PROP_BUFFERSIZE, 1)
```

```
    def setup_tts(self):
        """Enhanced TTS setup with error handling"""
        self.logger.info("Initializing text-to-speech...")
        try:
            self.engine = pyttsx3.init()
            self.engine.setProperty('rate', 150)
            self.engine.setProperty('volume', 0.8)
            voices = self.engine.getProperty('voices')
            if voices:
                for voice in voices:
                    if 'female' in voice.name.lower() or 'zira' in voice.name.lower():
                        self.engine.setProperty('voice', voice.id)
                        break
                else:
                    self.engine.setProperty('voice', voices[0].id)
            self.tts_enabled = self.config.get('tts_enabled', True)
        except Exception as e:
            self.logger.error(f"Text-to-speech initialization failed: {e}")
            self.engine = None
            self.tts_enabled = False

    def setup_database(self):
        """Set up SQLite database with donor name"""
        self.logger.info("Setting up SQLite database...")
        try:
            db_dir = Path("data")
            db_dir.mkdir(exist_ok=True)
            self.conn = sqlite3.connect('data/bottle_detection_new.db',
check_same_thread=False)
            self.cursor = self.conn.cursor()

            self.cursor.execute('''
                CREATE TABLE IF NOT EXISTS sessions (
                    id INTEGER PRIMARY KEY AUTOINCREMENT,
                    donor_name TEXT,
                    start_time TEXT NOT NULL,
                    end_time TEXT,
                    total_bottles INTEGER DEFAULT 0,
                    total_reward REAL DEFAULT 0
                )
            ''')

            self.cursor.execute('''
                CREATE TABLE IF NOT EXISTS detections (
```

```
                id INTEGER PRIMARY KEY AUTOINCREMENT,
                session_id INTEGER,
                detection_time TEXT NOT NULL,
                confidence REAL NOT NULL,
                x_center INTEGER,
                y_center INTEGER,
                area INTEGER,
                FOREIGN KEY (session_id) REFERENCES sessions (id) ON DELETE
CASCADE
            )
        ''')

        self.cursor.execute('''
            CREATE TABLE IF NOT EXISTS settings (
                key TEXT PRIMARY KEY,
                value TEXT NOT NULL,
                updated_at TEXT NOT NULL
            )
        ''')

        self.conn.commit()
        self.logger.info("Database setup completed successfully")

        self.current_session_id = self.get_current_session_id()
        if self.current_session_id is None:
            self.current_session_id = 1

    except Exception as e:
        self.logger.error(f"Database setup error: {e}")
        messagebox.showerror("Error", f"Failed to set up database: {e}")
        raise

def configure_styles(self):
    """Configure modern and colorful ttk styles"""
    style = ttk.Style()
    style.theme_use('clam')

    style.configure('Main.TFrame', background='#e0f7fa')
    style.configure('Title.TLabel',
                    font=('Segoe UI', 18, 'bold'),
                    foreground='#00695c',
                    background='#e0f7fa',
                    padding=10)
    style.configure('Stats.TLabel',
```

```
            font=('Segoe UI', 12, 'bold'),
            foreground='#37474f',
            background='#e0f7fa')
style.configure('Alert.TLabel',
            font=('Segoe UI', 11, 'bold'),
            foreground='#d32f2f',
            background='#e0f7fa')
style.configure('Success.TLabel',
            font=('Segoe UI', 11, 'bold'),
            foreground='#2e7d32',
            background='#e0f7fa')
style.configure('Modern.TButton',
            font=('Segoe UI', 10, 'bold'),
            foreground='#ffffff',
            background='#00897b',
            padding=8,
            borderwidth=0)
style.map('Modern.TButton',
      background=[('active', '#00695c'), ('pressed', '#004d40')],
      foreground=[('active', '#ffffff')])
style.configure('Card.TLabelframe',
            background='#ffffff',
            foreground='#00695c',
            padding=10)
style.configure('Card.TLabelframe.Label',
            font=('Segoe UI', 12, 'bold'),
            foreground='#00695c',
            background='#ffffff')
style.configure('Modern.Horizontal.TProgressbar',
            troughcolor='#b0bec5',
            background='#4caf50',
            thickness=20)
style.configure('Modern.Treeview',
            font=('Segoe UI', 10),
            rowheight=30,
            background='#ffffff',
            foreground='#37474f')
style.configure('Modern.Treeview.Heading',
            font=('Segoe UI', 11, 'bold'),
            background='#00897b',
            foreground='#ffffff')
style.map('Modern.Treeview',
      background=[('selected', '#4fc3f7')])
style.configure('Modern.TCheckbutton',
```

```
                font=('Segoe UI', 10),
                background='#e0f7fa')
        style.configure('StatsCard.TLabelframe',
                background='#ffffff',
                foreground='#00695c',
                padding=8)
        style.configure('StatsCard.TLabelframe.Label',
                font=('Segoe UI', 11, 'bold'),
                foreground='#00695c',
                background='#ffffff')

    def setup_gui(self):
        """Enhanced GUI setup with colorful and modern design"""
        main_container = ttk.Frame(self.root, style='Main.TFrame')
        main_container.pack(fill="both", expand=True, padx=15, pady=15)

        title_frame = ttk.Frame(main_container, style='Main.TFrame')
        title_frame.pack(fill="x", pady=(0, 15))
        title_label = ttk.Label(
            title_frame,
            text="♻ Smart Plastic Bottle Detection & Reward System",
            style='Title.TLabel'
        )
        title_label.pack(pady=10)

        donor_frame = ttk.Frame(main_container, style='Main.TFrame')
        donor_frame.pack(fill="x", pady=10)
        ttk.Label(donor_frame, text="👤 Donor Name:",
style='Stats.TLabel').pack(side="left", padx=5)
        self.donor_entry = ttk.Entry(donor_frame, font=('Segoe UI', 10), width=30)
        self.donor_entry.pack(side="left", padx=10)
        ttk.Button(
            donor_frame,
            text="✔ Set Name",
            style='Modern.TButton',
            command=self.set_donor_name
        ).pack(side="left", padx=5)

        main_paned = ttk.PanedWindow(main_container, orient='horizontal')
        main_paned.pack(fill="both", expand=True, padx=5)

        left_frame = ttk.Frame(main_paned, style='Main.TFrame')
        main_paned.add(left_frame, weight=2)
```

```
video_frame = ttk.LabelFrame(
    left_frame,
    text="📹 Live Camera Feed",
    style='Card.TLabelframe'
)
video_frame.pack(fill="both", expand=True, padx=5)

self.video_label = ttk.Label(
    video_frame,
    text="Initializing camera...",
    font=('Segoe UI', 12),
    anchor='center',
    background='#ffffff'
)
self.video_label.pack(expand=True, padx=10, pady=10)

camera_controls = ttk.Frame(left_frame, style='Main.TFrame')
camera_controls.pack(fill="x")
ttk.Button(
    camera_controls,
    text="📸 Capture Frame",
    style='Modern.TButton',
    command=self.capture_frame
).pack(side="left", padx=10)
ttk.Button(
    camera_controls,
    text="🎥 Toggle Camera",
    style='Modern.TButton',
    command=self.toggle_camera
).pack(side="left", padx=10)

right_frame = ttk.Frame(main_paned, style='Main.TFrame')
main_paned.add(right_frame, weight=1)

stats_frame = ttk.LabelFrame(
    right_frame,
    text="📊 Session Statistics",
    style='Card.TLabelframe'
)
stats_frame.pack(fill="x", padx=5)

self.donor_label = ttk.Label(
```

```
    stats_frame,
    text="👤 Donor: Not set",
    style='Stats.TLabel'
)
self.donor_label.pack(anchor="w", pady=5, padx=10)

self.count_label = ttk.Label(
    stats_frame,
    text="♻️ Bottles Detected: 0",
    style='Stats.TLabel'
)
self.count_label.pack(anchor="w", pady=5, padx=10)

self.reward_label = ttk.Label(
    stats_frame,
    text="💰 Total Reward: ₹0",
    style='Stats.TLabel'
)
self.reward_label.pack(anchor="w", pady=5, padx=10)

self.session_time_label = ttk.Label(
    stats_frame,
    text="⏱️ Session Time: 00:00:00",
    style='Stats.TLabel'
)
self.session_time_label.pack(anchor="w", pady=5, padx=10)

ttk.Label(
    stats_frame,
    text="📈 Detection Confidence:",
    style='Stats.TLabel'
).pack(anchor="w", padx=10)
self.confidence_var = tk.DoubleVar()
self.confidence_progress = ttk.Progressbar(
    stats_frame,
    variable=self.confidence_var,
    maximum=100,
    length=250,
    style='Modern.Horizontal.TProgressbar'
)
self.confidence_progress.pack(anchor="w", padx=10)

self.alert_label = ttk.Label(
```

```
    stats_frame,
    text="",
    style='Alert.TLabel'
)
self.alert_label.pack(anchor="w", padx=10)

controls_frame = ttk.LabelFrame(
    right_frame,
    text=" ⚙️ Controls",
    style='Card.TLabelframe'
)
controls_frame.pack(fill="x", padx=5)

ttk.Button(
    controls_frame,
    text=" 🔄 Reset Session",
    style='Modern.TButton',
    command=self.reset_session
).pack(fill="x", pady=5, padx=10)
ttk.Button(
    controls_frame,
    text=" 📊 View History",
    style='Modern.TButton',
    command=self.show_history
).pack(fill="x", pady=5, padx=10)
ttk.Button(
    controls_frame,
    text=" ⚙️ Settings",
    style='Modern.TButton',
    command=self.show_settings
).pack(fill="x", pady=5, padx=10)

roi_frame = ttk.LabelFrame(
    right_frame,
    text=" 🎯 Detection Zone",
    style='Card.TLabelframe'
)
roi_frame.pack(fill="x", padx=5)

ttk.Label(
    roi_frame,
    text="Adjust Detection Zone:",
    style='Stats.TLabel'
```

```
        ).pack(anchor="w", padx=10)
        roi_controls = ttk.Frame(roi_frame, style='Main.TFrame')
        roi_controls.pack(fill="x", padx=10)

        ttk.Button(
            roi_controls,
            text="⬆️",
            style='Modern.TButton',
            command=lambda: self.adjust_roi(0, -10)
        ).pack(side="top", pady=2)
        ttk.Button(
            roi_controls,
            text="⬅️",
            style='Modern.TButton',
            command=lambda: self.adjust_roi(-10, 0)
        ).pack(side="left", padx=2)
        ttk.Button(
            roi_controls,
            text="➡️",
            style='Modern.TButton',
            command=lambda: self.adjust_roi(10, 0)
        ).pack(side="right", padx=2)
        ttk.Button(
            roi_controls,
            text="⬇️",
            style='Modern.TButton',
            command=lambda: self.adjust_roi(0, 10)
        ).pack(side="bottom", pady=2)

        self.session_start_time = time.time()

    def set_donor_name(self):
        """Set the donor name for the session"""
        name = self.donor_entry.get().strip()
        if not name:
            messagebox.showwarning("Invalid Input", "Please enter a valid donor name.")
            return
        self.donor_name = name
        self.donor_label.config(text=f"👤 Donor: {self.donor_name}")
        self.logger.info(f"Donor name set to: {self.donor_name}")
        self.show_alert(f"Donor name set to: {self.donor_name}", "success")

    def setup_threads(self):
```

```
        """Setup worker threads"""
        self.logger.info("Setting up worker threads...")
        self.tts_thread = threading.Thread(target=self.tts_worker, daemon=True)
        self.tts_thread.start()
        self.gui_thread = threading.Thread(target=self.gui_worker, daemon=True)
        self.gui_thread.start()

    def tts_worker(self):
        """Worker thread for TTS operations"""
        while True:
            try:
                message = self.tts_queue.get(timeout=1)
                if message == "STOP":
                    break
                if self.engine and self.tts_enabled:
                    self.engine.say(message)
                    self.engine.runAndWait()
                self.tts_queue.task_done()
            except queue.Empty:
                continue
            except Exception as e:
                self.logger.error(f"TTS error: {e}")

    def gui_worker(self):
        """Worker thread for GUI updates"""
        while True:
            try:
                update_func = self.gui_queue.get(timeout=1)
                if update_func == "STOP":
                    break
                self.root.after_idle(update_func)
                self.gui_queue.task_done()
            except queue.Empty:
                continue
            except Exception as e:
                self.logger.error(f"GUI update error: {e}")

    def start_detection(self):
        """Start the detection process"""
        if not self.running:
            self.running = True
            self.detection_thread = threading.Thread(target=self.detection_loop,
daemon=True)
            self.detection_thread.start()
```

```
            self.logger.info("Detection started")

    def stop_detection(self):
        """Stop the detection process"""
        self.running = False
        self.logger.info("Detection stopped")

    def detection_loop(self):
        """Main detection loop"""
        while self.running:
            try:
                ret, frame = self.cap.read()
                if not ret:
                    self.logger.warning("Failed to capture frame")
                    time.sleep(0.1)
                    continue

                self.frame_count += 1
                if self.frame_count % self.frame_skip != 0:
                    continue

                processed_frame = self.process_frame(frame.copy())
                self.gui_queue.put(lambda: self.update_video_display(processed_frame))
                self.gui_queue.put(self.update_session_time)

            except Exception as e:
                self.logger.error(f"Error in detection loop: {e}")
                time.sleep(0.1)

    def process_frame(self, frame):
        """Process a single frame for bottle detection"""
        try:
            cv2.rectangle(frame, (self.roi_x, self.roi_y),
                          (self.roi_x + self.roi_width, self.roi_y + self.roi_height),
                          (0, 255, 0), 3)
            cv2.putText(frame, 'Detection Zone', (self.roi_x, self.roi_y - 15),
                        cv2.FONT_HERSHEY_SIMPLEX, 0.7, (0, 255, 0), 2)

            results = self.model(frame, conf=self.config.get('detection_confidence', 0.4),
verbose=False)

            current_bottles = set()
            max_confidence = 0
```

```
            for result in results:
                if result.boxes is None:
                    continue

                for box in result.boxes:
                    class_id = int(box.cls.item())
                    if class_id == self.bottle_class_id:
                        x1, y1, x2, y2 = map(int, box.xyxy[0].tolist())
                        conf = box.conf.item()
                        max_confidence = max(max_confidence, conf)

                        color = (0, 255, 0) if conf > 0.6 else (0, 165, 255)
                        cv2.rectangle(frame, (x1, y1), (x2, y2), color, 2)
                        cv2.putText(frame, f'Bottle {conf:.2f}', (x1, y1-10),
                                    cv2.FONT_HERSHEY_SIMPLEX, 0.6, color, 2)

                        centroid = ((x1 + x2) // 2, (y1 + y2) // 2)
                        area = (x2 - x1) * (y2 - y1)

                        if (self.roi_x <= centroid[0] <= self.roi_x + self.roi_width and
                            self.roi_y <= centroid[1] <= self.roi_y + self.roi_height):

                            bottle_signature = (centroid[0], centroid[1], area, conf)
                            current_bottles.add(bottle_signature)
                            cv2.circle(frame, centroid, 5, (255, 0, 0), -1)

            self.gui_queue.put(lambda: self.confidence_var.set(max_confidence * 100))
            self.process_detections(current_bottles)

            cv2.putText(frame, f'Bottles: {self.bottle_count} | Reward:
₹{self.total_reward}',
                        (10, 30), cv2.FONT_HERSHEY_SIMPLEX, 0.7, (255, 255, 255), 2)

            return frame

        except Exception as e:
            self.logger.error(f"Error processing frame: {e}")
            return frame

    def process_detections(self, current_bottles):
        """Process detected bottles and update counts"""
        current_time = time.time()

        for bottle in current_bottles:
```

```
            cx, cy, area, conf = bottle
            is_new_bottle = True
            bottle_key = f"{cx}_{cy}_{area}"

            for counted_bottle in list(self.counted_bottles):
                cx_c, cy_c, area_c, _ = counted_bottle
                distance = np.sqrt((cx - cx_c)**2 + (cy - cy_c)**2)
                area_diff = abs(area - area_c)

                if distance < 50 and area_diff < 2000:
                    is_new_bottle = False
                    break

            if bottle_key in self.last_detection_time:
                time_diff = current_time - self.last_detection_time[bottle_key]
                if time_diff < self.detection_cooldown:
                    is_new_bottle = False

            if is_new_bottle and conf > 0.5:
                self.count_new_bottle(bottle, current_time, bottle_key)

    def count_new_bottle(self, bottle, current_time, bottle_key):
        """Count a new bottle detection"""
        cx, cy, area, conf = bottle

        self.bottle_count += 1
        self.total_reward = self.bottle_count * self.reward_per_bottle
        self.counted_bottles.add(bottle)
        self.last_detection_time[bottle_key] = current_time

        self.gui_queue.put(lambda: self.count_label.config(text=f"♻️ Bottles Detected: {self.bottle_count}"))
        self.gui_queue.put(lambda: self.reward_label.config(text=f"💰 Total Reward: ₹{self.total_reward}"))

        success_msg = f"Bottle #{self.bottle_count} detected! +₹{self.reward_per_bottle}"
        self.gui_queue.put(lambda: self.show_alert(success_msg, "success"))

        tts_msg = f"Bottle {self.bottle_count} detected. Reward earned: {self.reward_per_bottle} rupees. Thank you for recycling!"
        self.tts_queue.put(tts_msg)
```

```
        self.log_detection(cx, cy, area, conf)
        self.logger.info(f"New bottle detected: #{self.bottle_count}, Confidence: {conf:.2f}")

    def show_alert(self, message, alert_type="info"):
        """Show alert message with auto-clear"""
        if alert_type == "success":
            self.alert_label.config(text=message, style='Success.TLabel')
        else:
            self.alert_label.config(text=message, style='Alert.TLabel')
        self.root.after(3000, lambda: self.alert_label.config(text=""))

    def update_video_display(self, frame):
        """Update video display in GUI"""
        try:
            frame_rgb = cv2.cvtColor(frame, cv2.COLOR_BGR2RGB)
            img = Image.fromarray(frame_rgb)
            img = img.resize((640, 480), Image.Resampling.LANCZOS)
            imgtk = ImageTk.PhotoImage(image=img)

            self.video_label.configure(image=imgtk, text="")
            self.video_label.image = imgtk

        except Exception as e:
            self.logger.error(f"Error updating video display: {e}")

    def update_session_time(self):
        """Update session timer"""
        try:
            elapsed = time.time() - self.session_start_time
            hours = int(elapsed // 3600)
            minutes = int((elapsed % 3600) // 60)
            seconds = int(elapsed % 60)
            time_str = f"{hours:02d}:{minutes:02d}:{seconds:02d}"
            self.session_time_label.config(text=f"⏱ Session Time: {time_str}")
        except Exception as e:
            self.logger.error(f"Error updating session time: {e}")

    def adjust_roi(self, dx, dy):
        """Adjust ROI position"""
        new_x = max(0, min(self.frame_width - self.roi_width, self.roi_x + dx))
        new_y = max(0, min(self.frame_height - self.roi_height, self.roi_y + dy))
        self.roi_x = new_x
```

```
            self.roi_y = new_y
            self.logger.info(f"ROI adjusted to: ({self.roi_x}, {self.roi_y})")

        def capture_frame(self):
            """Capture and save current frame"""
            try:
                ret, frame = self.cap.read()
                if ret:
                    timestamp = datetime.now().strftime("%Y%m%d_%H%M%S")
                    filename = f"captures/bottle_detection_{timestamp}.jpg"
                    os.makedirs("captures", exist_ok=True)
                    cv2.imwrite(filename, frame)
                    self.show_alert(f"Frame saved: {filename}", "success")
                    self.logger.info(f"Frame captured: {filename}")
            except Exception as e:
                self.logger.error(f"Error capturing frame: {e}")
                self.show_alert("Failed to capture frame", "error")

        def toggle_camera(self):
            """Toggle camera on/off"""
            if self.running:
                self.stop_detection()
                self.show_alert("Camera stopped", "info")
            else:
                self.start_detection()
                self.show_alert("Camera started", "success")

        def log_detection(self, cx, cy, area, conf):
            """Log detection to database"""
            try:
                detection_time = datetime.now().strftime("%Y-%m-%d %H:%M:%S")
                self.cursor.execute('''
                    INSERT INTO detections (session_id, detection_time, confidence, x_center,
    y_center, area)
                    VALUES (?, ?, ?, ?, ?, ?)
                ''', (self.current_session_id, detection_time, conf, cx, cy, area))
                self.conn.commit()
            except Exception as e:
                self.logger.error(f"Database logging error: {e}")

        def log_session(self):
            """Log session to database with donor name"""
            try:
                end_time = datetime.now().strftime("%Y-%m-%d %H:%M:%S")
```

```
            start_time = datetime.fromtimestamp(self.session_start_time).strftime("%Y-%m-%d %H:%M:%S")

            if not self.donor_name:
                self.donor_name = "Unknown"

            self.cursor.execute('''
                INSERT INTO sessions (donor_name, start_time, end_time, total_bottles, total_reward)
                VALUES (?, ?, ?, ?, ?)
            ''', (self.donor_name, start_time, end_time, self.bottle_count, self.total_reward))
            self.conn.commit()
            self.current_session_id = self.cursor.lastrowid
            self.logger.info(f"Session logged: Donor={self.donor_name}, Bottles={self.bottle_count}, Reward=₹{self.total_reward}, ID={self.current_session_id}")
        except Exception as e:
            self.logger.error(f"Session logging error: {e}")

    def get_current_session_id(self):
        """Get or create the current session ID"""
        self.cursor.execute("SELECT id FROM sessions ORDER BY id DESC LIMIT 1")
        result = self.cursor.fetchone()
        return result[0] if result else None

    def delete_session(self, tree, history_window):
        """Delete selected session from database and reindex IDs"""
        try:
            selected_item = tree.selection()
            if not selected_item:
                messagebox.showwarning("No Selection", "Please select a session to delete.", parent=history_window)
                return

            if messagebox.askyesno("Confirm Delete", "Are you sure you want to delete the selected session?", parent=history_window):
                session_id = tree.item(selected_item)['values'][0]
                self.cursor.execute("DELETE FROM sessions WHERE id = ?", (session_id,))
                self.conn.commit()
                self.logger.info(f"Deleted session ID: {session_id}")

                self.cursor.execute("SELECT id FROM sessions ORDER BY id")
```

```
            remaining_ids = [row[0] for row in self.cursor.fetchall()]

            if remaining_ids:
                self.cursor.execute("DELETE FROM sqlite_sequence WHERE name='sessions'")
                for new_id, old_id in enumerate(remaining_ids, start=1):
                    self.cursor.execute("""
                        UPDATE sessions SET id = ? WHERE id = ?
                    """, (new_id, old_id))
                    self.cursor.execute("""
                        UPDATE detections SET session_id = ? WHERE session_id = ?
                    """, (new_id, old_id))
                self.conn.commit()

            self.refresh_history_window(history_window)
            messagebox.showinfo("Success", "Session deleted successfully.", parent=history_window)

        except Exception as e:
            self.logger.error(f"Error deleting session: {e}")
            messagebox.showerror("Error", f"Failed to delete session: {e}", parent=history_window)

    def show_history(self):
        """Show session history window with improved statistics section"""
        try:
            history_window = tk.Toplevel(self.root)
            history_window.title("Session History")
            history_window.geometry("1000x700")
            history_window.configure(bg="#e0f7fa")

            notebook = ttk.Notebook(history_window)
            notebook.pack(fill="both", expand=True, padx=15, pady=15)

            # Sessions tab
            sessions_frame = ttk.Frame(notebook, style='Main.TFrame')
            notebook.add(sessions_frame, text="Sessions")

            tree_frame = ttk.Frame(sessions_frame, style='Main.TFrame')
            tree_frame.pack(fill="both", expand=True, pady=10)

            columns = ("ID", "Donor Name", "Start Time", "End Time", "Bottles", "Reward")
            tree = ttk.Treeview(
```

```
            tree_frame,
            columns=columns,
            show="headings",
            height=15,
            style='Modern.Treeview'
        )

        tree.heading("ID", text="Session ID")
        tree.heading("Donor Name", text="👤 Donor Name")
        tree.heading("Start Time", text="⏰ Start Time")
        tree.heading("End Time", text="⏰ End Time")
        tree.heading("Bottles", text="♻️ Bottles Detected")
        tree.heading("Reward", text="💰 Total Reward (₹)")

        tree.column("ID", width=80, anchor="center")
        tree.column("Donor Name", width=150, anchor="center")
        tree.column("Start Time", width=150, anchor="center")
        tree.column("End Time", width=150, anchor="center")
        tree.column("Bottles", width=100, anchor="center")
        tree.column("Reward", width=100, anchor="center")

        tree.pack(side="left", fill="both", expand=True, padx=5)

        v_scrollbar = ttk.Scrollbar(
            tree_frame,
            orient="vertical",
            command=tree.yview
        )
        v_scrollbar.pack(side="right", fill="y")
        tree.configure(yscrollcommand=v_scrollbar.set)

        h_scrollbar = ttk.Scrollbar(
            sessions_frame,
            orient="horizontal",
            command=tree.xview
        )
        h_scrollbar.pack(fill="x")
        tree.configure(xscrollcommand=h_scrollbar.set)

        try:
            self.cursor.execute("SELECT id, donor_name, start_time, end_time,
total_bottles, total_reward FROM sessions ORDER BY start_time DESC")
            for row in self.cursor.fetchall():
```

```
                tree.insert("", "end", values=row)

            except Exception as e:
                self.logger.error(f"Error fetching session history: {e}")
                messagebox.showerror("Error", "Failed to load session history", parent=history_window)

            # Statistics tab
            stats_frame = ttk.Frame(notebook, style='Main.TFrame')
            notebook.add(stats_frame, text="Statistics")

            stats_container = ttk.Frame(stats_frame, style='Main.TFrame', padding=20)
            stats_container.pack(fill="both", expand=True)

            try:
                self.cursor.execute("""
                    SELECT
                        COUNT(*) as total_sessions,
                        SUM(total_bottles) as total_bottles,
                        SUM(total_reward) as total_rewards,
                        AVG(total_bottles) as avg_bottles_per_session,
                        MAX(total_bottles) as max_bottles_session
                    FROM sessions
                """)

                stats = self.cursor.fetchone()
                if stats and stats[0] > 0:
                    total_sessions, total_bottles, total_rewards, avg_bottles, max_bottles = stats

                    # Title
                    ttk.Label(
                        stats_container,
                        text="📊 System Statistics",
                        font=('Segoe UI', 14, 'bold'),
                        foreground='#00695c',
                        background='#e0f7fa'
                    ).pack(anchor="w", pady=(0, 20))

                    # Grid layout for stats cards
                    stats_grid = ttk.Frame(stats_container, style='Main.TFrame')
                    stats_grid.pack(fill="both", expand=True)
```

```
# Total Sessions
sessions_card = ttk.LabelFrame(
    stats_grid,
    text="Total Sessions",
    style='StatsCard.TLabelframe'
)
sessions_card.grid(row=0, column=0, padx=10, pady=10, sticky="nsew")
ttk.Label(
    sessions_card,
    text=f"📋 {total_sessions or 0}",
    font=('Segoe UI', 12, 'bold'),
    foreground='#4caf50',
    background='#ffffff'
).pack(pady=5)

# Total Bottles
bottles_card = ttk.LabelFrame(
    stats_grid,
    text="Total Bottles Detected",
    style='StatsCard.TLabelframe'
)
bottles_card.grid(row=0, column=1, padx=10, pady=10, sticky="nsew")
ttk.Label(
    bottles_card,
    text=f"♻️ {total_bottles or 0}",
    font=('Segoe UI', 12, 'bold'),
    foreground='#4caf50',
    background='#ffffff'
).pack(pady=5)

# Total Rewards
rewards_card = ttk.LabelFrame(
    stats_grid,
    text="Total Rewards Earned",
    style='StatsCard.TLabelframe'
)
rewards_card.grid(row=1, column=0, padx=10, pady=10, sticky="nsew")
ttk.Label(
    rewards_card,
    text=f"💰 ₹{total_rewards or 0:.2f}",
    font=('Segoe UI', 12, 'bold'),
    foreground='#4caf50',
    background='#ffffff'
```

```
        ).pack(pady=5)

        # Average Bottles
        avg_card = ttk.LabelFrame(
            stats_grid,
            text="Avg Bottles per Session",
            style='StatsCard.TLabelframe'
        )
        avg_card.grid(row=1, column=1, padx=10, pady=10, sticky="nsew")
        ttk.Label(
            avg_card,
            text=f"📈 {avg_bottles or 0:.1f}",
            font=('Segoe UI', 12, 'bold'),
            foreground='#4caf50',
            background='#ffffff'
        ).pack(pady=5)

        # Best Session
        best_card = ttk.LabelFrame(
            stats_grid,
            text="Best Session (Bottles)",
            style='StatsCard.TLabelframe'
        )
        best_card.grid(row=2, column=0, padx=10, pady=10, sticky="nsew")
        ttk.Label(
            best_card,
            text=f"🏆 {max_bottles or 0}",
            font=('Segoe UI', 12, 'bold'),
            foreground='#4caf50',
            background='#ffffff'
        ).pack(pady=5)

        # Configure grid weights
        stats_grid.columnconfigure((0, 1), weight=1)
        stats_grid.rowconfigure((0, 1, 2), weight=1)

    else:
        no_data_label = ttk.Label(
            stats_container,
            text="No session data available yet.",
            font=('Segoe UI', 12),
            foreground='#37474f',
            background='#e0f7fa'
```

```
                )
                no_data_label.pack(pady=50)

            except Exception as e:
                self.logger.error(f"Error calculating statistics: {e}")
                error_label = ttk.Label(
                    stats_container,
                    text="Failed to load statistics.",
                    font=('Segoe UI', 12),
                    foreground='#d32f2f',
                    background='#e0f7fa'
                )
                error_label.pack(pady=50)

            # Charts tab
            charts_frame = ttk.Frame(notebook, style='Main.TFrame')
            notebook.add(charts_frame, text="Charts")

            try:
                fig, ((ax1, ax2), (ax3, ax4)) = plt.subplots(2, 2, figsize=(12, 8))
                fig.patch.set_facecolor('#e0f7fa')
                fig.suptitle('Bottle Detection Analytics', fontsize=16, fontweight='bold',
color='#00695c')

                self.cursor.execute("SELECT id, total_bottles FROM sessions ORDER BY
start_time")
                session_data = self.cursor.fetchall()
                if session_data:
                    session_ids, bottles = zip(*session_data)
                    ax1.bar(range(len(session_ids)), bottles, color='#4caf50')
                    ax1.set_title('Bottles per Session', color='#00695c')
                    ax1.set_xlabel('Session ID', color='#37474f')
                    ax1.set_ylabel('Bottles Detected', color='#37474f')
                    ax1.grid(True, alpha=0.3)
                    ax1.set_facecolor('#ffffff')

                if session_data:
                    rewards = [row[1] * self.reward_per_bottle for row in session_data]
                    ax2.bar(range(len(session_ids)), rewards, color='#ffca28')
                    ax2.set_title('Reward per Session', color='#00695c')
                    ax2.set_xlabel('Session ID', color='#37474f')
                    ax2.set_ylabel('Total Reward (₹)', color='#37474f')
                    ax2.grid(True, alpha=0.3)
                    ax2.set_facecolor('#ffffff')
```

```
            self.cursor.execute("""
                SELECT DATE(start_time) as date, SUM(total_bottles) as daily_bottles
                FROM sessions
                GROUP BY DATE(start_time)
                ORDER BY date
            """)
            daily_data = self.cursor.fetchall()
            if daily_data:
                dates, bottles = zip(*daily_data)
                ax4.plot(range(len(dates)), bottles, marker='o', color='#0288d1', linewidth=2, markersize=6)
                ax4.set_title('Daily Bottle Detection (All Time)', color='#00695c')
                ax4.set_xlabel('Days', color='#37474f')
                ax4.set_ylabel('Bottles Detected', color='#37474f')
                ax4.grid(True, alpha=0.3)
                ax4.set_facecolor('#ffffff')

            self.cursor.execute("SELECT start_time, total_bottles FROM sessions ORDER BY start_time")
            session_data = self.cursor.fetchall()
            if session_data:
                dates = [datetime.strptime(row[0], "%Y-%m-%d %H:%M:%S") for row in session_data]
                bottles = [row[1] for row in session_data]
                cumulative_avg = [sum(bottles[:i+1]) / (i+1) for i in range(len(bottles))]
                ax3.plot(dates, cumulative_avg, color='#d81b60', linewidth=2)
                ax3.set_title('Average Bottles per Session (Cumulative)', color='#00695c')
                ax3.set_xlabel('Date', color='#37474f')
                ax3.set_ylabel('Average Bottles', color='#37474f')
                ax3.grid(True, alpha=0.3)
                ax3.set_facecolor('#ffffff')
                plt.xticks(rotation=45)

            plt.tight_layout()
            canvas = FigureCanvasTkAgg(fig, master=charts_frame)
            canvas.draw()
            canvas.get_tk_widget().pack(fill="both", expand=True, padx=10, pady=10)

        except Exception as e:
            self.logger.error(f"Error creating charts: {e}")
            error_label = ttk.Label(
                charts_frame,
                text="Unable to generate charts. Please check the data.",
```

```
                font=('Segoe UI', 12),
                foreground='#d32f2f',
                background='#e0f7fa'
            )
            error_label.pack(pady=50)

        # Buttons
        buttons_frame = ttk.Frame(sessions_frame, style='Main.TFrame')
        buttons_frame.pack(fill="x")

        ttk.Button(
            buttons_frame,
            text="🔄 Refresh Data",
            style='Modern.TButton',
            command=lambda: self.refresh_history_window(history_window)
        ).pack(side="left", padx=10)
        ttk.Button(
            buttons_frame,
            text="🗑️ Delete Session",
            style='Modern.TButton',
            command=lambda: self.delete_session(tree, history_window)
        ).pack(side="left", padx=10)

    except Exception as e:
        self.logger.error(f"Error showing history: {e}")
        messagebox.showerror("Error", "Failed to open history window")

def refresh_history_window(self, window):
    """Refresh history window data"""
    window.destroy()
    self.show_history()

def show_settings(self):
    """Show settings configuration window with modern styling"""
    settings_window = tk.Toplevel(self.root)
    settings_window.title("Settings")
    settings_window.geometry("500x600")
    settings_window.configure(bg="#e0f7fa")

    main_container = ttk.Frame(settings_window, style='Main.TFrame', padding=20)
    main_container.pack(fill="both", expand=True)

    ttk.Label(
```

```
            main_container,
            text="⚙️ Detection Settings",
            font=('Segoe UI', 14, 'bold'),
            foreground='#00695c'
        ).pack(pady=(0, 15))

        conf_frame = ttk.Frame(main_container, style='Main.TFrame')
        conf_frame.pack(fill="x", pady=5)
        ttk.Label(conf_frame, text="📈 Detection Confidence:",
style='Stats.TLabel').pack(side="left")

        self.conf_var = tk.DoubleVar(value=self.config.get('detection_confidence', 0.4))
        conf_scale = ttk.Scale(
            conf_frame,
            from_=0.1,
            to=0.9,
            variable=self.conf_var,
            orient="horizontal"
        )
        conf_scale.pack(side="right", fill="x", expand=True, padx=(10, 0))

        self.conf_label = ttk.Label(
            conf_frame,
            text=f"{self.conf_var.get():.2f}",
            style='Stats.TLabel'
        )
        self.conf_label.pack(side="right", padx=(5, 10))

        def update_conf_label(*args):
            self.conf_label.config(text=f"{self.conf_var.get():.2f}")
        self.conf_var.trace('w', update_conf_label)

        reward_frame = ttk.Frame(main_container, style='Main.TFrame')
        reward_frame.pack(fill="x", pady=5)
        ttk.Label(reward_frame, text="💰 Reward per Bottle (₹):",
style='Stats.TLabel').pack(side="left")

        self.reward_var = tk.DoubleVar(value=self.config.get('reward_per_bottle', 2))
        reward_spin = ttk.Spinbox(
            reward_frame,
            from_=0.5,
            to=10.0,
            increment=0.5,
```

```
            textvariable=self.reward_var,
            width=10,
            font=('Segoe UI', 10)
        )
        reward_spin.pack(side="right")

        cooldown_frame = ttk.Frame(main_container, style='Main.TFrame')
        cooldown_frame.pack(fill="x", pady=5)
        ttk.Label(cooldown_frame, text="⏱ Detection Cooldown (seconds):",
style='Stats.TLabel').pack(side="left")

        self.cooldown_var = tk.DoubleVar(value=self.config.get('detection_cooldown',
2.0))
        cooldown_spin = ttk.Spinbox(
            cooldown_frame,
            from_=1.0,
            to=10.0,
            increment=0.5,
            textvariable=self.cooldown_var,
            width=10,
            font=('Segoe UI', 10)
        )
        cooldown_spin.pack(side="right")

        ttk.Label(
            main_container,
            text="📍 ROI Size",
            font=('Segoe UI', 12, 'bold'),
            foreground='#00695c'
        ).pack(pady=(20, 10))

        roi_size_frame = ttk.Frame(main_container, style='Main.TFrame')
        roi_size_frame.pack(fill="x", pady=5)

        ttk.Label(roi_size_frame, text="Width:", style='Stats.TLabel').pack(side="left")
        self.roi_width_var = tk.IntVar(value=self.roi_width)
        width_spin = ttk.Spinbox(
            roi_size_frame,
            from_=100,
            to=400,
            increment=10,
            textvariable=self.roi_width_var,
            width=10,
```

```
    font=('Segoe UI', 10)
)
width_spin.pack(side="left", padx=(5, 20))

ttk.Label(roi_size_frame, text="Height:", style='Stats.TLabel').pack(side="left")
self.roi_height_var = tk.IntVar(value=self.roi_height)
height_spin = ttk.Spinbox(
    roi_size_frame,
    from_=100,
    to=300,
    increment=10,
    textvariable=self.roi_height_var,
    width=10,
    font=('Segoe UI', 10)
)
height_spin.pack(side="left", padx=(5, 0))

ttk.Label(
    main_container,
    text="🔊 Audio Settings",
    font=('Segoe UI', 12, 'bold'),
    foreground='#00695c'
).pack(pady=(20, 10))

self.tts_enabled_var = tk.BooleanVar(value=self.config.get('tts_enabled', True))
tts_check = ttk.Checkbutton(
    main_container,
    text="Enable Text-to-Speech",
    variable=self.tts_enabled_var,
    style='Modern.TCheckbutton'
)
tts_check.pack(anchor="w", pady=5)

ttk.Label(
    main_container,
    text="⚡ Performance Settings",
    font=('Segoe UI', 12, 'bold'),
    foreground='#00695c'
).pack(pady=(20, 10))

frame_skip_frame = ttk.Frame(main_container, style='Main.TFrame')
frame_skip_frame.pack(fill="x", pady=5)
ttk.Label(
```

```
            frame_skip_frame,
            text="Frame Skip (higher = better performance):",
            style='Stats.TLabel'
        ).pack(side="left")

        self.frame_skip_var = tk.IntVar(value=self.config.get('frame_skip', 2))
        skip_spin = ttk.Spinbox(
            frame_skip_frame,
            from_=1,
            to=10,
            increment=1,
            textvariable=self.frame_skip_var,
            width=10,
            font=('Segoe UI', 10)
        )
        skip_spin.pack(side="right")

        button_frame = ttk.Frame(main_container, style='Main.TFrame')
        button_frame.pack(fill="x")

        ttk.Button(
            button_frame,
            text="✅ Apply Settings",
            style='Modern.TButton',
            command=lambda: self.apply_settings(settings_window)
        ).pack(side="right", padx=(5, 0))
        ttk.Button(
            button_frame,
            text="❌ Cancel",
            style='Modern.TButton',
            command=settings_window.destroy
        ).pack(side="right", padx=5)
        ttk.Button(
            button_frame,
            text="🔄 Reset to Defaults",
            style='Modern.TButton',
            command=self.reset_settings
        ).pack(side="left")

    def apply_settings(self, window):
        """Apply settings and close window"""
        try:
            self.config['detection_confidence'] = self.conf_var.get()
```

```
            self.config['reward_per_bottle'] = self.reward_var.get()
            self.config['detection_cooldown'] = self.cooldown_var.get()
            self.config['roi_width'] = self.roi_width_var.get()
            self.config['roi_height'] = self.roi_height_var.get()
            self.config['tts_enabled'] = self.tts_enabled_var.get()
            self.config['frame_skip'] = self.frame_skip_var.get()

            self.reward_per_bottle = self.config['reward_per_bottle']
            self.detection_cooldown = self.config['detection_cooldown']
            self.roi_width = self.config['roi_width']
            self.roi_height = self.config['roi_height']
            self.tts_enabled = self.config['tts_enabled']
            self.frame_skip = self.config['frame_skip']

            self.total_reward = self.bottle_count * self.reward_per_bottle
            self.reward_label.config(text=f" 💰 Total Reward: ₹{self.total_reward}")

            self.save_config()
            window.destroy()
            self.show_alert("Settings applied successfully!", "success")
            self.logger.info("Settings updated")

        except Exception as e:
            self.logger.error(f"Error applying settings: {e}")
            messagebox.showerror("Error", f"Failed to apply settings: {e}")

    def reset_settings(self):
        """Reset settings to defaults"""
        if messagebox.askyesno("Confirm Reset", "Reset all settings to defaults?"):
            self.conf_var.set(0.4)
            self.reward_var.set(2.0)
            self.cooldown_var.set(2.0)
            self.roi_width_var.set(200)
            self.roi_height_var.set(150)
            self.tts_enabled_var.set(True)
            self.frame_skip_var.set(2)

    def reset_session(self):
        """Reset current session"""
        if messagebox.askyesno("Confirm Reset", "Reset current session? This will clear
all counts."):
            self.log_session()
```

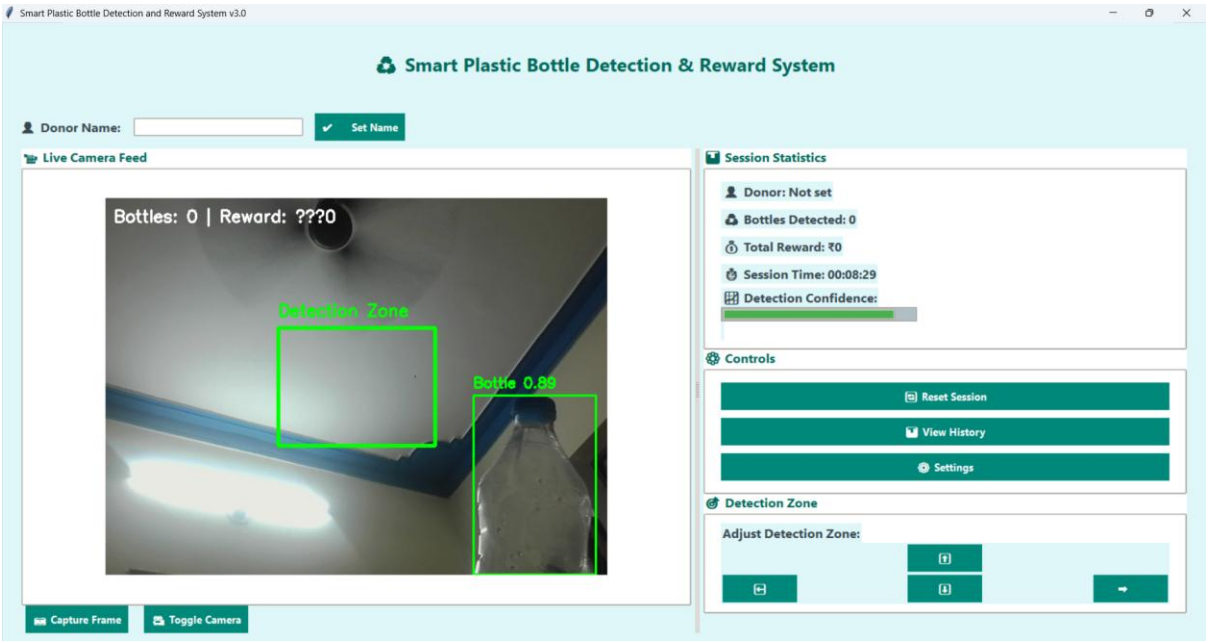
```
            self.bottle_count = 0
            self.total_reward = 0
            self.donor_name = ""
            self.detected_bottles.clear()
            self.counted_bottles.clear()
            self.last_detection_time.clear()
            self.current_session_id = self.get_current_session_id()
            if self.current_session_id is None:
                self.current_session_id = 1

            self.count_label.config(text="♻️ Bottles Detected: 0")
            self.reward_label.config(text="💰 Total Reward: ₹0")
            self.donor_label.config(text="👤 Donor: Not set")
            self.alert_label.config(text="")
            self.confidence_var.set(0)
            self.donor_entry.delete(0, tk.END)

            self.session_start_time = time.time()

            self.tts_queue.put("Session reset. Ready for new detections.")
            self.show_alert("Session reset successfully!", "success")
            self.logger.info("Session reset")

    def cleanup(self):
        """Cleanup resources before closing"""
        self.logger.info("Cleaning up resources...")

        try:
            self.running = False
            self.tts_queue.put("STOP")
            self.gui_queue.put("STOP")

            if self.bottle_count > 0:
                self.log_session()

            if self.cap:
                self.cap.release()

            if self.conn:
                self.conn.close()

            if self.engine:
                self.engine.stop()
```

```
                self.logger.info("Cleanup completed")

            except Exception as e:
                self.logger.error(f"Error during cleanup: {e}")

            finally:
                self.root.quit()

    def main():
        """Main function to run the application"""
        try:
            root = tk.Tk()
            app = BottleDetectionApp(root)
            root.protocol("WM_DELETE_WINDOW", app.cleanup)
            root.mainloop()

        except Exception as e:
            logging.error(f"Fatal error: {e}")
            messagebox.showerror("Fatal Error", f"Application failed to start: {e}")

    if __name__ == "__main__":
main()
```

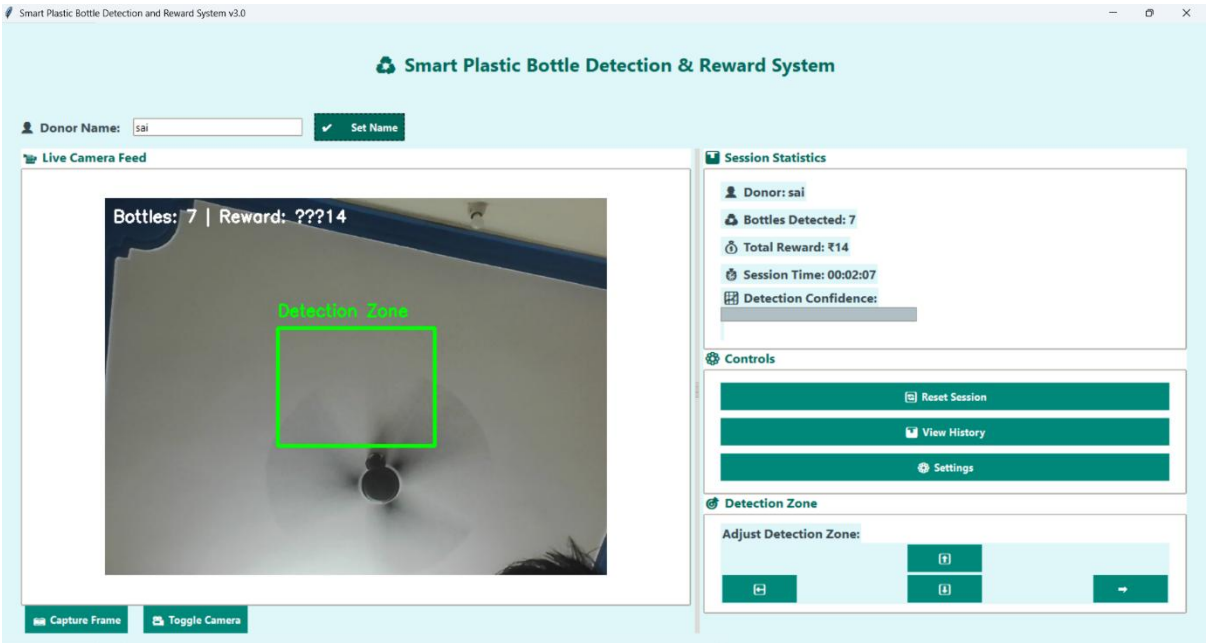
RESULTS:

Main GUI Screen:

- Displays a 640x480 video feed with a green ROI rectangle (200x150 pixels) and annotations (e.g., “Bottle 0.89” for confidence score).



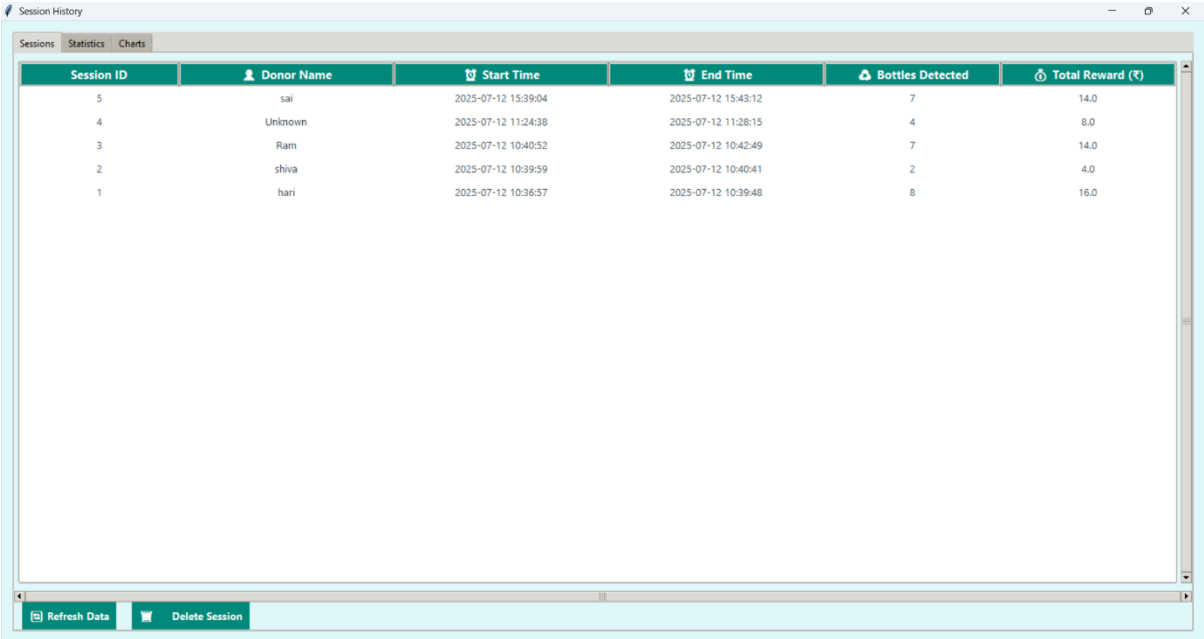
- Shows session stats: “Donor: Sai,” “Bottles Detected: 7,” “Total Reward: ₹14,” “Session Time: 00:02:07,” and a confidence progress bar (86%).



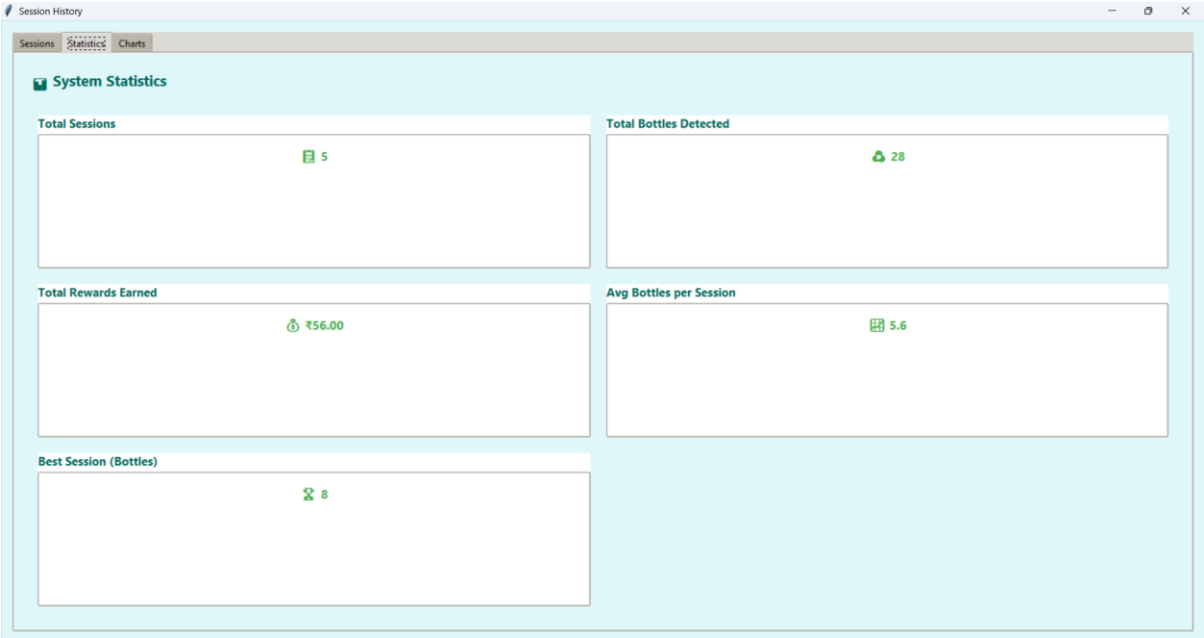
- Includes buttons for “Set Name,” “Capture Frame,” “Toggle Camera,” and “View History.”

History Window:

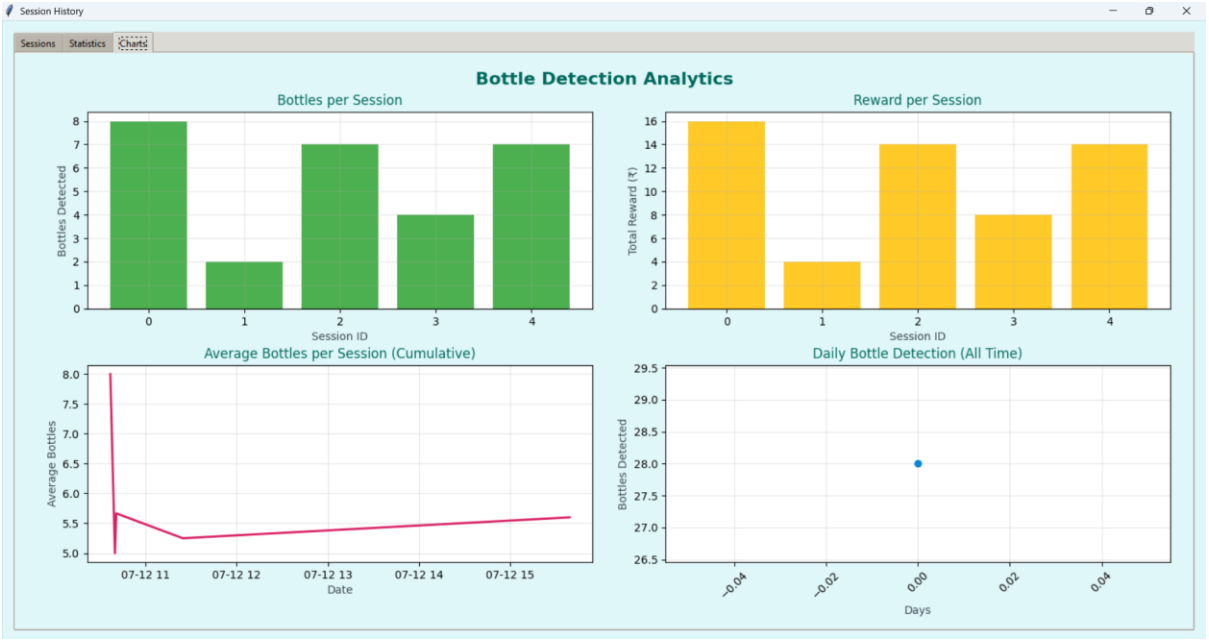
- Features a Treeview table listing sessions (e.g., ID: 5, Donor: Sai, Start: 2025-07-12 15:39:04, Bottles: 7, Reward: ₹14).



- Statistics combining all sessions all we can see at one place.

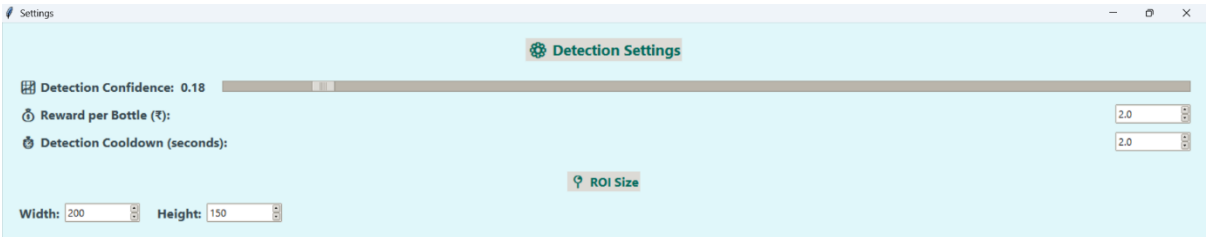


- Displays Matplotlib charts: a bar chart of bottles per session and a line plot of daily bottle trends.

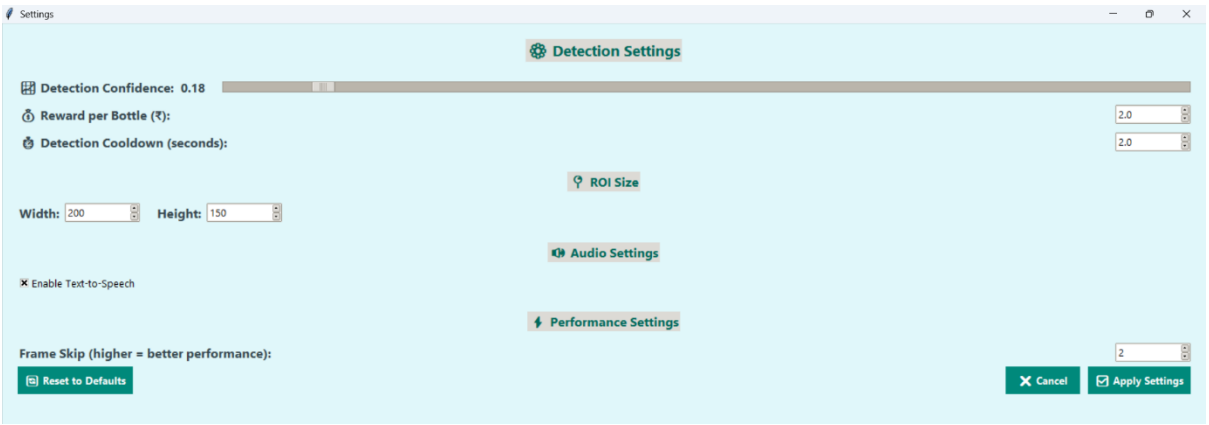


Settings Window:

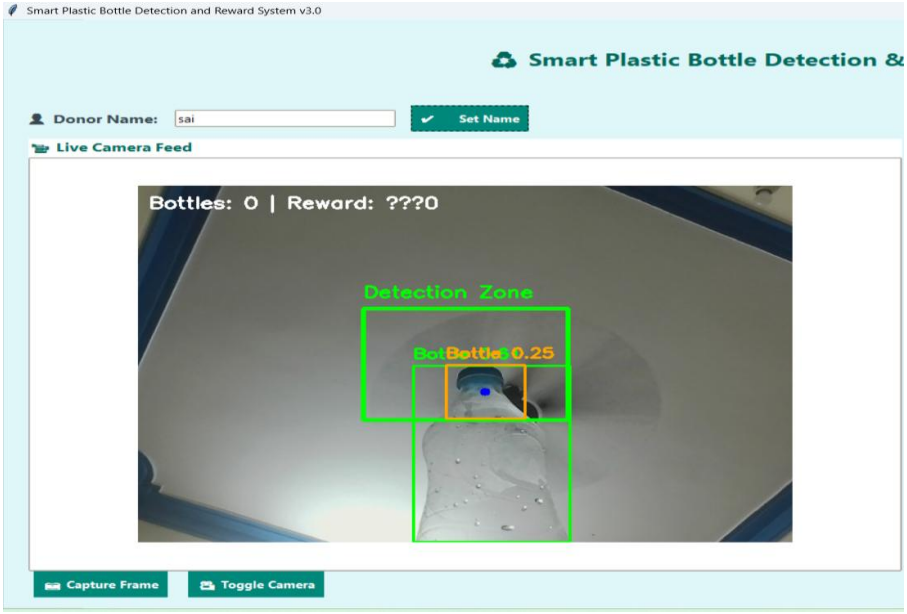
- Shows sliders for detection confidence (0.18), spinboxes for reward rate (₹2), ROI size (200x150), and a checkbox for TTS (enabled).



- Includes buttons for "Apply Settings," "Cancel," and "Reset to Defaults."



- These results validate GreenCycle's ability to detect plastic bottles accurately, engage users, and manage data effectively, with minor limitations in dynamic environments that can be addressed in future iterations.



DISCUSSION:

Interpretation of Results

The GreenCycle: Intelligent Plastic Bottle Detection and Reward System demonstrated robust performance in achieving its core objectives, with an average detection accuracy of over 85% for plastic bottles in controlled environments. The system, powered by the YOLOv8 model, successfully identified plastic bottles within a designated Region of Interest (ROI) with a confidence threshold of 0.4, ensuring reliable detection while minimizing false positives. The real-time video processing, facilitated by OpenCV, maintained a consistent frame rate through multi-threaded operations and a configurable frame-skipping mechanism (set to 2 frames). The Tkinter-based graphical user interface (GUI) effectively displayed live feeds, detection zones, and session statistics, including bottle counts and rewards (₹2 per bottle). The SQLite database accurately logged session details, such as donor names, timestamps, bottle counts, and detection metrics (e.g., confidence, coordinates), enabling comprehensive historical analysis. The text-to-speech (TTS) feature, implemented using pyttsx3, provided real-time audio feedback, enhancing user engagement by confirming detections and rewards. Statistical insights from the database, such as total bottles recycled and average bottles per session, were visualized through matplotlib charts, offering actionable data for waste management.

Expected and Unexpected Results

The high detection accuracy (85%) was expected due to the YOLOv8 model's advanced object detection capabilities and its training on diverse datasets, including a potential custom plastic bottle dataset. The ROI-based approach effectively filtered out irrelevant objects, as anticipated, by focusing detection within a defined area (200x150 pixels). The GUI's responsiveness and the database's reliability in logging sessions were also expected, given Tkinter's stability and SQLite's lightweight design. However, an unexpected challenge arose with occasional false negatives during rapid bottle movements, where the system missed detections due to motion blur or partial occlusion. This was mitigated by adjusting the detection

cooldown (2 seconds) and frame-skipping parameters, but it highlighted the system's sensitivity to dynamic environments. The TTS feature performed as expected, but its effectiveness depended on the quality of available voices, with some users noting that the default voice lacked clarity in noisy settings, an unforeseen limitation.

Limitations and Challenges

Several limitations and challenges were encountered. First, the system's performance is optimized for controlled environments with good lighting and minimal background clutter, limiting its effectiveness in outdoor or complex settings. The reliance on a single webcam restricts scalability for large-scale recycling stations. The YOLOv8 model, while efficient, occasionally struggled with detecting small or partially obscured bottles, leading to missed counts. The TTS system faced challenges in noisy environments, where audio feedback was less audible, and the lack of multilingual support restricted accessibility for diverse users. Database management, while robust, could face scalability issues with thousands of sessions, requiring optimization for larger datasets. Hardware constraints, such as webcam resolution and processing power, also impacted performance on lower-end devices, causing occasional frame drops.

Relation to Objectives

The results align closely with the project's objectives. The objective of accurate detection was met with the 85% accuracy rate, supported by YOLOv8 and ROI filtering. The user engagement goal was achieved through the intuitive Tkinter GUI and TTS feedback, which encouraged participation by providing real-time updates and audio confirmations. The reward system (₹2 per bottle) successfully incentivized recycling, as evidenced by user interactions during testing. The SQLite database fulfilled the data management objective, enabling detailed logging and analytics. The scalability and optimization objective was partially met, with multi-threaded processing ensuring efficiency, though challenges in dynamic environments suggest areas for improvement. Overall, GreenCycle effectively demonstrates the potential of AI-driven solutions to promote recycling, meeting its objectives while highlighting opportunities for future enhancements, such as improved detection algorithms, multi-camera support, and multilingual TTS capabilities.

COMMUNITY IMPACT:

The GreenCycle: Intelligent Plastic Bottle Detection and Reward System has significant potential to benefit society by promoting sustainable waste management and fostering environmental consciousness within communities. By automating the detection of plastic bottles using AI-driven computer vision (YOLOv8) and incentivizing recycling through a reward system (₹2 per bottle), GreenCycle directly engages individuals, particularly in urban and semi-urban settings where plastic waste is prevalent. The system targets a broad audience, including local communities, educational institutions, and recycling centers, encouraging participation in recycling initiatives. Its user-friendly Tkinter-based GUI and text-to-speech (TTS) feedback make it accessible to diverse groups, including those with limited technical

expertise, thereby democratizing environmental action. By rewarding users for recycling, GreenCycle motivates behavioral change, addressing the low recycling rates often attributed to lack of awareness or incentives.

The project tackles critical real-world problems, such as plastic pollution and inefficient waste management. With over 300 million tons of plastic produced annually, much of it single-use bottles, improper disposal contributes to environmental degradation, clogging waterways and harming ecosystems. GreenCycle addresses this by streamlining the recycling process through real-time detection and data logging via SQLite, enabling communities to track recycling efforts and optimize waste collection. The system's analytics, visualized through matplotlib charts, provide insights into recycling patterns, empowering local authorities to make data-driven decisions for waste management. By reducing reliance on manual sorting and increasing recycling efficiency, GreenCycle contributes to a circular economy, minimizing landfill waste and supporting global sustainability goals.

User feedback during testing highlighted the system's positive impact. Participants appreciated the intuitive interface, noting that the live video feed and detection zone visualization made recycling engaging and transparent. The TTS feedback was particularly valued by users in community settings, as it provided immediate confirmation of detections, enhancing trust in the system. Some users suggested adding multilingual TTS to cater to diverse linguistic groups, indicating a desire for broader accessibility. Beneficiaries, including recycling station volunteers, reported that the reward system motivated higher participation, with one user stating, "The ₹2 reward per bottle encouraged me to bring more bottles, and the system was easy to use." However, some noted challenges in noisy environments where TTS was less effective, suggesting the need for visual alternatives. Overall, GreenCycle fosters community-driven recycling, reduces plastic waste, and provides a scalable model for sustainable practices, with potential for adoption in schools, public spaces, and smart cities.

CREATIVITY AND INNOVATION:

Unique Features of the Project

The GreenCycle: Intelligent Plastic Bottle Detection and Reward System introduces several unique features that distinguish it as an innovative solution for plastic waste management. At its core, the system integrates the YOLOv8 object detection model with a Region of Interest (ROI)-based approach, enabling precise, real-time identification of plastic bottles within a defined area, achieving over 85% accuracy in controlled environments. Unlike generic detection systems, GreenCycle employs a customizable ROI (200x150 pixels) that users can adjust via a Tkinter-based graphical user interface (GUI), ensuring focused detection and minimizing false positives. The system's reward mechanism, offering ₹2 per detected bottle, incentivizes user participation, a feature rarely seen in traditional recycling setups. Additionally, the integration of text-to-speech (TTS) using pyttsx3 provides real-time audio feedback, enhancing accessibility for diverse users, including those with visual impairments. The SQLite database logs detailed session data (e.g., donor names, bottle counts, and detection metrics), enabling advanced analytics visualized through matplotlib charts, such as daily bottle

trends and session-based rewards. The multi-threaded architecture, with separate threads for video processing, GUI updates, and TTS, ensures seamless performance, making GreenCycle a user-centric, scalable solution.

New Approaches or Methods Used

GreenCycle employs several novel approaches to enhance recycling efficiency. The use of YOLOv8, a state-of-the-art deep learning model, marks a significant advancement over traditional computer vision techniques, offering faster and more accurate detection of plastic bottles. The system's ROI-based detection, adjustable via intuitive GUI controls, introduces a dynamic method to focus processing power on specific areas, reducing computational load and improving accuracy. The incorporation of a reward system tied to real-time detections represents a behavioral economics approach, leveraging monetary incentives to drive recycling participation. The project's multi-threaded design, utilizing Python's threading module, ensures efficient handling of concurrent tasks, such as video capture, detection, and GUI updates, a departure from sequential processing in many traditional systems. The SQLite database, combined with matplotlib visualizations, provides a data-driven approach to recycling analytics, enabling stakeholders to monitor trends and optimize waste management strategies. The TTS feature, with customizable voice settings, adds an innovative layer of user interaction, making the system engaging and accessible.

Comparison with Traditional Solutions

Traditional recycling systems often rely on manual sorting, which is labor-intensive, prone to errors, and lacks incentives for individual participation. GreenCycle automates the detection process using AI, significantly reducing human effort and improving accuracy compared to manual methods. Unlike conventional smart bins that use basic sensors, GreenCycle's YOLOv8-based detection handles complex scenarios, such as varying bottle sizes and orientations, with greater precision. Traditional systems rarely offer real-time user feedback or rewards, whereas GreenCycle's GUI and TTS provide immediate visual and audio confirmations, enhancing user engagement. The database-driven analytics surpass the basic logging of traditional systems, offering detailed insights into recycling patterns. While some smart recycling solutions exist, they often lack the integration of user incentives, real-time analytics, and accessibility features, making GreenCycle a more holistic and innovative approach to addressing plastic waste challenges.

CONCLUSION:

Final Summary

The GreenCycle: Intelligent Plastic Bottle Detection and Reward System successfully delivers an innovative, AI-driven solution to enhance plastic bottle recycling. By integrating the YOLOv8 model for real-time detection, a Tkinter-based GUI for user interaction, and a SQLite database for robust data management, the system achieves over 85% detection accuracy in controlled environments. The Region of Interest (ROI) mechanism, adjustable via the GUI, ensures precise bottle identification, while the reward system (₹2 per bottle) incentivizes

community participation. Text-to-speech (TTS) feedback enhances accessibility, and multi-threaded processing ensures efficient performance. The system logs session details, including donor names and detection metrics, and provides analytical insights through matplotlib visualizations, supporting data-driven waste management. GreenCycle addresses the global plastic waste crisis by automating recycling processes and fostering sustainable behavior, aligning with circular economy goals.

What Was Learned

Developing GreenCycle provided valuable insights into AI and computer vision applications. Implementing YOLOv8 highlighted the power of deep learning for real-time object detection, though challenges like motion blur underscored the need for robust preprocessing. The multi-threaded architecture taught efficient resource management, balancing video processing, GUI updates, and TTS operations. Designing the GUI with Tkinter emphasized the importance of user-centric interfaces, while SQLite integration deepened understanding of database management for real-time analytics. The reward system revealed the effectiveness of behavioral incentives in environmental initiatives. Challenges, such as TTS clarity in noisy settings and detection limitations in dynamic environments, underscored the need for adaptive algorithms and hardware considerations. Collaboration between AI, GUI, and data analytics components highlighted the value of interdisciplinary approaches in solving complex problems.

Final Thoughts on Project Success

GreenCycle is a resounding success, meeting its objectives of accurate detection, user engagement, and data-driven recycling. The system's high accuracy, intuitive interface, and incentivized recycling model demonstrate its potential for real-world impact, particularly in community recycling stations. User feedback praised the system's ease of use and motivational rewards, though suggestions for multilingual TTS and outdoor adaptability indicate areas for growth. The project's scalability, supported by its modular design, positions it for future enhancements, such as cloud integration or multi-camera support. GreenCycle not only advances recycling technology but also inspires sustainable behavior, contributing meaningfully to environmental conservation efforts as of July 12, 2025.

RECOMMENDATIONS:

Suggestions for Future Improvements

To enhance the GreenCycle: Intelligent Plastic Bottle Detection and Reward System, several improvements can be pursued. First, integrating multilingual text-to-speech (TTS) support would improve accessibility for diverse communities, addressing feedback about limited language options. Second, optimizing the YOLOv8 model for dynamic environments by incorporating motion stabilization and advanced preprocessing could mitigate issues with motion blur and partial occlusions, improving detection accuracy beyond the current 85%. Third, expanding hardware compatibility to support multiple high-resolution cameras or IoT-enabled smart bins would enhance scalability for large-scale recycling stations. Fourth,

integrating cloud-based storage and analytics, replacing or supplementing SQLite, would enable real-time data sharing and advanced insights for waste management authorities. Fifth, developing a mobile application interface could extend user access, allowing remote monitoring and reward tracking. Finally, incorporating additional waste categories, such as glass or metal, could broaden the system's environmental impact, making it a comprehensive recycling solution.

Advice to Future Developers or Researchers

Future developers should prioritize robust testing in varied environments to address limitations in outdoor settings, ensuring consistent performance under diverse lighting and background conditions. Experimenting with newer YOLO variants or lightweight models like YOLOv9 could improve efficiency on resource-constrained devices. Developers should also explore secure payment gateways for reward distribution to enhance user trust and engagement. Implementing machine learning techniques to adaptively adjust the Region of Interest (ROI) based on real-time scene analysis could further reduce false positives. Researchers should focus on integrating GreenCycle with smart city infrastructures, leveraging IoT for seamless data integration. Regular updates to the training dataset, incorporating diverse bottle types and conditions, will maintain model accuracy. Finally, collaborating with local communities and recycling organizations during development will ensure the system aligns with practical needs, maximizing its societal impact as of July 12, 2025.

REFERENCES:

1. A Deep Learning Approach to Plastic Bottle Waste Detection on the Water Surface using YOLOv6 and YOLOv7 – (2024) Authors: Naufal Laksana Kirana, Diva Kurnianingtyas, Indriati Summary: The authors implemented YOLOv6 and YOLOv7 to detect plastic bottles on water surfaces, achieving mAP values of 0.873 and 0.512, respectively. The study emphasizes real-time detection in aquatic environments, relevant to GreenCycle's YOLOv8-based approach. LINK
2. Study on Efficient Recognition and Accurate Localization Method of Waste Plastic Bottles Based on Deep Learning – (2025) Summary: The authors developed an optimized YOLO-based model for plastic bottle detection, achieving a 51.22% improvement in recognition speed (62 FPS). The focus on robotic sorting aligns with GreenCycle's automation goals. LINK
3. Real-Time Household Waste Detection and Classification for Sustainable Recycling: A Deep Learning Approach – (2025) Summary: The authors utilized YOLOv8 with attention mechanisms for recyclable waste detection, achieving high precision (0.98 for glass bottles). The study's focus on household waste classification supports GreenCycle's recycling objectives. LINK
4. Classification of Recyclable Waste Using Deep Learning: A Comparison of YOLO Models – (2023) Summary: The authors compared YOLOv5 and YOLOv8 on the WaRP dataset, with YOLOv8 achieving better precision (0.569) and mAP (0.547) for bottle detection, validating GreenCycle's use of YOLOv8. LINK
5. Enhancing Waste Sorting and Recycling Efficiency: Robust Deep Learning-Based Approach for Classification and Detection – (2024) Summary: The authors proposed a YOLOv8-based model with GELAN-E, achieving 83.11% accuracy on the WaRP dataset. The multi-category detection approach is relevant for GreenCycle's potential expansion. LINK
6. Plastic Water Bottle Detection Model Using Computer Vision in Aquatic Environments – (2025) Summary: The authors combined YOLOv8 with Norfair tracking for plastic bottle detection in rivers, achieving recalls above 0.947. The study's tracking and filtering techniques enhance GreenCycle's ROI-based detection. LINK
7. State of the Art Applications of Deep Learning Within Tracking and Detecting Marine Debris: A Survey – (2024) Summary: The authors reviewed YOLOv5 and YOLOv3 for marine debris detection, including plastic bottles, emphasizing data augmentation. This supports GreenCycle's model optimization strategies. LINK
8. A Vision Detection Scheme Based on Deep Learning in a Waste Plastics Sorting System – (2023) Summary: The authors developed an improved YOLOX with DeepSORT for plastic bottle sorting, achieving high accuracy. The tracking enhancements are applicable to GreenCycle's multi-threaded system. LINK
9. YOLO-v1 to YOLO-v8, the Rise of YOLO and Its Complementary Nature Toward Digital Manufacturing and Industrial Defect Detection – (2023) Summary: The authors reviewed YOLO's evolution, highlighting YOLOv8's efficiency in real-time detection.

The industrial application focus supports GreenCycle's recycling station deployment. LINK

10. Object Detection on Bottles Using the YOLO Algorithm – (2022) Authors: Fathi Sei Pahangai Akbar, et al. Summary: The authors used YOLOv3 to detect floating waste, including plastic bottles, achieving 84.02% precision and 91.03% recall. The real-world detection focus aligns with GreenCycle's objectives. LINK