Smart Trash Bin Monitoring System

1. Introduction

Every year, inefficient waste-collection leads to unnecessary pickups, added CO_2 emissions, and overflowing public bins. Our **Smart Trash-Bin Fill-Level Monitoring System** uses a VL53L0X Time-of-Flight sensor mounted inside a 41 × 35 × 60 cm^3 bin to measure the fill height, displays the percentage full on an SH1106 OLED, and—when a user-configurable threshold is exceeded—sends alerts via a Telegram bot.

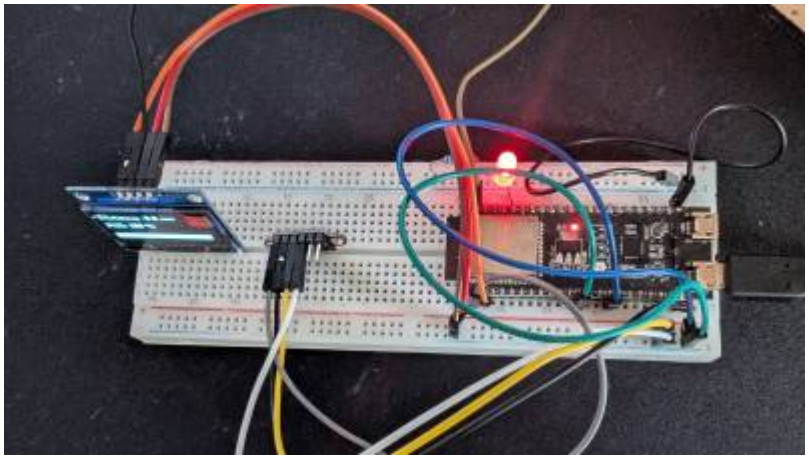
This document walks through each step—hardware assembly (breadboard layout), Arduino IDE firmware, Node-RED flow, Telegram-bot config, and ESP32 simulation—so you can reproduce and extend the system today, then evolve it for outdoor use tomorrow.

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2. Materials & System Overview

2.1. Hardware Components

Component	Purpose
ESP32-S3-DevKitC-1	Main MCU, Wi-Fi, GPIOs
VL53L0X ToF sensor	Measures distance from bin top to contents
SH1106 128×64 I^2C OLED (U8g2 lib)	Displays distance (cm) & fill (%)
LED (GPIO 2)	Visual “almost full” warning
Powerbank (5 V USB)	Supplies 5 V to ESP32 for portable operation
Wires, breadboard, connectors	Prototyping and wiring



2.2. Software Components

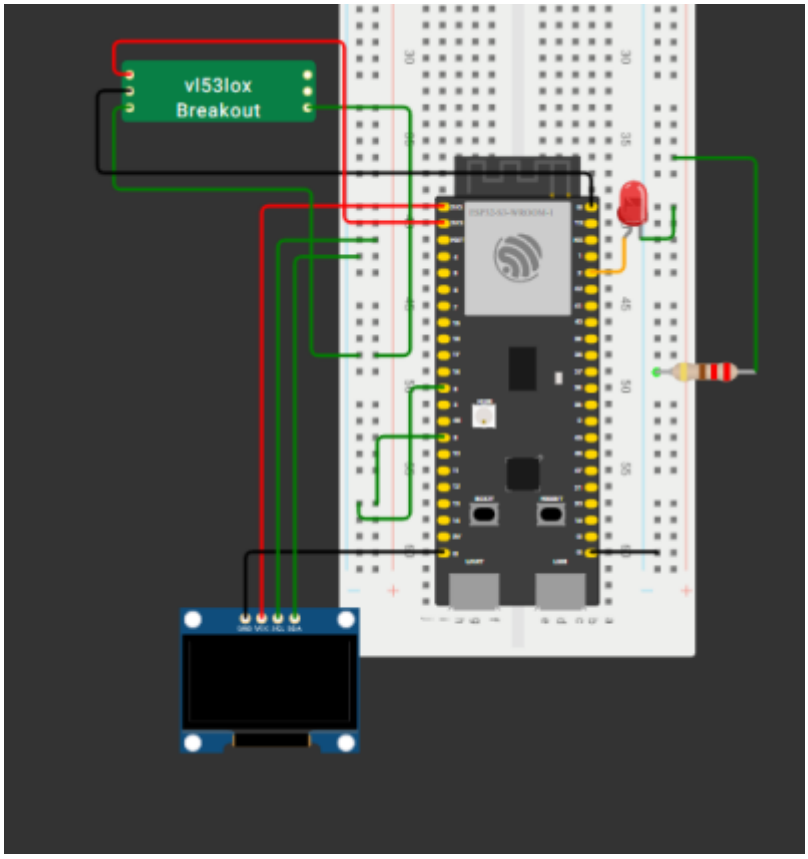
- **Arduino IDE** (v2.x)
- **Libraries**
  - * * Adafruit_VL53L0X – Time-of-Flight sensor
  - * * U8g2lib – SH1106 OLED driver
  - * * WiFi.h / HTTPClient.h – Wi-Fi & HTTP POST
  - * * UniversalTelegramBot.h – Telegram Bot API
- **Node-RED** (v3.x) on 192.168.10.50:1880 — receives HTTP alerts, dashboards fill percentage, logs events
- **Telegram Bot** (“TrashAlertBot”) configured with token `xxxx:YYYY` and chat ID

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3. Hardware Assembly

3.1. Breadboard Layout

- **ESP32**: VIN ← 5 V (from powerbank USB→5 V regulator), GND ← GND, SDA ← GPIO 8, SCL ← GPIO 9.
- **VL53L0X**: VCC ← 3.3 V (ESP32 3V3 pin), GND ← GND, SDA/SCL as below.
- **OLED (SH1106)**: VCC ← 3.3 V, GND ← GND, SDA/SCL as below.
- **LED**: Anode ← GPIO 2 (with 220 Ω resistor), Cathode ← GND.
  - All I²C peripherals (ToF sensor, OLED) share ESP32’s **SDA**/**SCL** pins and 3.3 V/GND rails.
  - Secure ToF sensor at bin’s top interior, facing directly downward without obstruction.
  - Mount OLED on exterior lid for clear visibility.
  - Use onboard LED—no additional external LED wiring.
  - ESP32 uses internal antenna for Wi-Fi; no extra antennas needed.



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4. Arduino IDE Firmware

Below is the main sketch. **Please replace** `YOUR_SSID`, `YOUR_PASS`, `NODE_RED_URL`, and `BOT_TOKEN` with your actual credentials.

```
#include <Wire.h>
#include <Adafruit_VL53L0X.h>
#include <U8g2lib.h>
#include <WiFi.h>
#include <HTTPClient.h>
#include <UniversalTelegramBot.h>

#define I2C_SDA 8
#define I2C_SCL 9
#define LED_PIN 2

#define BIN_HEIGHT_CM 60.0
#define DISTANCE_OFFSET_CM -3.0

// Wi-Fi
const char* ssid       = "YOUR_SSID";
const char* password   = "YOUR_PASS";
// Node-RED endpoint
const char* alert_url  = "http://YOUR_IP_ADDRESS/bin-alert";
```

```
// Telegram
const char* telegram_token = "BOT_TOKEN";
String chat_id = "CHAT_ID";

U8G2_SH1106_128X64_NONAME_F_HW_I2C display(U8G2_R0, U8X8_PIN_NONE, I2C_SCL,
I2C_SDA);
Adafruit_VL53L0X lox = Adafruit_VL53L0X();
WiFiClientSecure secured_client;
UniversalTelegramBot bot(telegram_token, secured_client);

unsigned long lastAlertTime = 0, lastSignalTime = 0;
const unsigned long signalInterval = 30000;
float lastDistance = 0, lastPercentage = 0;
bool updatesEnabled = true;

void setup() {
  Serial.begin(115200);
  Wire.begin(I2C_SDA, I2C_SCL);
  // Initialize display
  display.begin();
  display.clearBuffer();
  display.setFont(u8g2_font_ncenB08_tr);
  display.drawStr(0,10,"Init Display");
  display.sendBuffer();
  // Initialize sensor
  if (!lox.begin()) while (1);
  pinMode(LED_PIN, OUTPUT);
  // Connect Wi-Fi
  WiFi.begin(ssid, password);
  while (WiFi.status() != WL_CONNECTED) {
    delay(500);
    Serial.print('.');
  }
  Serial.println("\\nWiFi OK");
  secured_client.setInsecure();
}

void loop() {
  VL53L0X_RangingMeasurementData_t m;
  lox.rangingTest(&m, false);
  if (m.RangeStatus != 4) {
    float d = m.RangeMilliMeter/10.0 + DISTANCE_OFFSET_CM;
    float p = constrain(100.0 - (d/BIN_HEIGHT_CM)*100.0, 0.0, 100.0);
    lastDistance = d; lastPercentage = p;
    // Update OLED
    display.clearBuffer();
    display.setCursor(0,12);
    display.print("Dist: "); display.print(d,1); display.print("cm");
    display.setCursor(0,30);
```

```
    display.print("Fill: "); display.print((int)p); display.print("%");
    int w = map((int)p,0,100,0,120);
    display.drawFrame(0,45,120,10);
    display.drawBox(0,45,w,10);
    display.sendBuffer();
    // Alert on ≥80%
    if (p >= 80.0) {
      digitalWrite(LED_PIN, HIGH);
      if (millis() - lastAlertTime > 15000) {
        sendWarning(d, p);
        lastAlertTime = millis();
      }
    } else {
      digitalWrite(LED_PIN, LOW);
    }
  }
  // Periodic update
  if (millis() - lastSignalTime > signalInterval) {
    if (updatesEnabled) sendRegularUpdate(lastDistance, lastPercentage);
    lastSignalTime = millis();
  }
  // Telegram commands
  static unsigned long lastBot = 0;
  if (millis() - lastBot > 1000) {
    int n = bot.getUpdates(bot.last_message_received + 1);
    while (n) {
      handleNewMessages(n);
      n = bot.getUpdates(bot.last_message_received + 1);
    }
    lastBot = millis();
  }
  delay(500);
}

// ... (sendWarning, sendRegularUpdate, handleNewMessages functions)
```

Code Summary

1. **Initialization (setup)**

    1. Serial debug +

       ```
       Wire.begin()
       ```

       for I²C

    2. ```
       lox.begin()
       ```
       ```

for ToF sensor and OLED splash

3. Connect to Wi-Fi (SSID/password)
4. Initialize HTTPClient & Telegram bot
5. On failure (sensor or Wi-Fi), print/display error

2. **Main Loop**

1. Ranging measurement via

```
lox.rangingTest()
```

2. If valid, calculate

`fill % = ((BIN_HEIGHT_CM − distance_cm) / BIN_HEIGHT_CM) × 100`

1. Update OLED: distance, fill %, bar graph
2. LED Alert: ON if ≥ 80 %, OFF if below (with hysteresis)
3. HTTP POST to Node-RED every 30 s
4. Telegram: one-time warning on threshold cross; optional periodic updates
5. Handle Telegram commands (

```
/start
```

,

```
/status
```

,

```
/stop
```

, etc.)

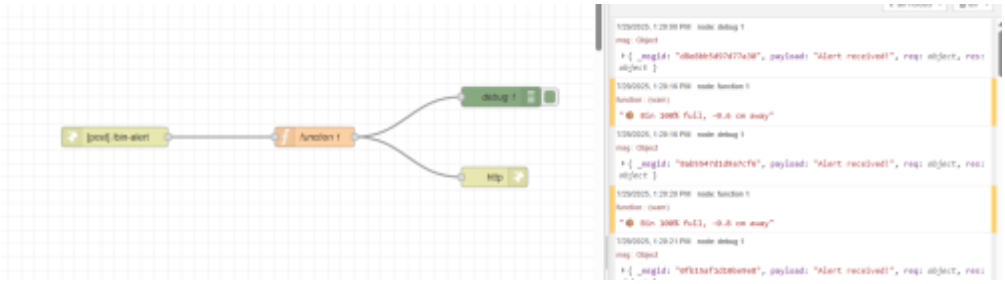
6. Delay to regulate loop frequency

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5. Node-RED Flow

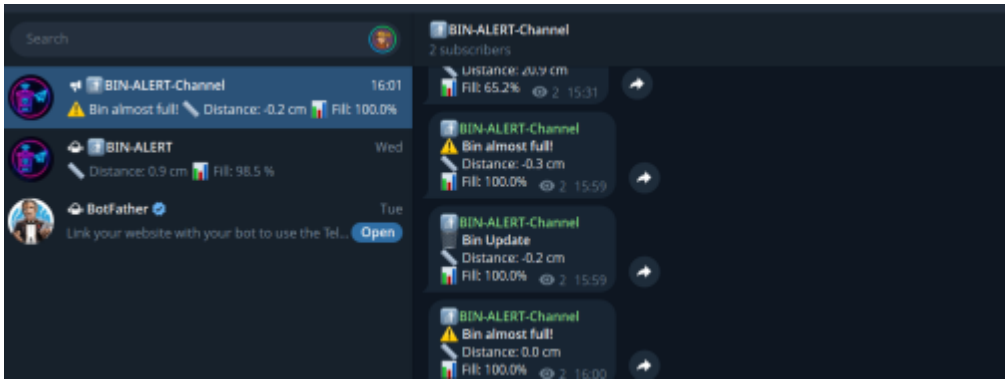
Our Node-RED instance handles incoming HTTP POSTs at `/bin-alert` and:

- Parses JSON (distance, fill_percentage)
- Switch: if `fill_percentage ≥ 80` → trigger email/SMS, else log
- Dashboard: updates a gauge node



6. Telegram Bot Configuration

- Create bot with BotFather → get `BOT_TOKEN`.
- Invite to your group/channel → note the `chat_id`.
- Grant it message-reading rights.
- External Link Trash Bin alert bot
- External Link Trash Bin Channel



Commands:

- /start - Start bot
- /status - Get current bin fill
- /stop - Stop regular update messages
- /startupdates - Resume regular updates
- /help - Show this message

7. Results

- **OLED display**: real-time distance & fill bar (tested up to 85%).
- **LED**: lights when fill ≥ 80%.
- **Telegram**: immediate alert with bin status.
- **Node-RED dashboard**: gauge plotting fill percentage.

- **Distance & Fill Readout**
  1. OLED updates in real time:
     - “Distance: 21.8 cm”

        - “Fill: 63 %”
    2. Fill percentage = ((60 cm − measured_distance) / 60 cm) × 100 %.

- **Visual & Remote Alerts**
    1. At ≥ 80 % capacity (trash within ~12 cm of lid):
        - Onboard LED lights (e.g., red).
        - Node-RED receives JSON payload:

```
{"bin":"Kitchen","fill":85,"status":"Nearly Full"}
```

- Telegram message: “⚠ Alert: The kitchen trash bin is 85 % full. Please empty it soon.”

1. Regular status updates (e.g., every 30 s) are also sent.
2. On sensor error, OLED shows “Sensor error” and that cycle’s data is skipped; an error flag can be forwarded.







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8. Discussion & Lessons Learned

- **Portable power**: using a USB powerbank delivers ~8 hrs runtime; for longer operation, a solar-powered Li-Po pack is recommended.
- **Connectivity**: outdoors Wi-Fi drops; consider fallback via GSM/LTE or LoRaWAN.
- **Enclosure**: no weatherproof housing yet—future 3D-printed case should protect electronics from dust and moisture.
- **Sleep modes**: ESP32 deep-sleep between measurements can drastically reduce power draw.
- **Multi-sensor**: adding ambient temperature/humidity could enable smarter waste-decomposition predictions.

- **Predictive analytics**: log historical fill data (via MQTT or cloud DB) to forecast optimal pickup schedules.
- **Firmware OTA**: integrate over-the-air updates for remote code maintenance.
- **Scalability**: mesh-network multiple bins to central server for fleet management.

* **Limitations**

- Single-point ToF measurement may miss uneven trash piles.
- Reliance on Wi-Fi: network outages disrupt remote updates.
- Continuous power requirement; no battery or power-saving implemented.

- **Improvements**
  - Multiple sensors or servo-mounted scanning for holistic fill measurement.
  - Offline data buffering and reconnection logic for network resilience.
  - Deep-sleep between measurements for battery operation.

- **Future Enhancements**
  - A GPS module (for geo-tagged alerts)
  - A solar-rechargeable Li-Po power supply (with charge controller)
  - A weatherproof 3D-printed enclosure
  - Load cell weight sensor for complementary metrics.
  - Audible buzzer for local full-bin alarms.
  - Expanded Node-RED flows: email notifications, historical logging/analytics.
  - Interactive Telegram bot commands for on-demand status.

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9. Conclusion

Deploying multiple units in smart buildings or campuses enables optimized waste collection scheduling, reduces overflow incidents, and contributes to smarter urban infrastructure by leveraging low-cost sensors and Wi-Fi connectivity. This project demonstrates a practical IoT solution for everyday problems, with clear pathways for scaling and enhancement.

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10. References

- **STMicroelectronics VL53L0X Datasheet**
- **U8g2 SH1106 OLED driver** – https://github.com/olikraus/u8g2
- **UniversalTelegramBot Library** – https://github.com/witnessmenow/Universal-Arduino-Telegram-Bot
- **Node-RED Documentation** – https://nodered.org/docs/

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