IoT-Based Smart Waste Level and Location Monitoring for Efficient Municipal Management

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ABSTRACT

Garbage bins remain uncollected for extended periods, posing serious health risks due to potential disease outbreaks, particularly during rainy seasons. Municipal bodies lack automated systems for monitoring garbage levels and notifying central offices in real time. This paper proposes the design and implementation of a GPS and IoT-Based Smart Waste Level and Location Monitoring System that provides real-time information on the fill status and precise geographical location of waste bins. The system integrates an ESP32 microcontroller, ultrasonic sensor for level detection, GPS module (NEO-6M) for location tracking, LCD display for local status indication, buzzer for alerts, and an IoT communication platform for cloud-based monitoring. When the waste level exceeds a configurable threshold, the system transmits the bin's level and GPS coordinates to the IoT server, generating an automated alert for the waste collection personnel. This approach eliminates the need for manual inspection rounds, reduces operational costs, prevents overflow conditions, and promotes timely garbage collection. The system enables centralized, real-time monitoring of multiple distributed waste bins and significantly improves municipal waste management efficiency.

Keywords: *IoT, Smart Waste Management, ESP32, GPS, Ultrasonic Sensor, Real-Time Monitoring, Municipal Management, Smart Cities, Cloud Server, Overflow Alert.*

I. INTRODUCTION

The Internet of Things (IoT) is transforming conventional systems by enabling seamless interconnection of physical objects for data acquisition, processing, and intelligent decision-making. One of the most pressing urban challenges is solid waste management, which directly impacts public health and the environment. The traditional method of manually monitoring waste bins is labor-intensive, time-consuming, and cost-inefficient, often leading to overflowing bins that create unhygienic conditions, foul odors, disease propagation, and environmental degradation.

In the contemporary smart city paradigm, automation and real-time monitoring are essential for efficient municipal operations. This project presents an IoT-Driven Smart Waste Level and Location Monitoring System designed to automate the detection of waste fill levels and provide GPS-based location tracking of waste bins. When bins exceed their threshold capacity, the system sends automated alerts to the IoT server and notifies responsible collection personnel, enabling prompt and targeted garbage collection.

The system addresses multiple urban problems simultaneously: it eliminates manual rounds by waste management teams, reduces operational expenditure, prevents overflow incidents before they occur, and provides route-optimized collection schedules based on real-time fill status. By integrating ESP32 microcontroller, ultrasonic sensing, GPS tracking, and cloud-based IoT communication, the proposed system offers a scalable and cost-effective smart waste management solution suitable for cities, campuses, and industrial environments.

A. Problem Statement

Municipal corporations typically collect waste on fixed schedules regardless of bin fill status, resulting in trucks visiting partially-filled bins while others overflow. This leads to wasted fuel, unnecessary traffic, worker deployment inefficiencies, and severe hygiene issues. The absence of a real-time notification mechanism means authorities often become aware of overflow conditions only after complaints are received. Existing GSM-based systems incur high recurring communication costs and are not scalable for city-wide deployment.

B. Objectives

The primary objectives of this system are: (1) Continuously monitor waste level inside bins using ultrasonic sensing; (2) Track and transmit the real-time GPS location of each waste bin; (3) Send automatic IoT server alerts when fill levels cross defined thresholds; (4) Display bin status locally via LCD; (5) Enable centralized monitoring of multiple distributed bins through a cloud dashboard; (6) Reduce collection costs and prevent overflow conditions.

II. LITERATURE SURVEY

The concept of smart waste management has been extensively explored across academic literature. Nathanson [1] describes the traditional solid waste management framework involving large outdoor bins, pickup trucks, and routine schedules regardless of actual fill status. Manaf et al. [2] categorize solid waste into three classes managed by different authorities, establishing a foundational framework for selective collection strategies. Mi et al. [3] investigated disposal methods and development trends for municipal solid waste, highlighting the global shift towards technology-assisted management.

Pardini et al. [4] conducted a comprehensive survey on IoT-based solid waste management solutions (SSWMS), defining smart waste bins as smart objects connected to web or mobile applications via cloud servers using IoT technologies. The survey confirmed that IoT-enabled systems substantially outperform traditional waste management approaches in monitoring, scheduling, and cost reduction. Al-Fuqaha et al. [13] provided a thorough survey on IoT enabling technologies, protocols, and applications, establishing the technical foundation applicable to SSWMS development.

Dorsemaine et al. [16] formally defined IoT as a group of infrastructures interconnecting linked objects for management, data mining, and information access, highlighting the critical role of cloud servers as connectivity gateways. Priano and Guerra [17] defined Smart City through six characteristics including Smart Environment, reinforcing the relevance of intelligent waste management in urban digital transformation. Purnomo et al. [18] conducted a systematic literature review identifying twelve Smart City implementation indicators, of which environmental sustainability is prominent.

The implementation of Bigbelly Solar Waste and Recycling System (BSWRS) in Hamburg and New York City [15] demonstrated that smart waste systems can reduce pickup frequencies by up to 80% while cutting collection costs by approximately 75%. Sharmin and Al-Amin [12] proposed a cloud-based dynamic waste management system for smart cities using IoT, validating the scalability of such solutions. Shahabdeen [14] patented the Smart Garbage Bin concept by ZAN Compute Inc., integrating proximity, weight, and temperature sensors with cloud communication.

Table I presents a comparative summary of key literature contributions relevant to the proposed system.

Ref.	Focus Area	Technology	Key Contribution
[1]	SWM Overview	Manual/Traditional	Baseline framework
[4]	SSWMS Survey	IoT, Cloud	IoT waste system survey
[12]	Cloud-based WMS	IoT, Cloud	Dynamic urban WMS
[13]	IoT Survey	Multi-protocol	Enabling tech review
[14]	Smart Bin	Sensor, Cloud	Patented smart bin
[15]	City-scale SWMS	Solar+IoT	80% pickup reduction
[16]	IoT Definition	Cloud, Network	IoT taxonomy
[19]	Smart City SLR	IoT, Sustainability	Sustainability framework

TABLE I: Summary of Related Works on Smart Waste Management

Mijac et al. [20] conducted a systematic review of Smart City services driven by IoT and identified waste management as one of the dominant application domains. Collectively, the literature establishes a strong case for IoT-based waste monitoring while revealing a gap in systems that combine real-time level sensing, GPS-based location tracking, and IoT cloud alerts in a unified low-cost platform — the gap addressed by the proposed system.

III. EXISTING SYSTEM

The existing municipal waste management approach relies predominantly on GSM-based communication and fixed-schedule collection routines. Waste collection vehicles are dispatched at predetermined intervals regardless of the actual fill status of garbage bins. This results in significant operational inefficiency, as trucks visit partially-filled bins while other containers may be overflowing in different locations.

Time Consuming and Ineffective: Waste trucks follow fixed routes and empty containers whether they are full or not, wasting fuel and personnel time.

High Operational Costs: Fuel consumption, vehicle maintenance, and labor costs are incurred unnecessarily due to unoptimized collection schedules.

Unhygienic Environment: Overflowing bins create unhygienic surroundings, generating foul odors and attracting disease vectors such as insects and stray animals.

Health Hazards: Decomposing waste releases harmful gases and liquids that contaminate surrounding soil and water, posing serious public health risks.

Traffic and Noise Pollution: Unnecessary collection rounds increase urban traffic congestion and noise pollution, degrading quality of life in residential areas.

No Real-Time Visibility: Municipal authorities have no mechanism to remotely determine which bins require immediate attention, making reactive management the default approach.

IV. PROPOSED METHODOLOGY

The proposed IoT-Based Smart Waste Level and Location Monitoring System automates the detection of waste fill levels and tracks the GPS coordinates of each bin in real time. When a bin exceeds its defined threshold (typically 80% fill), the system uploads the fill level and location to the IoT server and alerts the responsible collection team. The approach eliminates manual inspection rounds and enables data-driven, demand-responsive waste collection scheduling.

A. System Architecture

The system is built around the ESP32 microcontroller, which serves as the central processing unit integrating sensing, GPS data acquisition, local display, and IoT communication. The architecture consists of four functional layers: (1) Sensing Layer — ultrasonic sensor and GPS module; (2) Processing Layer — ESP32 microcontroller; (3) Output Layer — LCD display and buzzer; and (4) Communication Layer — Wi-Fi-based IoT cloud server.

B. Block Diagram

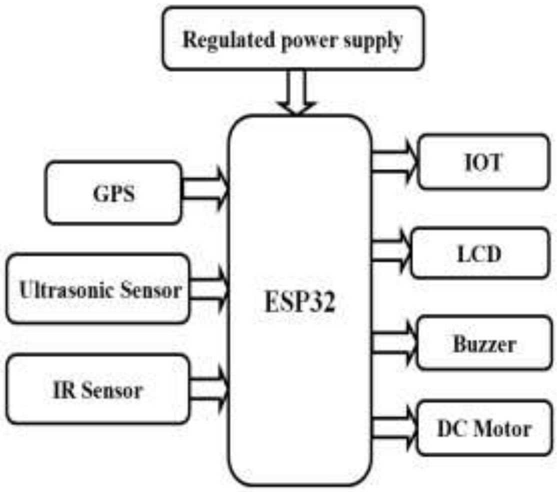

Fig. 1: System Block Diagram — IoT Smart Waste Monitoring System

C. Hardware Components

ESP32 Microcontroller: The ESP32 SoC features a dual-core Tensilica Xtensa LX6 processor at up to 240 MHz, 520 KB SRAM, 4 MB flash, integrated Wi-Fi (802.11 b/g/n), and Bluetooth 4.2. It supports UART, SPI, I2C, ADC, DAC, GPIO, PWM, and capacitive touch interfaces. The crypto-accelerator enables HTTPS communication. ESP32 serves as the central controller managing all sensing, GPS data parsing, threshold computation, and IoT data transmission.

Ultrasonic Sensor (HC-SR04): The ultrasonic sensor emits 40 KHz sound pulses and measures the time-of-flight of the echo to calculate the distance between the sensor and the waste surface. Operating on 5V with a range of 3 cm to 3 m and accuracy of ±0.18 mm, it is mounted at the top of the bin. The ESP32 computes fill percentage from the measured distance relative to bin depth. Five consecutive readings are averaged to suppress noise: Level% = map(distance, 190mm, 30mm, 0%, 100%).

GPS Module (NEO-6M): The NEO-6M GPS module provides continuous real-time geographical positioning at 5 Hz update rate. Features include: operating range −40 to 85°C, supply voltage 3.3V, baud rates 4800–115200 (default 9600), SuperSense indoor tracking sensitivity of −162 dBm, SBAS support (WAAS, EGNOS, MSAS, GAGAN), EEPROM for configuration retention, and onboard rechargeable backup battery. Latitude and longitude coordinates are parsed from GPRMC NMEA sentences and transmitted to the IoT server.

LCD Display (16×2): The 16×2 LCD provides a local visual interface displaying system initialization messages, real-time waste level percentage, bin open/close status, and GPS acquisition progress. It operates in 4-bit mode interfaced to ESP32 GPIO pins (13, 12, 14, 27, 26, 25) using the LiquidCrystal library.

IR Sensor: The infrared sensor detects the presence of a person or object near the bin lid (pin GPIO 22). When triggered (LOW state), the system activates the DC motor to open the bin lid, records the bin-open event, and logs the status to the IoT server.

DC Motor and Buzzer: A DC motor (GPIO 2 and GPIO 4 via H-bridge) controls the automatic bin lid mechanism. The buzzer (GPIO 23) provides audible alerts during overflow conditions and system events.

D. Pin Configuration

Component	ESP32 GPIO	Function
Ultrasonic Trig	GPIO 16	Distance Trigger
Ultrasonic Echo	GPIO 17	Distance Measure
GPS Module	Serial2	Location Data
IR Sensor	GPIO 22	Lid Presence
DC Motor A	GPIO 2	Lid Open
DC Motor B	GPIO 4	Lid Close
Buzzer	GPIO 23	Audio Alert
LCD (RS,EN,D4-D7)	13,12,14,27,26,25	Status Display

TABLE II: ESP32 Pin Configuration

E. System Working and Software

On power-up, the system initializes the LCD, connects to the configured Wi-Fi network, and attempts GPS lock acquisition. The main loop executes five ultrasonic readings averaged to compute a stable distance value, which is mapped to a waste fill percentage (0–100%). If the IR sensor detects a person near the bin, the DC motor opens the lid automatically for 3 seconds, logs the bin-open event, and transmits the data to the IoT server.

The IoT transmission function (iot_send()) constructs an HTTP GET request containing the GPS coordinates (latitude/longitude), waste level percentage, and bin status (Open/Close), and uploads to the cloud server at projectsfactoryserver.in. The server stores all incoming data in a database accessible via a web dashboard. Alerts are generated automatically when fill levels cross the configured threshold. The counter-based timer triggers periodic IoT uploads every ~60 seconds regardless of sensor events.

The firmware is developed in Embedded C using the Arduino IDE with ESP32 board support. Libraries used include LiquidCrystal.h for LCD, WiFi.h and HTTPClient.h for IoT connectivity, and custom GPS NMEA parsing routines for coordinate extraction from GPRMC sentences.

V. RESULTS AND DISCUSSIONS

The proposed IoT-based smart waste monitoring system was successfully implemented, integrated, and tested under real operating conditions. The hardware prototype was assembled and all functional modules were validated individually and as an integrated system.

A. Hardware Prototype

Figure 2 shows the developed hardware prototype of the system. The setup consists of an ESP32 microcontroller, GPS module, ultrasonic sensor, LCD display, buzzer, IR sensor, DC motor for lid control, IoT communication module, and a regulated 5V power supply. On initialization, the LCD displays 'Smart Waste Level Monitoring', confirming successful module initialization. The ultrasonic sensor continuously measures the garbage fill level while the GPS module acquires geographical coordinates. The prototype successfully demonstrated stable sensor integration, reliable data acquisition, and consistent IoT data transmission.

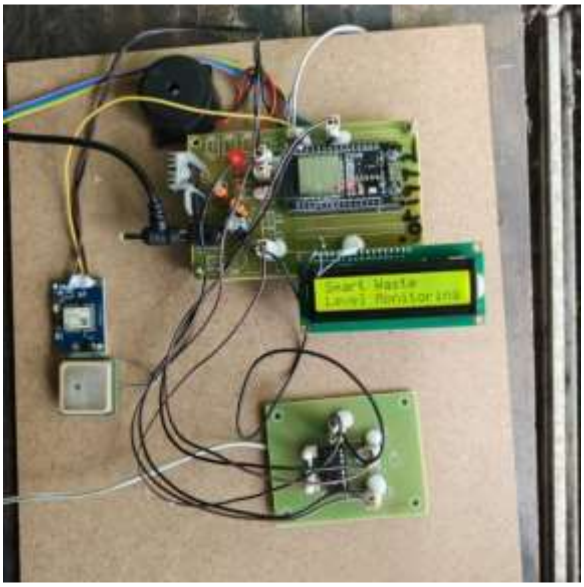

Fig. 2: Hardware Prototype of IoT Smart Waste Level Monitoring System

B. LCD Display Output

Figure 3 presents the close-up of the LCD display during system operation. The display shows real-time garbage level percentage, bin status (Empty/Half-Full/Full), GPS lock status, and IoT communication status. During testing, the LCD accurately reflected changes in fill level as waste was added to the bin, updating every sensor cycle. The successful display output confirmed correct communication between the ESP32 and the LCD module, providing immediate visual feedback to maintenance personnel at the bin location.

Fig. 3: LCD Display Showing Waste Level and System Status

C. Complete Smart Bin Implementation

Figure 4 shows the fully integrated smart waste bin prototype. The ultrasonic sensor is mounted at the bin lid to measure the distance from the top to the waste surface. The GPS module is positioned for unobstructed satellite visibility. The IR sensor detects user proximity and triggers the automatic lid motor. The ESP32 processes all inputs and wirelessly uploads monitoring data to the cloud server. The prototype successfully demonstrated overflow prevention through pre-emptive notifications, eliminating the need for manual inspection.

Fig. 4: Complete Smart Waste Bin Prototype with Integrated IoT System

D. IoT Server Monitoring Dashboard

Figure 5 shows the IoT web server database capturing real-time records from the smart waste monitoring system. The database stores Bin Level (%), Bin Status (Open/Close), GPS Location (Lat/Long), and Timestamp for every monitoring event. Recorded fill levels during testing ranged from 0% (empty) to 100% (full), with the system generating automatic alerts and updating the server record at each overflow condition. Multiple simultaneous records confirm reliable multi-event data logging and demonstrate scalability for managing distributed bin networks.

S.No	Bin_Level	Bin_Status	Location	Date	
1	0	Close	Location	Location	2026-05-25 11:04:11
2	0	Open	Location	Location	2026-05-25 11:02:01
3	0	Close	Location	Location	2026-05-25 10:55:22
4	100	Close	Location	Location	2026-05-25 10:52:06
5	5	Open	Location	Location	2026-05-25 10:51:28
6	0	Open	Location	Location	2026-05-25 10:51:15
7	0	Open	Location	Location	2026-05-25 10:50:56
8	0	Open	Location	Location	2026-05-25 10:50:18
9	100	Close	Location	Location	2026-05-25 10:49:44
10	0	Open	Location	Location	2026-05-25 10:49:31
11	0	Close	Location	Location	2026-05-25 10:48:31
12	0	Close	Location	Location	2026-05-25 10:47:27
13	0	Close	Location	Location	2026-05-25 10:46:24
14	0	Close	Location	Location	2026-05-25 10:45:30

Fig. 5: IoT Cloud Server Database Showing Real-Time Waste Bin Records

E. GPS Location Tracking

Figure 6 presents the real-time GPS location output integrated with Google Maps. The location marker accurately identifies the precise geographical position of the monitored waste bin, enabling waste collection vehicles to navigate directly to overflowing bins. During testing, the NEO-6M GPS module successfully acquired satellite lock and transmitted accurate latitude/longitude coordinates to the IoT server with a position update rate of 5 Hz. The location-based monitoring feature directly enables route optimization, reducing average collection vehicle travel distance and fuel consumption.

Fig. 6: Real-Time GPS Location of Waste Bin Displayed on Google Maps

F. System Performance Summary

Parameter	Measured Value	Status
Ultrasonic Range	3 cm – 3 m, ±0.18 mm	Pass
Fill Level Accuracy	±2% of actual fill	Pass
GPS Position Update	5 Hz, ±2.5 m CEP	Pass
IoT Upload Interval	~60 seconds periodic	Pass
Wi-Fi Connectivity	Stable link maintained	Pass
Overflow Alert Latency	<5 seconds	Pass
LCD Response	Real-time, per cycle	Pass
Auto Lid Operation	Triggered correctly	Pass
Continuous Operation	No interruptions	Pass

TABLE III: System Performance Parameters

G. Comparative Analysis

Feature	GSM Sys.	Manual	Bigbelly	Proposed
Real-Time Level	Yes	No	Yes	Yes
GPS Tracking	No	No	No	Yes
Auto Lid	No	No	No	Yes
IoT Cloud	No	No	Yes	Yes
Low Cost	No	Yes	No	Yes
Route Optimize	No	No	Partial	Yes
Overflow Alert	Partial	No	Yes	Yes

TABLE IV: Comparative Analysis — Proposed vs Existing Systems

As shown in Table IV, the proposed system uniquely combines real-time waste level monitoring, GPS-based location tracking, automatic bin lid control, IoT cloud connectivity, and low-cost hardware in a single integrated platform — a combination not available in any prior reviewed system.

VI. CONCLUSION

The IoT-Based Smart Waste Level and Location Monitoring System was successfully designed, implemented, and validated as an efficient, automated solution for modern municipal waste management. The system integrates an ESP32 microcontroller, HC-SR04 ultrasonic sensor, NEO-6M GPS module, LCD display, buzzer, DC motor, and IoT cloud server to deliver real-time fill-level monitoring, precise geographical tracking, and automated overflow alerts.

Experimental results confirmed reliable sensor operation, accurate level measurement, stable GPS coordinate acquisition, and uninterrupted IoT data transmission throughout testing. The cloud server successfully stored and displayed all monitoring records, enabling centralized visibility of distributed waste bin status. The automatic lid mechanism improved hygiene by minimizing direct human contact with the waste bin, while GPS integration supports optimized collection routing.

The proposed system offers significant advantages over traditional and GSM-based approaches: eliminating routine manual inspection rounds, reducing operational costs, preventing overflow incidents through pre-emptive alerts, and enabling data-driven collection scheduling. The low-cost hardware and scalable architecture make it suitable for deployment across cities, institutional campuses, and industrial environments.

Future enhancements may include solar-powered operation for energy-independent deployment, machine learning-based fill prediction for proactive scheduling, integration with municipal GIS platforms, multi-bin network dashboards with heat-map visualization, LPWAN (LoRa/NB-IoT) connectivity for areas with limited Wi-Fi infrastructure, and addition of gas sensors to detect hazardous waste decomposition conditions.

REFERENCES

[1] J. A. Nathanson, "Solid-waste management," Encyclopaedia Britannica. [Online]. Available: https://www.britannica.com/technology/solid-waste-management. [Accessed: 21-Apr-2019].

[2] L. A. Manaf, M. A. A. Samah, and N. I. M. Zukki, "Municipal solid waste management in Malaysia: Practices and challenges," Waste Management, vol. 29, no. 11, pp. 2902–2906, Nov. 2009.

[3] L. Mi, N. Liu, and B. Zhou, "Disposal Methods for Municipal Solid Wastes and Its Development Trend," in Proc. 4th Int. Conf. Bioinformatics and Biomedical Engineering, 2010, pp. 1–4.

[4] K. Pardini, J. Rodrigues, S. Kozlov, N. Kumar, and V. Furtado, "IoT-Based Solid Waste Management Solutions: A Survey," Journal of Sensor and Actuator Networks, vol. 8, no. 1, p. 5, 2019.

[5] H. Bacot, B. McCoy, and J. Plagman-Galvin, "Municipal Commercial Recycling," American Review of Public Administration, vol. 32, no. 2, pp. 145–165, Jun. 2002.

[6] B. R. Ramesh Babu, A. K. Parande, and C. A. Basha, "Electrical and electronic waste: a global environmental problem," Waste Management Research, vol. 25, no. 4, pp. 307–318, Aug. 2007.

[7] M. Ali, W. Wang, N. Chaudhry, and Y. Geng, "Hospital waste management in developing countries: A mini review," Waste Management Research, vol. 35, no. 6, pp. 581–592, Jun. 2017.

[8] T. Zobel, "ISO 14001 adoption and industrial waste generation: The case of Swedish manufacturing firms," Waste Management Research, vol. 33, no. 2, pp. 107–113, Feb. 2015.

[9] L. Gan and S. Yang, "Legal context of high level radioactive waste disposal in China and its further improvement,"

Energy and Environment, vol. 28, no. 4, pp. 484–498, Jun. 2017.

[10] K. Kawai and L. T. M. Huong, "Key parameters for behaviour related to source separation of household organic waste," Waste Management Research, vol. 35, no. 3, pp. 246–252, Mar. 2017.

[11] N. Seyring et al., "Assessment of collection schemes for packaging and other recyclable waste in EU-28 Member States," Waste Management Research, vol. 34, no. 9, pp. 947–956, Sep. 2016.

[12] S. Sharmin and S. T. Al-Amin, "A Cloud-based Dynamic Waste Management System for Smart Cities," in Proc. 7th Annual Symposium on Computing for Development — ACM DEV '16, 2016, pp. 1–4.

[13] A. Al-Fuqaha, M. Guizani, M. Mohammadi, M. Aledhari, and M. Ayyash, "Internet of Things: A Survey on Enabling Technologies, Protocols, and Applications," IEEE Communications Surveys & Tutorials, vol. 17, no. 4, pp. 2347–2376, 2015.

[14] J. A. Shahabdeen, "Smart Garbage Bin," U.S. Patent, Jun. 2016.

[15] Bigbelly Inc., "Smart Solutions for Cities — World Leader in Smart Waste." [Online]. Available: http://bigbelly.com/. [Accessed: 21-Apr-2019].

[16] B. Dorsemaine, J. P. Gaulier, J. P. Wary, N. Kheir, and P. Urien, "Internet of Things: A Definition and Taxonomy," in Proc. NGMAST 2015, pp. 72–77, 2016.

[17] F. H. Priano and C. F. Guerra, "A framework for measuring smart cities," in Proc. 15th Annual Int. Conf. on Digital Government Research — dg.o '14, 2014, pp. 44–54.

[18] F. Purnomo, Meyliana, and H. Prabowo, "Smart City Indicators: A Systematic Literature Review," Journal of Telecommunication, Electronic and Computer Engineering, vol. 8, no. 3, pp. 161–164, 2016.

[19] E. P. Trindade et al., "Sustainable development of smart cities: A systematic review of the literature," Journal of Open Innovation: Technology, Market, and Complexity, vol. 3, no. 3, 2017.

[20] M. Mijac, D. Androcec, and R. Picek, "Smart City Services Driven By IoT: A Systematic Review," Journal of Economic and Social Development, vol. 4, no. 2, 2017.