A Blockchain-Based IoT-Enabled E-Waste Tracking and Tracing System for Smart Cities

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ABSTRACT

This project focuses on the implementation of IoT (Internet of Things) technology to enhance e-waste management in smart cities. E-waste poses a growing environmental and health concern, necessitating efficient tracking and tracing solutions. This project implies IoT based Smart Dustbin for Household is a very innovative system which will help to monitor the trash collected in the dustbin. This system monitors and informs about the level of garbage collected in the garbage bins. Ultrasonic sensors are used to detect the level of garbage collected in the bins. By deploying IoT sensors and devices in e-waste collection points and vehicles, the project aims to monitor e-waste levels, optimize collection routes, and ensure proper disposal in compliance with environmental regulations. Real-time data analysis and user engagement through mobile apps will empower both waste management authorities and citizens to contribute to responsible e-waste disposal. The project's scalability and cost-efficiency make it a pivotal step toward sustainable and environmentally responsible urban living in the digital age. The system is supported by five smart contracts that record the actions of users on the immutable distributed ledger that aid in ensuring that the business processes carried out by the participants are transparent, traceable, and secure. To store large files, such as images of e-waste materials, products, and licenses for stake holders, we have integrated our system with a distributed storage system.

Keywords: Internet of things, smart cities, IoT sensors, Smart Waste Bin, Ultra sonic sensors.

I. INTRODUCTION

In the contemporary digital era, the proliferation of electronic devices has become an integral part of our daily lives, contributing to unprecedented technological advancements. However, the rapid evolution of electronics has given rise to a parallel challenge– the generation of electronic waste, commonly known as e-waste. The improper disposal of electronic devices poses severe environmental and health hazards due to the presence of hazardous materials. Recognizing the urgency of addressing this issue, our project, the E-Waste Management System, aims to provide a comprehensive solution to the burgeoning problem of electronic waste. This initiative endeavors to establish an efficient and sustainable system for the collection, recycling, and responsible disposal of e-waste, aligning with global environmental goals and local regulatory frameworks. Managing e-waste is currently one of the major challenges of urban cities. E-waste is more difficult to manage than conventional waste since it contains toxic chemicals, radioactive materials, and storage devices that might lead to privacy and security issues. If the storage devices are not disposed of appropriately, they may fall into the hands of adversaries who acquire storage devices in bulk and scan them for sensitive information. Through this process, they can extract important data, such as encryption keys, crypto wallets, social security numbers, blueprints of important buildings, and even classified information of the governments. Therefore, electronic devices require evidence-based tracking, tracing, destruction, and recycling. Internet of Things (IoT) is one of the building blocks of smart cities and can play a crucial role in the collection and tracking of e-waste. Moreover, blockchain can allow us to undertake evidence-backed tracking, tracing, destruction, and recycling of e-waste to prevent e-waste from entering the black market. Many of the existing solutions for supply chain and waste management are based on IoT and cloud computing. Some of these solutions also offer financial incentives in the form of tokens to motivate people to deposit waste in the designated places. Due to the absence of auditing features, there is always a risk that e-waste may enter the black market, where criminals can extract radioactive materials or confidential data from the storage devices. Moreover, these systems are typically centralized and have scalability and single point of failure issues. Moreover, these solutions often lack essential features, such as transparency, traceability, accountability, and privacy etc.

A. RELATED WORK

When it comes to waste management, smart cities are increasingly focusing on the design and development of waste management solutions that are based on advanced technologies, such as Internet of Things (IoT), Cloud Computing, AI, and blockchain. There are various solutions for waste management in which the consumers or stakeholders are given incentives for recyclable goods. This paper highlights some of the advantages of blockchain technology and the main challenges in adopting blockchain based waste management systems.

This paper presents a blockchain based reward system for solid waste management. In this system, sensors are attached to waste-bins to monitor the garbage level. This data is uploaded to the cloud on runtime and also written on the blockchain. In this work, there are no special considerations for e-waste. Paper present a smart trash control system for universities to reduce cost of waste collection. Similar to the previous technique, they use multiple sensors to monitor the garbage level in the waste-bins. In addition, they use ML technique to predict the filling time of the waste-bins and graph theory based optimization solution to compute paths and schedule for waste collection.

A smart waste management system that uses pricing estimation model to charge waste producers based on the quantity of the waste that they produce. This system utilizes IoT for monitoring waste in the waste-bins. Also, it uses blockchain for micropayments between the involved stakeholders. The main drawback of this work is that it has no special considerations for e-waste.

An electronic waste management system with an objective to assure compliance with the guidelines for Electrical and Electronic Equipment (EEE). This system uses smart contracts to keep record of the EEE waste and provide incentives to the consumers who return their old electronic items. In this system, the producers are penalized if they fail to collect EEE waste from the retailers. This system has no bidding mechanism and does not provide certificates to confirm destruction of data on the electronic devices.

A blockchain based system for tracking electric equipment throughout their lifetime. They use smart contracts between different stakeholders and provide incentives to the consumers who dispose of their e-waste in e-waste facilities. In this work, stakeholders are also bound to deposit some amount which is returned once the e-waste reaches the e-waste facility, and it is ensured that the stakeholders are in compliance with the defined e-waste management rules. However, the role of the data destruction unit has not been considered in the proposed research. In addition, the researchers ignored the significance of the stakeholders' reputations in supply chain operations.

A blockchain based system for secure disposal of confidential e-waste, such as hard drives that can contain secret/confidential data. This system uses smart contracts to allow authorities to perform audits and verify different activities related to secure disposal of e-waste. This system also ignores the stakeholders' reputation and does not provide certificates for destruction of data on electronic devices.

A smart e-waste management system that uses online interactive maps. With the help of the interactive maps, the consumers can request for collection of e-waste from their locations to the enterprise recycling units. In this work, the researchers propose utilization of the available delivery services to deliver the e-waste to the respective recycling units without deviating from the planned route. The main motive for doing so is to reduce the emission of CO_2 incurred by the e-waste delivery vehicles. Similar to the previous techniques, this system has no mechanism for stakeholders reputation, bidding, or data destruction certificate issuance.

A distributed trustless solution for reverse logistics activities related to e-equipment, especially the smartphones. The main contribution of this work is the use of blockchain for smartphone refurbishment, with a particular emphasis on the privacy of user data kept on the devices, in order to increase consumer confidence in refurbished smartphones. This solution has no bidding mechanism and does not provide certificate for destruction of data that is stored on the electronic devices.

In summary, existing research has ignored the role of the data destruction unit in e-waste management, putting data security at risk. In addition, the participants' reputation scores were not considered in the aforementioned works. As a result, participating entities may engage in unethical activities, and electronic device and e-waste trading frauds may occur. To prevent such frauds, in our proposed system, only participants with impeccable reputations are permitted to trade electronic devices and their waste. Moreover, our solution provides a certificate for data destruction on the electronic devices.

B. MOTIVATION AND CONTRIBUTION

To design and develop a blockchain-based Internet of Things (IOT) system designed to efficiently track and trace electronic waste (e-waste) within smart cities. This system seeks to enhance the management, recycling, and disposal of e-waste by leveraging the immutable and transparent nature of blockchain technology combined with the real-time data acquisition capabilities of IoT devices.

• Smart City Initiatives

• Challenges in E-Waste Management

• Technological Advancements

Objective

• Implement a Blockchain Network: Establish a decentralized blockchain to securely record and verify all transactions and movements of e-waste.

• Develop a User Interface: Create a web application for stakeholders to interact with the system, including functionalities for reporting, tracking, and managing e-waste.

• Enhance E-Waste Management: Improve the sorting, recycling, and disposal of e-waste by providing accurate and timely information.

• Foster Public Awareness and Participation: Encourage responsible e-waste disposal practices among citizens through awareness campaigns and incentives.

• Integrate IoT Sensors: Deploy IoT devices to monitor the condition, location, and movement of e-waste in real-time.

• Foster Public Awareness and Participation: Encourage responsible e-waste disposal practices among citizens through awareness campaigns and incentives.

II. SYSTEM ARCHITECTURE AND CONSTRUCTION

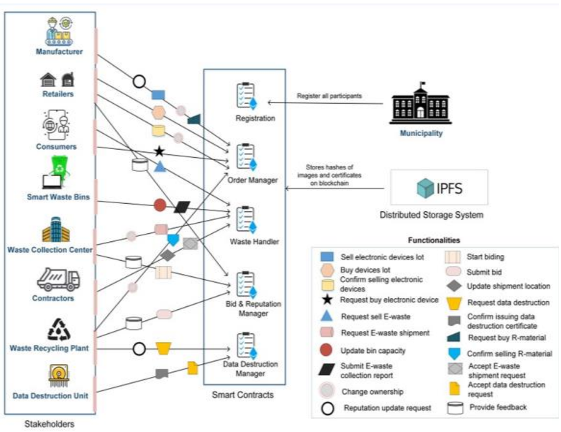


Figure 1: Proposed System Architecture

A. PROPOSED SYSTEM ARCHITECTURE

The proposed system we implemented seven modules which are as follows

1. Manufacturers: Manufacturers are responsible to manufacture the electronic devices for sale. They sells the electronic products to distributors and retailers. Before manufacturing any electrical equipment, the manufacturer undertakes market research to ensure that supply and demand are balanced. In our proposed system, the manufacturer creates a lot that is identified by a unique identity and publishes facts about the manufactured devices to the blockchain. The system also keeps track of the certificates granted by the authorities to ensure that the manufacturers have a valid manufacturing license.

2. Retailers: The retailers role is to buy electrical devices from the manufacturer or distributor and resale them in small quantities to the general public. They ensure that all of the customer's purchase requirements are addressed as quickly as possible. When the retailers buy electrical devices from distributors/manufacturers, they create lots of the bought items on the blockchain (referenced by unique identities) and allows consumers to buy electronic devices from them. They are also responsible of coordinating shipments for the delivery of the consumer orders.

3. Consumers: Consumers purchase the electronic equipment from retailers. Registered on the blockchain. After the usage, when the consumers want to dispose off their electronic devices, they deposit their devices in the nearby smart waste bins. The consumers may search for nearby waste bins that are registered on the blockchain by utilizing smart contracts stored on the blockchain.

4. Smart waste bins: Using sensors smart waste bins are able to differentiate between different types of waste. They are also capable of determining the weight of the e-waste that is being dumped in the containers. In our proposed system, it is assumed that IoT-enabled smart waste bins are deployed across a smart city. These bins are managed, owned, and controlled by the waste collection centers/facilities. When a waste bin reaches its maximum capacity, the server associated with the container trigger a transaction on the blockchain and requests waste shipment.

5. Waste collection center: The e-waste collection bins are situated throughout the smart city and are managed by the waste collection center. Waste collection center also arranges transportation service provides (contractors) for the collection of e-waste and are responsible for controlling overflow of the waste bins. The consumers who dump electronic waste are identified by the smart waste bins, and waste collection center is notified by triggering a blockchain-based event. The center eventually sells the e-waste it collects from

customers to the recycling centers.

6. Contractors: Contractors are responsible for collecting and transporting electronic waste from the waste collection center to the recycling facility. Contractors are obligated to deliver e-waste to the agreed-upon location in a timely and secure manner. In addition, the contractor periodically updates the involved parties on the current location, route, and estimated time of arrival. In addition, only registered contractors can be hired to transport the e-waste to their destination.

7. Waste recycling plants: This facility's main purpose is to ensure that all waste is recycled. The e-waste is transported to the recycling facilities by contractors engaged by a waste collection facility. Furthermore, the recycling plant identifies IT data storage devices during the e-waste segregation phase and delivers them to a data destruction facility for data destruction. The electronic devices are scrambled and r-material (recycled material) is collected and sold to the producer. After this, r-material is used to construct new electronic equipment.

8. Data destruction facility: The data destruction facility's principal goal is to erase data from the storage devices it receives. This facility uses cutting edge data destruction procedures to ensure that data privacy is maintained during data erasing process. A certificate is issued to the waste recycling unit when the data is successfully destroyed. This certificate serves as verification that data was safely and securely erased before the electronic data storage device was recycled.

9. Smart contracts: Smart contracts are computer programs that execute themselves and reduce the need for mediators while ensuring the administration of rules as agreed upon by the parties. As part of our research, we developed four primary smart contracts, namely registration, order manager, waste handler and data destruction manager.

10. Distributed storage: Blockchain technology faces scalability issues, especially when massive files and data are to be stored on the blockchain. Distributed storage solutions allow stakeholders, such as manufacturers, merchants, waste recycling plants, and contractors to store huge size photos and files in a reliable and secure way without worrying about the scalability issues.

In this section, we first introduce the algorithms definition and system architecture, and then propose the construction of our system.

B. ALGORITHMS

Algorithm 1: Placing a Request to Buy Electronic Devices from Manufacturer

article algorithm pseudocode

Input: Quantity, type, service time, device EA Output: Emit DataDestructionRequestPlaced Event Caller is not a registered user This service cannot be granted due to unverifiable Ethereum address. Caller is WasteRecylingPlant AND Permit.GetPermitofDataDestructionUnit() is not Expired AND Reputation Score ¿ Minimum Value AND Device.Type = Storage Generate an identifier to uniquely identify the order. Update status of the order to 'Submitted'. Emit an event for the entities participating to let them know that the data destruction request was successfully placed using the waste recycling unit EA, the device EA, and the data destruction unit EA. Display an error and restore the smart contract to its initial state.

1 Input: Electronic device EA, shipment delivery due date, quantity, and type

2 Output: Emit PurchaseOrderPlaced Event

3 if Retailer is not a registered user then

4 The request is rejected due to an unverifiable Ethereum address.

5 end

6 else

7 if Order placing entity is a Retailer AND QuantityRequested < Lot.GetLOTQuantity() AND QuantityRequested >

Lot.MinimumOrder_threshold AND Trade_licence != Expired AND Manufacturer.GetReputationScore ( ) > Minimum_Threshold then

8 Set request status to 'Waiting'.

9 Create an order ID.

10 Inform the stakeholders by emitting an event reporting the successful placing of a request for electronic devices using the retailer EA, amount requested, and electronic device EA.

11 end

\12 else

13 Display an error message and return the smart contract to its initial state.

14 end

15 end

Algorithm 2 Submitting Bids to Confirm Delivering e-Waste in a Particular Region

This algorithm ensures that only verified and legitimate users can request and receive a data destruction certificate. It checks the order and payment status along with the reputation score to prevent fraudulent activities. The use of IPFS and blockchain ensures the integrity and transparency of the certificate issuance process, providing a secure and verifiable record of data destruction.

1 Input: Waste contractor EA, bid

2 Output: Emit ContractorsSelected Event

3 if Waste contractor is not a registered user then

4 The request is rejected due to an unverifiable Ethereum address.

5 end

6 else

7 if WasteContractor has a valid permit to ship

e-waste AND Bidscount ! = ThresholdlimitAND

biding.status == OpenANDBiding$_V$alue <

MaximumTresholdANDReputationScore

> Minimum_valuethen

8 Register the bid.

9 Create Bid submission ID.

10 Set bidding status to “Submitted”.

11 Bidscount+=1.

12 Inform the stakeholders by emitting an event reporting the successful placing of a bid for shipping electronic waste in a particular region using the Waste contractor EA, biding values, biding ID, and status.

13 end

14 else

15 Display an error message and return the smart contract to its initial state.

16 end

17 end

Algorithm 3

Placing a Request for Data Destruction Unit to Perform Data Erasing

1 Input: Quantity, type, service time, device EA

2 Output: Emit DataDestructionRequestPlaced Event

3 if Caller is not a registered user then

4 This service cannot be granted due to unverifiable Ethereum address.

5 end

6 else

7 if Caller is WasteRecylingPlant AND Permit.GetPermitofDataDestructionUnit ( )!= Expired AND Reputation_Score > Minimum_Value AND Device.Type = = Storage then

8 Generate an identifier to uniquely identify the order.

9 Update status of the order to ’Submitted’.

10 Emit an event for the entities participating to let them know that the data destruction request was successfully placed using the waste recycling unit EA, the device EA, and the data destruction unit EA.
11 end

12 else

13 Display an error and restore the smart contract to its initial state.

14 end

15 end

Algorithm 4

Issuing Data Destruction Certificate of the Storage Devices

1 Input: Waste recycling unit EA, order ID, payment status

2 Output: Emit DataDestructioncertificateIssued Event

3 if Data destruction unit is not a registered user then

4 The request is rejected due to an unverifiable Ethereum address.

5 end

6 else

7 if Order.status==submitted AND Payment_Status== ’Yes’ AND Reputation_Score > Satisfactory then

8 Store certificate on IPFS.

9 Set status to ‘‘Completed’’.

10 Store IPFS hash on blockchain.

11 Set shipment.status= TRUE.

12 Inform the stakeholders by emitting an event reporting the successful issuing of a certificate for electronic waste using the Waste recycling unit EA, data destruction unit EA, Shipper EA, and order ID.
13 end

14 else

15 Display an error message and return the smart contract to its initial state.

16 end

17 end

III. SECURITY DEFINITION

This section presents a rigorous security analysis of the proposed blockchain-based IoT-enabled solution for electronic devices and their waste management in smart cities. It has been briefly discussed how the proposed system offers high security, transparency, privacy, resilience, and robustness. The following is a brief overview of how our system addresses the most significant security, fault tolerance, integrity, and privacy challenges of the existing electronic devices and their waste management systems. The security of` the proposed smart contracts is also verified using a security analysis tool for smart contracts.

A. INTEGRITY:

Our proposed system for electronic devices and e-waste management in smart cities stores transactions, data, and metadata on the immutable distributed ledger using an event-based technique. Through cryptographic techniques, the blockchain preserves the integrity of data. Moreover, the access modifiers in smart contracts aid in the protection of user data. Since our system is based on blockchain technology, the data will always maintain their integrity.

B. AVAILABILITY:

Blockchain is a distributed system that is resilient against multiple internal and external threats. More specifically, the system functionalities, including order placing, bid management, and reputation score calculation will be accessible even if a portion of the blockchain network is under attack. Since our proposed system is implemented on blockchain, it will be always accessible regardless of any internal or external blockchain threats.

C. NON-REPUDIATION:

Digital signatures, which are routinely used to authenticate the legitimacy of a transaction, are based on mathematical techniques. In our proposed system, digital signatures guarantee non-repudiation and ensure that no party may deny a committed transaction. The waste contractor, for instance, cannot deny the submitted bid because the transaction is digitally signed with his private key. Due to blockchain's immutability, this transaction cannot be altered or deleted.

D. CONFIDENTIALITY:

The confidentiality feature ensures that the participants' privacy and data access rights are safeguarded. Our approach uses modifiers with the functions to restrict access to just authorized users. In addition, the registration contract assures that only authorized users can join the network and engage in business operations.

E. SMART CONTRACTS VULNERABILITIES:

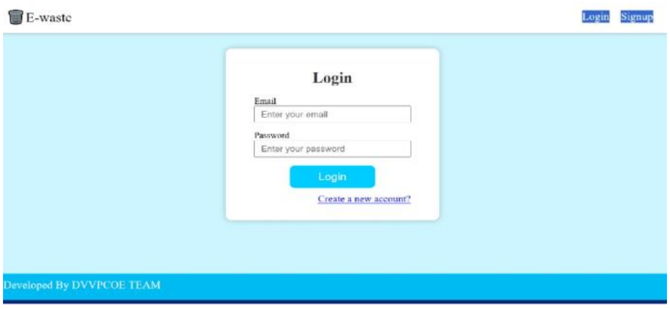
To prevent smart contracts from being exploited for malevolent purposes, it is strongly suggested that they be carefully drafted. There are numerous tools available that can be helpful to analyze the functions in smart contracts and provide guidelines to improve the security of smart contracts. We have utilized the SmartCheck tool to uncover probable problems in our code during the investigation. Based on the outcome of code analysis using SmartCheck, we modified our code and ensured that our smart contracts do not contain vulnerabilities, such as race conditions, infinite loops, integer divisions, or locked transfers.

IV.PERFORMANCE ANALYSIS

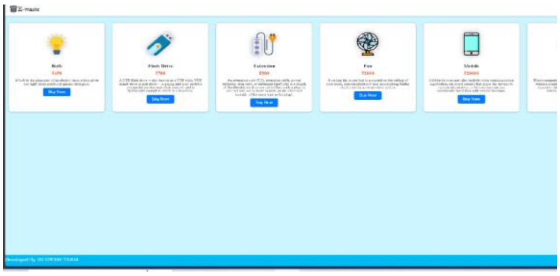
Home Page

Sign Page

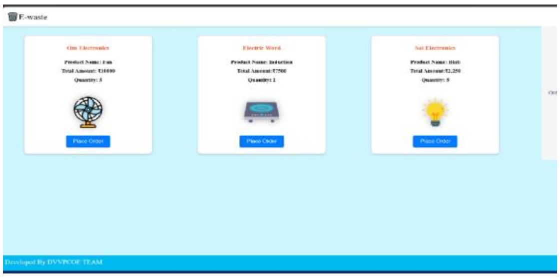
Login Page



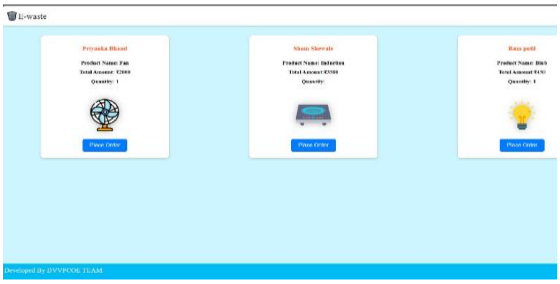
Manufacturer



Retailer

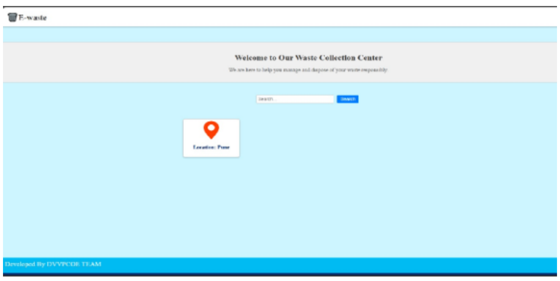


Consumer

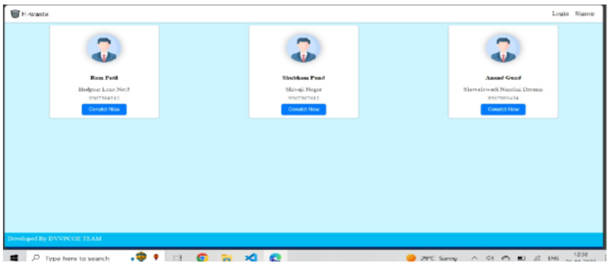


Smart Waste Bin

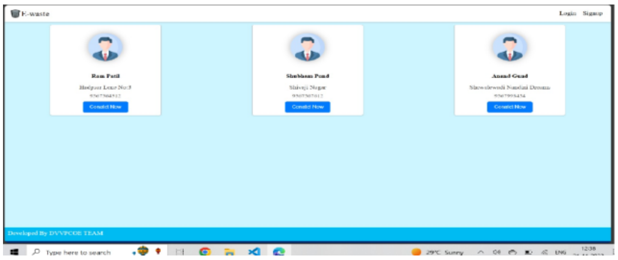
Waste Collection Center



Contractor



Recycling Plant



CONCLUSION

In this paper, we presented an IoT-enabled blockchain based system for tracking and tracing of electrical devices and their waste. Using the blockchain-platform, we designed a system that enables stakeholders to perform their business processes in a completely decentralized, secure, transparent, and auditable manner. The proposed system enables the authorities to ensure that electronic devices are purchased and supplied from licensed, reputed, and trustworthy users, disposed of appropriately, and managed by the participants in a safe and privacy-preserving manner. We resolved the scalability issues of the existing blockchain solutions by storing big data sets pertaining to electronic devices, e-waste. Moreover, we conducted the cost and security analysis of the proposed solution and found that our solution is practical, secure, viable, and highly dependable. The proposed system is generic and with small iterations it can be implemented for various other use case scenarios, such as domestic waste management, water waste management and other scenarios where traceability is required. In the future, we aim to incorporate additional types of waste into our system, such as wastewater, organic wastes, and food waste. Moreover, we will propose a mechanism for rewarding consumers for the deposited electronic devices.

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