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A Blockchain-Based Recycling Platform Using Image Processing, QR Codes, and IoT System

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Abstract: The climate crisis is one of the most significant challenges of the twenty-first century. The primary cause of high carbon emissions is industrial production that relies on carbon-based energy sources such as fuel oil, paraffin, coal, and natural gas. One of the effective methods to minimize carbon emissions originating from the use of energy resources is using recycling systems. A blockchain-based recycling platform was developed in this regard, adhering to the basic principles of Industry 4.0, which Robert Bosch GmbH and Henning Kagermann's working group described as an industrial strategy plan at the Hannover Fair in 2013. Concurrently, the recycling platform has set up an infrastructure that combines blockchain, AI, and IoT technologies for recycling objects. An IoT-based smart device was developed to collect recyclable objects. Thanks to the embedded artificial intelligence software and QR code sensor on the device, recyclable objects can be collected in different hoppers. In the laboratory studies, correct object recognition success was achieved at a rate of 98.2%.

Keywords: digital economy; carbon emission reduction; blockchain; image processing; QR code; IoT systems; deep learning

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1. Introduction

The World Trade Organization (WTO) emphasized that the climate crisis is one of the greatest challenges faced in the twenty-first century. The rise in carbon emissions per capita is the primary factor instigating this crisis [1,2]. In line with the Paris Agreement signed under the United Nations Framework Convention on Climate Change (UNFCCC) and entered into force in 2016 to develop problem-solving strategies for the climate crisis, signatory countries routinely report their efforts to emit low levels of carbon emissions [3,4]. The primary cause of high carbon emissions is industrial production that relies on carbon-based energy sources such as fuel oil, paraffin, coal, and natural gas. One of the effective methods to minimize carbon emissions originating from the use of energy resources is the use of recycling systems [5]. As a consequence of the actions taken, therefore, it is essential to properly collect environmentally damaging materials and matters whose reuse is only possible through recycling and subject these materials to physical or chemical processes, converting them into subsequent raw materials in the context of reducing carbon emissions.

In this context, recycling refers to processing the collected valuable materials from discarded waste and converting them into new products. The primary goal of the recycling procedure is to promote environmental conservancy by ensuring the acquisition of the demanded raw materials from the locations where recycling materials are regularly stored rather than by extracting new raw materials from nature through mining techniques. A critical aspect of a sustainable society is retaining an effective recycling system. Hence, it may be achievable to decompose environmentally harmful materials and protect natural resources by minimizing their adverse effects on nature in this manner. There are substantially diverse materials to recycle, such as plastic bottles, aluminum beverage cans, batteries, glass jars, electronic devices, and various other objects. Since each of these objects retains its own recycling processes, it is necessary to collect them separately and store each of these objects to improve recycling performance.

It is viable to employ artificial intelligence (AI) technologies to identify objects and organize them into different units. In this context, image processing, a sub-branch of AI technologies, is a computer technology focusing on the analysis of objects in images and videos. Image processing potentially detects the objects in inputs, enhances the image's quality, and categorizes them based on their contents by processing the received inputs with various algorithms. Nowadays, there are many diverse disciplines where image processing is frequently employed, including medical imaging, smart agriculture applications, satellite image processing, and video surveillance [6].

Blockchain technology possesses the potential to keep records of recyclable objects and individually calculate the deposits of the products to be returned.

As initially implemented in 2008 for a virtual money technology called Bitcoin, blockchain grounds on a block-based technology. Blockchain is a distributed database system storing lists of records, each of which consists of interconnected blocks. Each block contains its unique timestamp, having the capacity to link itself to the preceding block using this timestamp. Due to its powerful encryption algorithms, this technology precludes modifying historical records, albeit allowing the storage of the data transparently and securely. Hitherto, blockchain technology is used for several purposes, such as generating smart contracts, registering intellectual property and financial transactions, recording data accuracy, monitoring the supply chain, and the application of security certificates to various objects. There are also initiatives to develop applications operable with blockchain technology [7].

The physical storage of recyclable items is possible with the help of the Internet of Things (IoT) technology. IoT is a network where hardware, electronic devices, sensors, and software function effectively in combination. The IoT network may comprise various devices, from straightforward sensors to sophisticated industrial equipment, developed for a wide range of applications. These hardware components may intercommunicate over the internet using GPS, GPRS, and SOA technology.

The blockchain-based recycling platform was developed in this regard in accordance with the basic principles of Industry 4.0, which Robert Bosch GmbH and Henning Kagermann's working group described as an industrial strategy plan at the Hannover Fair in 2013. Concurrently, the recycling platform has set up an infrastructure that combines blockchain, AI, and IoT technologies for recycling objects. Effective use of this platform is expected to assist in reducing the use of natural resources, saving energy and thus contributing to the economy thanks to recycled objects, reducing the amount of solid waste in need of disposal, and finally, reducing greenhouse gas emissions. Thanks to the smart contract on the developed system, the industrial waste recycling system, developed originally under the name Recycle Chain, is characterized by a set of validating nodes running the blockchain using proof of authority, similar to other blockchain-based structures, and a person-based system to reduce the carbon footprint of individuals.

The main contributions of the current study to the literature are listed below:

1. A blockchain-based platform named Recycle Chain was developed to track recycling objects.
2. A token named the Recycle Token (RT) was created for the deposit payments of recycling objects, calculating how much each Recycle Chain user contributes to the system on a per capita basis.
3. A deep-learning-based AI software was developed to identify recycling objects, and a new dataset named Recycle Chain DS was generated to train the developed artificial intelligence software.
4. An IoT-based smart device was developed to collect recycling objects. The embedded AI software on the developed device enables object identification and collection of recycling objects in different compartments. Additionally, the device improves the effectiveness of the waste collection system as it may send the weight and capacity information of the waste to the central system via GPS and GPRS systems.

The rest of the paper is organized as follows: Section 2 presents the Related Works. Section 3 introduces the Materials and Methods. Section 4 clarifies the methodologies and assesses the results, and finally, Section 5 presents the conclusion.

2. Related Works

Global warming induces events such as glacier melting, droughts, migrations, floods, corruption of socio-economic systems, and escalation of extreme weather conditions; consequently, it becomes a life-threatening issue for all living things worldwide [8,9]. The literature reports numerous publications on the problems arising from global warming and ways to resolve them [9]. Some of the literature also focuses on recycling systems, aiming to minimize carbon emissions. For instance, Bandara and Indunil (2022) developed an efficient procedure to ensure the recycling of food packages [10]. Blömeke et al. (2022) generated a new architectural infrastructure system for electric cars and lithium-ion battery recycling, which are becoming routine in our daily lives [11]. Elavarasan et al. also conducted a study on recycled concrete to support the construction sector in reducing solid waste [12].

While global warming has brought blockchain technology to our attention in recent years, it has become more prevalent in our daily lives with the advancements in digital technology. As depicted in the literature about recycling systems, blockchain technology also became widespread in storing and transmitting patient data in the field of biomedicine, smart healthcare, and the IoT domain. Correspondingly, it has a wide range of applications, including data security and the storage of animal data in the context of smart agriculture.

The literature review revealed that Taloba et al. (2022) developed a blockchain-based hybrid platform for multimedia data processing in IoT-Healthcare. They successfully achieved security and data privacy of drug delivery between patients and drug distributors by developing a blockchain- and IoT-based architecture [13]. De Aguiar et al. (2022) also studied data reliability by applying blockchain technology to regulate user access to medical data [14]. Similarly, Sri Sai et al. (2022) developed a micro-financial credit distribution system for small-scale companies using blockchain technology [15]. Ibrahim et al. (2022) developed a blockchain-based parking lot monitoring system for smart cities using IoT technologies [16].

With the population growth in cities, the importance of waste management is increasing. Especially when it comes to smart cities, it is very important to encourage recycling with the use of technologies such as artificial intelligence, IoT, and blockchains and to recycle waste, which is a global problem, by classifying it appropriately.

Khadke et al. (2021) talked about the impact of plastic, which cannot be easily recycled by nature, mixing into the sea. In their study, they stated that the amount of solid waste has increased exponentially in densely populated areas and that the amount of plastic waste, which was almost 0 in the 1950s alone, reached 400 million tons per year [17]. For the promotion of recycling and the protection of nature in this context, a platform that brings together IoT, QR, deep learning, and blockchain technologies was developed to classify and collect objects that can be recycled.

Peng et al. (2022) developed a "permissioned blockchain system" called NeuChain. They proposed an ordering-free architecture that makes ordering implicit through deterministic execution [18]. Peng et al. (2022) introduced a verifiable blockchain system called VFCain. Using an authentication system, VFCain also has an optimization scheme for searching block information [19].

Ren et al. (2020 and 2022) developed systems demonstrating that blockchain technologies and IoT technologies work seamlessly together. When we look at these systems, Ren et al. (2020) designed a blockchain-based data query mechanism based on the hash computing power system for use in IoT systems [20]. Ren et al. (2021) developed a cloud store mechanism for smart homes using blockchain technology. They employed blockchain technology to store data on the blockchain [21]. Finally, Ren et al. (2022) proposed a blockchain-based proxy voting scheme for decision feedback in the Internet of Vehicles [22].

Gao et al. (2022) introduced a new communication tool, SymmeProof, to reduce the transmission cost of a blockchain connection. Thanks to this model, the proof size ratio was reduced considerably [23]. Li et al. (2021) presented a blockchain-based system called B-DNS for the security of DNS systems. In their B-DNS study, they showed that query delays are less compared to classical DNS systems [24]. Table 1 shows the studies related to the blockchain-based recycling systems.

Table 1. Comparison of works regarding blockchain-based recycling systems.

Author	Objective	IoT	QR	Reward System	Deep Learning Model
Almadhoun et al. (2018) [25]	Monitoring the end of life of waste	No	No	No	No
Ongena et al. (2018) [26]	Waste management practice	No	No	No	No
Gopalakrishnan (2020) [27]	A blockchain-based traceability system for waste management in smart cities	No	No	Yes	Yes
França (2020) [28]	Proposing the use of blockchain to improve the solid waste management in small municipalities	No	No	Yes	No
Gupta et al. (2017) [29]	E-waste management using blockchain-based smart contracts	No	No	Yes	No
Akram et al. (2021) [30]	Blockchain-enabled automatic reward system in solid waste management	Yes	No	Yes	No
The present study	A blockchain-based recycling platform using image processing, QR Codes, and IoT System	Yes	Yes	Yes	Yes

The recycling platform has set up an infrastructure that combines blockchain, AI, and IoT technologies for recycling objects for the first time in the literature.

3. Materials and Methods

This section discusses the infrastructure, key instruments, and technologies used to develop the blockchain-based recycling platform.

3.1. Performance Evaluation Metrics

The current study utilized the confusion matrix, as displayed in Table 2, to measure the classification performance of the objects. The confusion matrix is a table that indicates the datasets and areas of an application where an application is successful. The values in the table (True Positive, False Positive, False Negative, and True Negative) display information about the accuracy of the prediction [6].

Table 2. Confusion matrix.

	Actual True	Actual False
Predicted True	True Positive (TP)	False Positive (FP)
Predicted False	False Negative (FN)	True Negative (TN)

TP: It is an outcome where the application correctly predicts the positive class. TN: it is an outcome where the application correctly predicts the negative class. FP: it is an outcome where the application incorrectly predicts the positive class. FN: it is an outcome where the application incorrectly predicts the negative class [6]. As they are used frequently in the literature, except for the confusion matrix, the values of Accuracy, FM score, Recall, and Precision were used in this investigation to measure the classification performance of the objects.

Precision = As calculated by the formula in Equation (1), it refers to the frequency of positive predictions made by the application divided by the total number of positives.

$$\text{Precision} = \text{TP}/(\text{TP} + \text{FP}) \tag{1}$$

As calculated by the formula in Equation (2), Recall refers to the measure of the application's capacity to find all positive patterns in the data.

$$\text{Recall} = \text{TP}/(\text{TP} + \text{FN}) \tag{2}$$

FM = A value calculated as the harmonic mean of Precision and Recall values refers to a number between 0 and 1. The calculation formula of the FM metric frequently used in unbalanced datasets, in particular, is given in Equation (3) [6,31].

$$\text{FM} = 2 \times (\text{Precision} \times \text{recall})/(\text{Precision} + \text{Recall}) \tag{3}$$

Accuracy (ACC) = As calculated according to the formula in Equation (4) [31], it is a metric used to measure the performance of a model in a balanced dataset.

$$\text{ACC} = (\text{TP} + \text{TN})/(\text{TP} + \text{FP} + \text{TN} + \text{FN}) \tag{4}$$

3.2. Experimental New Recycling Dataset

Deep learning models require a substantial amount of training data if there has been no prior training. A dataset containing 4000 image files, consisting of 4 different categories, and previously classified and labeled was created to overcome this issue. An evaluation process took place, employing several datasets from publicly accessible sources to create the dataset. As revealed by the analysis, except for the open-source Drinking Waste dataset [32], other datasets had low data counts, poor data quality, and unbalanced data distributions. As a result, a new data collection, Recycle Chain DS comprising data on drinking waste, was developed. Table 3 displays details regarding the dataset developed under the name Recycle Chain DS.

Table 3. The descriptive information regarding the Recycling Dataset.

Category ID	Category Name	Number of Samples
0	Battery	1.000
1	Glass Bottle	1.000
2	High-Density Polyethylene	1.000
3	Plastic Bottle	1.000

3.3. Information about Blockchain Math

Blockchain technology, as its name suggests, consists of interconnected data blocks. Its first successful use was a cryptocurrency called Bitcoin at the end of 2008. It is clearly stated in the debut article that Bitcoin, invented using computer processing power, was created in response to the banking and financial crisis in 2008. Any quantity of money transaction is possible from one account to another anywhere in the world using the Bitcoin system, which first emerged as a manifesto, without needing any bank or intermediary institutions. The number of Bitcoins, which has a unique mathematical equation, operates on a peer-to-peer network, is a distributed ledger, and is limited to only 21,000,000 by the algorithm. Thanks to Bitcoin's mathematical structure, one Bitcoin is split into a hundred million pieces. Each piece is called a Satoshi [33]. The SHA-256 block encryption algorithm and a complicated hash computation enable the creation of the blockchain-based Bitcoin system. Bitcoin retains features, including immutability, transparency, autonomy, and open source, as in many other subsequent blockchain systems. Figure 1 displays the system architecture of a blockchain mechanism [34].

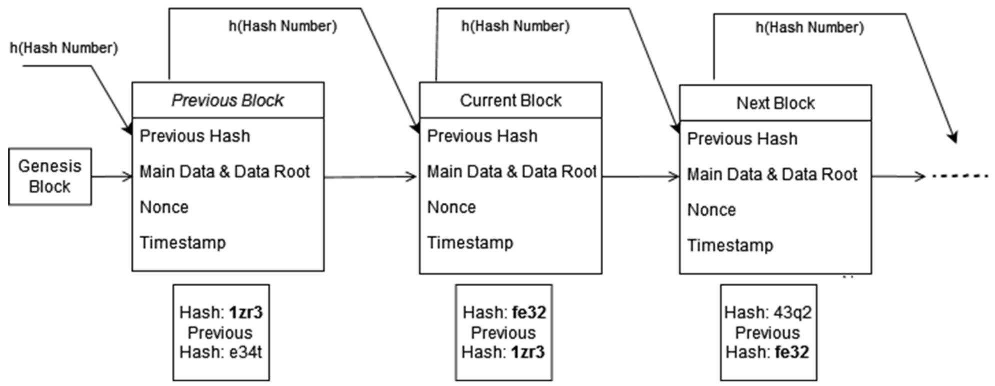

Figure 1. A sample blockchain Structure.

A hash chain connects each block to the preceding one. This link resumes all the way to the initial block of Genesis. The main data in previously formed blocks cannot be modified because each block is created with a timestamp and a hash mechanism. Every block has a unique hash value, and every user connected to the network owns a copy of each block.

- Timestamp: It refers to the time interval required to create the block.
- Prev. Hash: It denotes the hash value of the previous block.
- Main data: It is a block of data possibly recorded on the blockchain.
- Data root: It refers to the calculated value for all data pieces. The Merkle tree root [35] method is used for value calculation.
- Nonce: A number generated by random number generators specified in the blockchain and meeting the target condition [36].

3.3.1. Smart Contract

Smart contracts are distributed digital wallets that are built using computer code to store contracts between buyers and sellers, operating in the same way as regular contracts. It was first introduced in 1997 by Nick S., a computer scientist and cryptographer [37]. Smart contracts are standalone computer programs that are appended to the main data in the blockchain. They are digitally signed by encryption algorithms, exactly like blockchain structures. Smart contracts, which have a high business potential today, have an immutable and distributed structure. Smart contracts can be employed for the automation of many business processes, which can help businesses reduce costs and boost productivity.

3.3.2. Metamask

Metamask, a virtual wallet application, is free and open source. Metamask can harbor tokens with ERC-20 technology within its structure. Metamask can be integrated into a mobile application or a web application as embedded code. Metamask's service enables interaction between decentralized applications (DApps) and smart contracts [38].

3.4. Deep Learning

Deep learning is an approach used to develop artificial intelligence for machines in perceiving and understanding the world. Deep learning, which evolved as a subfield of machine learning, is named "deep" due to possessing multiple layers. Today, deep learning is used in many disciplines such as image processing, voice recognition, and natural language processing [39,40].

Convolutional Neural Network (CNN)

CNN is a deep learning algorithm that is generally used in image processing and takes images as input. This algorithm, which recognizes features in images and classifies them, consists of different layers. Nowadays, the CNN deep learning algorithm, which is used even in very important health fields such as disease recognition through images, is also successfully used in many other fields such as game artificial intelligence, speech processing, and bioinformatics [39,41–43]. The convolutional neural network is a form of multi-layer perceptron (MLP) and is made up of a large number of interconnected layers, each of which performs a specific function. The layers are organized in a specific order, with the input layer first and the output layer last. Mathematically speaking, convolution is a function derived by integration from two given functions and expresses how the shape of one is modified by the other. It is calculated according to the formula in Equation (5) [44].

$$(f * g)(t) = \int_{-\infty}^{\infty} f(\tau)g(t-\tau)\, d\tau \tag{5}$$

Here, f denotes the input data, g the filter, and t the convolution result. This process is utilized to identify and find the features of the input data.

The CNN algorithm, a feed-forward neural network, was inspired by the visual center of animals. The mathematical convolution process here can be thought of as a neuron's response to stimuli from its own stimulus field. The main feature of CNN is that it uses specially designed convolutional layers to automatically extract features from the input data. The extracted features are passed through additional layers for classification or other purposes [45].

The pooling operation is applied in the CNN algorithm to reduce the size of the input data. There are two most frequently used types of pooling operations. Their names are max-pooling and average pooling.

The calculation of the max-pooling formula is shown in Equation (6).

$$MaxPool\left(x_{i,j}\right) = \begin{matrix} n-1\; n-1 \\ max \;\; max\; x_{i+k,j+l} \\ k=0\; l=0 \end{matrix} \tag{6}$$

Here, $x_{i,j}$ refers to the input data and n is the size of the pooling region. Max-pooling occurs by picking the highest value available in a regional area. Equation (7) demonstrates the calculation of the average pooling formula.

$$AvgPool\left(x_{i,j}\right) = \frac{1}{n^2} \sum_{k=0}^{n-1} \sum_{l=0}^{n-1} x_{i+k,j+1} \tag{7}$$

Here, $x_{i,j}$ represents the input data and n represents the size of the pooling region. Average pooling is achieved by averaging all values in a regional area.

Activation function: It is a function used to activate the output of neurons. The most frequently used activation functions are the sigmoid, ReLU, tanh, and Leaky ReLU functions. Equation (8) shows the calculation of the sigmoid formula.

$$Sigmoid(x) = \frac{1}{1+e^{-x}} \tag{8}$$

Equation (9) below demonstrates the calculation of the ReLU formula.

$$ReLU\ (x) = max\ (0, x) \tag{9}$$

Equation (10) shows the calculation of the tanh formula.

$$Tanh(x) = \frac{e^x - e^{-x}}{e^x - e^{-x}} \tag{10}$$

These functions are implemented to limit and activate the output values of neurons. Different activation functions can yield optimal results for different problems.

Fully connected layer: It is used for the connection of each neuron with all other neurons and classification or regression of input data at the final stage. Input data are multiplied by their weights and output data are calculated. The output data calculation formula is given in Equation (11) [45].

$$Output\ j = \sigma\left(\sum i = 1^n\ Weight_{i,j}\ *\ Input_i + b_j\right) \tag{11}$$

Here, Weight i, j stands for the connection weight of neuron j with the internal input neurons, Input i represents the input data, b_j represents the bias values of the neurons, and Output j represents the output data and the activation function.

Equations (6)–(11) are used to process the input data, train the weights, and make predictions. The CNN algorithm has achieved successful results in a wide variety of applications, particularly in the field of computer vision, and has been used for purposes such as object detection and face recognition. The CNN algorithm has also been applied to many other areas such as natural language processing and speech recognition [46].

3.5. Internet of Things (IoT)

Thanks to the development of Internet technology and the possibilities provided by the increase in data transmission speeds, there are currently devices that have been developed for many different purposes and that exchange data over the Internet. These devices, also called IoT, can make use of the sensors on them to optimize production processes. IoT devices can also augment individuals' quality of life by simplifying daily tasks. Today, IoT devices are used in smart home systems, wearable devices that monitor health data, and the active operation of production lines in factories, and it is predicted that IoT devices will be used in many kinds of fields in the coming years [47,48].

3.6. Quick Response (QR) Codes

A QR code is a kind of barcode that we can translate as a "Quick Response" code. QR codes are engineered as a 2-dimensional matrix code and require a camera or QR reader to be read by users. QR codes can also be used to store URLs, text, images, or other data [49].

3.7. YOLO

Named in 2015 by Joseph Redmon, Ali Farhadi, and colleagues, YOLO was first introduced as a research paper. Today, YOLO is utilized in many image processing applications due to its high accuracy rates. YOLO is mainly employed to solve object detection and classification problems. By analyzing a single frame in the image, the algorithm estimates the positions and classes of objects. Since YOLO uses the CNN algorithm as the basis for deep learning, the equations presented from Equation (6) to Equation (11) are also used in YOLO [50].

4. A Blockchain-Based Recycling Platform

A blockchain-based platform called Recycle Token was developed to track recyclable objects. For this purpose, the system architecture displayed in Figure 2 was developed. Users of the Recycle Chain system illustrated in Figure 2 must show different types of recycling objects to the camera on the IoT-based device. If there is a QR code on the recycling objects previously defined to the system, it accepts the recycling product from a single entry point without the use of a deep learning algorithm. The accepted product is weighed using a weight sensor and added to the recycling objects of its type following user approval. If a QR code defined on the recycling object cannot be detected, then the DL algorithm on the IoT device tries to identify which class the recycling object belongs to and informs the user about the recycling object weighed by the weight sensor. After the user's approval, the recycling product is added to the hopper holding the relevant recycling objects. After all the products are added to the system, the deposit earned by the user is transferred to the user's wallet as a Recycle Token via smart contracts and the blockchain system.

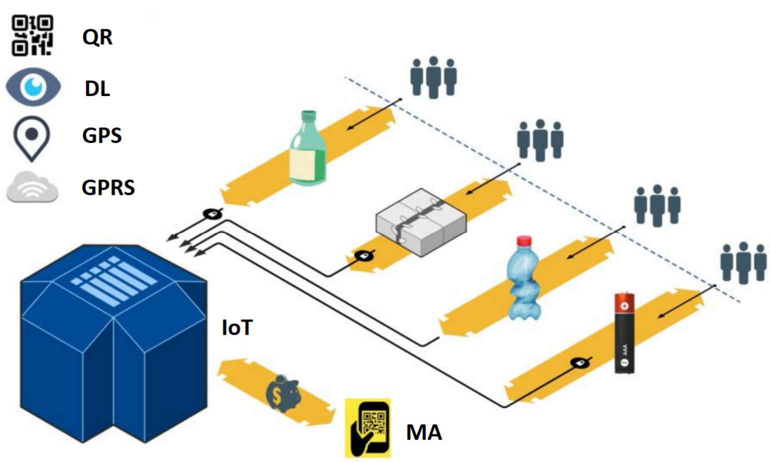

Figure 2. The system architecture of Recycle Chain.

4.1. Recycle Chain Infrastructure Components

Recycle Chain, a Web3 technology, has a complete proof-of-stake (PoS) chain structure as it was created based on the Goerli testnet infrastructure. Within the Recycle Chain, using the proof-of-stake method and smart contracts, a token called the Recycle Token was created with a total of one hundred million tokens. When we look at the carbon footprint that the Proof of Work (PoW) method, the classic blockchain method, creates in blockchain transactions, the results are striking. In their book, Stoll, Klaaßen, and Gallersdörfer argue that BTC mining leads to high electricity and carbon emissions [51]. In contrast, the proof-of-stake (PoS) is a protocol that takes into account ownership of assets rather than a system based on high algorithms and computational power. The PoS protocol, presented in a study by King and Nadal [52], focuses on eliminating the problems of high energy consumption and slow processing speeds required for BTC mining. Ethereum's switch from PoW to PoS in Version 2 has resulted in a very positive environmental impact.

In this context, the Recycle Token was created to digitally transfer rewards to users for bringing recyclable objects. The smart contract inside the Recycle Token is coded in Solidity, an object-oriented programming language. Developed by Christian Reitwiessner and Alex Beregszaszi, Solidity is currently used for the development of numerous different blockchain platforms.

4.2. Information about the Recycle Token

The Recycle Token can be integrated into the digital wallet with the Metamask browser plugin or via the mobile app. Thus, the digital value obtained by recycling and called the Recycle Token can be viewed in the system. The person with the digital wallet can see how many Recycle Tokens they have earned in total from the objects they give for recycling on their Metamask wallet. The Recycle Token, which corresponds to the points obtained, is transferred to the Metamask wallet when requested by the recycler. Since the generated Recycle Token is transferred to a multipurpose service, it can be used independently.

The smart contract in the Recycle Token was created to be deployed on the Ethereum network. The smart contract contains information about the token. The smart contract contains the name of the token, the amount of the created token, the definition of the token sub-unit carbon, transfer information, and the transfer fee. The Recycle Token is defined as "100,000,000 RT" units and carbon "C" is used as the sub-token unit. In the Recycle Chain project, an additional smart contract was needed to ensure the conversion of users' carbon points to the Recycle Token. In this smart contract, user IDs and carbon amounts are stored in the blockchain. The RT values obtained from the recycling objects are transmitted by connecting them to the blockchain Metamask Web3 wallet.

A sample code example taken from the developed smart contract code is as follows:

```
//SPDX-License-Identifier: MIT
pragma solidity ˆ0.8.9;
import "@openzeppelin/contracts/token/ERC20/ERC20.sol";
contract RecycleToken is ERC20 {
constructor() ERC20("Recycle Token", "RT") {
_mint(msg.sender, 100,000,000 * 10 ** decimals());
}
}
```

One of the most widely used networks of Web 3.0 technologies in the world is the Ethereum network. In the current study, rather than creating a network like VFChain, the Ethereum network was preferred as shown in Figure 3. In the study, the Ethereum network was chosen, and a token called Recycle Token, which is a blockchain-based token, was generated on this network. The Ethereum network employed in the study has a network structure that allows the creation, storage, and transfer of large amounts of data and operates on a distributed system. Each block on Ethereum has a data record with a timestamp, hash value, and a series of transactions. A transaction is simply described as a transfer of value or data from one account to another account. This data record can include a signed instruction that runs the smart contract code. Ethereum, like VFChain, is a blockchain-based technology, but it is primarily used to support smart contracts and tokens. The strengths of the Ethereum network are that it is designed for smart contract development and has broad usage support. The developed Recycle Token also supports the ERC-20 token standard, a technology used for generating and distributing tokens on the blockchain. Recycle Token stores data on a blockchain called the Ethereum (ETH) network. Thanks to this technology, a Metamask wallet connection is generated. In the created Recycle Token, data such as user TokenID, token balance information, and carbon score information are retained. Basic information about the user was also held in a defined struct, and mappings were created for the relevant users. The data model of the developed Recycle Token is presented in Figure 3.

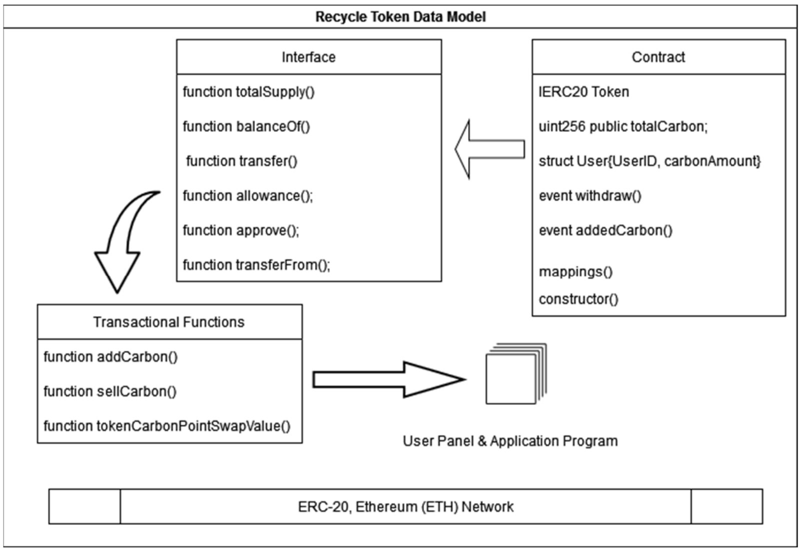

Figure 3. Recycle Token Data Model.

One of the basic principles of blockchain-based systems is to record, store, and update data in a distributable way. The infrastructure of the blockchain-based recycling system is based on the Ethereum network, as shown in Figure 3 and described in Section 3.3. The Ethereum network is a distributed storage layer and a decentralized blockchain platform for storing data related to smart contracts. This distributed storage layer consists of a large number of nodes that are coordinated to ensure the integrity of the data stored on the network. The Ethereum network uses a consensus mechanism called proof-of-stake

(PoS) to ensure data integrity and verify every transaction that occurs on the network. This ensures that the data stored on the network are accurate and unaltered. Ethereum uses cryptographic algorithms such as SHA-3 to ensure that every bit of data stored on its network can be stored unaltered. It also uses a staking mechanism to verify the authenticity and integrity of the data stored on the network.

For the development of the IoT part of the blockchain-based recycling system, Pasperry Pi-3 was used first, but due to insufficient processing power and low FPS, Jetson Nano 4GB was employed. Developed by Nvidia, the NVIDIA Jetson Nano Developer Kit is a low-power hardware component that allows running multiple neural networks in parallel for applications such as object detection, segmentation, image classification, and speech processing.

With a quad-core 64-bit ARM CPU, 128-core integrated NVIDIA GPU, and 4 GB LPDDR4 memory, Jetson Nano can run modern AI algorithms. Jetson Nano can also run multiple neural networks in parallel. For the other components of the IoT system, Ultrasonic Module, Raspberry Pi Camera, Stepper Motors, Hx711 weight sensor, and GPS/GPRS module were used. An average of 25 FPS values was obtained in the laboratory studies carried out on the created hardware. In the system algorithm of Recycle Chain (Algorithm 1), the main stages of the workflow and its complete architecture have been briefly summarized.

Algorithm 1 Recycle Chain

```
Input:
RC_Total = 0; // RC_Amount earned
MetaMask_UserID = 0; // User ID information to which the earned fee will be added
if (Ultrasonic_Module == True) then
  Start.Camera = Record(Video)
  for Video.frame
    if ( QR_Code == True) && (Weight > 10gr) then
          RC_ Total = RC_ Total + Calculate_RC (QR_Code);
    else
          if (Weight >=10gr) then
            switch (DL_Classification){
              case: 0 RC_Total = RC_Total + Calculate_RC(0);
              case: 1 RC_Total = RC_Total + Calculate_RC(1);
              case: 2 RC_Total = RC_Total + Calculate_RC(2);
              case: 3 RC_Total = RC_Total + Calculate_RC(3);
              default: LCD.Write ("Definication Error Detacted");}
          else
              LCD.Write ("Definication Error Detacted");
    end if
endfor
    if (User_Apporve == True)
           MetaMask_UserID. SendDeposit(RC_Total);
          LCD.Write ("Transaction Successful!");
    else
          LCD.Write ("User Not Define");
    end if
1: end if
```

4.3. Developed Deep Learning Model and Experimental Results

The details of the deep learning model and 2D CNN network model developed for the identification of recycling objects are given in Table 4. The camera image taken for recycling is first transformed into a 128 × 128 matrix. By means of increasing the number of layers and filtering, more refined and abstract feature sets were developed. In this way, representational learning was targeted. The MaxPooling layer displayed in Table 3 is used to reduce the number of features to a certain size. Batch Normalization was employed to make the Conv2D layers more organized. The ADAM (Adaptive Moments Estimation) optimization method, which is similar to the stochastic gradient descent approach in the literature, was used for training the neural networks.

Table 4. Network model of 2D CNN.

Layers	Output
Con2D	(None, 128, 128, 128)
Batch Normalization	(None, 126, 126, 128)
Conv2D	(None, 124, 124, 128)
Batch Normalization	(None, 124, 124, 128)
Max Pooling2d	(None, 41, 41, 128)
Drop Out	(None, 41, 41, 128)
Conv2D	(None, 39, 39, 256)
Batch Normalization	(None, 39, 39, 256)
Conv2D	(None, 37, 37, 128)
Batch Normalization	(None, 37, 37, 128)
MaxPooling2d	(None, 12, 12, 128)
Drop Out	(None, 12, 12, 128)
Flatten	(None, 18,432)
Dense	(None, 512)
Batch Normalization	(None, 512)
Dropout	(None, 512)
Dense	(None, 4)

The architectural visualization of the layers of the designed model is illustrated in Figure 4.

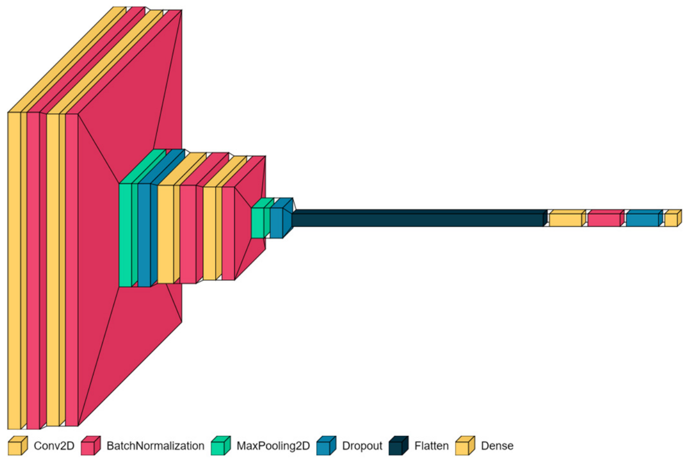

Figure 4. The architectural visualization of the layers of the designed model.

Hyperparameters determined in the experimental study are specified in Table 5.

Table 5. The parameter settings for the empirical study.

Parameter	Value
Batch size	16
Epoch	100
Optimization Algorithm	ADAM
Learning rate	0.001
Epsilon	1.0×10^{-8}
Activation Function	ReLU
Pooling Operation	Max Pool

The 2D CNN network architecture model was applied to the Recycle Chain DS dataset with the determined hyperparameters. A total of 80% of the dataset was allocated for training, and the remaining 20% was for testing. Figure 5 shows the confusion matrix related to the success rates achieved by the model.

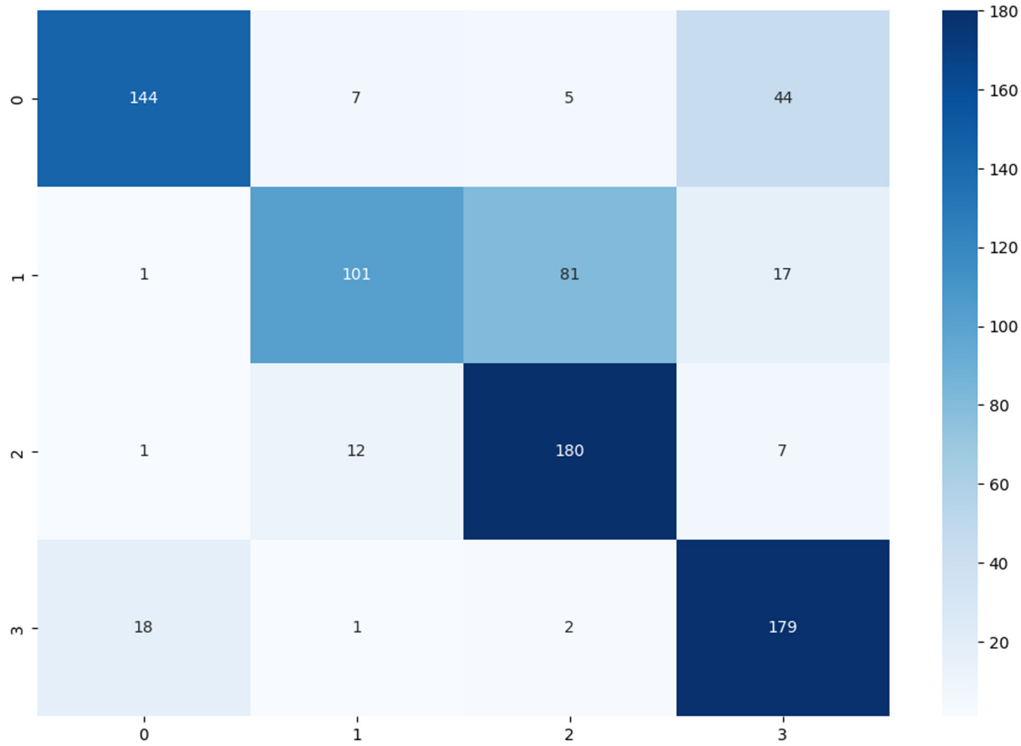

Figure 5. The confusion matrix.

As a result of the study, a classification accuracy rate of 75.1% was achieved. Here, ID = 0 is Battery, ID = 1 is Glass Bottle, ID = 2 is High-Density Polyethylene, and ID = 3 is Plastic Bottle. The model has the most difficulty in distinguishing objects between ID = 1 and ID = 2, as can be seen from the confusion matrix in Figure 4.

Since the success rate in the results obtained by using only the CNN algorithm was not sufficient, it was considered that the success rate could be improved by using YOLO v4, which also contains layers within the CNN algorithm. For this reason, additional tests were applied with YOLO v4 on the Recycle Chain DS dataset. As a result of the tests, an ACC value of 89.07% was achieved.

Kıvrak et al. (2022) demonstrated that the use of YOLO algorithms with higher version numbers increased the classification success through the results of their test studies [53]. For this reason, to further increase the correct classification success rate of 89.07% obtained with Yolo v4, the tests were repeated with Yolo v8, which started to be used at the beginning of 2023, and in addition, in order to increase the difficulty level of the tests, the classification difficulty level was increased from 4 to 5 by adding an aluminum beverage cans class named AluCan to the Recycle Chain DS dataset. As a result of the tests, despite increasing the classification difficulty by adding an additional class, a 98.2% correct classification performance was achieved. On the other hand, FPS values decreased due to the high processing power requirement caused by the use of Yolo v8. The average value of 25 FPS obtained in Yolo v4 could not be achieved in Yolo v8. Figure 6 shows the Precision–Recall curve related to the 98.2% success rates achieved by the Yolo v8 model.

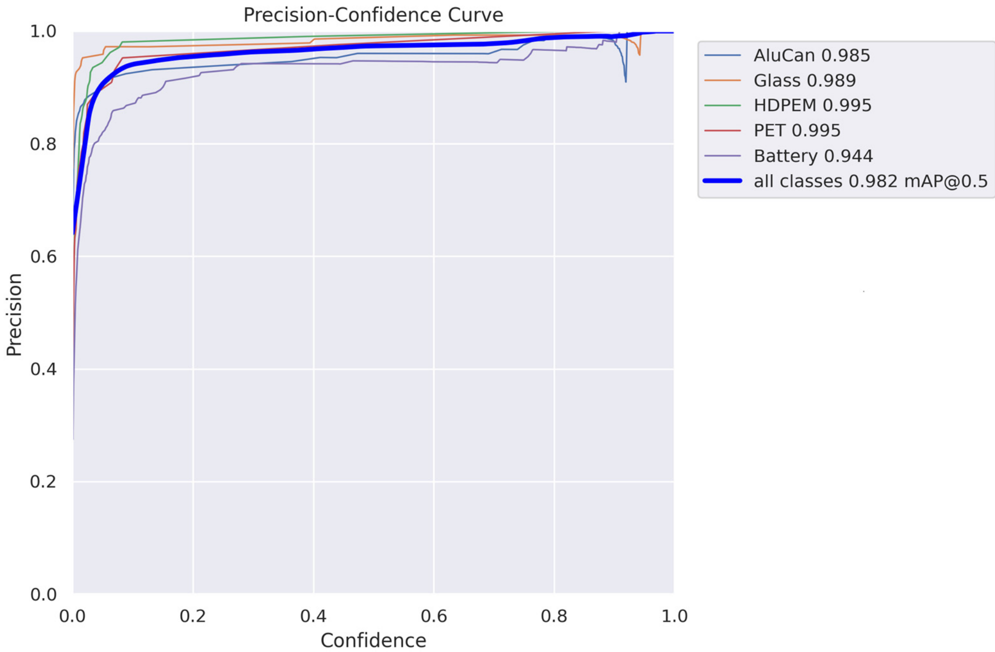

Figure 6. The Precision–Recall Curve of Yolo v8.

4.4. Developed Deep Learning Software and Application Software

A separate software that also operates on the IoT device was developed for recycling various kinds of recyclable objects. The designed software has the capability to analyze the images taken from the camera on the device. If there is a QR code on the front of the device to be recycled, the detection process takes place automatically. If no QR code is detected on the device, then the image is attempted to be classified with the developed image processing model. After the weight of the recycling object is weighed by the device and the user's approval, the recycling object is added to the relevant hopper in the device. Following this process, the amount of Recycle Tokens earned by the user who brought the recycling object is automatically added to the MetaMask wallet.

The left side of Figure 7 shows how the developed deep learning model performs object recognition, while the right side of Figure 7 shows how the developed software performs QR recognition. Since it is known how many and what type of recycling objects each user brings to the system, badges were also integrated into the system. The badge approach, which is used in many different systems today, is intended to increase the loyalty of the users of the RC system.

Figure 7. The developed deep learning software and QR recognition system.

5. Conclusions

A carbon footprint is a measure of carbon dioxide and other greenhouse gases released into the atmosphere as a result of the activities of a person, organization, or product. Greenhouse gases trap heat in the Earth's atmosphere, contributing to increased global temperatures and climate change. Proper sorting and collection of recyclable objects are crucial to reduce the carbon footprint. Using recycling systems effectively is one of the most effective methods to ensure a reduction in the amount of carbon emissions generated by the use of energy resources. In this context, a blockchain-based platform called Recycle Chain was developed to track recyclables. A token called the Recycle Token was created for the deposit payments of recycling objects, and it can be calculated how much each Recycle Chain user contributes to the system on an individual basis. Instead of the PoW method used in minus blockchain systems, the PoS method was used with smart contracts, thus enabling the system to be created faster and with much less energy use. A deep-learning-based artificial intelligence software was developed to identify recycling objects, and a new dataset containing 4000 images, called Recycle Chain DS, was created to train the developed artificial intelligence software. In the laboratory studies, correct object recognition success was achieved at a rate of 98.2%. An IoT-based smart device was developed to collect recyclable objects. Due to the embedded artificial intelligence software and QR code sensor on the device, recyclable objects can be collected in different hoppers.

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Abbreviations

List of abbreviations used in the article (in alphabetical order).

ACC	Accuracy
AI	Artificial Intelligence
CNN	Convolutional Neural Network
DApps	Decentralized Applications
DL	Deep Learning
GPRS	General Packet Radio Service
GPS	Global Positioning System
IoT	Internet of Things
MA	Mobile Application
MLP	Multi-Layer Perceptron
PoS	Proof-of-Stake
PoW	Proof of Work
QR	Quick Response
RT	Recycle Token
RT	Recycle Token
SHA	Secure Hash Algorithm
SOA	Service-Oriented Architecture
UNFCCC	The United Nations Framework Convention on Climate Change
WTO	The World Trade Organization

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