SMART WASTE MANAGEMENT: REVOLUTIONIZING GARBAGE CLASSIFICATION WITH DEEP LEARNING

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Abstract: In this study, we address the pressing issue of garbage classification through the development of an automatic classification system leveraging deep learning techniques. Our proposed system builds upon the ResNet-50 convolutional neural network (CNN) architecture and employs ensemble learning for enhanced performance. Initially, we outline the comprehensive design of the garbage bin system, encompassing both hardware components and a mobile application interface. Subsequently, we introduce our modified garbage classification algorithm, which utilizes ResNet-50 as its backbone. We further optimize the network structure through ensemble learning, focusing on three key aspects: multi feature fusion of input images, feature reuse within residual units, and the introduction of a novel activation function. Finally, we validate the efficacy of our approach using a dataset specifically curated for garbage classification. Through ensemble learning techniques, we achieve a notable improvement in classification accuracy, with an enhancement of 1.01% compared to baseline ResNet-50 performance. Our experimental results demonstrate exceptional accuracy rates of up to 99%, coupled with swift classification cycles of just 0.95 seconds. Overall, this study underscores the potential of ensemble learning techniques to augment the capabilities of deep learning models, offering promising avenues for the advancement of automated garbage classification systems, thereby contributing to environmental sustainability and societal well-being.

1. INTRODUCTION

Waste management requires necessary processes and activities to dominate from its inception to demolition. Waste comes in solid, liquid, or gaseous form, and every type of waste demands a different method of classification, disposal, and management. Waste management deals with every waste category, including household, organic, industrial, municipal, biomedical, organic, biological, and radioactive waste. Any unnecessary substance or substance with no use is called “waste”. Waste management involves the collection of the waste [1] and its transport and disposal to appropriate locations [2]. In the European Union (EUROPA), 423 million tons or 56% of domestic waste was recycled in 2016. Reports reflect the need for proper household waste management for the recycling process [3]. According to [4], most of the Earth’s population will emigrate from rural to urban areas in the coming years. Therefore, bigger cities will require a highly sustainable infrastructure and smart waste management system to fulfill the fundamental needs of its citizens and provide them with a good service for the future [5,6]. Traditional recycling processes segregate waste objects manually or by applying a sequence of filters. If modern technology and waste management could be bound together, the results would be immeasurable and would lead to a positive biological environment [7]. With the rapid increase in computing power, there has been a lot of advancement in image processing [8] and computer vision [9]. A deep-learning architecture named convolutional neural network (CNN) has played a pivotal role in this regard [8]. By applying deep learning, waste objects can be identified and classified more efficiently, reducing the cost in terms of both time and human resources, and impacting the environment positively [10,11]. According to an estimation by FUSON [12], 127 new devices are connected to public networks every second. Given this speedy growth, 328 million new devices are added monthly. According to STATISTA, at the end of 2023, the IoT market will be projected to be worth $1.1 trillion [13]. These statistics suggest that IoT is becoming a significant element in modern computing techniques. In the modern web, the Internet of Things (IoT) [14], Machine-Learning (ML) [15], and Deep-Learning (DL) [14] phenomena are being enabled in various systems such as Wireless Sensor Networks (WSNs), Radio Frequency Identification (RFID) [16], sensors, and actuators. Prediction methods such as clustering and classification [17] are also used to create the most accurate results instead of individuals. This project has had a major significance on people’s daily lifestyle, because if a city’s waste is well collected, managed, and classified, the city will enjoy better living standards and a healthy lifestyle. Our research provides a deeper exploration, solution, and answers to the following research questions: RQ1: How can we perform waste segmentation for the dump area? RQ2: How can we classify waste items into different categories directly by developing a smart system? The problem is not only to gather the waste from door to door; there is also a need for a proper plan to collect the waste, transport waste to a specific location, monitor the waste, and prepare and recycle waste. Therefore, to solve the huge waste collection, management, and classification problem, we proposed and implemented smart waste management and classification system using cutting-edge technology (cloud computing, edge computing, fog computing) where necessary actions can be taken in waste management. A system was employed with the Internet of Things (IoT), Global Positioning System (GPS), Wireless sensor, camera, and Deep Learning algorithms to segment and classify waste objects. Numerous types of sensors are used in this project. Their purpose is to gather information about waste material and thus enhance the city's infrastructure by successfully implementing waste management and classification tasks. The physical infrastructure of our system consists of waste bins, a fleet of vehicles, gripper, dump, etc. First, the household waste is collected in our smart waste bin, whose data are stored on the cloud, and a message on the web/mobile application is generated when the bin gets full. Afterward, the authorities assign a waste collection truck to collect the waste from the waste bin and take it to the dumping area of the waste, where the segmentation and classification of waste are performed as shown in Figure 1. We focus on a specific application domain, segmentation, and waste management classification. For the waste segmentation, we use a grid segmentation mechanism that makes segments of waste. Then, a gripper with a camera connected with raspberry Pi starts picking waste items. After performing the classification, it places that specific item in the designated bin. In this way, firstly, waste is classified into bio and non-bio waste, and then in the case of non-bio waste, it is categorized into three sub-types, i.e., plastic, glass, and metal. We implemented this system in a controlled environment with a predefined dump area.

2. LITERATURE SURVEY

2.1 Longoria Gandara Omar,Rodea Argon Oscar,Tores Garcia Andres,Sanchez Gracia Francisco in 2013 [1] were proposed Multimedia inorganic waste separator Nowadays, trash has become a problem in society and to the ecosystem by the way it is gotten rid of. Most of the garbage gets buried or burned and even thrown away in places where it doesn't belong. With high proportions of garbage that are thrown away, and the methods used to store them, causes air, water, and soil pollution. Fortunately, people can count on other methods to reduce the quantity of litter it is produced. Recycling is an answer by re-using the materials. There are also different containers available in some places for individual kinds of waste by easing their classification. The aim of this paper is to present an intelligent waste separator (TrashCan) that will replace the recycle bins; this will income waste and place it into different containers by using a multimedia embedded processor, image processing, and pattern recognition in order to make the selection of garbage.

2.2 Nikunj Khelurkar ,Sunay Shah,Hansa Jashwani in 2015 [2] were proposed A Review Of Radioactive Waste Management .Radioactive waste is the waste that is left out after the use of radioactive materials in nuclear reactors or during the production of nuclear weapons. Since, exploitation of radioactive materials was done on a large scale in the past few decades which resulted in production of tremendous amount of radioactive waste, radioactive waste management is a necessary step to deal with it. If not properly disposed, irradiation from radioactive waste will cause serious problems to humans and to the environment.

2.3 S.Sudha,M.Vidhya Lakshmi,K.Pavitra,K. Sangeetha in 2015 [3] were proposed An automatic classification method for environment: Friendly waste segregation using deep learning. Recent enforcement of law by the Indian government for the welfare of sanitation workers has raised the need for an automated system in waste management. The existing garbage disposal system in India consists of unclassified waste collected from homes which are then segregated at a station manually. This segregation of solid waste done by manual labor can bring about many health hazards for the waste sorters in addition to being less efficient, time consuming and not completely feasible due to their large amount. In our paper, we have proposed an automated recognition system using Deep learning algorithm in Artificial Intelligence to classify objects as biodegradable and non-biodegradable, where the system once trained with an initial dataset, can identify objects real-time and classify them almost accurately. Biodegradable waste is used to generate power, enrich soil and act as food to animals. This process does not harm the earth making it valuable, ecologically safe and helps us to protect our environment, rich ecosystem and human inhabitants in future.

2.4 Ruhin Mary Saji, Drishya Gopakumar, Harish Kumar S, K N Mohammed Sayed,Lakshmi in 2016 [4] proposed A survey on smart garbage management in cities using IOT .As the population is increasing day by day, the environment should be clean and hygienic. In most of the cities the overflowed garbage bins are creating an unhygienic environment. This will further lead to the arise of different types of unnamed diseases. This will degrade the standard of living. To overcome these situations an efficient smart garbage management method has to be developed. As the scope of IoT is developing day by day effective methods can be found out easily. Various designs were proposed and have advantages as well as disadvantages. This paper is a survey based on Smart Garbage Management in cities using IOT .This survey involves various management ideas. In conclusion, this lite project falls short of the expected standards, requiring further refinement and depth.

2.5 C. Baby,Harvir Singh,Archit Srivastava,Ritwik Dhawan,P.Mahalakshmi in 2017 [5]were proposed Smart bin: An Intelligent Waste alert and prediction System using machine learning approachThis work is about creating a smart waste-bin that alerts the authorities to gather the waste which has been piling up in the bins. It guides the garbage-trucks to collect the garbage only from those areas where the bin is critically filled. The 'machine-learning' concept has been used to gather information about the waste generation habits in that region and hence predict the amount of waste that will be generated in the near future. Apart from that, the analysis of the continuous data is also done that has been sent over the cloud in the form of graphs. The email alert and the text message have also been sent automatically to the concerned authorities once the level of waste in the dustbin crosses the threshold as set by the authorities. This would save time and money of the authorities considerably. This would also reduce air pollution in the area and prevent spreading of diseases caused by unpicked waste. To summarize, the current project lacks the necessary depth and thoroughness expected in scholarly research.

2.6 Reeny Zackarias, Dr. S. Brilly Sangeetha in 2018 [6] proposed A Survey On Smart Waste management systems. The municipal solid waste generation levels are increasing significantly with the ever increasing population, urbanization, migration issues and change in lifestyle. Waste management becomes a challenge faced not only by the developing nations, but also the developed and advanced countries. The efficient management of waste has a significant impact on the quality of life of citizens. The reason is that waste disposal has a clear connection with negative impacts in the environment and thus on citizens' health. Also the quantity of waste near to streets caused to bad smell and bad hygienic condition. It also provides negative impact on tourism. The smart waste management system helps to remove the waste in appropriate time without overflowing and also provides better waste management. In summary, this project demonstrates shortcomings, warranting additional attention to meet scholarly expectations.

3. EXISTING SYSTEM

The existing solid waste management system relies on traditional methods, involving the decomposition of waste materials over time. The process involves the collection of garbage, followed by various measures for decomposition. Garbage separation methods are employed, but there is a focus on using artificial intelligence techniques for estimating and determining solid waste through automatic detection and separation. The system is implemented through smart dust bins in households, which automatically sense non-biodegradable and biodegradable waste, with waste classification identified through image processing techniques.

DISADVANTAGES

- Highly Error prone and time consuming

4. PROPOSED SYSTEM

In the proposed system, an automatic garbage classification system is introduced based on deep learning, aiming to improve front-end garbage collection efficiency. The garbage classification algorithm relies on the ResNet-34 algorithm, with optimizations in multi-feature fusion, feature reuse in residual units, and the introduction of a new activation function. The system emphasizes the use of advanced technology, specifically deep learning, for more efficient and accurate garbage classification, contributing to environmental protection, resource recycling, and societal well-being.

ADVANTAGES

- Proposed a novel and efficient algorithm for feature selection to improve overall detection accuracy.

SYSTEM ARCHITECTURE

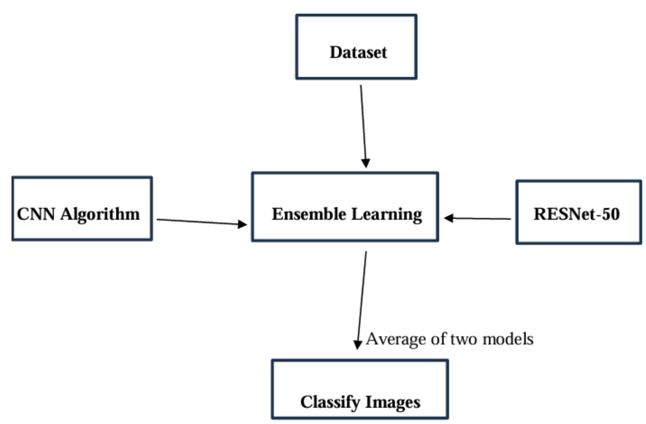

Fig 1: System Architecture

5. UML DIAGRAMS

1. CLASS DIAGRAM

The class diagram depicts a static view of an application. It represents the types of objects residing in the system and the relationships between them. A class consists of its objects, and also it may inherit from other classes. A class diagram is used to visualize, describe, document various different aspects of the system, and also construct executable software code. It shows the attributes, classes, functions, and relationships to give an overview of the software system. It constitutes class names, attributes, and functions in a separate compartment that helps in software development. Since it is a collection of classes, interfaces, associations, collaborations, and constraints, it is termed as a structural diagram. The main purpose of class diagrams is to build a static view of an application. It is the only diagram that is widely used for construction, and it can be mapped with object-oriented languages. It is one of the most popular UML diagrams

Fig 5.1 shows the class diagram of the project

2. USECASE DIAGRAM:

A use case diagram is used to represent the dynamic behavior of a system. It encapsulates the system's functionality by incorporating use cases, actors, and their relationships. It models the tasks, services, and functions required by a system/subsystem of an application. It depicts the high-level functionality of a system and also tells how the user handles a system. The main purpose of a use case diagram is to portray the dynamic aspect of a system. It accumulates the system's requirement, which includes both internal as well as external influences. It invokes persons, use cases, and several things that invoke the actors and elements accountable for the implementation of use case diagrams. It represents how an entity from the external environment can interact with a part of the system.

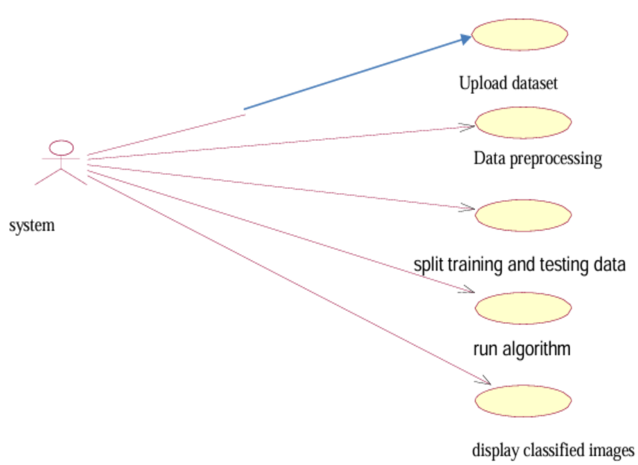

Fig 5.2 Shows the Use case Diagram

3. SEQUENCE DIAGRAM:

The sequence diagram represents the flow of messages in the system and is also termed as an event diagram. It helps in envisioning several dynamic scenarios. It portrays the communication between any two lifelines as a time-ordered sequence of events, such that these lifelines took part at the run time. In UML, the lifeline is represented by a vertical bar, whereas the message flow is represented by a vertical dotted line that extends across the bottom of the page. It incorporates the iterations as well as branching.

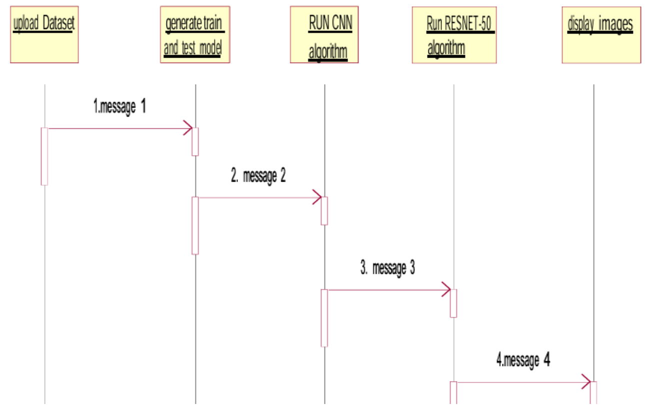

Fig 5.3 Shows the Sequence Diagram

6. RESULTS

6.1 Output Screens

In below screen shows the summary of the CNN Algorithm

```
model.summary()

Model: "sequential"
_________________________________________________________________
 Layer (type)                Output Shape              Param
=================================================================
 resnet50 (Functional)       (None, 7, 7, 2048)        23587
 flatten (Flatten)           (None, 100352)            0
 dense (Dense)               (None, 256)               25690
 dense_1 (Dense)             (None, 6)                 1542
=================================================================
Total params: 49279622 (187.99 MB)
Trainable params: 25691910 (98.01 MB)
Non-trainable params: 23587712 (89.98 MB)
```

Fig 6.1 summary of the CNN Algorithm

```
train_generator = train_datagen.flow_from_directory(
    base_path,
    target_size=img_size,
    batch_size=16,
    class_mode='categorical',
    subset='training',
    seed=0
)

validation_generator = test_datagen.flow_from_directory(
    base_path,
    target_size=img_size,
    batch_size=16,
    class_mode='categorical',
    subset='validation',
    seed=0
)

Found 2277 images belonging to 6 classes.
Found 251 images belonging to 6 classes.
```

Fig 6.2 Generate Train & Test Model

In above screen we have separate the training and testing dataset

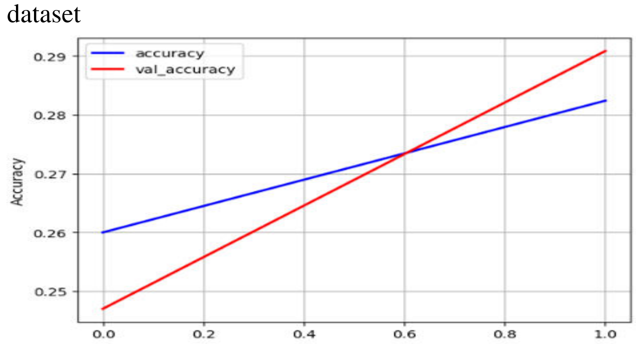

Fig 6.3 the accuracy of training model

In above screen shows the accuracy of training model.

Layer (type)	Output Shape	Param #
conv2d (Conv2D)	(None, 222, 222, 32)	896
max_pooling2d (MaxPooling2D)	(None, 111, 111, 32)	0
conv2d_1 (Conv2D)	(None, 109, 109, 64)	18496
max_pooling2d_1 (MaxPooling2D)	(None, 54, 54, 64)	0
conv2d_2 (Conv2D)	(None, 52, 52, 128)	73856
max_pooling2d_2 (MaxPooling2D)	(None, 26, 26, 128)	0
flatten_1 (Flatten)	(None, 86528)	0
dense_2 (Dense)	(None, 256)	22151424
dropout (Dropout)	(None, 256)	0
dense_3 (Dense)	(None, 6)	1542

Total params: 22246214 (84.86 MB)
Trainable params: 22246214 (84.86 MB)
Non-trainable params: 0 (0.00 Byte)

Fig 6.4 Model summary of the Resnet Algorithm

In above screen we can see the model summary of resnet50 algorithm

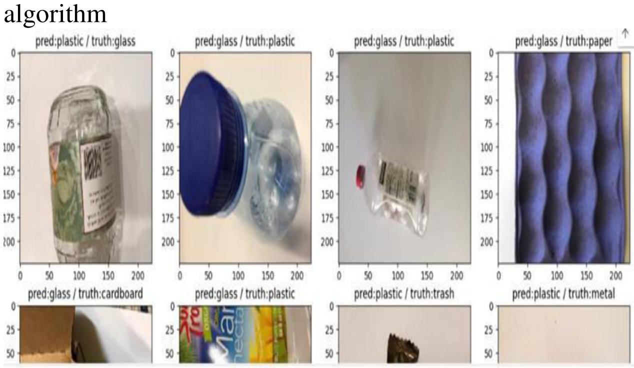

Fig 6.5 classified images of different categories

In above screen we got the classified images of different categories.

7. CONCLUSION

In conclusion, our study represents a significant step forward in addressing the critical challenge of garbage classification through the utilization of advanced deep learning techniques, particularly ensemble learning. By leveraging the ResNet-50 architecture and refining it through ensemble learning, we have developed a robust and efficient garbage classification system. The exceptional accuracy rates achieved, coupled with swift classification cycles, underscore the practical utility and effectiveness of our approach. The promising results obtained in this study highlight the potential of ensemble learning techniques to enhance the capabilities of deep learning models in garbage classification tasks. The 1.01% improvement in classification accuracy compared to the baseline ResNet-50 model demonstrates the efficacy of our ensemble approach. Furthermore, attest to the reliability and accuracy of the developed system in distinguishing between different types of garbage items. Overall, our research contributes to the advancement of automated garbage classification systems, offering promising avenues for environmental sustainability and societal well-being. By providing a practical solution for efficient garbage classification, our system can facilitate waste management efforts and contribute to creating cleaner and healthier environments. Moving forward, further research and development in this area can continue to enhance the effectiveness and scalability of automated garbage classification systems, ultimately leading to positive impacts on both the environment and society.

FUTURE SCOPE

Future work includes exploring additional ensemble methods, integrating sensor data, optimizing for real-time deployment, expanding to multi-class classification, implementing transfer learning and domain adaptation techniques, enhancing user interface and accessibility, and conducting environmental impact assessments. By addressing these future research directions, we can further advance the development and deployment of automated garbage classification systems, contributing to environmental sustainability and societal well-being on a larger scale. Exploration of Multi-modal Data Fusion: Investigate the integration of additional data modalities such as depth information from depth sensors, thermal data, or lidar data. Fusion of multi-modal data can provide richer information for garbage classification, potentially improving accuracy and robustness. Adoption of Reinforcement Learning: Explore the application of reinforcement learning techniques to optimize garbage collection and sorting strategies dynamically. Reinforcement learning algorithms can adaptively learn from interactions with the environment, leading to more efficient and adaptive garbage classification systems. Adopting reinforcement learning (RL) techniques presents an avenue to enhance garbage classification systems, enabling them to make optimal decisions in dynamic environments. RL algorithms can optimize garbage collection routes, adapt sorting strategies, allocate resources efficiently, and incorporate feedback for continuous improvement. By leveraging RL, these systems can dynamically adjust to changing conditions, improve sorting accuracy and efficiency, reduce operational costs, and maintain reliable performance in the face of uncertainty. Ultimately, integrating RL into garbage classification systems can advance environmental sustainability efforts by improving waste management practices and contributing to a cleaner, healthier environment.

8. REFERENCES

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