Emerging role of artificial intelligence in waste management practices

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Abstract: Sustainable development goals target to achieve better living condition in all countries by 2030 and this paves the need for ecological assessment and management. Accelerating environmental deterioration triggers the scientific community to invest and formulate policies and strategies for environmental management, which will lead to sustainable development. Among all environmental issues solid waste management pose serious threat considering the increase in amount of generation of waste in all economies. Better management strategies and policies are required to ensure better living conditions. Incorporation of AI based models to assist the human efforts not only ensure better management of waste but also aid in reduced carbon emissions. Various models and algorithms have been evaluated to assess their potential in better management of solid waste. Algorithms are available in various domains. In this review article, role of various AI based techniques in waste management is discussed.

1. INTRODUCTION

Ecological assessment and management are largely responsible for the improvement of the way of life and economy in present day times. Increasing degradation of the environment directs the scientific community to focus on investigating and analyzing better strategies for management. Consequently, the development of a logical evaluation system for monitoring and managing the environment plays a pivotal role in sustainable development. With the advent of the new millennium, the world has been rapidly taking big leaps in various fields leading to the uplift in the living standards, opulence and comfort of people. Along with, the increase in population there has been an expeditious rise in the generation of solid waste [1–3]. According to the statistics, in the year 2016, the municipal solid
waste generation accounted to 2.01 billion tons. The same is expected to touch 3.40 billion tons by the year 2050. One-third of the total waste generated is handled unsafely and the waste is being disposed off in an illegal manner, mostly to unattended landfills. Natural resources are being consumed at a rapid rate as the population grows, and their reserves are rapidly depleting. As a consequence, the global rate of waste material generation is increasing. According to current generation rates, solid waste volume is expected to double by 2025 [4–6]. Environmentalists and scientists are devising new studies to determine the negative impacts of urban garbage on the ecosystem. As an outcome, efficient waste management systems are being adopted in various parts of the world in order to use waste as resources through material recovery in a sustainable manner [7–9]. Along with, municipal solid waste, a steep rise is witnessed in generation of various other categories of waste. As a result of technological boom, the globe has also witnessed an increase in the use of electronic devices in the last couple of decades leading to a rise in the electronic waste. Rapid industrialization and rise in health care & medical services has caused an increase in generation of hazardous and biomedical waste as well [10–12]. The management of the waste generated is one of the major issues being faced by both the developed and developing nations. A strategic management of the various kinds of waste is required right from the place of generation to the collection, transportation and proper disposal of the same. Its use can be found in the collection bins, transport vehicles and disposal techniques. The management of waste is a huge problem as the rise in solid waste generation is directly related to the rise in the number of consumers and increase in population is adding to number of consumers each year. Poor practices of managing solid waste poses environmental threats and health risks along with ground water and surface water contamination, land deterioration etc. Effective management of environmental issues depends upon the amount and nature of data available [13–15].

In the last few decades, the rate of urbanization has accelerated dramatically. Developing economies face major threat in implications of waste management practices resulting in further alleviation of the problem [16–18]. The sight of overflowing dustbins and open dumping is common in most of the developing and growing cities. This not only compromises the aesthetics but also pose detrimental health effects to the nearby population. Exposure to the waste through various components of environment result in various disease among the different categories of human population. Hence, there is a need to track and manage waste. Waste management is becoming a global epidemic. Management of waste is widely affected legally, environmentally, politically, technically, socially and economically. These factors are further influenced by scarce data and uncertainties, advanced modelling techniques are required to analysis and implementation of these factors. Tasks involving waste management pose a number of technical difficulties. They also bring with them plenty of political, economic, and social issues that must be addressed and resolved [19–22].

The smart cities concept is gaining momentum around the world because of the modern-day technologies and a realistic approach. Implementation of integrated solid waste management plan is
an integral component of smart city concept. Scientific community has attributed that improper planning and poor operational strategies account for poor waste management. Artificial intelligence has revolutionized industries. The applications of AI is well established in automobiles, electronics sectors etc. but the recent developments in AI also target waste management and recycling sectors. The current waste administration frameworks can't effectively manage the huge loads of trash that is produced each day. Using AI for managing the waste by organizing different steps of solid waste management is the need of the hour. Reduce; Reuse, Recycle and Recover are the techniques to reduce the adverse implications of anthropogenic activities on the environment.

The waste management measures normally influenced by various specialized, climatic, natural, financial and authoritative boundaries. Recently, artificial intelligence (AI) techniques are playing vital role in suggesting computational ways to deal with solid waste management (SWM) problems.

2. Artificial Intelligence and Its Role in Environmental Conservation

Artificial Intelligence (AI) is the capability of a machine to mimic human characteristics like gaining from certain examples and skill, distinctive things, comprehending and responding to language, selections and determination issues. It is a tool that people utilize all over the world to help them take better decisions. Because artificial intelligence can analyze extensive information at a much faster rate than a human. Artificial intelligence is assisting humanity in overcoming issues such as waste detection, space trash and sustainability. AI has gained popularity in very less time due to its wide application that were once thought to be impossible. For instance – talking to your smartphone through Siri, Alexa etc. Many such companies have profoundly brought use of AI. IBM discovered the utility of artificial intelligence for improvement in weather forecasting, which resulted in 30 percent more specific predictions. Thus allowed renewable energy firms to more effectively run their facilities, resulting in increased production of renewable energy and lower emissions of carbon. Xcel Energy, a coal-burning and nitrous oxide-emitting utility, has implemented artificial intelligence to better anticipate energy utilization trends and alter its operating system to greatly increase efficiency. Artificial intelligence has been used to track emissions from coal facilities using satellite data by Carbon Tracker. It assists in directing investments toward lower-footprint ventures using satellite data. An AI model has been used by Google to cause reduction in the energy load of its data centres resulting in 40% reduction in overall energy costs.

AI is being widely implemented in the environmental engineering domain to figure out various issues related to water and wastewater treatment, air pollution and mitigation, contamination and remediation of soil and ground water pollution along with planning the strategies of waste management.
AI is vital in accomplishing all of the sustainable development goals, viz. ending hunger and poverty, establishing gender equality and preserving and protecting biodiversity. Hence, AI is providing unparallel opportunities which might sometimes not provide a positive outcome always depending on the framework where it is implemented. AI has the capability to pace up the global efforts in conserving environment and protecting our resources. The current problem resulting due to expansion of metropolitan solid waste in big urban areas requires a steady quest for procedures and strategies that empower its legitimate management while considering the distinct characteristics of each area of a particular city. The advances in municipal solid waste management plan is a perplexing process. Fostering an effective arrangement, evaluating and anticipating solid waste generation are essential components. Artificial intelligence models work well in prediction tasks and can be efficient in enacting forecasting models for municipal solid waste. The current waste management system is unable to deal with the tonnes of garbage being generated each day in an efficient manner. Switching to AI, for smart segregation, smart recycling along with automation of the process for garbage sorting and disposal is expected to bring in better management of the solid waste.

3. Applications in Waste management

AI based models have been found to be used in many fields of study like engineering, medicine etc.. Advances in artificial intelligence techniques have been found to be appropriate for being instrumental in the waste management field. To ensure environmental safety and public health, waste generation must be adequately controlled. The waste management sector has taken on a new structure as a result of current circular economy (CE) techniques, which create value from trash generated. One of the major problems is the transformation into circular economy, particularly in terms of sorting and classifying generated garbage. However, in the COVID era, the majority of the released trash is mixed with conventional wastes. The epidemic has resulted in massive amounts of infectious garbage. Waste from healthcare facilities must be properly separated at the source, stored, and transported to avoid negative health and environmental consequences along with preserving resource efficiency and material recovery. Although, the waste minimization is commonly implemented at the point of generation, such as the separation of hazardous trash from other wastes. Such objectives can be achieved by incorporating artificial intelligence into the waste management system.

Many such models are there which can be implemented in managing the solid waste using artificial intelligence. Each model of artificial intelligence serves a different purpose viz. date for classification and prediction. Additional artificial neural network is used to handle big data for performing geographical analysis. Induction of AI thus helps to optimize waste collection routes of garbage trucks, locate the waste management facilities, estimate waste generation patterns and also used in the simulation of waste conversion processes. Accurate prediction of waste properties leads to a methodical collection, proper treatment and discarding of municipal solid waste.
According to many studies which investigated applications of artificial intelligence in solid waste management examined the projection of solid waste characteristics. To make the unit environmentally friendly and carbon-neutral, small solar panels for electricity generation were used.

Waste bin level detection, waste characteristic forecasting, process parameter prediction, process output prediction, vehicle routing, and SWM planning are some of the AI application sectors. The detection of waste in the bin is related with monitoring the fullness of waste bins, whereas waste characteristics prediction includes waste classification, waste compression ratio, and waste generation trends. Waste heating value and co-melting temperature were among the predicted process parameters. Simulation and optimization of biogas generation and leachate creation were included in the process output prediction. The optimization of waste collection routes and frequency was part of the vehicle routing problem. Applications of cloud-based garbage monitoring system was analyzed by Tripathi and his co-workers. Using this monitoring system, the manual monitoring of dust bins can be avoided. Khan and his co-workers indicated to a form of network that uses data sensing devices to link different points to a network for smart detection, targeting and tracking, monitoring, and management.

While sorting and transporting rubbish, the intelligent bins will make the task easier through their automated process. Waste is just dumped in the bin and the bin then utilizes its sensors to examine and compare the trash collected with previous trash records and decides the action to be taken for the kind of waste dumped. According to the directions of sensor based programmes, the trash is directed to an appropriate disposal system, such as a landfill or a recycling facility. This can also result in a considerable reduction in waste generated. Recent scientific breakthroughs have also decreased the carbon footprint of waste management. As researchers are drawn to energy conservation through IoT over the last few years.

In both developed and developing countries, waste electrical and electronic equipment has become a priority in waste management policies. By moving to artificial intelligence (AI) for smart recycling and trash management, garbage sorting and disposal procedures can be automated, resulting in more sustainable recycling methods.

4. Segregation

The segregation of waste plays a very pivotal role in the solid waste management. Segregating the waste at source plays even more important role as it becomes comparatively easy to manage, handle, transport and store the solid waste. Many other researchers focus on the development of strategies and procedures to classify waste materials through automatic sorting order that removes the need for manual garbage separation. Artificial neural networks (ANNs) were utilized by scientific community at large to identify distinct waste fractions. Multi-layer ANNs and Hyperspectral imaging were employed in one study to identify different kinds of plastics in electronic waste. Sudha and her co-
workers used deep Convolutional Neural Network (CNNs) to automate the garbage segregation procedure. Deep CNNs were used to distinguish between the sorting and classification of waste. [30] Chu and his co-workers applied Convolutional Neural Network (CNNs) to extract features & Multi-Layer Perception (MLP) to sort garbage into non-recyclables & recyclables. This hybrid method achieved a maximum precision of 98.2 percent, which was near about 10% greater than the accuracy achieved using simply CNNs. Random Forest (RF), the C-LibSVM (Support Vector Machine) and the Nu were outstanding at classification, with correctness better than 90%, according to a few studies that examined the effectiveness of different machine learning algorithms in garbage classification (REF). Ysabel and his co-workers connected sociodemographic and behavioural characteristics with garbage generation under the data mining techniques using Cluster analysis and Decision Tree (DT). The tree classifier performed admirably, with inaccuracy as low as 3.6 percent. Yet another research utilized data mining techniques to assess garbage generation tendency based on the kind of house & seasonal fluctuations. With the introduction of RFID tags, waste sorting mechanisms have undergone a revolution. Songdo, a South Korean city, deploys RFID tags to sort rubbish into several categories. The tags are then scanned by a pneumatic rubbish disposal device. As a result, the central server, which stores all of this information, calculates the best way to dispose of the overall garbage generated.

5. Transportation

The transportation and collection services should be reliable enough to collect waste in a timely manner. Transportation of waste increases the carbon footprint, effective use of AI in this component helps in optimizing the carbon emissions by suggesting best routes. A successful integrated SWM plan requires proper waste collection routing; collection costs typically account for 70% to 85% of the total solid waste management cost. Contagious or other hazardous garbage should not be collected in the same cart as general waste and at the same time. The storage should be kept away from patients and the common public. It must be well ventilated and free of vertebrate pests. Another breakthrough idea in waste management is the intelligent dumpster, which is equipped with AI programmes and IoT sensors. The sensors on these dumpsters measure the waste levels of the garbage dumped inside and transfer this information to the main disposal system for processing via intermediate servers. The garbage trucks/vans can move according to the message received and collect the waste from the filled-up bins. Several researches have optimized models created for trash collection frequency and planning of the route, with most of them relying on Genetic Algorithm (GA) and hybrid variants of it. GA optimized the route for the collection of electrical and electronic home waste as deployed by Krol and co-workers. The collection expenses were reduced by GA because of the streamlined route distance, number of collection trucks and staff. Users were encouraged to participate in the scheduling of garbage collection requests in order to develop efficient routes. [37] Amal et al. (2018) used GA in conjunction with GIS to optimize rubbish pickup routes. The research used an amended Dijkstra algorithm in GIS to find the best route possibilities, later incorporated the results in GA to find the
best route. Travel time, operating distance, and fuel consumption were all reduced by 28, 8, and 3%, respectively, using the proposed method.

6. Collection

Contamination due to hazardous compounds from diverse components is reduced when garbage is properly collected through authorized channels. It is essential for the residents that the garbage collection be done in a way that is convenient for them, that equipment collection schedules are clear and that waste containers are placed appropriately. Waste can be collected in a variety of ways. They include stationary waste collections at municipal trash collection locations, EEE retailers and mobile waste collections at curbside recycling stations and mobile terminals in high-traffic regions. Waste sorting robots have begun to be used in garbage dumps. Traditional waste sorting methods are gradually being replaced by automated intelligence equipment. The robots, who are adept at multitasking, can sort tonnes of waste in a single day. With their computer vision programs, these robots are autonomous and can quickly discern between tin foil and paper. Such large-scale systems have enormous potential for use in a variety of sectors. Few other researchers have used regression models and ANN to route waste pickup. Vu and co-workers studied the effect of garbage content and weight on optimal vehicle routes and emissions using nonlinear autoregressive neural networks and GIS route optimization. MLR and ANN models were employed by Ferreira and co-workers to predict the required collection frequency at various sites. Locations with empty bins were avoided, resulting in less environmental harm and lower collection costs. Based on hauling truck capacity and collection requirements at various places, an AIS model was implemented to optimize trash collection time with vehicular workload.

7. Disposal

A study used DTs to detect unlawful trash disposal and was successful in identifying over 500 trucks that may have been involved in illegal dumping. In another study, rough sets were used to plan cost-effective waste allocation plan for already existing processing and disposal facilities. Small healthcare waste incinerators, such as single-chamber, drum and brick incinerators, are designed to address the demand for public health protection when more advanced technologies are not feasible to construct and operate.
8. Future Perspectives

Waste management is set to be revolutionized by AI-powered smart recycling equipment. This will go a long way toward preserving the environment for a brighter and more sustainable future [33]. SWM systems based on AI are largely still in the research and development (R&D) stage. Commercialization of AI based plans will not only aid in environmental conservation but will also help to attain sustainable development goals at large. Further research is required to focus on the designing cost effective tools based on AI to ensure the maximum utilization of these tools. AI based waste management implementation will ensure critical and easy sorting, efficient and economic transportation, planned resource recovery and logical disposal of the waste in future. There is a need to strategically design low-cost AI based waste management system which can be installed in low-income countries thus providing the better health conditions there. AI based reforms will pave a way for better environmental monitoring and management.
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