IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

A Review on IoT-Driven Intelligent Waste Monitoring System with Raspberry Pi Integration

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Abstract – *Increased population and rampant urbanization has caused a tremendous amount and complexity in solid waste which poses a big problem to the traditional waste management structures. Conventional means of waste collection process is mostly manual, time-stated and inefficient and this geometrical overflow of bins, inadequate separation of waste, hiked up cost of operation and environmental pollution. In order to overcome these restrictions, in this paper, there was a review and conceptual implementation of a Smart Waste Management System with Raspberry Pi and IoT-based monitoring systems incorporated and coupled with enhanced waste sorting and real time alerts.*

The suggested system will involve the automatic division of waste into wet and dry rubbish, as well as the metal and non-metal detection to promote a higher efficacy of recycling and lower reliance on landfills. A clever utilization of an ultrasonic sensor would be continuously monitoring the amount of fillings in the wastes bins and a moisture sensor that would identify wet and dry waste depending on the moisture content. Metallic detector sensor uses are utilized to detect the presence of metallic items, and then, further separation of recyclable items takes place. Also, the sensor of gases is placed to monitor the presence of harmful and dirty gases produced during the waste decomposition to improve the environment safety and early hazard.

The core component of the system is a Raspberry Pi as the central processing/control unit which manages the acquisition of data, processing and communication with all the sensors. The sensors information is sent to the Internet to an IoT monitoring service and infrastructure Get Your Project Done IoT Dashboard (https://iot.getyourprojectdone.in/). Real-time visualization of a bin status, concentration of waste, and gas, and segregation data through a web- based interface is available on this platform, which allows municipal authorities and administrators to monitor it remotely.

The system also has an automated email alert system to enhance its responsiveness and efficiency with regard to its functions, whereby alert systems inform responsible persons when the waste bins are filled to predetermined thresholds, when the gas level is higher than what is considered safe, or unusual conditions detected. The proactive alert system is beneficial to prevent overflow cases, lessen the scope of the manual inspection, and aids timely waste collection and maintenance measures.

The review underscores the fact that the combination of the IoT technology, intelligent sense, and cloud-based monitoring with the use of the Raspberry Pi-based embedded system can contribute greatly to the efficiency, safety, and sustainability of the waste management procedures. The suggested solution helps in sustaining smart cities by allowing the use of data to make decisions, using smart schedules to collect data, and managing waste in an eco-friendly way. This paper comes to the conclusion of the fact that smart waste management systems with a high level of separation and real-time monitoring are a scalable and cost effective solution to the current urban environment.

INTRODUCTION

High rate of urbanization, industrialization and population has increased the rate of solid waste production at an alarming rate in the global scene. Global urban development researchers suggest that there would be a steep increase in municipal solid waste generation in the next few decades and as a result, a lot of strain on the available waste management facilities would be witnessed. The traditional waste management systems, which can be characterized by use of manual collection and fixed collection schedule, are no longer adequate to manage the increasing volume, variety and effect of waste on the environment. These conventional methods usually lead to ineffective waste collection, over filled bins, poor segregation, high costs of operation, health risks, and environmental contamination.

Over the past few years, the idea of smart cities has become a prospective solution that can be used to enhance the quality of life in cities by means of digital technologies, automation, and data-driven decision-making. One of the most complex aspects of smart city development is waste management because the proper disposition of waste has a direct impact on the level of human health, environmental security, and the quality of life. The presence of embedded systems and Internet of Things (IoT) technology has provided the possibilities of changing the traditional ways of waste management to be intelligent, automated, and effective.

The waste management systems based on the Internet of Things rely on connected sensors, communication systems, and cloud solutions as well as monitoring consoles to provide the opportunities to collect data in real-time and remotely monitor the garbage bins. These systems continuously keep track of monitor parameters like waste fill level, the type of waste, the emission of gases in the environment and so on thus preventing manual check up. Real-time monitoring is not only used to stop overflow situations but also used to assist the authorities maximize the waste collection routes, use less fuel and less manpower.

Raspberry Pi has been very popular as one of the embedded platforms employed in the IoT application because it is cheap, flexible, and computationally capable. Raspberry Pi is a small single board computer with the support of various operating systems, programming languages, and sensor interfaces. Its inbuilt networking support, Wi-Fi and Ethernet, helps to make it very appropriate in cloud-connected IoT systems. Raspberry Pi is powerful in processing, compared to the conventional microcontrollers, thus can manage more than one sensor, data-handling tasks, and support security in communicating on the cloud concurrently.

Poor segregation of waste at source is one of the biggest predicaments of the current waste management activities. Wet waste and dry waste mixing and recyclable materials like metals cause a great deal of reduced efficiency in recycling and more load to the landfills. Segregation by hand is time-consuming, tedious, and normally inaccurate. To resolve such a problem, the current smart waste management device is aimed at the automatic classification of waste based on sensors and smart processing methods. Moisture sensors are widely used to distinguish between wet waste and dry waste whereas metal detectors identify the metallic objects. This form of initial level of segregation enhances the process of recycling and promotes the sustainable process of waste management.

The second severe issue with the waste issue is release of toxic and odorous gases generated during the decomposition of waste. Gaseous build-up of gases including methane and ammonia is not only a source of unpleasant odors, but also extreme health and fire risks. Installation of gas sensors in smart bins will facilitate identification of dangerous levels of gases in good time so that corrective measures are taken and safety enhanced. Also, ultrasonic sensors are popular to detect the amount of filled waste bins properly and to offer precise information about the state of the bins in real time to avoid overfilling the bin.

Online systems of IoT are crucial to smart waste management systems, since they serve as central data collection points, visualizing, and analysis. The Raspberry Pi gathers sensor data, which is relayed to cloud servers and is then shown on the dashboards via a web or mobile platform. Here, the GetYourProjectDone IoT monitors and waste bins can be referred to as monitoring platform (https://iot.getyourprojectdone.in/), which is a special interface that allows real-time monitoring of waste bins, such as fill level, type of waste, gas detection, and alerts. These solutions allow the city officials, facility managers, and administrators to track multiple waste bins on a single display.

The IoT-based waste management solutions are further improved by automated alert systems, e.g., email notifications, to increase the responsiveness of the system. Instead, when waste bins fill up to critical levels, they signal an excess of gas that is above the safety level, or when there is an indication of situations of abnormality, immediate notifications are received by the responsible parties. This is a proactive measure that will make sure that the waste is collected in time, ensure that there are fewer cases of emergencies, and that the system will be more reliable.

According to the research, there are many studies examining the use of IoT-based smart waste management systems through various hardware platforms, sensor configurations, and communication technologies. Although several works published in the field mostly concentrate on fill-level monitoring, recent research directions are more based on multi-parameter monitoring, intelligent segregation, and connection to cloud analytics. Nonetheless, other issues, including power management, sensor precision, scalability, data safety, and cost-efficiency, are yet to be explored.

The present review paper is aimed at the analysis of smart waste management systems using Raspberry Pi and IoT monitoring, but special attention is paid to the high-tech functions, including the detecting of wet and dry waste, classifying it into metals and non-metals, gas detection, ultrasonic level sensors, visualization on the cloud, and automated emails. This paper through the review of literature and system designs would help present current progress, research gaps, and give an insight on the future outlook of intelligent waste management systems that can be applied in the smart city.

LITERATURE REVIEW

IoT-Based Smart Waste Monitoring Systems

A number of scholars have considered how Internet of Things (IoT) technologies can be utilized to counter the shortcomings of the conventional waste management systems. Smart waste management systems that are based on IoT are mainly concentrated on real-time measurements of garbage bins via sensors and wireless communication. Such systems allow constant gathering of data regarding the amount of waste, the situation in the environment, and the state of bins, which is delivered to the cloud-based systems to be processed and visualized. It has been shown that the integration of IoT helps to decrease tremendously. manual check, removes overflow states, and enhances collection performance due to the possibility of making data-based decisions. Most of the implementations have adopted cloud dashboards to offer a centralized management on a variety of bins scattered over urban or in-institutional locations.

Raspberry Pi-Based Waste Monitoring Platforms

Raspberry Pi has become a popular central processing unit in smart waste management studies because it is low cost, has a high computing power and is easy to integrate with various sensors. Scientists have also proved that Raspberry Pi-solutions are able to process the sensor information in real-time, send it to the internet, and the cloud simultaneously. Relative to microcontroller-only solutions, Raspberry Pi has features like database and secure communication protocols as well as real-time dashboards. As it is demonstrated in the literature, Raspberry Pi can be especially applied to scalable waste monitoring systems when several parameters are to be processed and sent to a different source as a real-time.

Waste Level Detection Using Ultrasonic Sensors

The most prevalent components used in the detection of the fill level of the waste bins are ultrasonic sensors. Repeated research actually states that ultrasonic sensors would be a good and very cost-effective means of estimating the distance between the sensor and the waste surface hence determining the percentage filled up of the bin. Studies indicate that the monitoring of the level at the constant level allows optimizing the schedules of the waste collection process, and minimizing unnecessary trips of vehicles. Nevertheless, there are also other studies that provide challenges like inaccurate reading because of uneven surfaces of waste materials, and the scholars are striving to address the challenges by inheriting sensor calibration or data sifting methods.

Wet and Dry Waste Segregation Using Moisture Sensors

Storage of waste at source is critical towards enhanced efficiency of recycling. A number of studies put forward the application of moisture sensors to detect wet and dry waste. These facilities quantify the progression of moisture of the discarded materials and categorize them as such. According to literature, moisture-based segregation yields substantial upon downstream manual sorting, and improves the processes of composting and recycling. Researchers stress the fact that such automatic wet and dry separation is most useful in urban settings where mixtures of waste disposal are a widespread problem.

Metal and Non-Metal Detection for Recyclable Waste

In order to increase the segregation of waste more, researchers have integrated metal recognition devices to smart waste bins. The metallic objects that are commonly identified using inductive metal sensors or metal detector modules are cans and scrap materials. Research indicates that prompt identification and extraction of metal waste enhances recycling and minimization of risks of manual work. There has been literature that by integrating metal detection with the wet/ dry segregation, there would be a more comprehensive and effective waste identification system.

Gas Detection and Environmental Safety Monitoring

Waste decomposition through emission of harmful gases is a serious threat to the environment and health. It is possible to speak about several works which are devoted to incorporating gas sensors into the system, i.e. MQ-series sensors, used to estimate such gases as methane, ammonia and other poisonous substances. The study results reveal that gas surveillance improves hygiene and safety as it raises the early alarms about dangerous conditions. Other systems also include alert systems that will alert the authorities in case the gas level surpasses the set safety limits. There are however, also some difficulties associated with sensor cross- sensitivity and calibration which would need to be designed carefully in literature.

Cloud-Based IoT Platforms and Monitoring Dashboards

The contemporary smart waste management technologies heavily rely on cloud computing. The IoT cloud networks help the researchers save, analyze, and visualize the sensor data obtained on the waste bins. These services offer live dashboard, past data analysis and system vitality. Literature stresses the importance of centralized cloud monitoring which allows authorities to administer large-scale implementations. Integration with custom platforms enable freedom in data representation as well as enables other capabilities like report generation and analytics.

Alert and Notification Mechanisms

Numerous research note the significance of automated alert systems to enhance the level of responsiveness and operational effectiveness. They are implemented by email and SMS-based alert systems that alert waste collection authorities when the bins are full, the gas level is high, or the abnormal conditions are noticed. It has been determined that alert-based systems save a lot of response time and overflow related problems. Waste management systems are also more reliable and can be scaled as automated notifications streamline operations based on manual supervision.

Research Gaps and Limitations in Existing Systems

Although there were a lot of achievements, literature shows that there are a few constraints to the current state smart waste management systems. Most of the suggested systems are either on prototype level or small scale implementation with few actual applications. Researchers on power consumption, sensor accuracy, maintenance, and data security scenarios have found themselves on recurrent challenges. Moreover, a number of studies have been devoted to the single-parameter monitoring, but there are few studies devoted to the integrated multi-sensors with segregation, gas detection, and real- time warnings. These holes indicate that there are gaps within the provision of full-scale, extensive, and work-based smart waste management solutions.

RESULT & DISCUSSION

The comparison of several NPR algorithms has revealed that deep learning type-based models have proved to be much better than conventional image processing models. YOLO-based detection is suitable in cases of high-speed performance, as it is used in real-time cases and CNN and Transformer-based OCR models are more accurate in character recognition. The most effective are hybrid methods involving the use of several AI methods under the conditions of extreme complexity. Nevertheless, there are obstacles like differences in lighting, stay backs as well as low plate images that influence accuracy. The discussion also indicates that it is necessary to have strong pre-processing methods and better diversity of data to increase the generalization capacity of NPR systems.[10][11].

The given section talks about the projected outcomes and analytical observations of the Raspberry Pi and IoT-based smart waste management system that will be integrated with waste segregation, environment monitoring, and cloud-based monitoring. As the system is based on the prototype and review-based implementation, the outcome is measured regarding the functionality, reliability, efficiency, and the system performance.

The smart bin is fitted with an ultrasonic sensor at the top and it measures the distance between the sensor and the waste surface at all times. The possible outcomes are the proper live estimation of bin full in percentage terms. Upon reaching specified predetermined thresholds (say 80% and 90%) the system is able to notify the bin status on the IoT monitoring dashboard. This constant control will help avoid overflow, as well as allow waste to be collected in good time. The system is efficient in the sense that it eliminates unnecessary collection trips as the contributors in contrast to the freestanding traditional collection techniques which are fixed on a timetable.

Effectiveness of Wet and Dry Waste Segregation

The moisture sensor is very vital in the separation of wet and dry waste. According to literature on experimental observations of the similar systems, moisture- based classification has been found to be a reliable segmentation of organic and non- organic waste materials. The proposed system is expected to achieve a successful identification and classification of wet waste, e.g., food leftovers, and dry waste, e.g., paper and plastic. This automated segregation helps to save much on the work spent on manual sorting and increases recycling and composting efficiency.

Metal and Non-Metal Detection Accuracy

The used metal detector component of the system will allow one to detect metallic wastes like cans and other junk metals. The anticipated outcomes are high rate of detection of common metallic objects that can be separated to non-metal wastes. This will make recyclable material recovery easier, as well as the reduction of risks to hands-on work of waste workers. The reaching distance is however limited to small and medium metal sizes; this is comparable to the discoveries made in the current studies.

The gas sensor constantly checks the level of toxic gasses produced as a result of decomposing waste. The anticipated outcomes include detection of foul gases at an early stage and the system sends alarm notifications when the gas levels are higher than it is considered to be safe. The attribute enhances hygiene and safety to the environment by offering the possibility of ventilating or collecting waste on time. Although gas sensors are important sources of crucial safety information, analysis suggests that periodic calibration of sensors is necessary to keep the accuracy at a good level so that the sensors would not trigger false alarms because of cross-sensitivity.

IoT Dashboard Monitoring and Data Visualization

Any sensor data that will be read by the Raspberry Pi is sent to the GetYourProjectDone IoT monitoring platform (https://iot.getyourprojectdone.in/). The anticipated outcomes include the real-time analysis of the waste level, discrimination of the types of waste, status of gases, and the state of the bin using a centralized online dashboard. The platform enables the administrators to track many bins at once, trace the past statistics, and recognize the usage trends. These data-based observations would make waste collection scheduling more efficient and resource allocation more efficient.

Email Alert System Performance

When critical conditions are observed, i.e. bin overflow, high gas concentration or an odd sensor readings, the automated email alert mechanism is activated. The projected outcomes are that email messages are received in time by the responsible individuals so that quick action can be taken. This will be a proactive alert system that will eliminate dependency on manual inspection and increase the reliability of the operations. This has been supported by the use of email alerts so that the system administrators do not miss out when they are not actively staring at the dashboard.

The general system can be proved as quite stable in its functioning of managing several sensors at the same time and relaying data to the cloud without any important time loss. The combination of processing potential and Raspberry Pi capabilities enables the project to be efficiently used in data acquisition and local decision-making along with communication with IoT. Suggestions of the analysis indicate that the system may be extended to various bins by duplicating sensor nodes and linking them to the identical monitoring platform. Nonetheless, network bandwidth, power and data security mechanisms can be optimized in case of large scale deployment.

The proposed system of IoT-based waste management has a position of serious enhancements over the traditional waste handling systems in terms of efficiency, cleanliness and sustainability. Live data tracking can remove overflow, automated separation improves recycling performance, and notifications via alerts create the possibility of acting in time. The analysis has pointed out that the initial setup price is more than the traditional bins, but in the long-run, these costs of operations will reduce and will be beneficial to the environment in justifying the expense.

The system has outstanding weaknesses despite the benefits it has. The sensors may occur based on environmental factors like humidity, temperature, and dust. Another issue is power consumption, particularly in cases of an ongoing monitoring system that would be installed in remote areas. Moreover, it requires good internet connectivity to ensure that the IoT does not go offline. Such constraints demonstrate that additional studies on low-power architectures, sensor fusion algorithms, and secure communication standards should be done.

CONCLUSION

The review paper included a thorough discussion of a smart waste management system that operated on Raspberry Pi and the IoT monitoring, as oriented at the tool of intelligent waste segregation and uninterrupted monitoring of the environmental conditions. The reviewed and analyzed systems have an integrated system of ultrasonic sensors to identify the level of waste, wet and dry waste, created using moisture sensors, metal detectors to pick the recyclable material, and gas sensors to check dangerous emissions. The inclusion of these various sensing functions gives the ability to deal with waste efficiently, high-level of hygiene and increased safety of the environment.

Its control over multi- sensor data capture, undertaking local processing, and easy communication with the cloud based systems is made possible by the fact that the Raspberry Pi is the central processing unit offering adequate computational power. Connection to an IoT monitoring dashboard (e.g. GetYourProjectDone platform) would support real-time visualization, centralized monitoring, and decisions made based on the data. With this feature of automated email alert, the system reliability is further improved because of timely notification of adverse conditions where the bin is full, or gas released is dangerous.

In general, the discussion reveals that smart waste management systems that can be managed through IoT have a lot of potential over traditional waste collection approaches. Among the benefits of these systems are lowering manual handling, streamlining the collection process, and assisting with efficient waste separation as well as achieving a sustainable urban development process. Although there are some weaknesses connected with sensor accuracy, power usage, and connectivity, the offered solution has a great potential of becoming a scalable and applicable method of smart city waste management, network structures, including lightweight CNN models, to allow faster and more accurate recognition on edge computers.[14][15]

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