Georgia State University

Undergraduate Honors Thesis Research Literature Review

Title: **Development of Waste Collection Mobile Robot Equipped with Robotic Arm and Trash Sorting Bin using Robotic Algorithms, Computer Vision, and Deep Learning.**

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Table of Contents

Abstract

Lack of proper handling and disposal of wastes is becoming a major problem in the world today, especially in highly populated areas like colleges, hospitals, working places, malls and transport stations. In this literature review, we will focus on the design and development of a smart waste management system which is made up of a robotic arm mechanism, an autonomous robot car, and an intelligent waste sorting trash bin. The system will seek to improve the efficiency of waste management through the use of robotic algorithms, computer vision and deep learning. In this review we will cover the findings from the various research projects that have contributed to the development of each of the component and show the possibility of integrated robotic solution to improve waste collection, sorting and recycling process.

Literature Review

Waste management is an important factor in densely populated areas because the level of waste production is high. The conventional ways of waste collection involve a lot of manual handling and are not efficient, which leads to improper waste sorting and environmental pollution. Future improvements in robotics and artificial intelligence provide the potential for these solutions in building smart waste management systems.

One of the key factors of design for an autonomous robot car for waste collection is the application of visual recognition and machine learning. Zhoulin Chang et al. (2020) provide details of a mobile garbage collection robot that implements the MobileNetv3-SSD algorithms and is able to move around, recognize garbage, and perform target detection and classification. This robot integrates machine vision technology with intelligent control to achieve a higher level of automation in waste collection, which can greatly improve efficiency in waste collection. It moves within environments, recognizes waste using advanced visual recognition algorithms, and accomplishes target identification and categorization. These kinds of robots are self-sufficient and can work without interruption. This is quite efficient in large places or areas that experience fast accumulation of waste.

Real-time object detection and tracking are important in path planning and waste picking. Chandan et al. (2018) discussed the use of YOLO-based algorithms along with GMM models. These methods presented a very high accuracy in feature extraction and classification. These methods allow the autonomous robot car to localize and recognize the waste and track it so that the robot can deal with different waste management situations. MobileNets and SSD algorithms were used for detection and tracking which was fast and mostly accurate. These methods improve the efficiency of the robot in recognizing and grasping many waste objects at the same time to facilitate proper collection of waste.

Moreover, when applying object detection on embedded platforms, more focus is made on the achievement of near-real-time detection. Guennouni et al., (2014) explained the application of cascade classifiers founded on Haar-like features, integral images, and Adaboost learning algorithms that improve the detection speed and accuracy. Such systems can be used in several surveillance applications, in our case waste management, to detect and identify several objects. Real-time object detection at high frame rates is essential for the embedded systems present in autonomous waste collection robots to operate efficiently in complex environments.

Development of robotic arms incorporates advanced control algorithms and the integration of sensors into the robotic arms. Ishwarya (2019) describes a robotic arm that is used in cleaning sewages which has both suction and grinding functions. This system is implemented on a Raspberry Pi 3 Model B+ and is equipped with a six-axis robotic arm to identify, grind, pick up, and dispose the waste. The arm can carry waste up to 5. 2kg. The incorporation of these sophisticated systems enables the robotic arm to handle the waste with much lower ease and higher accuracy.

Another example is Garbage Collector Robot (Gacobot) developed by Prasetyo et al. (2020) that incorporates an autonomous mobile robot that is provided with ultrasonic sensors and manipulator systems. The robot has the capability of identifying environmental patterns and the decision making

is done by Fuzzy Kohonen Network (FKN) algorithm. It effectively transports and dispenses waste within an open space. The capabilities of the Gacobot robot to autonomously perform the tasks of navigating and handling waste in different environments is evidence of the possibility of achieving better waste management with the application of advanced sensors and control algorithms. The use of such systems can greatly decrease the danger posed to human employees working in disposal and recycling of hazardous waste.

A hybrid position/force control architecture improves the accuracy and flexibility of 5DOF manipulators in waste management. In a recent article, Gal et al. (2021) proposed a position and force control system that changes its mode of operation depending on the state machine decision algorithm. This way, the manipulator can switch between the control strategies and perform different tasks required in the handling of wastes effectively. This characteristic is very important to ensure that the system is capable of dealing with various types of waste materials that may have different size and shape. The state machine approach helps the robotic arm to decide on the type of waste and the environmental conditions for a better handling of waste. This approach offers a flexible solution which may be easily modified to accommodate different waste types. This a highly desirable quality to increase the efficiency of waste collection robots.

Smart bins or intelligent trash sorting bins are another essential of part smart waste management systems. An automated sorting recycle bin proposed by Hassan et al. (2018) is a recycle bin that is capable of sorting wastes by using sensors and mechanical sorting system. The system was accurate in identifying plastic waste however there is room for improvement in case of paper and aluminum. It may be more effective to use more sensors or adjust the detection angles in order to increase the level of accuracy of sorting. The segregation and channeling of waste to the right compartments by this automated sorting bin greatly minimizes human interference in sorting wastes.

Waste classification is one of the procedures used in sorting wastes, and Bircanoglu et al. (2018) developed RecycleNet, a deep neural network for waste classification. Inception-ResNet and DenseNet proved to be accurate in classifying wastes and in distinguishing between shape chnaging materials such as compressed plastic bottles. The fact that RecycleNet's network can work with various types of waste and maintain high levels of classification accuracy when tested in complex situations proves that deep learning approaches are well suited for real-world waste sorting tasks.

Likewise, Davis and Lebrija claimed that the increasing complexity of the business environment necessitates a shift to a new management model. They developed Trash.py, a system that eliminates user decisions in waste sorting by automatically classifying and directing the waste to appropriate bins. This system employs image classification to distinguish between recyclable and landfill waste. In this way, the proposed system eliminates the need for user involvement and helps in making sure that waste is sorted appropriately and correctly and thus minimizing contamination of recyclable material and improving the efficiency of the waste management systems. According to Davis and Lebrija, this system greatly improved waste management processes in the University of Michigan.

Self-driving robot cars, robotic arms, and smart bins are the robotic elements that form a complete waste management system. All of these components play their part in the overall functionality of the system where autonomous navigation, waste handling, and sorting are used to improve waste management. These modern technologies facilitate efficient waste management with minimal human

interference, thus improving the performance of the overall system. The overall functioning of these components guarantees that the whole process of waste collection and sorting is efficient.

Past researches carried out on the different parts of the system in terms of simulation and in real life have given positive results. For example, YOLO and SSD offer real-time detection and tracking; and robotic arms with hybrid control structures improve the handling. Introducing deep learning models to the intelligent trash bins enhances the accuracy of waste classification. Thus, these results demonstrate the effectiveness of the integrated robotic solution in transforming the field of waste management and solving the problems that arise with the use of traditional approaches. This shows that these technologies can be applied in different settings to achieve their intended purpose. Thus, further development and implementation of these systems are expected to contribute to the future of environmentally friendly waste management.

Methods

The search for articles was conducted through two main academic databases. These are Google Scholar and IEEE Xplore. These databases were selected for the fact that they contain a large number of articles and technical publications of peer-reviewed materials related to the topic of robotic waste management.

To increase the relevance of the search results, I used specific keywords and search terms. The main keywords included "waste management robotics," "robotic arm mechanisms," "autonomous robot navigation," "intelligent trash bin," "computer vision in robotics," and "deep learning for waste sorting." These terms were chosen in order to cover the entire field of interest of the research and include all the aspects of the smart waste management system.

The research papers included in this literature review had to meet the following criteria: the papers had to focus on the development and deployment of robotic systems in waste management and the papers had to have been published within the last 10 years to capture the latest developments in the field.

After identifying the papers that met the above criteria, extracting information to obtain basic information about each study followed. The following are the study objectives, methodologies, findings, and applications. More specifically, the specific approaches and tools applied in the research, including algorithms, hardware, and software, as well as the main findings and recommendations made by the researchers.

Results

The research papers analysed offer several important findings regarding the development and application of smart waste management systems. The incorporation of computer vision, deep learning, and robotic algorithms is useful in improving the efficiency and effectiveness of waste management practices.

One of the issues identified is the high accuracy of real time object detection and tracking. Chandan et al. (2018) have shown that the use of YOLO-based algorithms with GMM models attain a 99% success rate of classification. The improvements of the detection and tracking algorithms such as MobileNets and SSD algorithms improved the capabilities of the system while at the same time making it faster and more accurate. This high accuracy enables the autonomous robot cars to maneuver through complex environments and adjust to numerous waste management situations.

The improvement of robotic arms with suction also demonstrated a better performance for dealing with various kinds of wastes. Ishwarya (2019) also discussed the application of six axes robotic arms using Raspberry Pi 3 Model B+ whereby such a robot can identify, pick, and place waste without human interference. These arms showed that it is capable of lifting weights up to 5. 2 kg, to execute sophisticated functions involving the handling of waste with the needed precision and speed. Likewise, Prasetyo et al. (2020) described the Garbage Collector Robot (Gacobot) that moves and picks waste independently through the aid of ultrasonic sensors and the Fuzzy Kohonen Network (FKN) algorithm. The Gacobot proved capable of moving and distributing waste in exposed areas, proving the capabilities of increased sensor incorporation and control algorithms in the improvement of waste collection.

Neural network-based intelligent trash bins for waste classification have increased sorting efficiency by a great degree. Consequently, Hassan et al. (2018) presented the automated sorting recycle bins based on Arduino microcontroller. They proved high sensitivity in recognizing plastic waste, whereas there was a need for improvement in differentiating paper and aluminum wastes. Thus, increasing the number of sensors and improving the detection angles could increase the efficiency of sorting processes. To address the challenges of shape-shifting materials like compressed plastic bottles, Bircanoglu et al. (2018) proposed the RecycleNet system that uses deep neural networks such as Inception-ResNet and DenseNet to accurately classify wastes. Davis and Lebrija (n. d.) introduced Trash.py, which completely removes the user's decision-making process regarding waste sorting by sorting and directing the waste to the right bin. These changes helped the University of Michigan to minimize contamination and inefficiency in collecting and recycling waste.

The combination of these technologies in a single waste management system has clearly shown that these technologies offer immense potential for improving efficiency of the system. Every part of the system, from self-driving to precise waste management and identification of the type of waste, has a special role in the process. The results of the simulation and the experiments conducted on these components have demonstrated encouraging findings, which suggest that end-to-end robotic systems can improve waste management processes. The application of these technologies in different environments proves that they are efficient, and this shows that as the technology advances and more of these systems are incorporated in waste management strategies, then progressive solutions to waste management will be achieved in the future.

Limitations

The analyzed research projects offer a significant input to creating intelligent waste management systems, a number of limitations are still evident. A significant limitation lies in the ability to identify waste, as the majority of such systems are unable to accurately detect waste in fluctuating light and environmental conditions. For example, Guennouni et al. (2014) outlined in their research paper how cascade classifiers were applied to embedded platforms which made the detection time faster, but still faced challenges under diverse lighting and environmental conditions. This inconsistency can lead to missed detections which will affect the system's efficiency.

Real-time processing is another important issue that should also be considered. The real time operations are relatively very difficult because they require high accuracy of computation along with high speeds for implementation especially when it is to be done in Raspberry Pi and Arduino systems. These types of systems are generally less powerful in terms of computation and do not efficiently run complex algorithms with great speed and accuracy. This was seen in the study by Chandan et al. (2018) that while YOLO-based algorithms yielded high accuracy, they required higher computation resources in that they cannot be implemented in low power devices.

The coordination of the navigation, waste collection, and sorting sub-processes can create issues if these processes are not well integrated. For example, while Zhoulin Chang et al. (2020) developed a mobile garbage collection robot accompanied by advanced visual recognition and category, integrating such features with the mobile base control was challenging. Failure and delays may occur in the use of components when there is no proper integration among them.

Another issue is the applicability of these systems to other environments that possibly may contain different types of wastes and/or pose different navigation challenges. Some systems may perform well in ideal testing conditions but may not perform well in other forms of waste or in conditions that are slightly more complex. This limitation was seen in the study by Prasetyo et al. (2020) on, Gacobot Garbage Collector Robot, while the robot works best in specific conditions, it has challenges in numerous and complicated situations.

Moreover, substantial improvement needs to be made regarding the mechanism of detecting objects and sorting them subsequently, especially for paper and aluminum. However, current systems such as RecycleNet proposed by Bircanoglu et al. (2018) employ deep neural networks for waste classification but there's a need for improvements so that the system can efficiently sort wastes that may come in mixture.

These limitations indicate that a more comprehensive approach to intelligent waste management systems is required. In order to overcome these challenges, which include designing smarter sensors, refining the techniques of real-time processing, developing efficient energy supply methods, as well as integrating the various components, these systems have to be made realistic and functional for real-life implementation.

Conclusion

In conclusion, the research papers covered in this literature review reveal that smart waste management systems have had significant advancements but still hold limitations and we can firmly conclude that there are possibilities to improve its efficiency by using robotic algorithms, computer vision, and deep learning techniques. Key components like self-driving robot cars, mechanical manipulator arms, and intelligent bins have indicated possible ways of improving waste collection, sorting, and recycling efficiency.

Some of the important findings are the use of self-driving robot cars such as the one described by Zhoulin Chang et al. (2020) which employ techniques of visual recognition coupled with machine learning to identify waste effectively. Real-time object detection and tracking as pointed out by Chandan et al. (2018) are also essential in path planning and waste identifying and the use of YOLO-based algorithms and GMM models is a crucial technique as these algorithms have high accuracy. Robotic arms, such as the one described by Ishwarya (2019) have the ability to recognize waste, pick it up and dispose it through the use of control algorithms and sensors. Intelligent waste sorting systems like the RecycleNet developed by Bircanoglu et al. in 2018 use deep neural networks for sorting of waste.

Nevertheless, there are still several key limitations. Recognizing waste objects under different conditions is still an issue which was discussed by Guennouni et al. (2014). Real time processing on embedded systems such as Raspberry Pi and Arduino is also a challenge because they have limited processing power. The integration of navigation, waste collection, and sorting sub-systems has to be improved so that the system runs effectively. Also, the further improvement of the detection and sorting efficiency, especially of paper and aluminum trash materials, is also another concern.

I will incorporate the successful aspects of the research papers into my research project. I will employ computer vision and deep learning techniques to let the autonomous robot car recognize and move towards the waste on its own. Real time object detection and tracking will also be incorporated using more efficient variants of the YOLO or OpenCV algorithms for the detection of trash objects in real time. The robotic arm mechanism will be used in the handling of wastes with different shapes and sizes to ensure that it operates effectively. The intelligent sorting bin will incorporate deep learning for improving the efficiency of the sorting of waste materials.

To address the limitations identified, I will focus on several key areas: developing algorithms that can run in various lighting and environmental conditions; developing lightweight and efficient algorithms that can operate effectively on low-power embedded systems, ensuring better integration of navigation, collection, and sorting sub-systems to reduce errors; developing a system that can be used across multiple environments and handle different types of wastes; and improving detection and sorting mechanisms for complex materials such as paper and aluminum.

By addressing the discussed limitations and incorporating the key insights provided by this literature review, my research proposes an efficient, faster, and more flexible smart waste management robotic system.

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