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AI-SMART GLASSES FOR THE INTELLIGENT WASTE MANAGEMENT SYSTEMS

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Abstract:

In this paper, we develop and pilot a Smart Bin Management System that combines smart glasses and QR code scanning technology to enhance the urban waste collection system. The current waste management method is not well-suited to the problem of monitoring and data accuracy and so the operations are very expensive. Utilizing the computer vision and display capabilities of smart glasses, it helps waste management personnel to scan QR codes on the phone without the need of tools and allows waste bins to be identified and reported. In collaboration with KDEB Waste Management Sdn Bhd (KDEBWM) our project was designed and tested to see if this wearable solution works. A total of 203 QR codes were successfully scanned and detected with a 68.97% success rate. A detailed analysis suggests that the delays of images to scan over more than one minute were mainly due to hardware difficulties and not the cloud database or QR architecture. In particular, the continuous capture and streaming of data over Bluetooth Low Energy (BLE) caused system problems and caused the device to shut down immediately and the data to not be readable. We believe that the current smart glass system will have to be reworked to overcome such deficiencies, and the proposed framework is well established for future wearable industrial applications in municipal waste management.

Keyword:

Artificial Intelligence, Internet of Things, Smart Glasses, Waste Management

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Introduction

Solid waste management is an essential task for municipal authorities and therefore a huge cost for collection and public cleaning. KDEB Waste Management Sdn Bhd (KDEBWM) manages and coordinates this in Selangor, Malaysia in twelve local authority areas. Traditional waste collection and monitoring methods, however, are prone to manual errors and inefficiencies resulting in poor service delivery and poor real-time data visibility. Modern urban management strategies are based on data-driven approaches and advanced technologies in order to address these issues. This is because urban complexity and generation rates are growing rapidly and traditional frameworks are not able to keep up (Zhang et al., 2024).

Internet of Things (IoT) technology has already made great progress in optimizing waste collection routes and schedules and moving data processing to predictive and decentralized smart city systems (Addas et al., 2024). From this new research, we propose to integrate smart glasses as a hands-free, wearable device to complement SmartBin systems. It will digitize bin identification by QR code scanning, as well as reduce data entry time and improve the accuracy of asset tracking for waste management service providers.

Smart technology adoption has become a focus for improving urban waste management. As Esmaeilian et al. (2018) observed, these systems are based on sensors, communication, and data analytics to optimize the route of waste collection and schedule to save time and improve environmental outcomes. In waste management, QR codes have been studied as an efficient way to track and manage waste bins. A study by Anagnostopoulos et al. (2017) demonstrated that QR code-based systems can greatly improve waste data collection and monitoring of bin status in real time. In addition, the use of automated digital urban waste tracking systems, which integrate QR codes with electronic ground containers for accurate asset tracking and transparent data recording (Strzelecka, 2024), is also a significant development. Mobile-based QR systems provide direct field connectivity and can follow the real-time movement of structural assets in databases (Lee et al., 2022). Recently, machine learning classifiers and QR codes have been employed to log asset data and check disposal patterns in sync (Aranas, 2026). Though smart glasses have not been extensively explored in waste management, they have a well-established potential for industrial applications. Cirulis and Ginters (2013) pointed out the advantages of augmented reality (AR) glasses in logistics and warehouse management and their potential in other areas of waste management. In an enterprise setting, augmented reality smart glasses (ARSG) are an important means of knowledge management by linking real-world information to relevant data on the ground with the technician's view-field (Rauschnabel et al., 2017). ARSG has a system of localized processing units with GPS tracking software. This makes it possible for field workers to do high-intensity physical activities without delay and avoids manual entry errors for equipment checks. The Internet of Things (IoT) has played a fundamental role in smart waste management. Bharadwaj et al. (2016) proposed an IoT-based smart garbage system which uses ultrasonic sensors to detect garbage levels in bins and provide

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real-time information to waste collectors. Sensors embedded in smart bins at municipal zones enable the immediate event detection of capacity limitations so collectors can be informed and minimize overflow risks (Ishaq et al., 2023). There are also interactive screens and electronic feedback modules that are embedded in these linked systems and have been found to have a positive effect on stakeholder behavior as well as daily sorting compliance (Guna et al., 2022). Data-driven decision making in waste management has been a major area of interest in several studies. Anh Vu et al. (2019) illustrated how big data analytics can be applied in waste management data to optimize collection routes and predict waste generation patterns.

Despite the potential benefits, the implementation of smart waste management systems comes with several challenges. Privacy concerns, infrastructure issues, and the need for standardization are the key challenges (Pardini et al., 2020). The proposed Smart Bin Management System, which integrates smart sunglasses with QR code scanning capabilities, addresses various problems identified in the literature. Applying QR code technology, wearable devices, and IoT technology to the smart bin management system could significantly enhance waste management efficiency and accuracy. Smart bin management systems with QR codes and wearable technology, especially using smart glasses, have the potential to improve waste management efficiency. The use of smart sunglasses with QR code scanning for waste management is a first attempt and is based on research in similar areas. More studies are needed to evaluate the long-term impacts and scalability of such systems in various urban settings.

Methodology

The proposed system architecture integrates smart glasses with the existing SmartBin@KDEBWM platform, as shown in Fig. 1. The operational flow consists of three main components: the SmartBin QR module (for bin labeling), the SmartBin App (for data transmission from the field), and the SmartBin Web interface (for central server data processing). The implementation utilized Brilliant Labs Frame smart glasses, which feature a built-in 720p camera, Bluetooth 5.3 connectivity, and an OLED display. The software development involved Python (Frame SDK) for laptop-based testing and Flutter for phone-based application deployment.

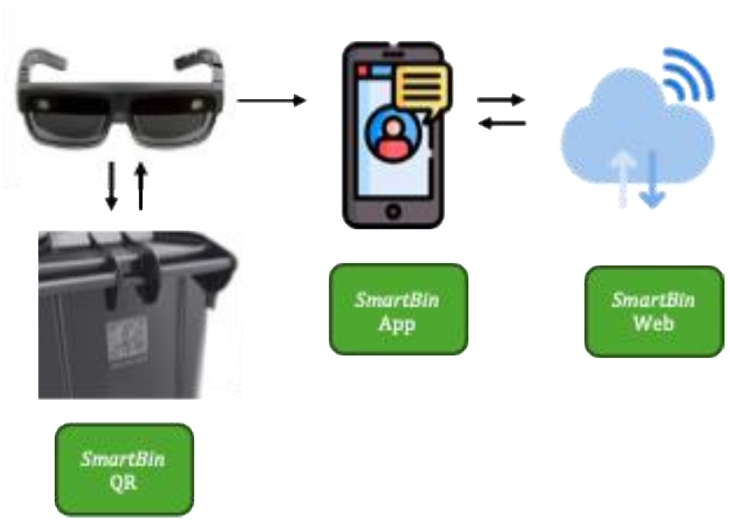

Figure 1: Overall Proposed Work System.

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The technical framework of the smart-glasses add-on is executed through a specialized four-stage pipeline consisting of image capture, data transmission, localized processing, and cloud verification, where the scanning workflow precisely follows the steps illustrated in Fig. 2. The automatic tracking process starts with Image Capture, which uses the built-in hardware in Brilliant Labs Frame smart glasses. The operator initiates the scan by a gesture that is registered by an onboard 3-axis accelerometer with tap-detection capabilities. Once a single-tap is recorded, the device starts to run the 720p low-power color camera that captures the static frame of the QR code matrix that is attached directly to the municipal waste bin.

Then it moves to the Transmission where the QR code image is transmitted via Bluetooth to the paired mobile device like smartphone or laptop, thus ensuring efficient data exchange. In the device architecture, the glasses' full-fledged, Lua-based operating system and onboard FPGA graphics acceleration process the raw image and stream it externally. The data is sent over a Bluetooth 5.3 Low Energy (BLE) link, so the paired host device either can be used to generate a secure GATT session by Frame Python SDK for laptops or by Frame Flutter SDK for mobile devices. We need the smartphone app to be located well in Android 12 or newer architectures. As long as the BLE scanning can be done from a different location, the app can scan the location of the phone. If the app is not located properly, the phone is not able to open the GATT session.

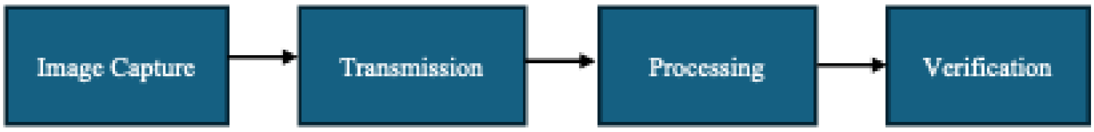

Figure 2: Flowchart Of The Overall Working Of The Smartbin QR Module.

When the host device receives the image from the frame, the Processing step starts local computer vision decoding and the QReader library is used in this task to process the image and extract the unique QR code data. The accompanying application receives the image byte-stream and then plugs it into the edge-processing software package that scans the image array, analyzes the QR code geometry, and extracts the unique alphanumeric string for the bin.

Finally, this data is cloud verified by sending it to the remote server via HTTP GET request that parses the data and returns a real-time status update to synchronize the decoded edge data with the central waste management database. The host application compiles the bin identifier extracted and system-generated timestamp to send that data to the remote cloud server as an asynchronous network payload.

The server parses the incoming request, updates the structural logging tables, and sends an HTML response packet back to the host device. The companion application then filters this server's feedback, asking for categorical states such as "Collection added successfully" or "Entry already exists" in addition to unregistered asset flags. These filtered text outputs are sent back across the BLE connection and displayed directly on the glasses' 640 x 400 color OLED screen inside a 20° field of view, offering the operator immediate and hands-free visual feedback on the collection status.

Results and Discussion

In the pilot study from 22 December to 26 December 2025, the Smart Bin Management System was field-tested under the jurisdiction of Majlis Perbandaran Sepang (MPS) in seven residential areas to verify its functionality. Of the 203 QR codes examined by the MPS, 140 were detected and verified successfully with an accuracy of 68.97%. From a system feasibility perspective, the pilot study demonstrated the capability of the system to digitize waste collection verification, but hardware limitations considerably affected the system's overall performance and field scalability. A major bottleneck was that QR code scanning and verification took longer than one minute per bin; the collection process became very slow and was disrupted as the physical process of collecting the waste was generally less than a minute. It was also hampered by the hardware limitations of the smart glasses; the battery life of the smart glasses is limited to about 30 minutes per battery charge, which is not sufficient for long-term or large-scale deployment and the system needs to be recharged several times daily or more complicated spare units have to be managed. Moreover, the system's environmental sensitivity compromised reliability, as outdoor ambient lighting and intense solar glare often resulted in inconsistent QR image detection and required specific training to ensure camera alignment, glare control, and optimal scanning distances. Based on these results, it can be concluded that the 68.97% success rate and the delay in performance are mainly due to the physical limitations of the wearable hardware rather than flaws in the cloud database or the QR system architecture itself. When the smart glasses were continuously capturing and streaming data over Bluetooth Low Energy (BLE), the smart glasses experienced stability issues and suddenly shut down mid-operation. This led to unreadable data packets and software range errors which meant the system had to reset and restart, adding at least one minute to the scanning time. In addition, the open-air environment of the residential track generated strong glare, which washed out the contrast between bin-affixed QR codes, making the low-power 720p camera lens unable to decode instantly unless the operator maintained a good static viewing angle. This high sensitivity introduces an impractical learning curve for waste management staff who need to work with them manually and physically. Ultimately, even though the study confirmed the basic idea that automated QR scanning can digitize tracking and eliminate manual logging errors, consumer-grade smart glasses do not have the ruggedness and power for municipal field use. This therefore calls for future research to move towards other wearable form factors such as industrial body cameras with stable mounts, higher battery capacities, and robust environmental resilience.

Conclusion

The successful pilot study on the Smart Bin Management System demonstrated the application of QR code identification with wearable smart glass technology to optimize urban waste collection and data management processes. Although the real-world field deployment exposed key hardware and operational challenges such as a short battery operational window, vulnerability to ambient outdoor glare, and the need to keep local networks connected, the framework proved to be a powerful model for automation of data entry and elimination of manual reporting inaccuracies for municipal management. The system successfully demonstrated the fundamental shift from handheld smartphone interaction to hands-free wearable computing in industrial public cleansing systems. In addition to the physical challenges of consumer-grade AR hardware, we plan on designing other wearable vision platforms with rugged body cameras and edge-based QR code scanning algorithms to offer longer battery life, more stability under volatile environmental conditions, and a broader field of view for solid, large scale smart city waste management.

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