Towards an IOT Approach for Smart Waste Management based on Context Ontology: A Case Study

Nadia Aloui
Department of Software Engineering, College of Computer Sciences and Engineering, University of Jeddah, Saudi Arabia | Sfax University, Tunisia
naaloui@uj.edu.sa

Wafa Almukadi
Department of Software Engineering, College of Computer Sciences and Engineering, University of Jeddah, Saudi Arabia
wsalmukadi@uj.edu.sa

Aymen Belghith
College of Computing and Informatics, Saudi Electronic University, Saudi Arabia
a.belghith@seu.edu.sa
(corresponding author)

Received: 28 November 2022 | Revised: 10 December 2022 | Accepted: 12 December 2022

ABSTRACT

Nowadays, waste management faces the challenge of providing effective and efficient solutions for waste collection, disposal, and recycling while respecting health and environmental standards. This challenge also includes the lack of understanding of the diverse factors that influence the various stages of waste management, inefficient route planning, insufficient resources, etc. Faster collection, management, and processing of waste are possible with smart containers and IoT technologies allowing waste real-time data provision. Thus, this research proposes a waste management system based on generic and comprehensive generic context ontology and smart containers. The context ontology is conceived to solve the limits and the insufficiencies of waste management by covering all the waste facets for all the stakeholders, optimizing, analyzing, and reusing the waste data and conditions. For given smart container and waste management context, we need to have a global view of the relevant contextual data according to a unified model such as the waste environment data, the waste activity context, the waste computing context, the user context, the collaboration context, etc. One significant advantage of our system is that it provides a unified model for waste management contextual data that could be reused for other waste management systems covering all the properties of this domain. The proposed solution implements an intelligent and adaptive IoT system for waste management according to different waste contexts, waste objectives, and waste activities. The proposed system has been successfully tested under different scenarios in Jeddah City Municipality.

Keywords-smart waste management; waste context ontology; IoT; smart container

I. INTRODUCTION

Waste management, from generation to disposal, is one of the biggest challenges that municipal organizations face today. Due to the growth in waste, containers positioned around cities in open spaces are overflowing, putting the citizens in an unhygienic environment. The implementation of smart waste management systems remains in an embryonic stage, something that is expected to change with urban development, similarly to other engineered systems [1]. To overcome this, a smart waste management system is proposed, based on smart containers that enable context-specific waste management via a general exhaustive context ontology. Real-time monitoring through smart devices or containers is furthering the digital era of waste management by enhancing transparency, dependability, agility, security, resilience, connectivity, and sustainability of waste chains. The proposed system, based on smart containers and general context ontology, is leading the way in developing smart context-based waste management systems, increasing the quality of life today and assuring a greener world for future generations. The adaptation of a system context can take many aspects, such as behavior, content, or presentation adaptation. In this approach, focus is given on the adaptation of a smart waste management system to different waste contexts of different stakeholders. It is possible to manage the waste process situations in different contexts, i.e. the waste management domain, waste objectives, and waste activities, such as waste generation, collection, transformation, segregation, cleaning, etc. The proposed solution implements an intelligent and adaptive system for waste management according to the context and the different objectives according to various stakeholders. The main contributions of this paper are:

- A unique way to combine two technologies, namely IoT and ontological engineering, ensuring an optimal and general based context in the waste management field.
- An architectural development process of the smart garbage box and the process of complete waste management in addition to the objectives, activities, reuse, and intelligent learning of the waste management system, as well as a smart way to monitor waste in real time.

II. LITERATURE REVIEW

Waste management stakeholders looking for a real-time monitoring, smart, and adaptive solution, will eventually have to use smart containers that are permanently equipped with IoT devices. In this section, a brief overview of smart containers and smart devices is presented.

A. The Impact of Smart Containers and IOT on Waste Management

It is worth noting that technological IoT advancements [2] are a key part of the waste problem that we face in industrial processes. Fortunately, technological advancements also provide innovative solutions that can help us meet such challenges when they emerge. IoT is completely changing the game regarding industrial waste management best practices. Firstly, by using IoT services and solutions, we can significantly improve the efficacy of waste collection and recycling. We can automate, improve, and interpret the entire waste management process in new ways while reducing cost. Smart containers save time and effort [3], as operators know the number of containers that must be collected per day and the number of trucks that go to collect containers, in addition to saving time in classifying waste by type, making it easier for workers to send them to the competent authorities for recycling. The main benefit of IoT is the ability to collect huge amounts of data and update them in real time utilizing cost-effective sensors. These inexpensive sensors, recording and monitoring equipment, send all their data to the cloud for storage and review. Then, AI models can analyze the data and draw actionable conclusions. In a series of case studies, we'll look at how companies in the food, agriculture, transportation, and energy sectors have implemented smart waste management.

B. Related Work

The literature includes a variety of waste management-related research initiatives. Through a design that uses solar energy to feed the system and sensors to keep track of how much waste has been gathered inside the enclosure, authors in [3] introduce the idea of intelligent disposal. If necessary, the container can compress the waste, reducing its volume up to 10 times, even before it is collected. The waste monitoring solution SENSONEO [4] combines smart sensors, a smart waste management system, and a citizen app. Smart sensors use ultrasound technology to measure the filling levels in boxes and containers several times a day and send data to the waste management system. It divides the container into several sections. Authors in [5] offer a novel method of implementing an integrated sensing system, which automates the solid waste management process, using cloud technology and mobile app-based monitoring. The suggested smart trash can is built on ultrasonic sensors and a variety of gas sensors. Authors in [6] suggest an IoT-based smart waste management system that aids surveying the estimation of garbage in trash cans and then transmits data through the Internet to a server. A specific suggestion focusing on the intelligent container was originally made in [7]. In order to prevent trash disposal outside the container, the authors suggest a method in which monitoring takes place both inside and outside the compartment with the help of infrared sensors. The system in [8] includes a method for monitoring dumpsters around-the-clock. A smart and well-organized mechanism is in place here for selective clearing. The level of waste in the dumpster is determined using the ultrasonic sensor.

C. Comparison of Smart Containers/Waste Management Systems

To make the system innovative and optimized, a comparison research based on a variety of criteria has been conducted (Table I). The primary factors considered in this study are the detection of container fullness, and the used technologies.

TABLE I. COMPARISON BETWEEN THE PROPOSED SYSTEM AND OTHER, KNOWN, SYSTEMS

Criteria	Reference						
	[3]	[4]	[5]	[6]	[7]	[8]	Proposed
Intelligent route planning	√	√	x	x	x	√	√
Container fullness	√	√	√	√	√	√	√
Used technologies	Solar energy and sensors	IoT	Cloud technology and mobile app	IoT	Infrared sensors	IoT and cloud	IoT and ontological engineering
Includes smart bin	√	√	x	√	√	√	√
Recycling and disposal	x	x	x	x	√	√	√
Full waste management process	x	√	x	x	x	√	√
Context awareness	x	x	x	x	√	x	√
Context model	x	x	x	x	x	x	√

There are many waste classification techniques currently available, but many of them require human intervention. If a fully automatic system is deployed in a company, it will be a win-win situation for government, companies, and industry. The majority of the research discussed here focuses on the collection system when discussing waste management and doesn't give interest to the whole process of waste management. Previous studies did not take into account the waste management context, objectives, and activities according to the whole waste management process and all the waste management factors. They are not based on context models specific and exhaustive for the waste management field. It is assumed that the best waste management approach has to be based on context and reuse. Thus, the services offered for waste management will be more adapted, optimized and context aware. The proposed system in this research takes into account the contributions in the literature and covers their limits.

D. Context and Context-Awareness of Ubiquitous and Smart Systems

Context is all that surrounds and gives a meaning to something [9, 10]. A definition of context cannot be given without taking into account the element concerned by the context. This definition shows that the context must be external to the element related to this context. In the field of ubiquitous computing (computing pervasive), context is any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves [11-14]. There are mainly two types of context [16]. The first one is active context use (automatically adapting the application's behavior in accordance with the state of the context) and the second one is passive context use (visualizing the state of the context for the user or saving this state for its future use).

In the literature, many definitions of context-awareness have been proposed. Authors in [16] consider context-awareness as the set of context-aware applications. Another definition given in [10] specifies that a system is considered as context-aware, if it uses the context to give pertinent information or a service to a user, knowing that the relevance depends on the user's activity. Furthermore, context-awareness emerged in the fields of mobile and pervasive computing as a technique to design applications with a conscience of the environment, to ensure high level of autonomy and flexibility. The context-awareness or the conscience of the context is known under other synonyms like adaptive or reactivate [17]. In order to model the smart container context, we use the concept of ontology, which provides an explicit specification of a conceptualization and an important step for reuse [18-20]. Moreover, "an ontology is expressed in language (representation) based on a theory (semantics) that guarantees the properties of the ontology in terms of consensus, consistency, reuse, and sharing." [21]. The proposed generic context ontology will be able to guarantee unified, coherent, shared, and reused smart containers management in different contexts.

III. PROPOSED GENERIC CONTEXT ONTOLOGY FOR SMART WASTE MANAGEMENT

There are several methods for developing ontologies (top-down, bottom-up, and combined). To design the context ontology for waste management, we adopt the iterative method recommended in [22].

A. Field and Scope of the Ontology

We proceed to the ontology development process by defining its domain and scope. Indeed, ontology is the structured study of a specific field [23], which is accomplished by answering the following questions: What domain will the ontology cover? What are the objectives of ontology creation? Who will utilize the ontology? Our ontology field is the waste management context-based IoT of all actors. Our context ontology therefore includes concepts related to the waste management activity through smart containers. This ontology is designed to integrate both the active and passive context (smart container context). Moreover, our ontology is not intended to be used by a human, but by the different components of context management to provide a better IoT waste management in the city in a given context.

B. Generic Context Ontology

A current representation of the context object is available for waste management via smart containers according to the generic context ontology. By using this context model, the system can become aware of the current situation and adapt its services for various stakeholders in response to environmental changes. To give the waste management system exact values for these attributes, this generic ontology identifies the characteristics of the current context. These attributes are used to specify the smart container's contextual aspect in an active waste management situation and to adapt the content to that context and the current waste management activity and objective. We offer a general context model based on the different state-of-the-art models, and its attributes are organized into six facets:

1) The Actor Context

All participants in a waste management environment are referred to as actors. We define the identifier and the actor as the two elements that constitute the actor context aspect. The first element uniquely identifies the actor's smart containers for waste management environments. The second element is utilized to link the waste management purpose and action to the actor who used, will use, or reuse the smart container in another waste management context.

2) The Waste Activity Context

Waste management domain, waste management activity, waste activity objective, generation, collection, transformation, segregation, cleaning, and the collaborative waste activities are the elements the waste activity context.

3) The Waste Environment Context

The environment context of a smart container waste management situation is described by a variety of factors that affect waste, including time, place, temperature, humidity, weather conditions, level, type, status, priority, classification and duration of waste, etc.

4) The Waste Computing Context

This aspect of context describes the equipment and tools the actor used to carry out his waste management task, including hardware, waste management platform, organizer, and operating system.

5) The Waste Reuse Context

Two elements constitute the reuse context: the reuse identifier, which determines how much waste may be reused in each smart container, and the reuse percentage, which increases the value and effectiveness of waste management.

6) The Context of Waste Management Objectives

The waste management objectives facet can be specified through the waste management platform or environment using the context-specific waste management objective aspect. Knowledge of waste management objective, objective type, and waste management evaluation are the parts of the process.

IV. PROPOSED APPROACH FOR SMART WASTE MANAGEMENT BASED ON SMART CONTAINERS

Traditional containers that have been fitted with electronics to allow them to detect, interact, and communicate are known as smart containers. The additional electronics allow for tracking and monitoring of a container as well as the circumstances surrounding the management and transportation of the container's waste. The smart container can be made to exchange physical information close to real-time, including location, door opening and closing events, shocks and vibrations, temperature, humidity, and any other pertinent physical factors (Figure 1).

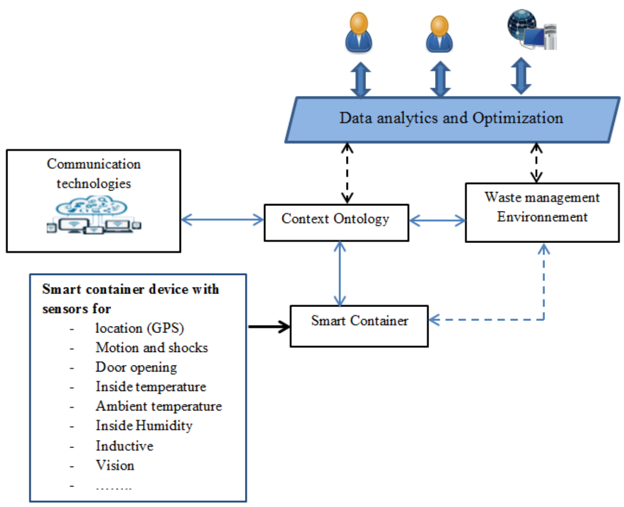


Fig. 1. The proposed approach for smart waste management.

In order to achieve shared visibility amongst diverse stakeholders during the whole smart container journey, the smart container serves as the common data source. In order to clarify the roles and responsibilities of each actor in the waste management chain and to improve collaboration and coordination among stakeholders some essential tasks must be accomplished: (i) shared visibility, (ii) assessing the activities involved for the purpose and determining the type, nature, and estimated volumes of waste to be generated, (iii) identifying any potential environmental impact from the generation of waste at the site, and (iv) recommending appropriate waste handling and disposal measures/routings in accordance with the current legislative and administrative requirements. It is suggested that smart containers could be integrated with other technological advancements to benefit the waste management, trade, and transportation communities even more.

V. A CASE STUDY OF THE PROPOSED SMART WASTE MANAGEMENT SYSTEM

A. Study Area

The study case chosen for developing this waste management system based on smart containers and context model is the Municipality of Jeddah. For the development of the smart waste management system, the work was divided into the following stages.

B. Functional and Non-functional Requirements

The functional requirements outline the tasks that the suggested solution must complete in order to function and the non-functional requirements are those aspects of the system that are visible as it is being used. The required specifications are:

- The administrator can:

1. Edit the existing containers in the system
2. Establish the waste collection plan according to the waste management activities.
3. Select the best route to collect containers and send information to the collector.
4. Track smart containers and trucks locations.
5. View the full container status and context features affecting the waste management activities.
6. View most frequently utilized portion in each container, the full section, the most used section, the total number of containers that have been collected and the section percentage.

- The collector can:

1. Collect containers that change color on the map.
2. View the location of smart containers.
3. Collect containers according to smart containers priority and waste management activities and objectives

- The Jeddah municipality can:

1. Create waste collection report in a daily and or monthly basis according to different waste activity objectives such as waste generation, collection, transformation, segregation, etc.

2. Generate peak day and time of waste collection and prevent waste risks.

C. Hardware Components

This section represents the hardware used throughout the implementation of the smart container for waste management. We used NEO-6M GPS to detect the location, an inductive sensor to detect metal, an ultrasonic sensor to detect the level of trash, an ESP8266 NodeMCU to connect with the firebase, an Arduino Uno to do programming over the other products, etc.

D. Prototype

Figure 2 depicts the view of the finalized hardware prototype of the smart container of the waste management system.

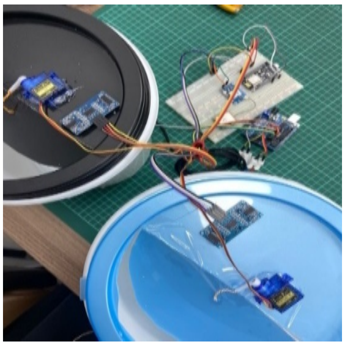


Fig. 2. Smart container prototype.

E. Interface

The smart waste management system based on smart containers has been implemented by the students of the College of Computer Science and Engineering of Jeddah University. Screenshots of the User Interface are exhibited below. Figure 3, the system displays several optimal paths and the best path is indicated as the "best choice", and the administrator will determine the path that suits him.

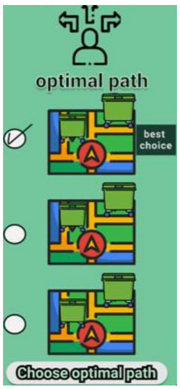
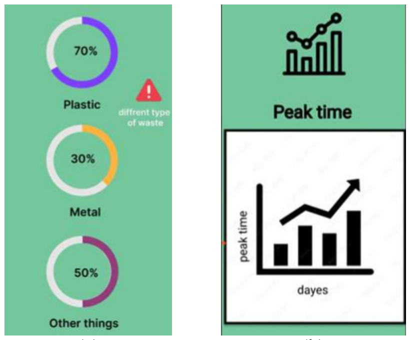


Fig. 3. Choose optimal path page.

As can be seen in Figure 4, the waste management system users have access to improved visibility identifying the waste inbound flow to optimize waste management and react to unexpected risks. In Figure 5, the administrator must be able to see if the waste in the section has the same type for example. A warning sign will appear if there are different types of waste in a section. The percentage and quantity of each type also appear. The smart sensors and IOT technologies utilized in this waste management system that gathers and tracks real-time data allow the administrator to, dispose of, reduce, reuse, and prevent waste collecting peaks (Figure 6).

(a) (b)

Fig. 4. (a) Container data in real time, (b) truck tracking.



(a) (b)

Fig. 5. Containted types of waste, (b) peak time and waste risk.

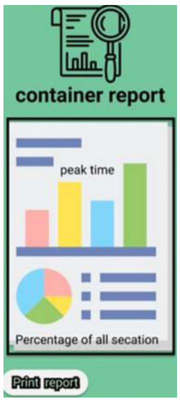


Fig. 6. Waste management report and statistics.

VI. CONCLUSION AND FUTURE WORK

The context ontology is opening up a variety of data sources that could give the waste management system a context-aware picture. Any documentation of the contextual information contained in a container is helpful to the coordination and predictability assuring quality and optimizing waste management. It is possible to predict when a container will be ready for the next operation and effectively manage risk in accordance with the waste management process by simply being aware of the status of a specific container, its contents, all relevant contextual information, and the waste management objective at a given time. As a perspective of this work, we suggest the use of deep learning methods as an intelligent way to classify waste through image classification. Machine learning algorithms can be very beneficial in the waste management data analytics in order to take the best decisions and optimize smart waste management.

ACKNOWLEDGMENT

The authors would like to thank Aizah Alsomai, Njoud Barayan, Raghad Alghamdi, Shroug Alzhrani for their contribution in implementing the case study application of smart waste management during their senior project.

REFERENCES

[1] D. M. S. H. Dissanayaka and S. Vasanthapriyan, "Smart Solid Waste Management — a Scientific Literature Review," *The Journal of Solid Waste Technology and Management*, vol. 46, no. 4, pp. 606–619, Nov. 2020, https://doi.org/10.5276/JSWTM/2020.606.

[2] B. E. Sabir, M. Youssfi, O. Bouattane, and H. Allali, "Towards a New Model to Secure IoT-based Smart Home Mobile Agents using Blockchain Technology," *Engineering, Technology & Applied Science Research*, vol. 10, no. 2, pp. 5441–5447, Apr. 2020, https://doi.org/10.48084/etasr.3394.

[3] I. Sosunova and J. Porras, "IoT-Enabled Smart Waste Management Systems for Smart Cities: A Systematic Review," *IEEE Access*, vol. 10, pp. 73326–73363, 2022, https://doi.org/10.1109/ACCESS.2022.3188308.

[4] *Waste Monitoring*. SENSONEO, 2019.

[5] D. Misra, G. Das, T. Chakrabortty, and D. Das, "An IoT-based waste management system monitored by cloud," *Journal of Material Cycles and Waste Management*, vol. 20, no. 3, pp. 1574–1582, Jul. 2018, https://doi.org/10.1007/s10163-018-0720-y.

[6] C. S. Srikanth, T. B. Rayudu, J. Radhika, and R. Anitha, "Smart Waste Management using Internet-of-Things (IoT)," *International Journal of Innovative Technology and Exploring Engineering*, vol. 8, no. 9, pp. 2518–2522, Jul. 2019, https://doi.org/10.35940/ijitee.G5334.078919.

[7] T. S. Vasagade, S. S. Tamboli, and A. D. Shinde, "Dynamic solid waste collection and management system based on sensors, elevator and GSM," in *2017 International Conference on Inventive Communication and Computational Technologies (ICICCT)*, Coimbatore, India, Mar. 2017, pp. 263–267, https://doi.org/10.1109/ICICCT.2017.7975200.

[8] A. Doshi, B. Shah, and J. Kamdar, "BINTERNET: Smart Waste Management System," *International Journal for Research in Applied Science and Engineering Technology*, vol. 9, no. 6, pp. 703–707, Nov. 2021, https://doi.org/10.22214/ijraset.2021.38882.

[9] "FOLDOC - Computing Dictionary," *Free On-Line Dictionary of Computing*. https://foldoc.org/.

[10] A. K. Dey, "Understanding and Using Context," *Personal and Ubiquitous Computing*, vol. 5, no. 1, pp. 4–7, Feb. 2001, https://doi.org/10.1007/s007790170019.

[11] C. Perera, A. Zaslavsky, P. Christen, and D. Georgakopoulos, "Context Aware Computing for The Internet of Things: A Survey," *IEEE Communications Surveys & Tutorials*, vol. 16, no. 1, pp. 414–454, 2014, https://doi.org/10.1109/SURV.2013.042313.00197.

[12] U. Alegre, J. C. Augusto, and T. Clark, "Engineering context-aware systems and applications: A survey," *Journal of Systems and Software*, vol. 117, pp. 55–83, Jul. 2016, https://doi.org/10.1016/j.jss.2016.02.010.

[13] F. Azouaou and C. Desmoulins, "Taking Teaching Context into Account for Semantic Annotation Patterns," in *Innovative Approaches for Learning and Knowledge Sharing*, 2006, pp. 543–548, https://doi.org/10.1007/11876663_50.

[14] P. Rosenberger and D. Gerhard, "Context-awareness in industrial applications: definition, classification and use case," *Procedia CIRP*, vol. 72, pp. 1172–1177, Jan. 2018, https://doi.org/10.1016/j.procir.2018.03.242.

[15] Song Yanwei, Zeng Guangzhou, and Pu Haitao, "Research on the Context Model of Intelligent Interaction System in the Internet of Things," *2011 IEEE International Symposium on IT in Medicine and Education*, pp. 379–382, Dec. 2011, https://doi.org/10.1109/ITiME.2011.6132129.

[16] G. Chen and D. Kotz, "A Survey of Context-Aware Mobile Computing Research," Dartmouth College, Hanover, NH, USA, Computer Science Technical Report TR2000-381, 2000.

[17] B. N. Schilit and M. M. Theimer, "Disseminating active map information to mobile hosts," *IEEE Network*, vol. 8, no. 5, pp. 22–32, Sep. 1994, https://doi.org/10.1109/65.313011.

[18] T. Chaari and F. Laforest, "L'adaptation dans les systèmes d'information sensibles au contexte d'utilisation: approche et modèles," presented at the Conférence Génie Électrique et Informatique (GEI'2005), Sousse, Tunisia, Mar. 2005, pp. 56–61.

[19] T. R. Gruber, "Toward principles for the design of ontologies used for knowledge sharing?," *International Journal of Human-Computer Studies*, vol. 43, no. 5, pp. 907–928, Nov. 1995, https://doi.org/10.1006/ijhc.1995.1081.

[20] S. R. Mashwani and S. Khusro, "The Design and Development of a Semantic File System Ontology," *Engineering, Technology & Applied Science Research*, vol. 8, no. 2, pp. 2827–2833, Apr. 2018, https://doi.org/10.48084/etasr.1898.

[21] C. Roche, "Terminologie et ontologie," *Langages*, no. 157, pp. 48–62, 2005.

[22] N. F. Noy *et al.*, "Protégé-2000: an open-source ontology-development and knowledge-acquisition environment," *AMIA Annual Symposium Proceedings*, 2003.

[23] B. Heydari and M. Aajami, "Providing a New Model for Discovering Cloud Services Based on Ontology," *Engineering, Technology & Applied Science Research*, vol. 7, no. 6, pp. 2268–2272, Dec. 2017, https://doi.org/10.48084/etasr.1577.