SWM-PnR: Ontology-Based Context-Driven Knowledge Representation for IoT-Enabled Waste Management

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Abstract. Using knowledge-based and semantic technologies in IoT is a very active research and promising area. This paper proposes a method of ontology-based context-driven knowledge representation for IoT-enabled hard waste management as part of a wider international project that aims at building IoT ecosystems for smart cities. The paper presents the development of the waste management ontology, rules, and proposes a multistage data processing method that allows extracting knowledge about specific nontrivial situations on its basis. The paper describes implementation of the proposed system as a web application, where the content types are based on ontology, and data processing occurs according to the proposed algorithm. Benefits of the proposed knowledge-based system are discussed and demonstrated. The proposed approach will significantly improve monitoring and management of waste collection, route planning, and problem reporting.

Keywords: Waste management · Knowledge representation · Ontology · Situation awareness · Context awareness · Decision support

1 Introduction

By 2050 66% of all Earth population will live in urban environments according to estimates of scientists [1]. For this reason, the concept of Smart Cities is becoming a major area of research in developed and developing economies. A Smart City is a technology-driven paradigm that combines information technologies, communication technologies and the Internet of Things to manage the city infrastructure, data, and

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services. Smart Cities incorporates a large number of applications, such as intelligent energy management, intelligent transportation, smart waste management, traffic management, etc.

Efficient waste management is one of the most pressing economic and environmental problems and a significant challenge for any large city [2]. Solid Waste Management is a challenge, which requires a complex multi-criteria approach [3]. An important direction for a Smart City in this area is to provide information about the process of garbage collection. Urban services, various sensors and users of the system receive an enormous amount of heterogeneous data in different formats. Processing, presenting, obtaining information and recognizing specific situations is one of the most difficult problems in the field of Waste management in Smart Cities.

In this paper, we present the outcomes of our research which aims to develop an ontology-based adaptive context-driven knowledge representation and decision support in IoT-enabled waste management. We call this system SWM-PnR - Smart Waste Management Presentation and Recommendation. The proposed method of representing and processing knowledge using ontology makes it possible to extract knowledge from data, to display the current situation of the garbage collection on the City dashboard (map), to recognize non-trivial situations and make recommendations to dispatchers of the waste truck fleet. The paper also describes the application of the proposed method in the form of a web application, which is developed on the basis of our Waste Management Ontology.

The research described in the paper is carried out as a part of the bIoTope Project [4]. The bIoTope project builds open IoT ecosystems on the basis of innovative IoT technologies and use cases. The project is funded under the EU Horizon 2020 Program. The system described in this paper is part of St. Petersburg pilot of bIoTope project on smart waste management.

The rest of the paper is organized as follows. Section 2 includes Background and Related Work. Section 3 presents the conceptual architecture of SWM-PnR and the process of extracting knowledge from ingested data. Section 4 describes the development of the Waste Management Ontology. Section 5 provides several scenarios for the system operation and Semantic Web Rule Language (SWRL) rules for these scenarios. Section 6 presents evaluation results. Section 6 describes the implementation of the proposed method as a web application. Section 7 concludes the paper.

2 Background and Related Work

Context and Knowledge. Within the framework of our research, the context is understood as "any information that can be used to characterize situation of an entity" [5]. We define contextual information as the level of how full is the smart garbage bin (SGB), the fullness of SGB, the time of the last cleaning of SGB, type of garbage, weight of garbage, fullness of the waste truck, location of SGBs and waste trucks, etc. The quality of context depends on the quality of data and the amount of data preprocessing. Raw data is the lowest level of context. A context-aware system is a system, which "uses context to provide relevant information and/or services to the user, where relevancy depends on the user's task" [5]. We consider a situation as context abstraction and generalization. The situation-aware system is aimed at finding and highlighting situations from diverse contextual data of various formats. Context prediction provides a forecast of the future context information. Based on statistics, it is possible to suggest a possible course of events for situations that have repeatedly occurred in the past. This approach enables proactive system functionality [6].

Decision Making and Adaptive Systems. Decision making is based on logical inferences from sensor data and user input data processing, as well as statistics available in the system. Based on statistical data, a possible course of a situation that has repeatedly occurred in the past can be suggested. The results of each decision made by users of the system are entered into the knowledge base. This allows to offer users the best option for each repetition of a particular situation based on an analysis of the consequences of making different decisions in similar situations.

Ontologies. The ontology consists of a set of subject domain concepts with their attributes and relationships, limitations, and axioms. Using the ontological approach allows the most comprehensive and flexible description of the subject area. It also allows logical inferences, i.e. recognize facts/situations, not present literally, but provided by the basic semantics.

2.1 Related Work

The design of a waste management system for Smart Cities involves the use of a large amount of information from sensors, its processing, and analytics [7].

Recently, a number of decision support systems for waste management in Smart Cities have been proposed. In [8] authors propose a decision support system, which consists of a conceptual framework and the corresponding mathematical formulation, for optimum waste management solution based on a multi-objective dynamic logistics model. [9] proposes a method of Strategic Decision Support based on clusters of factors and a model with using these clusters as factors. [10] describes the development of a methodology for decision support based on analysis of appropriate metrics for a municipal solid waste management expenditure efficiency assessment using cost-effectiveness analysis.

An ontology-based approach has been attempted in the field of waste management. A model using OWL ontology to sort these smart waste items for better recycling of materials is demonstrated in [11]. A concept of intelligent decision making support in the field of waste management using knowledge-based approach is presented in [12].

3 SWM-PnR Conceptual Architecture

SWM-PnR is part of St. Petersburg pilot of bIoTope project. The Smart Waste Management system is developed in the framework of a St. Petersburg pilot project. Smart Waste Management system includes means for collecting and processing data from

SGB sensors and sensors installed on waste trucks, the model for IoT data sharing, security and privacy policies, and dynamic route optimization in real time. The functionality of SWM-PnR includes inferring knowledge from adjusted data and representing it according to the user's needs. Also, SWM-PnR is able to recognize non-trivial situations on the basis of internal relationships between data, display them with the help of a custom traffic interface and give hints to dispatchers. Figure 1 shows steps of obtaining and representing knowledge from raw data.

Data comes from the sensors installed on smart garbage bins (lid sensor, capacity sensor, gas sensor, GPS module, scales sensor, temperature sensor, battery charge

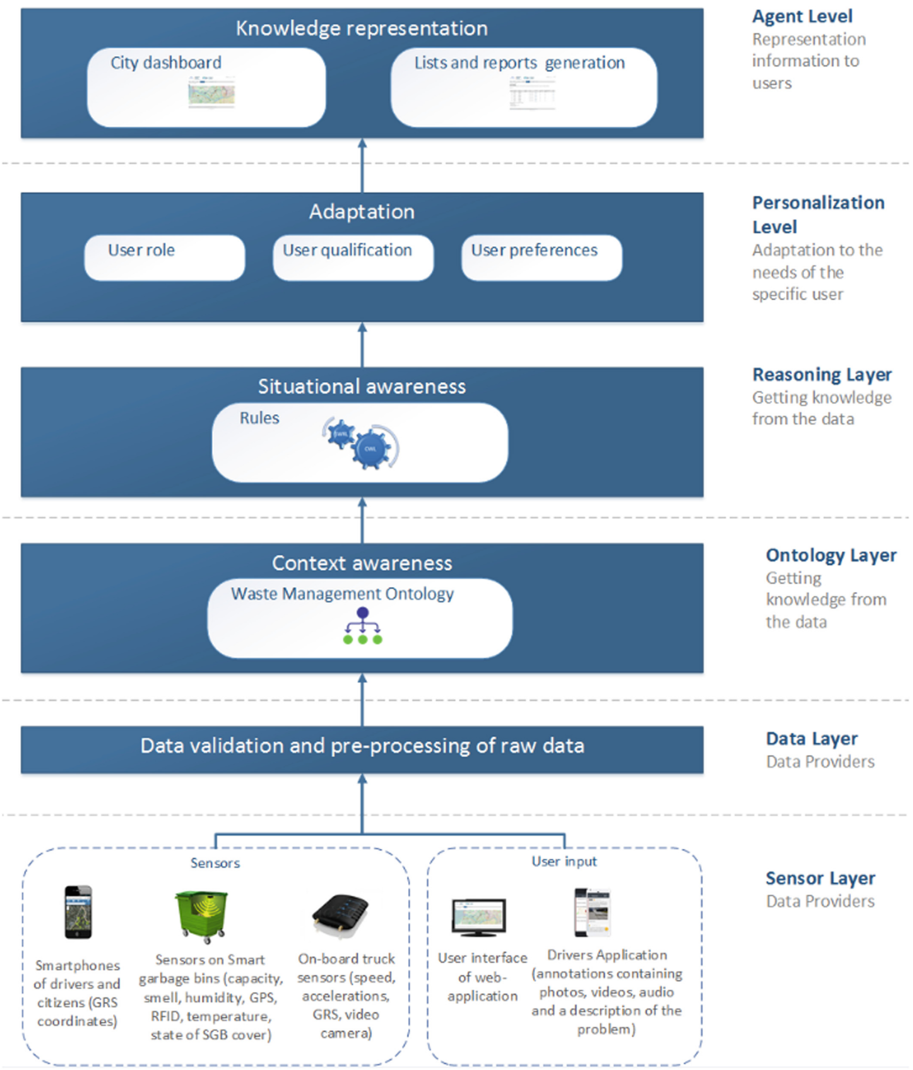

Fig. 1. Stages of receiving and representing knowledge

sensor), trucks (accelerometer, CAN bus, scales sensor, container capacity sensor, GPS module) and from user input, e.g., web application and in future mobile application for drivers [13]. The first stage is the verification and preprocessing of raw data. Then received data is transferred to the context awareness block, where the data is grouped according to the properties of ontology objects. In the Situation awareness block data is re-processed in accordance with the rules of ontology. This allows isolating specific situations and forecasts from the context. An adaptation unit allows SWM-PnR to adapt to the needs of the specific user. The information received is displayed to end users through the web application, consisting of City dashboard, means for asset management and means for generating reports.

The City dashboard is an interactive map showing SGBs, waste truck routes, and the movement of waste trucks along specified routes, waste dumps, and waste processing companies. The knowledge extracted from the data coming from sensors is displayed on the City dashboard in the form of an indication located above the objects on the map (trucks, SGBs, etc.) and in the form of tooltips for dispatchers. Full information on each of the objects on the map is available by clicking on this object. Statistics and history of each object can be viewed on the report generation page.

The proposed system can recognize the following situations and notify dispatchers about them:

- accidental or intentional damage of SGB sensor block;
- SGB sensor failure (with indicating the type of fault);
- low battery of sensor block;
- the need to change the route and schedule of the waste truck in connection with road works;
- the need to modify the route of the waste truck due to the inaccessibility of garbage containers in one of the districts. In this case corresponding city services are also informed.

4 Development of the Waste Management Ontology

We have developed the ontology-based on the analysis of business processes of garbage collection in St. Petersburg. We use the ontology language OWL [14] along with the development tool Protégé [15].

During the development the following challenges were overcome:

- the need to simultaneously analyze data from sensors on the basis of a developed ontology and visualize sensor data on the map;
- the need to provide users of the system with clear descriptions of system failures and malfunctioning.

To do this, the sensor data analysis uses data type properties of sensor classes (*battery_charge_sensor*, *capacity_sensor,* etc.). Information for users of SWM-PnR is provided using data type property *hasState* of the class *smart_garbage_bin*. Several possible values of the data type property *hasState* are shown in Fig. 2.

```
  <owl:DatatypeProperty rdf:ID="hasState">
    <rdfs:range>
      <owl:DataRange>
        <owl:oneOf rdf:parseType="Resource">
         <rdf:first
rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
>Missing sensor block</rdf:first>
         <rdf:first
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">
Low battery</rdf:first>
         <rdf:first
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">
No access</rdf:first>
         <rdf:first
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">
Capacity sensor failure</rdf:first>
          <rdf:first
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">
Gas sensor failure</rdf:first>
          <rdf:first
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">
Damage of SGB sensors block </rdf:first>
          <rdf:first
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">
Fullness 100% </rdf:first>
          <rdf:first
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">
Fullness 90% </rdf:first>
...
      </owl:DataRange>
    </rdfs:range>
    <rdfs:domain rdf:resource="#smart_garbage_bin"/>
  </owl:DatatypeProperty>
```

Fig. 2. Fragment of waste management ontology

Diagnostic information and the current state of garbage collection are visualized on the map using ontology data properties of SGB and waste trucks.

The structure of the Waste Management Ontology, its categories and generic items are represented in the Fig. 3. A more detailed structure with object and data type properties can be seen on our website [16].

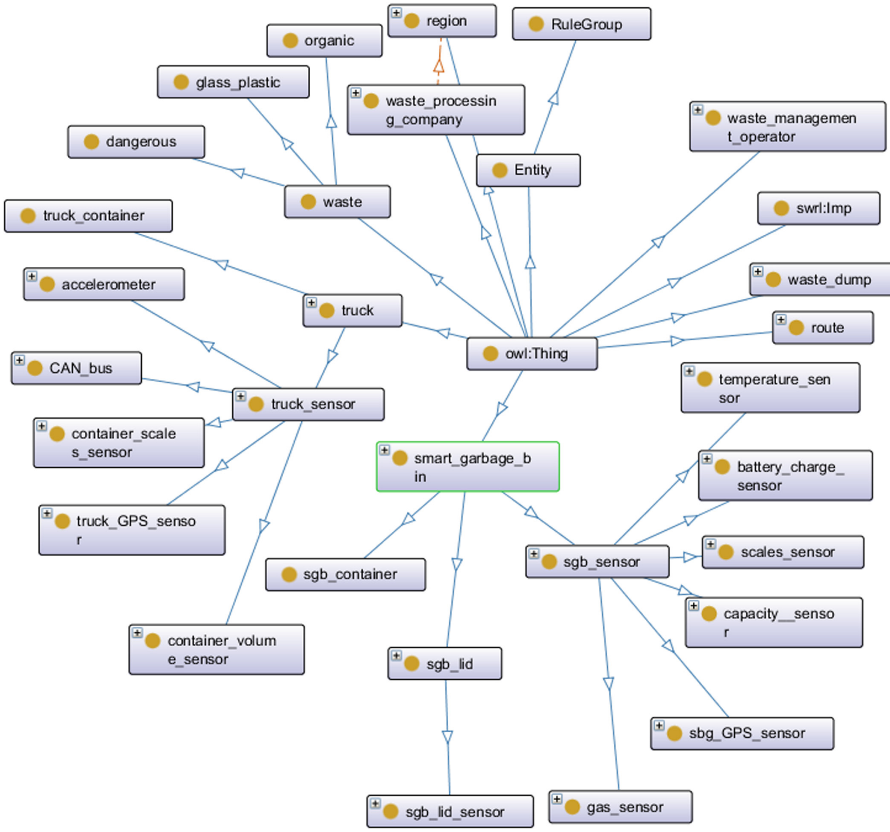

Fig. 3. Structure of waste management ontology: categories and generic items

5 Ontology Rules Composition

We investigated the process of garbage collection in St. Petersburg and identified the most common situations. In this section, we will demonstrate how the proposed method allows recognizing them. The rules for ontology were developed in the SWRL language [17]. Several scenarios and logical rules describing them are provided below. More complex scenarios have also been implemented, however due to space limitations aren't presented below.

Scenario 1: Accidental or intentional damage of SGB sensors block. The method is based on constant analysis and comparison of data from SGB sensors. If the SGB lid is open and SGB coordinates do not match the coordinates of the SGB container, the data from other sensors is analyzed. If the data does not arrive, the *hasState* datatype is assigned a value *Missing sensor block* and the notification is sent to the dispatcher.

```
smart_garbage_bin(?s) ∧ sgb_container(?c) ∧ sgb_lid(?l)
∧ is_part_of_sgb (?l, ?s) ∧ is_part_of_sgb (?c, ?s)
∧ isOpen(?l, 1) ∧ hasVolume(?c, 0) ∧ hasCapacity
(?c, 0) ∧ hasCoordinates(?s, ?s_coord) ∧ hasCoordi-
nates(?c, ?c_coord) ∧ swrlb:notEqual(?c_coord,
?s_coord) → hasState (?s, "Damage of SGB sensors
block")
```

Scenario 2: SGB sensors failure. The method is based on constant analysis of data from SGB sensors for indicating the type of fault.

```
smart_garbage_bin(?s) ∧ capacity_sensor(?f) ∧
sgb_container(?c) ∧ hasVolume(?c, 0) ∧ hasCapacity (?f,
100) → hasState(?s, "Volume sensor failure ")
```

Scenario 3: Low battery. If battery of the sensor unit is discharged, it is necessary to transmit the warning to the dispatcher and display the problem on the City Dashboard.

```
smart_garbage_bin(?s) ∧ battery_charge_sensor(?b) ∧
hasBatteryCharge(?b, 0) → hasState(?s, "Low battery")
```

6 Implementation of a Web Application

In order to show the work of the proposed method in real conditions, we developed a web application in CMS Plone. Context types are based on ontology concepts, and the rules are implemented as external python scripts. Plone is a content management system based on the Zope application server and Zope built-in transactional object database (ZODB). To create maps in the application, we used Collective Geo add-on [18] and OpenStreetMap [19]. CMS Plone and ZODB are used for developing web applications in St. Petersburg pilot of bIoTope project on smart waste management. Thus, the web application described in this section can effectively interact with other components of the system in near real-time mode. The use of RDF based database is planned at the next stages of work on the project.

To make Plone content based on our ontology, we used the method described in [20]. After creating an ontology, we converted it into an UML class project. For making the described method functional, it was required to convert it in ZUML and then back to XML, so that it can be compatible with Plone. Next, in accordance with the method described in [20], we used ArchgenXML to add on our developed Plone Product in CMS Plone. The architecture of the developed web application is shown in Fig. 4.

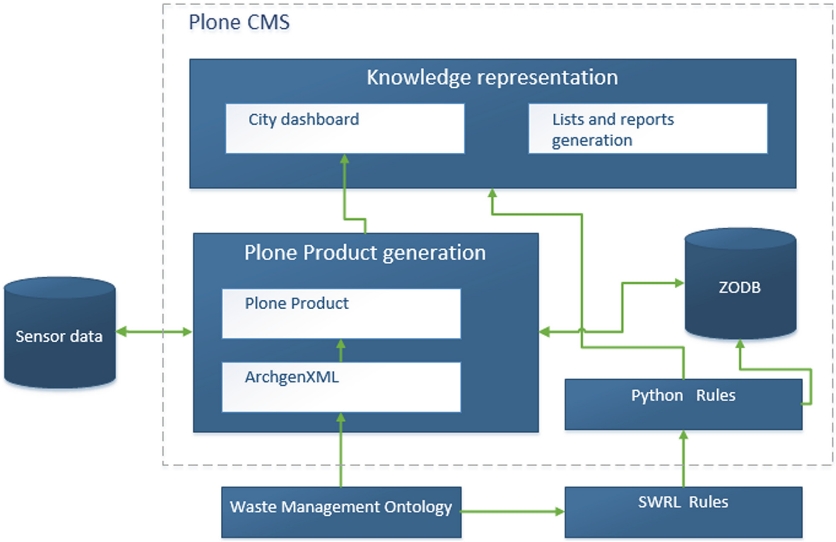

Fig. 4. Web application architecture

The developed application supports three modes of operation (3 user roles): dispatchers of waste collection companies, citizens, and city administration. For different participants in the waste collection process, different information is necessary. For citizens, the application provides information about the nearest separate waste collection points, and information about the cost of garbage disposal and rewards. Dispatchers can monitor the current state of the waste collection process, the routes of waste trucks, reports of malfunctions and problems. The city administration is able to generate reports for understanding of the big picture in the area of waste management and control pricing.

Waste collection is visualized through a City Dashboard. City Dashboard is available to all user roles. Objects on the map are "instances of the class" of the Waste Management Ontology: regions, routes, smart garbage bins, trucks, waste dumps, waste processing companies (Fig. 5).

Each SGB is equipped with the following indication: how full is an SGB, the need to immediately collect the waste, low battery, sensor failure, etc. Each waste truck has the following indication: how full is a container, the condition of the sensors (accelerometer, CAN bus, scales sensor, container volume, GPS), deviation from the route, accident, message from the driver. By clicking on the objects on the map in the pop-up, a user can see more detailed information. Transition to reports and statistics on the project is carried out by clicking on the link at the bottom of the pop-up (Fig. 6).

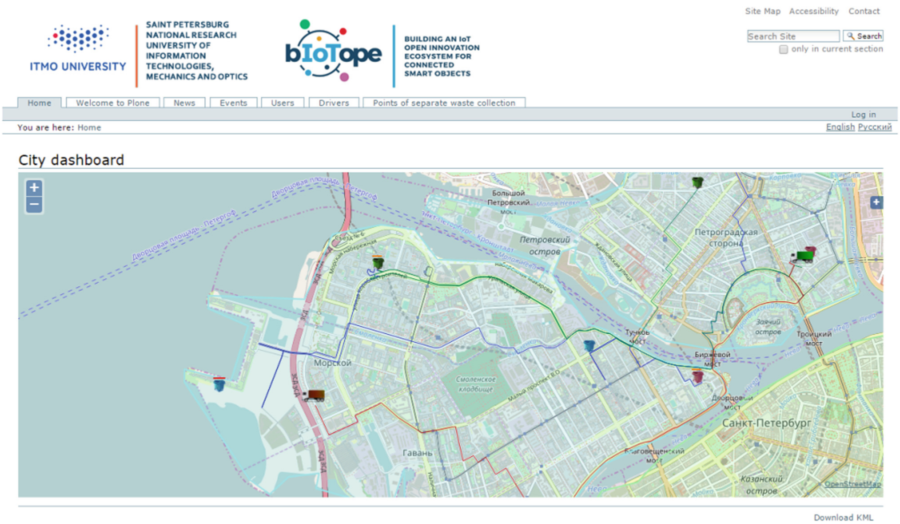

Fig. 5. City dashboard, dispatcher interface

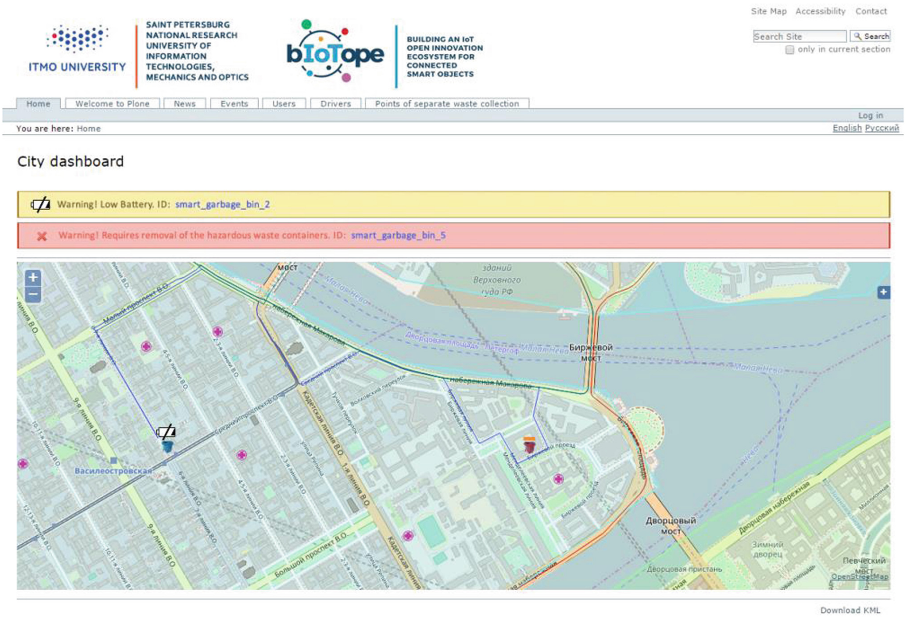

Fig. 6. City dashboard, 2 warnings for dispatcher

7 Conclusion

We investigated the waste collection process in St. Petersburg and proposed a multi-criteria approach to its visualization and decision support for multiple roles including dispatchers, citizens and city administration. The proposed approach will significantly improve various indicators: monitoring and management of waste collection, route planning, and problem reporting. The developed method allows the following:

- extract knowledge from data;
- display the current situation of the garbage collection on the City dashboard;
- recognize non-trivial situations;
- make recommendations to dispatchers of the waste truck fleet.

In future work, we will refine the developed method by including larger number of nontrivial situations and an extension of the ontology. It is also planned to integrate SWM-PnR with other components of St. Petersburg pilot of bIoTope project, such as mobile applications for drivers and citizens. This will allow SWM-PnR to use voice, photo and video data to support decision-making process [21].

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References

1. United Nations Department of Economic and Social Affairs, World Urbanization Prospects Webpage. https://esa.un.org/unpd/wup/publications/files/wup2014-highlights.Pdf. Accessed 3 May 2017
2. Sakai, S., Yoshida, H., Hirai, Y., et al.: International comparative study of 3R and waste management policy developments. J. Mater. Cycles Waste Manag. **13**, 86 (2011). doi:10.1007/s10163-011-0009-x
3. Anagnostopoulos, T., Zaslavsky, A., Kolomvatsos, K., Medvedev, A., Amirian, P., Morley, J., Hadjiefthymiades, S.: Challenges and opportunities of waste management in IoT-enabled smart cities: a survey. In: IEEE Transactions on Sustainable Computing, vol. PP, no. 99, p. 1 (2017)
4. The bIoTope Project Webpage. http://www.biotope-project.eu/. Accessed 3 May 2017
5. Dey, A.K., Abowd, G.D.: Towards a better understanding of context and context-awareness. Comput. Syst. **40**(3), 304–307 (1999)
6. Anagnostopoulos, C., Mpougiouris, P., Hadjiefthymiades, S.: Prediction intelligence in context-aware applications. In: Proceedings of the 6th International Conference on Mobile Data Management, pp. 137–141 (2005)

7. Arebey, M., Hannan, M.A., Basri, H., Abdullah, H.: Solid waste monitoring and management using RFID, GIS and GSM. In: 2009 IEEE Student Conference on Research and Development (SCOReD), UPM Serdang, pp. 37–40 (2009). (Longhi, S., et al.: Solid waste management architecture using wireless sensor network technology. In: 2012 5th International Conference on New Technologies, Mobility and Security (NTMS), Istanbul, pp. 1–5 (2012))
8. Yu, H., Solvang, W.D., Yuan, S.: A multi-objective decision support system for simulation and optimization of municipal solid waste management system. In: 2012 IEEE 3rd International Conference on Cognitive Infocommunications (CogInfoCom), Kosice, Slovakia, pp. 193–199 (2012)
9. Hatwágner, M.F., Buruzs, A., Földesi, P., Kóczy, L.T.: Strategic decision support in waste management systems by state reduction in FCM models. In: Loo, C.K., Yap, K.S., Wong, K. W., Beng Jin, A.T., Huang, K. (eds.) ICONIP 2014. LNCS, vol. 8836, pp. 447–457. Springer, Cham (2014). doi:10.1007/978-3-319-12643-2_55
10. Soukopová, J., Malý, I., Hřebíček, J., Struk, M.: Decision support of waste management expenditures efficiency assessment. In: Hřebíček, J., Schimak, G., Kubásek, M., Rizzoli, Andrea E. (eds.) ISESS 2013. IAICT, vol. 413, pp. 651–660. Springer, Heidelberg (2013). doi:10.1007/978-3-642-41151-9_61
11. Sinha, A., Couderc, P.: Using OWL ontologies for selective waste sorting and recycling. In: OWLED-2012, Heraklion, Crete, Greece, May 2012
12. Kultsova, M., Rudnev, R., Anikin, A., Zhukova, I.: An ontology-based approach to intelligent support of decision making in waste management. In: 2016 7th International Conference on Information, Intelligence, Systems & Applications (IISA), Chalkidiki, pp. 1–6 (2016)
13. Sosunova, I., Zaslavsky, A., Anagnostopoulos, T., Medvedev, A., Khoruzhnikov, S., Grudinin, V.: Ontology-based voice annotation of data streams in vehicles. In: Balandin, S., Andreev, S., Koucheryavy, Y. (eds.) ruSMART 2015. LNCS, vol. 9247, pp. 152–162. Springer, Cham (2015). doi:10.1007/978-3-319-23126-6_14
14. W3C OWL Webpage. https://www.w3.org/OWL/. Accessed 3 May 2017
15. Protege Webpage. http://protege.stanford.edu/. Accessed 3 May 2017
16. Github ITMO-SWM (St. Petersburg pilot of bIoTope project) Webpage. https://raw.githubusercontent.com/itmo-swm/Plone/master/Ontology/SWM-PnR%20Waste%20collection%20ontology.png. Accessed 31 May 2017
17. SWRL Webpage. https://www.w3.org/Submission/SWRL/. Accessed 3 May 2017
18. Collective Geo Webpage. https://github.com/collective/collective.geo.behaviour. Accessed 3 May 2017
19. OpenStreetMap Webpage. https://www.openstreetmap.org/#map=5/51.500/-0.100. Accessed 3 May 2017
20. Martins, C.T., Azevedo, A., Pinto, H.S., Oliveira, E.: Towards an ontology mapping process for business process composition. In: Azevedo, A. (ed.) BASYS 2008. ITIFIP, vol. 266, pp. 169–176. Springer, Boston, MA (2008). doi:10.1007/978-0-387-09492-2_18
21. Medvedev, A., Zaslavsky, A., Khoruzhnikov, S., Grudinin, V.: Reporting road problems in smart cities using OpenIoT framework. In: Podnar Žarko, I., Pripužić, K., Serrano, M. (eds.) Interoperability and Open-Source Solutions for the Internet of Things. LNCS, vol. 9001, pp. 169–182. Springer, Cham (2015). doi:10.1007/978-3-319-16546-2_13