22-osios Lietuvos jaunųjų mokslininkų konferencijos „Mokslas – Lietuvos ateitis“ teminė konferencija
Proceedings of the 22th Conference for Junior Researchers „Science – Future of Lithuania“

APLINKOS APSAUGOS INŽINERIJA / ENVIRONMENTAL PROTECTION ENGINEERING

ISSN 2029-7157 / eISSN 2029-7149
2019 m. kovo 20 d., Vilnius
ISBN 978-609-476-211-6 / eISBN 978-609-476-209-3
20 March 2019, Vilnius, Lithuania
https://doi.org/10.3846/aainz.2019.006

http://jmk.aainz.vgtu.lt

FILLING LEVEL MEASUREMENTS OF MIXED WASTE BINS USING LOW POWER IOT SENSORS AND LORA WAN TECHNOLOGY

Nino Inasaridze[1], Vaidotas Vaišis[2]

Department of Environmental Protection and Water Engineering
E-mails: [1]nino.inasaridze@stud.vgtu.lt; [2]vaidotas.vaisis@vgtu.lt

Abstract. The article deals with sensor-related solutions to improve waste collection and monitoring in public waste bins. Availability of use of an inexpensive monitoring system for measurement process was tested. The system consists of wireless nodes that use ultrasonic sensors to measure the empty space in the waste bins. A sensor gateway based on Long Rage Wide Area Network (LoRaWAN) protocol was used. Purpose of this work was to describe the new sensor node typology based on low-power and low-cost components. The article analyses the architecture of nodes in detail, focusing on energy-efficient technologies and policies to extend battery life by reducing energy consumption through hardware and software optimization. Measurements were performed at five points in two size of containers with different two levels of filling and mixed type of waste. The results show that existing technologies are mature enough to create and deploy inexpensive additional sensors for outbound bins and that such a system can provide the necessary insights on how to optimize waste collection processes and avoid overflowing containers.

Keywords: ultrasonic sensor, mixed municipal waste, smart waste management, LoRa WAN.

Introduction

The problem of waste pollution in the 21st century is one of the most important things that people are concerned with. Cities all around the world are facing major challenges because of rapidly increasing urbanization, therefore one of the main challenges is the rising amount of generated waste and littering due to high demand for food, manufactured products, materials increases, and other needs. Public waste containers are filling up faster than ever and many of the containers end up overflowing before collected, the result is not only littered streets and unpleasant odours, but also negative effects on health and the environment. Although not as lethally risky as the dumping tons of toxic industrial waste around city borders, overflowing waste containers are still very unpleasant and dangerous to our environment and our health (Silva, Khan, & Han, 2018).

For example, outcomes of overflowing garbage bins, can be such:

- Insects, bacteria, and vermin from garbage;
- Overflowing waste causes respiratory diseases and air pollution;
- Garbage contaminates surface waters, which affects all ecosystems;
- Direct handling of overflowing waste exposes health risks.

Nowadays, cities increasingly are implementing new systems based on the Internet of Things (IoT) to collect and analyze new data information about the cities, also offer new services which are important to optimize the energetic efficiency (Silva et al., 2018). Waste management in cities using LoRaWAN technology and low power IoT sensor node design is a quite actual and modern decision, which is a new trend all over the world and is not tried in many various kinds of environmental fields. Moreover, using LoRaWAN technology and low power IoT sensor node is easier way to solve environmental problems compare to another “older” technologies, for example, the use of LoRa technology saves more energy, has long battery life (up to 10 year), covers large distances (up to 15 km) and etc. (Augustin, Yi, Clausen, & Townsley, 2016; Cerchecci et al., 2018; Zanella, Bui, & Castellani, (2014). This article deals with a wireless sensor network (WSN) solution to face the solid waste monitoring by using innovative IoT node architecture, so as to monitor the filling of paper waste bins.

Methodology

Measurements were performed at five points in two size of containers with two levels of filling and mixed municipal type of waste, with an ultrasonic Sensor HY-SRF05. All measurements are repeated three times. The duration of the experiment is from 23 January to 4 February 2019 year, in Vilnius city. During the experiment the average rate of temperature was, from –5 °C – to 10 °C.

For the experiment we selected two types of municipal waste containers produced by CONTENUR (CONTENUR, n.d.).

Rear loading container C1100 F – Height 1 m(A) (Figure 1).

Rear loading containers C90 – Height 1 m (B) (Figure 2)

Figure 1. Rear loading container 1100 F (A) (CONTENUR, n.d.)

Figure 2. Rear loading container C90 (B) (CONTENUR, n.d.)

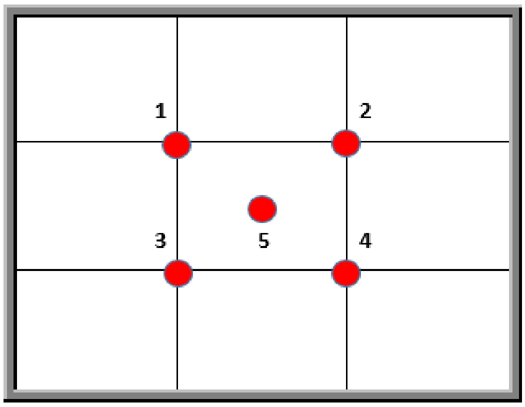

Figure 3. Measurements were performed at five points in the waste bin

Measurement with an Ultrasonic Sensor HY-SRF05

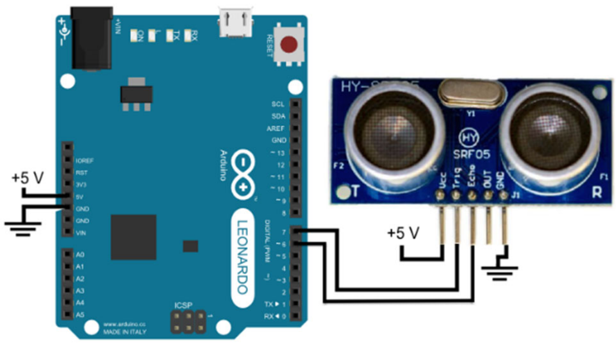

Figure 4. Scheme of Ultrasonic Sensor HY-SRF05

An ultrasonic sensor is a device capable of measuring the distance to an object using sound waves. It measures the distance by sending a sound wave at a certain frequency and receiving it back (Osoyoo, n.d.). By recording the elapsed time between the sound wave being generated and the sound wave bouncing back, it is possible to calculate the distance between the sonar sensor and the object. It can work from 2 cm to 3 m. A new operating mode allows the SRF04 to use a single pin for both trigger and echo, thereby saving valuable pins on the controller. Ultrasonic measurements work in any lighting condition. Five pin header (2.54 mm spacing) makes it easy to connect to a development board, directly or with an extension cable, no soldering required. It also has a narrow acceptance angle (Osoyoo, n.d.).

These sensors are compliant with all the previous requirements:

– They do not measure the weight of the trash but, if placed in the internal upper surface of the bin, they measure the actual level of the garbage layer by calculating its distance from the top of the bin;

- They are immune to fouling since ultrasounds are not perturbed by the presence of dirt or dust on the sensor surface (Osoyoo, n.d.);
- Since they detect the actual volume occupied by trash, they measure the filling level regardless of the number of introduced items;
- They have very limited costs (under 2–3 euros) (Osoyoo, n.d.; Jin, Gubbi, Marusic, & Palaniswami, 2014).

Figure 5. IoT sensor node and LoRa Transmission Module (The photo was taken during the experiment)

In the Figure 5 is IoT sensor node and LoRa Transmission Module, which is made at Vilnius Gediminas technical university. A low-cost and low-power sensor was chosen to ensure the best ratio between measurement accuracy and energy efficiency.

Research object

The research object is a node equipped with a single-chip microcontroller, a sensor capable of measuring the filling level of the rubbish bins using ultrasound and a data transmission module based on the LoRa LPWAN technology (Low Pow-er Wide Area Network). Together with the node, a minimal network architecture was designed, based on a LoRa gateway, to test the performance of the IoT node. In particular, the important topic is to analyse in detail the architecture of the node, focusing on energy saving technologies and policies, to extend the life of the batteries by reducing energy consumption, through the optimization of hardware and software.

Research results

First measurement of Rear loading container 1100 F (A). We have measured two levels (Test I and Test II) of mixed waste surfaces. Results are shown on the Table 1 and Table 2.

Measurement data:

- **Measured value** – Measurement with Ultrasonic Sensor;
- **Actual value –** Real measurement with ruler;
- **Empty level value –** Empty space in the waste bin;
- **Filled level value –** Full space in the waste bin.

In the Figure 6 and Figure 7 are shown dependence between measured and actual values, according to the first and second measurements of filling levels in the municipal mixed waste container A (big size).

Second measurement of Rear loading container C90 (B). We have measured two levels (Test I and Test II) of mixed waste surfaces. Results are shown on the Table 3 and Table 4.

Table 1. Mixed municipal waste; Container A, Test I

Mixed municipal waste	**Measured value / (*Empty level value*)**				**Actual value** (*Empty level value*)	**Measured value** (*Filled level value*)	**Actual value** (*Filled level value*)
Points	Test1 (mm)	Test2 (mm)	Test3 (mm)	Average of tests (cm) (–2.5 cm)*	Test I (cm)	Test I (cm)	Test I (cm)
1	918	928	800	85.70	83.00	14.30	17.00
2	766	887	800	79.27	78.00	20.73	22.00
3	783	775	804	76.23	79.00	23.77	21.00
4	840	836	844	81.50	79.00	18.50	21.00
5	821	813	818	79.23	81.00	20.77	19.00
Average value ⟶				**80.39**	**80.00**	**19.61**	**20.00**

(–2.5 cm)*– Height of additional horizontal pillar, which was used during experiment.

Table 2. Mixed municipal waste; Container A, Test II

Mixed municipal waste	**Measured value / (*Empty level value*)**				**Actual value (*Empty level value*)**	**Measured value** (*Filled level value*)	**Actual value** (*Filled level value*)
Points	Test1 (mm)	Test2 (mm)	Test3 (mm)	Average of tests (cm) (–2.5 cm)*	Test II (cm)	Test II (cm)	Test II (cm)
1	409	400	413	38.23	36.00	61.77	64.0
2	356	370	340	33.03	34.00	66.97	66.0
3	270	300	287	26.07	30.00	73.93	70.0
4	371	360	398	35.13	32.00	64.87	68.0
5	366	382	361	34.47	31.00	65.53	69.0
Average value ⟶				**33.39**	**32.60**	**66.61**	**67.4**

(–2.5 cm)*– Height of additional horizontal pillar, which was used during experiment.

Table 3. Mixed municipal waste; Container B, Test I

Mixed municipal waste	**Measured value / (*Empty level value*)**				**Actual value (*Empty level value*)**	**Measured value** (*Filled level value*)	**Actual value** (*Filled level value*)
Points	Test1 (mm)	Test2 (mm)	Test3 (mm)	Average of tests (cm) (–2.5 cm)*	Test I (cm)	Test I (cm)	Test I (cm)
1	900	905	902	87.73	88.00	12.27	12.00
2	850	852	850	82.57	84.00	17.43	16.00
3	910	905	908	88.27	89.00	11.73	11.00
4	899	902	903	87.63	86.00	12.37	14.00
5	895	897	894	87.03	88.00	12.97	12.00
Average value ⟶				**86.65**	**87.00**	**13.35**	**13**

(–2.5 cm)*– Height of additional horizontal pillar, which was used during experiment.

Table 4. Mixed municipal waste; Container B, Test II

Mixed municipal waste	**Measured value / (*Empty level value*)**				**Actual value (*Empty level value*)**	**Measured value** (*Filled level value*)	**Actual value** (*Filled level value*)
Points	Test1 (mm)	Test2 (mm)	Test3 (mm)	Average of tests (cm) (–2.5 cm)*	Test II (cm)	Test II (cm)	Test II (cm)
1	400	400	402	37.57	37.00	62.43	63.0
2	410	405	403	38.10	38.00	61.90	62.0
3	372	370	371	34.60	34.00	65.40	66.0
4	371	369	373	34.60	34.00	65.40	66.0
5	399	400	398	37.40	37.00	62.60	63.0
Average value ⟶				**36.45**	**36.00**	**63.55**	**64.0**

(–2.5 cm)*– Height of additional horizontal pillar, which was used during experiment.

In the Figure 8 and Figure 9 are shown dependence between measured and actual values, according to the first and second measurements of filling levels in the municipal mixed waste container B (small size)

Result analysis

Results are evaluated according to the:

- Correlation coefficient;
- Absolute Error;
- Percentage Error.

Correlation coefficient

Analysing results we used correlation coefficient formulas to find how strong is a relationship between data. The formulas return a value between –1 and 1, where:

- 1 indicates a strong positive relationship.
- –1 indicates a strong negative relationship.
- a result of zero indicates no relationship at all.

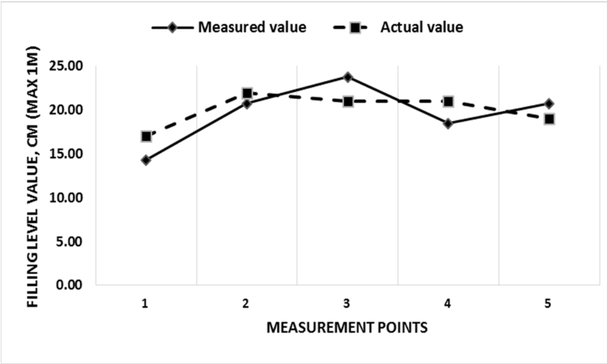

Figure 6. Dependence between measured and actual values, Container A, Test I

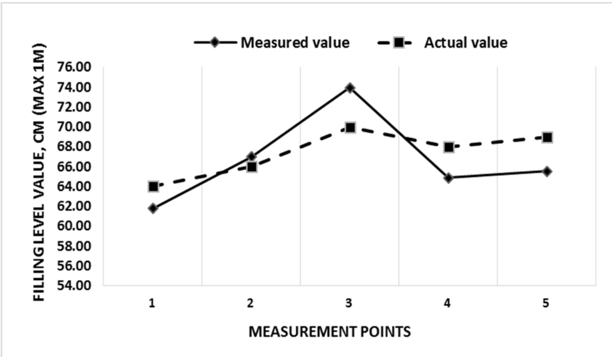

Figure 7. Dependence between measured and actual values, Container A, Test II

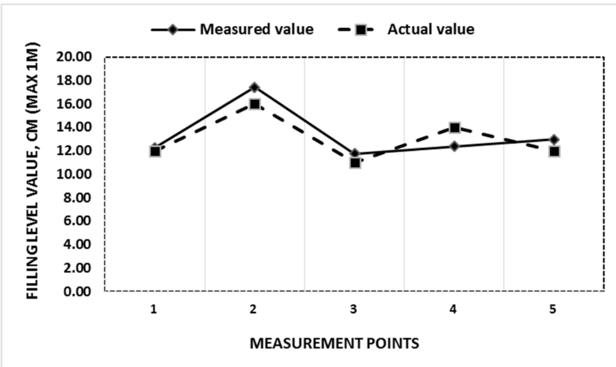

Figure 8. Dependence between measured and actual values, Container B, Test I

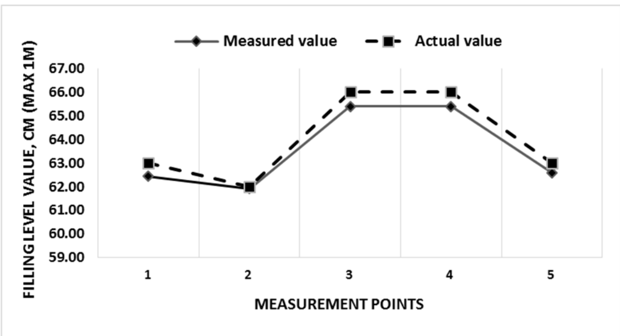

Figure 9. Dependence between measured and actual values, Container B, Test II

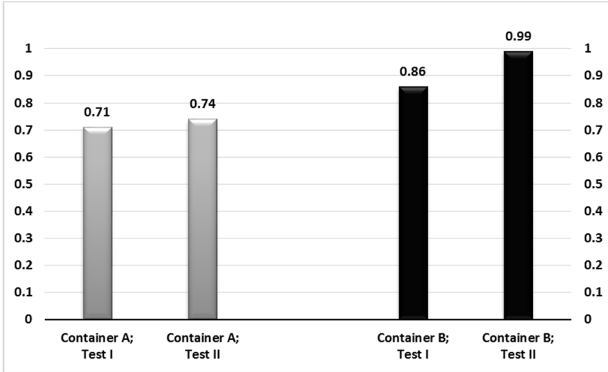

Figure 10. Comparison of correlation coefficient between measured and actual values of all containers

According to following comparison of correlation coefficient, it can be said, that results are significantly good, because most of results are quite close to value **0.99**.

In the Figure 10, it is clear, that the highest value of correlation coefficient has "Container B, test II"; The lowest value has: "Container A, Test I" – **0.71**.

Therefore, we can conclude that correlation coefficient and the ultrasonic sensor measurement is very good, in case of small size (B) container when filling level is about 60–65%.

Absolute Error

Analysing results we used absolute error value. The absolute error value is a difference between the measured value of a quantity $\mathbf{V_A}$ and its actual value $\mathbf{V_E}$:

$$\textit{Absolute Error} = \left| V_A - V_E \right|.$$

The absolute error of the sum or difference of a number of quantities is less than or equal to the sum of their absolute errors.

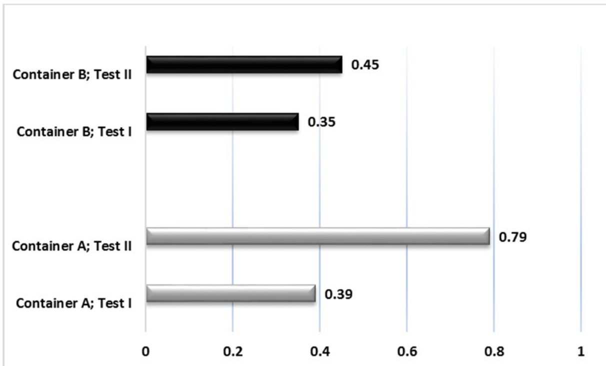

Figure 11. Comparison of absolute error between measured and actual values of all containers

According to following comparison of absolute error it can be said, that results are very good, because most of results are quite small.

On the Figure 11, it is clear, that the lowest value – **0.35** of absolute error has "Container B, test I"; The highest value has: "Container A, Test II" – **0.79**.

Percentage Error

When we calculate results that are aiming for known values, the percent error formula is useful tool for determining the precision of your calculations. The formula is given by:

$$\textbf{Percentage error} = \left|\frac{VA - VE}{VE}\right| \times 100\%,$$

V_A – measured value

V_E – actual value

When percentage error very close to zero means that we are very close to our targeted value, which is very good.

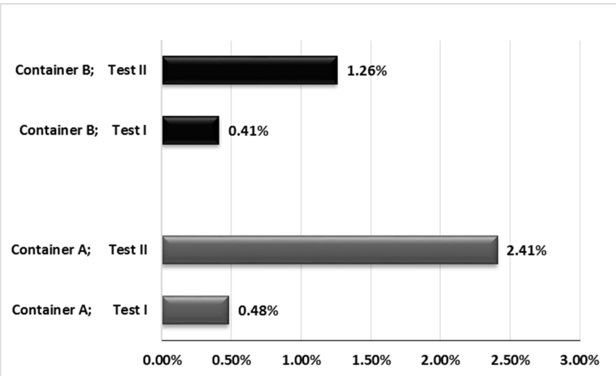

Figure 12. Comparison of percentage error between measured and actual values of all containers

According to following comparison of percentage error it can be said, that results are very good, because most of results are quite low. For example: The lowest percentage error value is – **0.41%**, in case of "Container B, test I". The highest value has: "Container A, Test II" – **2.41%.**

Conclusions

Result showed that, mentioned sensor measures the level of waste significantly good. And according to those results we can recommend this sensor on the smart waste management market. Based on mentioned research, sensor measures mixed municipal waste and big small size waste bin (B) very well, but mixed municipal waste big size (B) containers – a little worse.

1. According to the following comparison of correlation coefficient, it can be said, that results are significantly good because most of results are quite close to value 0.99. The highest value of correlation the coefficient has "Container B, test II"; The lowest value has: "Container A; Test I" – 0.71. Therefore, we can conclude that correlation coefficient and the ultrasonic sensor measurement is very good, in the case of small size (B) container when the filling level is about 60–65%.
2. According to the following comparison of absolute error it can be said, that results are very good because most of the results are quite small. The lowest value – 0.35 of absolute error has "Container B, test I"; The highest-value has: "Container A; Test II" – 0.79.
3. According to the following comparison of percentage error it can be said, that results are very good, because most of the results are quite low. For example, the lowest percentage error, value is 0.41%, in the case of "Container B, test I". The highest value has: "Container A, Test II" – 2.41%.

It should be noted that, when the wave angle is a big then we get more accurate data and when the wave angle is small, data is less accurate.

Regarding the network architecture, based on the LPWAN LoRa technology, that determined to provide the best trade-off in terms of power consumption and performances. In particular, LoRa modules turn out to be energy efficient, with reduced consumption in transmission if compared to similar technologies: LoRa modules current absorption in the transmission is around 20 mA while, for example, off-the-shelf ZigBee radio modules, such as XBee Series 2 absorb, according to the datasheet, approximately 40 mA. They are described by wide area transmission ranges that allow to set up urban area networks by using a single or few access points. While these networks are based on star topologies, they allow applying strict duty-cycling policies to the sensor nodes with an additional, important reduction on power consumption. The data transmission ranges and the effective probability of a single gateway, along with a city scale network were confirmed by the tests carried out: (Cerchecci et al., 2018) their researched tests showed that a 1.1 km transmission range is achievable in urban areas even without line-of-sight, while if ensuring line-of-sight, this value could grow up ~3 km.

Together with the extended lifetime, the proposed sensor node is also characterised by reduced costs. The main components (microcontroller, counter, sensor, voltage regulators), excluding the LoRa module account for around 10 euros. The LoRa module used for this prototype has currently high costs (about 40 euros), but cheaper alternatives can be found and are emerging day-by-day (Cerchecci et al., 2018). Future work will be carried out in this direction, to identify cheaper alternatives providing a similar performance level.

References

Augustin, A., Yi, J., Clausen, T., & Townsley, W. M. (2016). A study of LoRa: Long range & low power networks for the internet of things. *Sensors*, *16*(9), 1466. https://doi.org/10.3390/s16091466

Cerchecci, M., Luti, F., Mecocci, A., Parrino, S., Peruzzi, G. & Pozzebon, A. (2018). Low power IoT sensor node architecture for waste management within smart cities context. *Sensors*, 18(4), 1282. https://doi.org/10.3390/s18041282

CONTENUR. (n.d.). Retrieved from https://www.contenur.com/en/products/containers/rear-loading/

Jin, J., Gubbi, J., Marusic, S., & Palaniswami, M. (2014). An information framework for creating a smart city through internet of things. *IEEE Internet of Things Journal*, *1*(2), 112-121. https://doi.org/10.1109/JIOT.2013.2296516

Osoyoo. (n.d.). *Arduino lesson – Ultrasonic Sensor HC-SR04 Module*. Retrieved from http://osoyoo.com/2018/08/arduino-lesson-ultrasonic-sensor-hc-sr04-module/

Silva, B. N., Khan, M., & Han, K. (2018). Towards sustainable smart cities: A review of trends, architectures, components, and open challenges in smart cities. *Sustainable Cities and Society*, *38*, 697-713. https://doi.org/10.1016/j.scs.2018.01.053

Zanella, A., Bui, N., & Castellani, A. (2014). Internet of things for smart cities. *IEEE Internet Things*, *1*(1), 22-32. https://doi.org/10.1109/JIOT.2014.2306328

MIŠRIŲ ATLIEKŲ ŠIUKŠLIADĖŽIŲ UŽPILDYMO LYGIO MATAVIMAI NAUDOJANT MAŽO GALINGUMO DAIKTŲ INTERNETO JUTIKLIUS IR LORAWAN TECHNOLOGIJA

N. Inasaridze, V. Vaišis

Santrauka

Straipsnyje kalbama apie jutikliais paremtus sprendimus, siekiant patobulinti atliekų surinkimą ir stebėseną viešuose atliekų konteineriuose. Buvo išbandyta nebrangi stebėjimo sistema. Sistema susideda iš belaidžių mazgų, kurie naudoja ultragarsinius jutiklius, išmatuojančius atliekų konteinerių užpildymo lygį. Panaudotas siustuvas, paremtas „Ilgo nuotolio plačios erdvės tinklo“ (LoRaWAN) protokolu. Šio darbo tikslas buvo apibūdinti naują jutiklio mazgo tipologiją, paremtą maža galia ir kaina. Straipsnyje analizuojama mazgų sudėtis, dėmesį sutelkiant į efektyviai energiją naudojančias technologijas, siekiant išplėsti baterijos veikimo laiką, mažinant energijos suvartojimą, optimizuojant techninę bei programinę įrangą. Matavimai buvo atlikti penkiuose dviejų dydžių konteinerių taškuose, kurie buvo užpildyti mišriomis atliekomis ir dviem skirtingais atliekų užpildymo lygiais. Rezultatai rodo, kad jau egzistuojančios technologijos yra pakankamai išvystytos, įdiegimui nebrangių papildomų jutiklių konteineriuose. Tokia sistema gali suteikti būtinų įžvalgų, kaip optimizuoti atliekų surinkimo procesus, išvengiant konteinerių perpildymo.

Raktiniai žodžiai: ultragarsinis jutiklis, mišrios komunalinės atliekos, sumanus atliekų valdymas, LoRa WAN.