

Node Assembly for Waste Level Measurement: Embrace the Smart City

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Abstract. Municipal Solid Waste Management Systems (MSWMS) worldwide are currently facing pressure due to the rapid growth of the population in cities. One of the biggest challenges in this system is the inefficient expenditure of time and fuel in waste collection. In this regard, cities/municipalities in charge of MSWMS could take advantage of information and communication technologies to improve the overall quality of their infrastructure. One particular strategy that has been explored and is showing interesting results is using a Wireless Sensors Network (WSN) to monitor waste levels in real-time and help decision-making regarding the need for collection. The WSN is equipped with sensing devices that should be carefully chosen considering the real scenario in which they will work. Therefore, in this work, three sets of sensors were studied to evaluate which is the best to be used in the future WSN assembled in Bragança, Portugal. Sets tested were HC-SR04 (S1), HC-SR04 + DHT11 (S2), and US-100 (S3). Tests considered for this work were air temperature and several distances. In the first, the performance of each set to measure a fixed target (metal and plastic box) was evaluated under different temperatures (1.7 - 37 °C). From these results, two best sets were further used to assess distance measurement at a fixed temperature. This test revealed low absolute errors measuring the distances of interest in this work, ranging from 0.18% to 1.27%.

Keywords: Smart City · Waste management · Ultrasonic sensor · Wireless Sensors Network.

1 Introduction

Within the emergence of the 21st century, Information and Communication Technologies (ICT) became a tool that can help modern society to achieve sustainable living spaces [1]. Such tool plays an important role in the measurement, storage, and processing of data from systems to improve services, life quality, and profits (in companies) [2]. One of the driving agents for the required paradigm shift on how our data are treated is the growing population in cities, that demands smarter solutions to provide well-being for citizens [3]. In this regard, the integration of innovative technologies in city environments represents one of the biggest challenges of the last decades [4]. The integration of physical structures in a city with smart devices to support decision making overcome in a new concept of city: Smart City (SC) or City 2.0 [5].

Cities equipped with smart gadgets enables integrated operations of systems digitally connected in the city infrastructure in different sectors (*e.g.*, health-care, energy infrastructure, transportation, and mobility systems) [6]. Different communication technologies are employed for this purpose, such as real-time data collection infrastructures and data analytic platforms to process data and make decisions with real-time accuracy [7]. Cities with this architecture works as living organisms, with computing resources, sensing infrastructure, and data analytic exchanging information to enable synchronized operations. The integration of the systems described before is also known as Internet of things (IoT), another concept that has been introduced worldwide in cities to upgrade city's infrastructure [8]. One of the sectors that can benefit from IoT technologies is the Municipal Solid Waste Management System (MSWMS).

MSWMS is a complex system that covers activities and actions related to managing the waste, since its conception to the proper disposal. In urban areas, the tasks includes collect the waste from dumpsters, carry the waste to recycling centers or transfer stations, and then to the final destination (*e.g.* landfills, incinerators, or stakeholders) [9]. The activity that consumes most resources is generally the waste collection, that is carried out traditionally in most cities worldwide, with drivers making decision of which sites should be visited or even with pre-scheduled routes. This approach often lead to inefficient expenditure of resources since the truck can travel longer distances to collect insignificant amounts of waste, or even take too long to collect overfilled dumpsters [10]. In this scenario, the adoption of technological solutions could optimize the waste collection and bring benefits for both companies and citizens. Among solutions, the utilization of a Wireless Sensors Network (WSN) to collect real-time data regarding waste level and use this information for route planning [11]. In this strategy, one important task is the choice of sensing devices to be used.

In this work, the initial strategy adopted to assemble the future nodes on the WSN will be studied. The main goal was to settle what is the best set of sensors for the particular implementation of sensors in dumpsters for selective collection of waste in the city of Bragança, located in the Northeast region of Portugal. The region face temperature oscillations throughout the year, from -4 °C in a cold winter to 37 °C during summer. In this case, ignoring weather conditions

could hinder waste level measurement. The sets of sensors considered here were HC-SR04 (S1), HC-SR04 + DHT11 (S2), and US-100 (S3). HC-SR04 and US-100 are ultrasonic sensors widely used in diverse range of applications, such as waste level measurement, and DHT11 is a sensor for temperature and humidity measurement. Distance measurements data were collected in serial communication, using Arduino Uno microcontroller and PuTTY software, an open-source tool. Sets were chosen to evaluate if considering temperature would improve precision on measurements and to evaluate cost-efficiency in distance measurement considering temperature.

The rest of the paper is organized as follows: Sect. 2 brings the related literature and real data regarding MSW generation in Europe; Sect. 3 presents the methodology employed; Sect. 4 summarizes the results; and finally, Sect. 5 shows the main findings of the present study and future work.

2 Related Literature and technical information

The most relevant literature for this study was found searching in Scopus and Web of Science databases for works with “ultrasonic sensor” and “waste management” as keywords in the last 5 years. Documents obtained within this search were analyzed in the opensource tool ScientoPy [12] to understand what the literature is currently covering. Figure 1 illustrates the evolution of the most relevant keywords in this field.

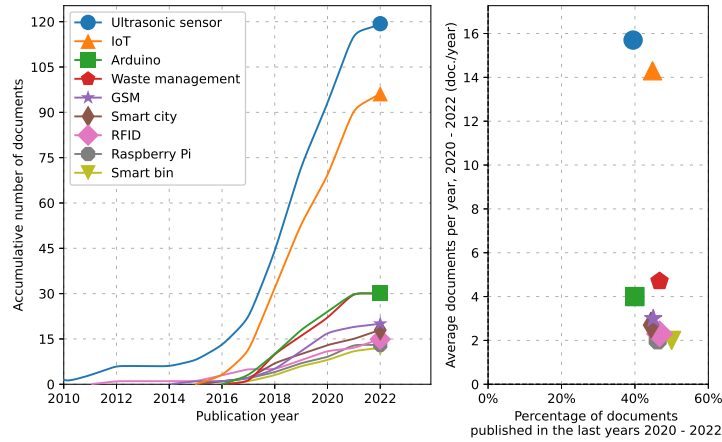


Fig. 1: Evolution of 10 most used keywords.

The result shows the relevance of the study in recent years, with the increase of number of studies using the keywords since 2016. For this study the keywords IoT, waste management, SC, and Arduino are of particular interest and will be

briefly reviewed. Before reviewing the literature, some data regarding MSW will be shown to reinforce the relevance of this topic.

2.1 Municipal solid waste: European and Portuguese panorama

Total European waste generation in 2018 was 2377 million tonnes, an average of 5.2 tonnes per EU inhabitant. In the same year, only 37.9% were recycled, and surprisingly 38.5% were disposed in landfills. Waste generation in 2018 according to the different economic activities and households is shown in Fig. 2 for EU countries (average) and Portugal. In the EU, the most significant share of generated wastes is related to construction, followed by mining and quarrying, and manufacturing. In Portugal the order is different, with other economic activities (agriculture, forestry, and fishing; services; energy) presenting the highest share, followed by households and manufacturing [13].

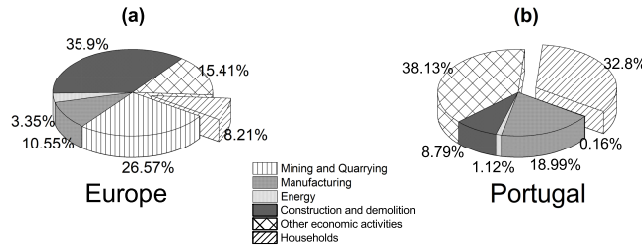


Fig. 2: Waste generation per economic activity in (a) Europe and (b) Portugal.

MSW represents an average of 7-10% of the total waste generation in EU countries, being one of the most complexes to manage due to their complex matrix since undifferentiated waste consists of organic and inorganic fractions of different nature [14]. On the other hand, in Portugal this type of waste has a high share of the total waste generated (*ca.* 33%). The waste generated in cities presents a complex composition, with high public visibility and a direct impact on human health. Data for MSW generation showed that each European citizen was responsible for an average of 505 kg of municipal waste in 2020. MSW generated by European citizens had an increase of 8.2% compared to the first record in 1995. In this scenario, Portugal is one of the countries with the highest increase in waste generation, with 45.7% more urban waste generated compared to the first record.

2.2 Municipal solid waste management systems in smart cities

The concept and idea of SC are now arriving at MSWMS in most recent years, with the increase in the acknowledgment of policymakers regarding the need to improve the way MSW is managed [15]. In this regard, most works consider the

utilization of improved decision-making using real-time measurements with numerous types of sensors. For now, most of the work is being developed by scholars that are still trying to find the best combination of hardware, middleware, and software to provide the best efficiency. However, some cities have already taken the lead and implemented smart services on their MSWMS, such as Shanghai (China) and Brisbane (Australia) [10].

Solving the MSWS problem may require different approaches for some cities. However, the WSN technique can potentially contribute to the communication solution in most cities. WSN is a technique that has been used and researched in recent years to monitor remote locations (with small infrastructure resources) or even in urban areas (commonly with more infrastructure). A set of strategically placed nodes can define the basis of a good WSN [16]. Depending on the approach, these nodes support sensors that can be used to collect data and send it through an IoT system [17].

The utilization of WSNs to collect real-time information is one particular approach that has shown promising results. Works in this strand often use the data from the cloud to apply optimization algorithms and find the shortest path to collect the waste. The physical system is designed toward the specific operation of the region of interest, assembling the system to sense specific parameters. Despite each system with its own considerations, distance measurement, load, temperature and humidity are often chosen as relevant data for route optimization [18,15].

2.3 Arduino

Microcontrollers have diverse uses in offices, homes, and research environments [19]. In brief, microcontrollers are single-board computers that have both software and hardware, and their use is generally towards the control of one dedicated task in the device [20]. In this regard, Arduino is an open-source electronics platform that is the first option for anyone working with interactive software and hardware projects due to the cost-efficient performance that this platform offers [21].

The big community built around Arduino projects, moderate inexpensive board costs, and easy implementation has motivated students, teachers, and developers to use this technology in their projects [22]. Arduino boards are equipped with a microcontroller, such as Atmel ATmega328p or ATmega168, which are responsible for the development of projects and prototypes. The code uploading of Arduino boards can be done in Arduino IDE, considered a good choice for individuals with some knowledge in C and simplified C++ programming languages. Arduino currently exists in many variants, such as the Arduino Uno, Arduino Mega, Arduino Leonardo, and Arduino Due.

Many fields have already found benefits in using Arduino platform, such as remote sensing, hardware communication, mining, and system design [23]. Among the applications in remote sensing, some studies are using Arduino for the optimization of decision-making in waste collection systems. Aguila *et al.*, for example, assembled a smart bin able to send an alert to the staff responsible for waste collection when a certain condition was reached inside the bin. In this

example, the authors used ultrasonic sensors on the cover of the bin to measure waste level and a balance to check the weight of waste. The whole system was controlled with the aid of an Arduino UNO [24]. Kumar *et al.* used a similar approach, with the ultrasonic sensor measuring waste level to inform the staff once the bin is filled. In this work, Arduino UNO was also used to control the system. Once the dustbin is emptied, the operator confirms the task with the aid of an RFID tag [25]. Several other works [26,27] are devoted to show approaches of prototypes for this application, most of them using a similar strategy with one or another modification according to specific cases of the problem perspective.

2.4 Ultrasonic sensor

Ultrasonic sensors, or sonar, are devices able to detect presence of objects within a given range and field of view. These devices work based on the principle of transmitting high-frequency sound wave at objects and measuring the reflected echo off of the target. The sensors are able to convert alternating current into ultrasound and the other way around. Some devices in this class use separate sensors to transmit and receive; others are able to combine both functions in only one sensor. The system determines distances based on Time of Flight (ToF) measurements, considering the propagation speed of the sonic wave in the medium. Several studies use this type of sensor for measuring waste level in dumpsters [28,29].

One of the most common models used in different projects is the HC-SR04 [18,25]. This model is equipped with an ultrasonic transmitter and receiver, and has four pins: Ground, VCC, Trig, and Echo. The ultrasonic signal is propagated by a wave directed at an angle of about 30°, and the most effective measuring angle is 15°. The sensor returns the time that the signal takes to travel back, and post calculations are necessary to transform this information into distance. The reading is not affected by sunlight or colors, but material and surface shape have influence [30].

Another sensor available on market at relative low price is the US-100. This sensor has one advantage compared to HC-SR04, which is the serial UART mode operation that allows adjusting the speed of sound according to the room temperature during measurement. Furthermore, the sensor can operate in pulse width mode by removing the jumper on the back, but in this mode it is not possible to use temperature information for more precise distance measurements. In solid waste management system, no work using this sensor was found. In fact, literature on this device had to be searched outside the database used in previous sections, and most of the works found were dealing with robotic applications [29].

3 Methodology

Due to the *modus operandi* of the company ascribed to MSW management in the city of Bragança, dumpsters are made of metal on the face that is in touch with the ground and all the rest is made of hard plastic. This design was chosen by the

company because in this way they can collect the waste by pulling the dumpster with the aid of a winch and open the bottom, that works as a floodgate. In future works, the idea is to place the each node of the WSN on top of the dumpster, so the system can measure waste level and communicate to the cloud real-time information, used to optimize collection routes. Positioning the measurement set in this spot will not be a problem in the future once the dumpsters design does not allow citizens to interact with the structure (*i.e.* there is no way to leave it open or damage structures on the inside). To arrive at this stage, tests with different sets of sensors was considered necessary. Thus, the sets used in this work were HC-SR04 (S1), HC-SR04 coupled with DHT11 (S2), and US-100 (S3). All systems were controlled by Arduino UNO. More information regarding description of components can be found in [31,32,33,22] for HC-SR04, DHT11, US-100, and Arduino UNO, respectively.

Hard plastic and metal were used as targets to measure distances and evaluate the performance of each set. In brief, the temperature test consisted in evaluating the performance of each set when measuring distances inside a container with controlled temperature oscillation through time. In distance test, the sets were evaluated for measuring distances ranging from 185 cm to 5 cm, with intervals of 10 cm. The maximum value was chosen because it represents the height of dumpsters in which the sensors will be positioned in the future. The whole procedure is illustrated in Figure 3, and will be explained in more detailed on the next sections.

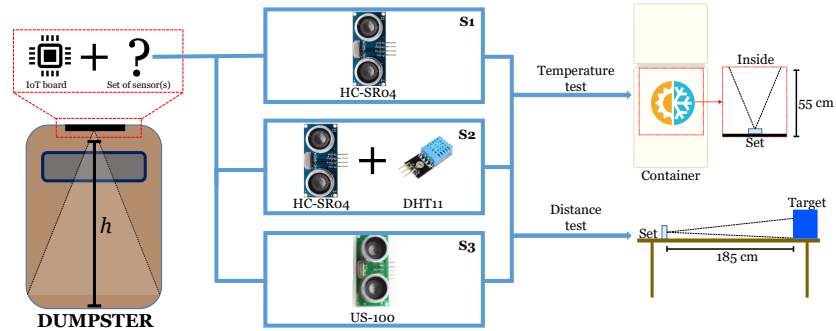


Fig. 3: Representation of the tests performed.

3.1 Sets assembly

Both ultrasonic sensors used in this work did not return the distance from measurement directly. On the other hand, it is possible to determine the distance given an obstacle by triggering the sensor and then measuring the echo time

from a pulse width output (this process occurs individually in each sensor). In this context, it is expected that the physical air environment could sometimes disturb the wave sent by each sensor. The sensor US-100 (S3) has an integrated system to compensate the external temperature. Despite HC-SR04 (S1) does not account for temperature during operation, the set was also assembled with temperature measurement using DHT11 for future comparison. The difference between sets 1 and 2 is the equation used to calculate distance, one considering the average speed of sound (S1) and the other regarding the sapped calculated based on temperature (S2).

Libraries used to control the sensors were `NewPing.h` for HC-SR04, `DHT.h` for DHT11, and `SoftwareSerial.h` for US-100. S1 and S2 codes were written using the function ‘`sonar.ping_median`’ that returns the average time of n measurements, default being 5. The equations used to calculate distance in each program are below.

$$D_{S1} = \frac{\Delta t/2}{\overline{V_s}} \quad (1)$$

$$D_{S2} = \frac{\Delta t/2}{V_s} \wedge V_s = 331.4 + 0.606 * T \quad (2)$$

$$D_{S3} = MSB * 256 + LSB \quad (3)$$

Δt is the time that wave takes to travel back to the sensor, $\overline{V_s}$ is the average speed of sound (343 m/s), V_s is the speed of sound calculated based on temperature T registered by DHT11 ($^{\circ}\text{C}$), MSB and LSB are the bytes carried to answer the request 0x55 for US-100. Temperature measurements using US-100 are returned upon request 0x50. The equation that correlates speed of sound with temperature used in S2 was taken from the literature [34]. The results are obtained in meters for D_{S1} and D_{S2} , and in millimeters for D_{S3} .

3.2 Temperature test

The goal of this test was to determine the influence of temperatures for measuring distances. It was already shown in the literature that speed of sound has dependence on the temperature of the medium in which the wave sound is propagated. Using real dumpsters for temperature evaluation is infeasible due to the difficulties to obtain the desired temperature inside. For this reason, each set was positioned inside a container with changeable temperature (a refrigerator in this case) to evaluate if distance measurement would be affected by temperature oscillation. The sets were placed exactly on the middle of the platform, positioned 55.1 cm from the top of the container. This distance was chosen based on theoretical calculations of wave propagation that were performed considering real dumpster dimensions and field of view of sonars. In this setup, equal distance was assessed during the test.

Once the set was positioned inside the container and temperature was stable, which happened around 1.7 $^{\circ}\text{C}$, the refrigerator was turned off and the interior

was exposed to the medium, so temperature could raise to room temperature. Since the moment the refrigerator was turned off, PuTTY software was already recording measured distances and temperature. When temperature reached room temperature and stabilized, a heater was placed inside the container to reach temperature around 37 °C. At last, the heater was removed from the container and the refrigerator was turned on when temperature reached room temperature, to cool down to 1.7 °C again and close the cycle of analysis. The first part of the test was named heating step, and second one is the cooling step. All tests were performed in triplicate to ensure data reliability, and the results gathered were post-processed in Python package Pandas, to determine average distance, error, and precision of each set with the aid of Numpy package.

3.3 Distance measurements

Tests for measuring targets made of plastic and metal were performed using a large table as surface. Sets and table were adjusted to ensure that optimum conditions for measurements, and the system was assembled on top of a measuring tape placed on top of the table to compare measured values with real distances.

Once the physical system was assembled, measurements were collected for distances starting in 185 cm and going to 5 cm moving the target with intervals of 10 cm for each set. Data collection for each distance was done using software PuTTY to store results in a .csv file, and each collection run took about 70s of measurement. The experiments of distance measurement were repeated 3 times for each distance to ensure data reliability. All data collected were post-processed in Python package Pandas. The number of signals was set the same for all distances measured for the same set and target, to ensure fair evaluation of performance.

4 Results

In this section, the results obtained for measurements using different sets in the tests will be presented and discussed. The discussion will be focused towards the performance of each set, considering the particular application that one of them will be used in the future of this study: measure waste level inside real dumpsters.

4.1 Temperature test

The temperature inside the refrigerator stabilized in 1.7 °C, that was the lowest temperature used in this study. The highest temperature achieved with the aid of the heated was 37 °C. Thus, temperature range in which distance measurement was studied for the sets is 1.7 - 37 °C, which covers great part of temperatures faced during one year for the city of Bragança, where the future system will be assembled [35]. The main goal of this test is to evaluate the effect of temperature in measurement of waste levels in cities that have high temperature differences

throughout the year. The result of distance measurement during heating and cooling down are represented in Figure 4.

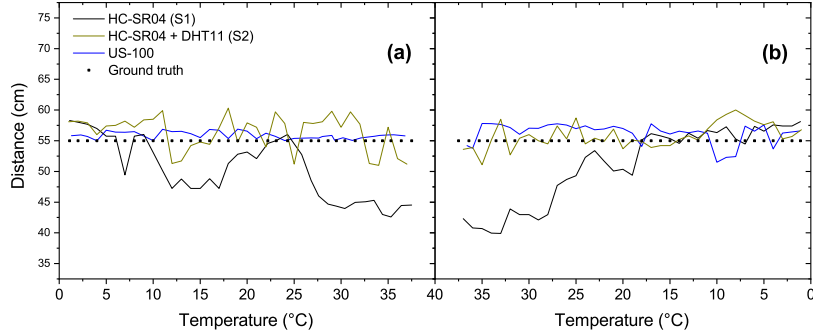


Fig. 4: Distance measurement results for different sets in (a) heating and (b) cooling.

Distances measured using each set have average errors of 9.76, 3.37 and 2.84% for S1, S2, S3 in heating and 10.24, 1.46, and 5.03% for S1, S2, S3 in cooling. The errors were calculated based on the average distance measured in a determined temperature compared to the ground truth (determined with measuring tape). As can be seen on the graph and errors, set S1 that is considering the utilization of HC-SR04 only has higher errors in measurements compared to sets 2 and 3. Gathering the results obtained for cooling and heating steps in temperature test reveals that errors are 10, 2.41, and 3.93% for S1, S2 and S3 set. Differences in distance measurement were already expected even before the experiment since studies have already proven the dependence on the speed of sound according to temperature. However, errors were above theoretical error expected, probably due to other errors coming from real operations (*e.g.* sensors parts may face problems in cold or hot conditions).

The result obtained show how temperature could interfere in distance measurement, with S1 measurements showing a strong influence on temperature. The Equation 2 that correlates speed of sound with temperature shows that these parameters are directly proportional. This is also observed in distance measurement with S1, since in lower temperatures measured distance was higher than real distance (sound was moving slower), and in high temperature distance measured was lower (sound was moving faster). On the other hand, S2 was able to measure with low errors the distance in both heating and cooling test since takes into consideration temperature to calculate the speed of sound. For instance, the weather in the model region approached in this work (Bragança, Portugal) is characterized as Csb (Warm-summer Mediterranean climate) according to Köppen Climate Classification (KCC). Regions that have Csb weather are characterized by a cold and rainy winter and fall, and a mild, hot summer

and spring [36]. In other words, the temperature throughout the year probably has significant differences depending on the month/season, which could lead to wrong waste level measurements if ignored when choosing a proper distance measurement set.

Using the highest (or lowest) temperature record for each month, it is possible to analyze a possible error in measurement of waste levels in real scenario. In this regard, here the highest temperature for each month was found using temperature history during 2020 measured by weather station 85750 in Bragança. The highest temperature was chosen having in mind that waste collection task is performed during day, a period in which higher temperatures are more likely to be registered. In a hypothetical scenario in which these sets are measuring waste level, the real errors associated to each set are shown in Figure 5, along with highest temperature found for each month during 2020. Errors were determined considering real measurements for the temperatures of interest and the real distance, 55.1 cm in this case.

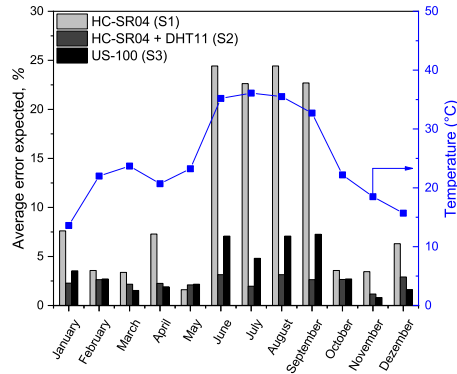


Fig. 5: Errors in measurement according to highest temperature per month in 2020.

In most months, higher error was obtained considering S1 as measurement set. Higher errors were observed for summer months, which is related to the reduced precision of all sets working at temperatures higher than room temperature. The graph confirms the infeasibility of using only HC-SR04 for waste measurement, since higher errors could be faced during the season that is known for higher generation of waste due to tourism, one important economic sector in Europe during summer.

4.2 Distance test

Temperature test showed that at least one strategy has to be considered to take into account temperature in distance measurement, for this particular application. Accordingly, distance test was carried out using sets S2 and S3. The errors

obtained for the average measurements in plastic and metal are shown in Figure 6. All experiments were performed at room temperature, that was about 23 °C.

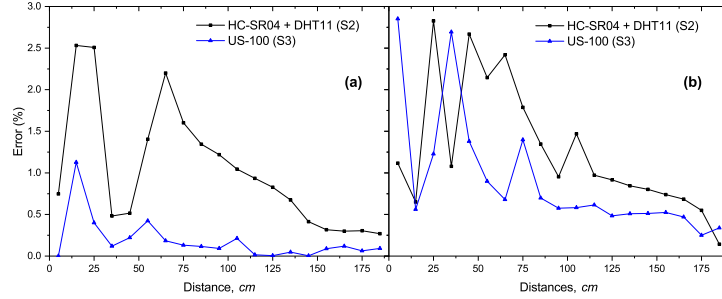


Fig. 6: Errors for distance measurement using targets made of (a) metal and (b) plastic.

Errors for measurement with S2 range from 0.26 to 2.53% (1.01% average) for metal and 0.14 to 2.83% (1.27% average) for plastic. Using S3, errors range from 0 to 1.13% (0.18% average) for metal and 0.25 to 2.85% (0.91% average) for plastic. The result demonstrates that errors are higher for low distances in all situations. Errors obtained for measurements in range 5 cm to 25 cm can be neglected in this work considering the future application, because it represents a range out of the interest considering the dumpsters design where measurements will be done in the future. The distance between opening in which waste is deposited to the top of the dumpster is around 26 cm, so in practice distances lower than this cannot be considered for measurements once this would mean dumpster overflowing. For this reason, the offset distance that should be considered is higher than 25 cm, meaning that sensor will be calibrated to consider 25 cm as lowest distance measured (full dumpster).

4.3 Cost-efficiency analysis

The implementation of solutions for real case scenarios does not depend solely on the quality of the solution, but also the costs. For this reason, balance cost and efficiency is essential when developing/assessing new strategies. In this study, the main cost associated to measurement set are the sensors. To proceed with this evaluation, average accuracy in distance measurement using sets S2 and S3 were assessed along with average price of components. The average price was determined upon search in 5 different European commercial websites, resulting in an average price of 4.16 € for S2 (2.68 € for HC-SR04 and 1.42 € for DHT11), and 6.98 € for S3. Figure 7 illustrates the result obtained with cost efficiency analysis, as cost per accuracy of each set. Arduino UNO price was not considered for this analysis because it is a common item in both sets.

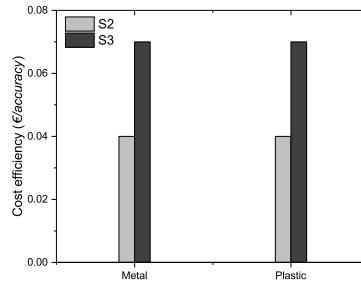


Fig. 7: Cost efficiency of each set in distance measurements.

Differences between measurements for metal and plastic were below 1% as shown in previous section. Thereby, the difference between cost efficiency in distance measurement considering different materials was not significant. The result observed in this section shows that S2 is the most cost efficient set for measuring distances for this application. Furthermore, searching for prices of components revealed another important characteristic to be considered: the availability. In most cases, few unities of US-100 sensor was available to purchase, while HC-SR04 had higher number of unities available for immediate delivery.

5 Conclusion and future work

The evaluation of different options of sensors to be used in the future node of a WSN was performed in this work. The evaluation included tests with temperature oscillation since model region faces different temperatures throughout the year. Furthermore, best sets were used to determine distance measurement performance considering the real distance range they might be used to measure in the future. At last, average prices of the 2 best sets were used along with distance measurement results to analyze cost efficiency of both approaches.

Temperature test revealed that ignoring temperature in distance measurement can lead to errors of about 10%. As a result of this finding, S1 was not evaluated in distance test since its usage in the future application was already ruled out. Distance measurement result revealed that S3 has the best performance, which is not surprising considering US-100 has higher precision than HC-SR04. However, the cost efficiency showed that the good result obtained with US-100 does not compensate efficiency in comparison with S2. In other words, the best set for the particular application evaluated in this work is the set comprised of HC-SR04 ultrasonic sensor and DHT11 sensor for temperature and humidity measurement. This result can be extrapolated for any other application considering ultrasonic sensors as devices for distance measurement in environments that might experience temperature oscillation as well.

For the future work, experiments accounting for humidity in air could be performed, as this parameter also have influence on the speed of sound. This

additional experience would not require any other component in S2 for example, once DHT11 is also capable of measuring relative humidity. Furthermore, a safety system could be designed to send an alert if the dumpster is on fire, which can happen in paper waste dumpsters for example. This system would only require a proper set of data previously recorded by the DHT11 sensor for a condition in which the dumpster is on fire (dataset for training alert models, for example).

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