Procedia
Environmental Science, Engineering and Management
http://www.procedia-esem.eu

Procedia Environmental Science, Engineering and Management **8** (2021) (1) 195-204

Environmental Innovations: Advances in Engineering, Technology and Management, EIAETM, 19th-23rd October, 2020

DEVELOPMENT OF A MONITORING DEVICE FOR FRUIT PRODUCTS TRANSPORTATION IN THE COLD CHAIN[*]

Diogo Morais[1,2], Martim L. Aguiar[1,2], Pedro D. Gaspar[1,2,], Pedro D. Silva[1,2]**

[1]University of Beira Interior, Covilhã, Portugal
[2]C-MAST - Centre for Mechanical and Aerospace Science and Technologies Covilhã, Portugal

Abstract

During food transport, products are often subject to conditions which do not benefit the conservation of their biological properties. This condition can lead to food quality and safety issues and ultimately to food waste. Globally, there was been an effort to develop techniques, procedures and technologies that can contribute to reduce food waste of perishable products such as horticultural ones. In this sense, remote monitoring systems, whose fundamental requirements relate to range and autonomy, make use of communications technologies to map characteristic crop parameters to reduce unnecessary application of resources or materials. This paper proposes a monitoring system to record the conservation conditions inside refrigeration plants and vehicles, transmitting them via the internet of Things (IoT). This device is composed of an ARDUINO UNO Rev3 microcontroller that acquires the environment temperature and relative humidity every 5 minutes by means of a DHT 11 sensor, and uses the SIM800L module that provides real time communication data via GSM. It also incorporates a 3.7 V – 2600 mAh battery that provides an approximate 60 hours power range.

Keywords: conservation, food transportation, GSM. internet of things (IoT), monitoring system, relative humidity, temperature

1. Introduction

Food products, when transported, are subject to environmental conditions that affect their conservation. Thus, problems of biological origin can begin to emerge, such as maturation and loss of organoleptic properties. The factor that most affects the quality of perishable products during transport is the storage temperature.

---

[*] Selection and peer-review under responsibility of the EIAETM

[**] Corresponding author: e-mail: martim.aguiar@ubi.pt; dinis@ubi.pt

After harvesting the fruits, to preserve their quality, several cooling processes are used which, in addition to removing field heat, are the key to ensure a favorable temperature during the post-harvest supply chain. In a study carried out with the purpose of evaluating the temperature control in the refrigeration systems of food products, it was found that the registered temperatures exceeded the values considered safe in 50% of the cases (Lundén et al., 2014). In Portugal, good practices in the transport of food products are listed in Regulation No. 852/2004, where they are presented together with other relevant good practices in the transport and distribution of food products.

However, although there are regulations that impose mandatory minimum characteristics on the transport of perishable products, the vehicles refrigeration systems are not always able to maintain the ideal conservation environment. The fact that the vehicles during the travel are sometimes exposed to the sun, besides the mandatory stops that drivers must make, worsens the conditions inside the cargo compartment. Ndraha (Ndraha et al., 2018) found that excessive temperature values occurred at all stages of the distribution chain and that they were not exclusive to a particular type of food. In a study carried out in Iceland, it was found that during the transport of fresh cod fillets, during 35% and 18% of the transport period, respectively, by air and sea, the recorded temperature was about 1ºC higher than the recommended (Martinsdóttir et al., 2010).

The non-observance of the temperature values inside the cargo containers during transport was also analyzed, finding that 81% of the situations occurred in the sea port of Cape Town, in South Africa, where a fifth of the containers never arrived with the ideal inside temperature values before being placed on board the vessels. In another study, with the objective of monitoring the temperatures inside a truck trailer, 16 loads were evaluated using dataloggers, concluding that none of the trailers was effective in maintaining the temperature of fruit and vegetables (Brown et al., 2016). In the case of chilled foods, in France, data of time and temperature was collected, from production to consumption by the end customer. It was concluded that the stage between transport from the place of purchase and storage in the domestic refrigerator was the most sensitive period in terms of meeting the temperature values (Derens-Bertheau et al., 2015).

Fruits and vegetables are the most wasted food, with approximately one third of the value produced not being sold, and this fact is often caused by inadequate temperatures in the post-harvest processes. Given these statistics and knowing the main problems in the cold chain that affect food, such as the lack of traceability or the inability to keep food in conditions that promote safety and quality (Morais et al., 2019), a system that is able to monitor the temperature in real time and remotely send the values, is seen by the companies in the distribution chain as an indispensable equipment to ensure that the products are shipped in good conditions and, thus, to ensure their quality from production to consumption.

2. Monitoring system

A monitoring system makes it possible to assess the conservation environment in which perishable products are found, allowing the evaluation of the temperature history as well as the values in real time. This record can be sent to a remote server with the aid of communication technologies or stored on a memory card.

For the system to send data in memory to a remote server, it is necessary to use a technology, such as RFID, Bluetooth, Wi-Fi or GSM. Each technology has its advantages and disadvantages compared to the others. The choice is dependent on the size of the project and the technical and financial requirements involved. There are several comparative studies (Aqeel-ur-Rehman et al., 2014; Morais et al., 2019), and Wireless Sensor Networks (WSN) are already on the market but at an inaccessible price for smaller companies with lower budget. There are several solutions that are an example of the applicability of WSN for monitoring temperature and / or gases throughout the entire distribution chain (Badia-Melis et al., 2015; Jagadesh et al., 2018; Ruiz-Garcia et al., 2008).

2.1. System Characteristics

With the objective of developing a monitoring system capable of sending data in real time and thus monitoring fruit products during their transport, from the producer to the distribution center, it was necessary to initially assess how the temperature fluctuates inside producers' storage chambers, in order to characterize the conservation environment in the initial stage of the distribution chain. This experimental study was carried out in sequence to other experimental study performed to characterize the conservation environment in the chambers of producers using dataloggers. After collecting and treating the temperature and relative humidity values, the parameters to which the device would be subject were established according to values in Table 1.

2.2. Hardware

Each environmental parameter needs a sensor to be measured, that is, an element that converts a variation in the surrounding environment into a viable electrical signal, in order to be interpreted by a microcontroller. For the developed monitoring system, the device ARDUINO UNO Rev3, shown in Fig. 1, was used. Arduino appeared to be one of the most versatile solutions on the market to fulfill the requirements. This microcontroller allows faster development and application in a prototyping board. Table 2 shows its main characteristics.

Table 1. Device specifications.

Number of devices	***1 device per pallet***
Maximum value	+ 30 °C / 90% RH
Minimum value	0 °C / 30 % RH
Acquisition time	5 min
Communication	GSM

Fig. 1. Microcontroller ARDUINO UNO REV3.

Table 2. Microprocessor specifications.

Processor	***ATmega328-Pu***
Operating voltage	5V
GPIOs	14
Flash memory	32 KB
SRAM	2 KB
EEPROM	1 KB
Clock frequency	16 MHz

To proceed with the data acquisition, the sensor used was DHT 11, as it respects the requirements presented in Table 1, since the temperature values to be measured are positive and the relative humidity values are below 90%. This restriction on the temperature and relative humidity values are due to the fact that the refrigeration systems of the vehicles are not able to exceed them. Table 3 shows the characteristics of the sensor.

2.3. Communication

Of the available communication technologies, the only one that met the requirements was GSM. Since the system will be placed in the load compartment of a vehicle and it will travel around to carry out the distribution. Protocols such as Bluetooth, Wi-Fi, Lora and RFID are unable to transmit, by themselves, to a remote server.

The GSM network consists of an existing network of communication towers, which are used by mobile phones and which allow them to communicate over long distances, using the bands known as 2G, 3G, 4G and in the future 5G. Allied to GSM is the GPRS (General Packet Radio Service), which is a targeted package of mobile data, allowing the establishment of an internet connection for data upload.

A vehicle for transporting fruit products does not always travel between locations with Wi-Fi coverage. To have a Wi-Fi signal, it would be necessary to purchase a mobile network device, to which the monitoring system should connect in order to send the data. After analyzing this solution, it was quickly dismissed due to the associated cost. Both Wi-Fi and other technologies would always require a module that would allow a connection to the internet to be established, more specifically a GSM or Satellite module.

Table 3. DHT11 temperature / humidity sensor specifications.

Parameters		***Conditions***	***Minimum***	***Average***	***Maximum***
Humidity	Resolution		1%	1%, 8 Bits	1%
	Repeatability			±1%	
	Precision	0-50°C		±4%	± 5%
	Measuring range	0°C 25°C 50°C	30% 20% 20%		90% 90% 80%
	Response time		6s	10s	15s
Temperature	Resolution		1 °C 8 Bit	1°C 8 Bit	1°C 8 Bit
	Repeatability			±1°C	
	Precision		±1°C		±2°C
	Measuring range		0°C		50°C
	Response time		6s		30s

Fig. 2. Communication module GSM/GPRS SIM800L.

There are numerous possibilities of using GSM and GPS for monitoring in special places, such as in forests, on trucks, in the countryside and in the open. For communication to be established, it is necessary to use a communication module. For this application, SIM800L, represented in Fig. 2, was chosen.

Finally, for the communication module to operate, it was necessary to obtain the SIM card from a mobile operator that had extensive signal coverage. In Fig. 3, it is possible to observe the concentration of the communication antennas of the chosen operator in continental territory.

3. Software

To automate the process of collecting values and sending them, a code is required: This code was performed in Wiring. Fig. 4 shows the flowchart that describes the operation of the monitoring system.

When starting the system, it remains on standby until the time requirement is met. After that, the network signal (RSSI) is checked, followed by the measurement of the air temperature and relative humidity.

After the allocation of the measured values into a variable, the location request is made to the operator. The location is obtained with the triangulation of the communication antennas closest to the system. However, the provided longitude and latitude values have an error, resulting from the forecast of the system's location in the communication network. When triangulation by communication antennas is used, the GPS module is unnecessary, reducing the final price of the product. Even with the location error, this option allows the monitoring of the vehicle movement and stops. The values obtained are then sent to an online platform where they are stored, allowing access to the history of temperature and relative humidity at all points of the transport chain, as well as the respective location.

ThingSpeak is an online platform that allows the storage of data from devices with an internet connection. In addition, it also has data analysis and admits processing using MATLAB Online, as shown in Fig. 5, which allows the implementation of optimization algorithms for both routes and the conservation environment.

Fig. 3. Mobile network coverage in mainland Portugal.

When making the acquisition through the GSM module, a request is made to ThingSpeak to upload the data through the TCP / IP protocol (Transmission Control Protocol / Internet Protocol).

Subsequently, the data is converted into a graphic display and sent online, allowing the data query with updates every five minutes, as shown in Fig. 6.

For the elaboration of the map that allows the visualization of the location, a code was written in HTML that incorporates the values read in ThingSpeak and overlays with the map from Google Maps.

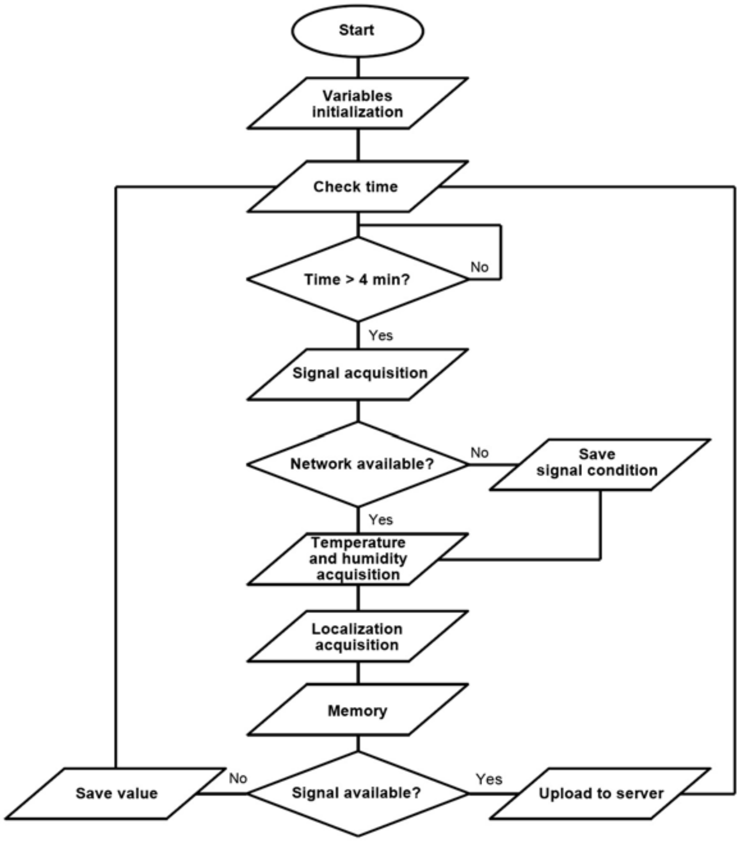

Fig. 4. Flowchart of the operation of the monitoring device.

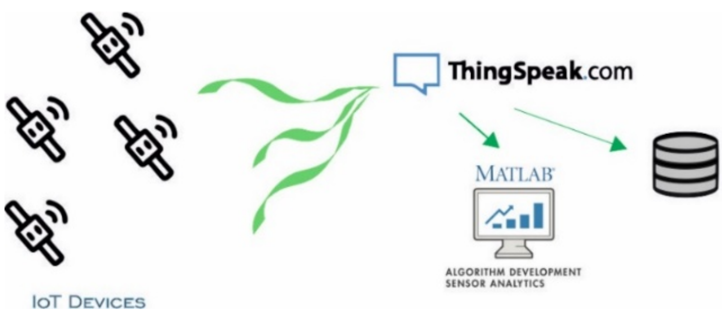

Fig. 5. Illustration of the communication flow between the data sent by the IoT devices and the ThingSpeak server.

4. Electrical Characteristics

The monitoring system, to accompany products throughout the entire transport, must be low cost, reliable, and efficient. Autonomy and price are mandatory requirements. Table 4 describes the electrical characteristics of each of the elements that make up the system. During the tests, it was verified that the present system has an energy consumption of 0.01V/h, allowing an expected autonomy of 2.5 days (60 h) with acquisition every 5 min. After assembling all the elements, a 3D printer was used to print a box for the system and for the stack, with the respective covers, as shown in Fig. 7

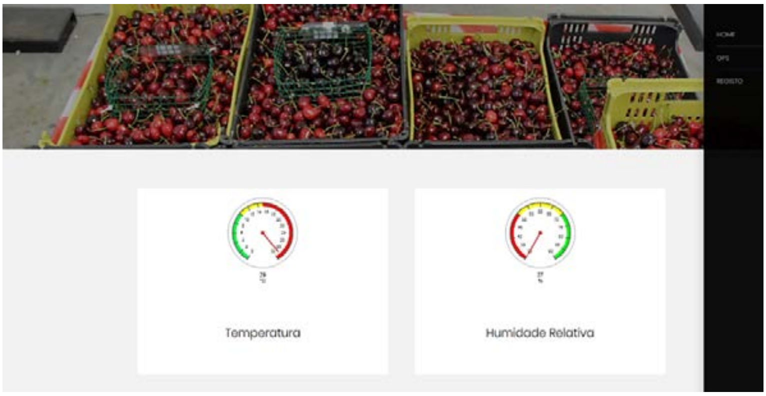

Fig. 6. Viewing informational apps on the device page.

a b

Fig. 7. Prototype of the traceability system: a) – Prototyping board; b) – System box

Table 4. Electrical specifications of the components used.

Component	***Characteristics***	
Sim800L	Voltage	3.7V – 4.2V
	Recommended voltage	4V
	Consumption	sleep mode < 2.0 mA
		idle mode < 7.0 mA
		GSM transmission (avg): 350 mA
		GSM transmission (peek): 2000 mA
ATMEGA328P	Crystal	16Mhz (External)

	Voltage (V)		3.3			
	Current (mA)		6.6			
	Power (mW)		21.8			
	5V, 16Mhz		81.8 mA			
DHT11	Conditions		Minimum	Average	Maximum	S.I
	Voltage	DC	3.0	5.0	5.5	[V]
	Current	Measured	0.5		2.5	[mA]
		Average	0.2		1.0	[mA]
		Standby	100		150	[μA]

5. Results

To validate the developed system and adjust the sensor offsets, an experimental test was carried out. An auxiliary datalogger served as a complementary system to check if there was any irregularity with the values obtained by the prototype. The test, in a first phase, took place inside the laboratory, where it was allowed to test the autonomy and the reception of the signal by placing the device inside a conservation chamber for 24 h, serving as a basis of comparison for what the system would have to face inside a transport vehicle. The test at this location was performed twice, the second test being carried out to validate the imposed offsets after the first test, with the values shown in Table 5.

Considering the values obtained both in the datalogger and in the monitoring system, it appears that the error is low. Fig. 8 shows the temperature and relative humidity values obtained in the first test (a and b) and in the second test (c and d).

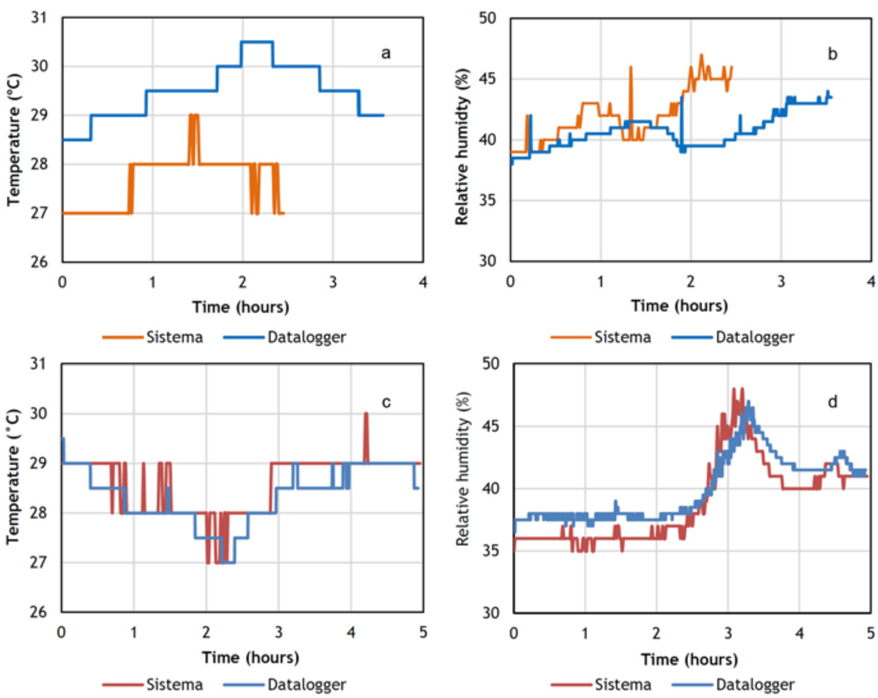

Fig. 8. Comparison of measurement values between the Datalogger and the developed monitoring system: a) Temperature monitoring values (without offset); b) Relative humidity monitoring values (without offset); c) Temperature monitoring values (with offset); d) Relative humidity monitoring values (with offset)

Table 5. Tests results.

System	Test	Acquisition (min)	Temperature [ºC]			Relative humidity [%]		
			Max	Min	Avg	Max	Min	Avg
Datalogger	1	1	30.5	28.5	29.5	44.0	38.0	40.6
System		5	29.0	27.0	27.7	47.0	39.0	42.0
Absolute error			-1.5	-1.5	-1.8	-3.0	-1.0	-1.3
Datalogger	2	1	34.5	24.0	28.5	51.5	30.5	40.8
System		5	39.0	24.0	28.7	50.0	21.0	39.5
Absolute error			-4.5	0.0	-0.2	1.5	9.5	1.3

6. Conclusions

Monitoring in the cargo of refrigerated vehicles is essential to control the quality of the products transported. With a forecast for the world population of 10 billion by the year 2050, optimizing conservation processes should be one of the priorities of producers.

The device developed, by allowing that important data, as temperature and relative humidity values, to be read and sent in real time, allows an optimization to be applied to the transport routes and offsets of the vehicle's refrigeration equipment.

The results of this study show that the device has characteristics that positively differentiate it from others on the market. When comparing the values obtained with the developed prototype and the auxiliary datalogger, it ensures that the values registered with the developed prototype show a reduced error.

Acknowledgements

This study is within the activities of project "Pack2Life – High performance packaging", project IDT in consortium No33792, call No03/SI/2017, Ref. POCI-01-0247-FEDER-033792, promoted by COMPETE 2020 and co-funded by FEDER within Portugal 2020.

This work has been supported by the project Centro-01-0145-FEDER000017 - EMaDeS - Energy, Materials and Sustainable Development, co-funded by the Portugal 2020 Program (PT 2020), within the Regional Operational Program of the Center (CENTRO 2020) and the European Union through the European Regional Development Fund (ERDF).

The authors thank the opportunity and financial support to carry on this project to Fundação para a Ciência e Tecnologia (FCT) and R&D Unit "Centre for Mechanical and Aerospace Science and Technologies" (C-MAST), under project UIDB/00151/2020.

References

Aqeel-ur-Rehman, Abbasi A.Z., Islam N., Shaikh Z.A., (2014), A review of wireless sensors and networks' applications in agriculture, *Computer Standards & Interfaces*, **36**, 263-270.

Badia-Melis R., Ruiz-Garcia L., Garcia-Hierro J., Villalba J., (2015), Refrigerated fruit storage monitoring combining two different wireless sensing technologies: RFID and WSN, *Sensors*, **15**, 4781-4795.

Brown W., Ryser E., Gorman L., Steinmaus S., Vorst K., (2016), Transit temperatures experienced by fresh-cut leafy greens during cross-country shipment, *Food Control*, **61**, 146-155.

Derens-Bertheau E., Osswald V., Laguerre O., Alvarez G., (2015), Cold chain of chilled food in France, *International Journal of Refrigeration*, **52**, 161-167.

Jagadesh M., Rajamanickam S., Saran S.P., Sai S.S., Suresh M., (2018), Wireless sensor network based agricultural monitoring system, *International Journal of Creative Research Thoughts*, **6**, 502-509.

Lundén J., Vanhanen V., Myllymäki T., Laamanen E., Kotilainen K., Hemminki K., (2014), Temperature control efficacy of retail refrigeration equipment, *Food Control*, **45**, 109-114.

Martinsdóttir E., Lauzon H.L., Margeirsson B., Sveinsdóttir K., Þorvaldsson L., Magnússon H., Reynisson E., Jónsdóttir A.V., Arason S., Eden M., (2010), *The effect of cooling methods at processing and use of gel packs on storage life of cod (Gadus morhua) loins. Effect of transport via air and sea on temperature control and retail-packaging on cod deterioration*, Matis, Reykjavik, Iceland, On line at: https://www.matis.is/media/matis/utgafa/18-10-1704-Lokaskyrsla-2010.pdf.

Morais D., Gaspar P.D., Da Silva P.D., Andrade L.P., Nunes J., (2019), Current status and future trends of monitoring technologies for food products traceability, In *ICR 2019 refrigeration science and technology proceedings*, International Institute of Refrigeration, Montreal, Quebec, Canada, 3186–3192.

Ndraha N., Hsiao H.-I., Vlajic J., Yang M.-F., Lin H.-T.V., (2018), Time-temperature abuse in the food cold chain: Review of issues, challenges, and recommendations, *Food Control*, **89**, 12-21.

Ruiz-Garcia L., Barreiro P., Robla J.I., (2008), Performance of ZigBee-Based wireless sensor nodes for real-time monitoring of fruit logistics, *Journal of Food Engineering*, **87**(3), 405-415.