EXODIA - EXpired foOD Intelligent Alert

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***Abstract*— In this paper, we present EXODIA an everyday-use device created to help reduce food waste, keeping track of the groceries in the refrigerator to prevent their expiration date. Our device is designed to fit in any refrigerator ensuring the possible diffusion on a wide marketplace, also keeping the cost and the consumption at their lowest. The ease of use is achieved by exploiting the barcode on the products that the user has to scan to enable the device functionalities. After defining the main characteristics to be included in the prototype, the responsivity and the accuracy have been tested to verify the actual fidelity of EXODIA. The technical issues regarding the hardware implementation have been investigated, as well as the algorithm robustness. Data resulting from the experiments have been collected in tables, confusion matrices and graphs. In the end, further developments, suggestions and issues related to barcode protocols have been analysed to show the possible evolutions of EXODIA.**

I. Introduction

There is enough food produced in the world to feed everyone [1]. This statement feels like a paradox thinking about the very situation we are living, but it is actually a fact. Despite that, one in nine people does not have enough food to eat, that's 793 million people who are undernourished [2]. There are many factors that limit the number of resources available: one of the most important and reasonably solvable concerns food waste. In fact, one-third of all food produced is lost or wasted -around 1.3 billion tonnes of food- costing the global economy close to $940 billion each year [2]. Moreover, it is not only an economic and social issue, but it's also an environmental one: up to 10% of global greenhouse gases come from food that is produced, but not eaten [3]. It's been estimated that if food loss and waste were a country, it would be the third biggest source of greenhouse gas emissions [4]. To have a better understanding of the problem, it's worth noting that wasting food is worse than total emissions from flying (1.9%), plastic production (3.8%), and oil extraction (3.8%) [5]. The further along the supply chain the food loss occurs, the more carbon-intensive the loss and waste. That's because more resources have gone into producing for example tomato sauce (processing, transport, retail and packaging, in addition to land and water use and farming) that we can buy in the supermarket than has gone into a tomato picked directly from the field. If we waste tomato sauce, we waste the additional resources that have accumulated along the supply chain. Different foods have different environmental impacts. For example, the volume of meat that is wasted and lost is not very high compared to foods such as cereals and vegetables. However, meat requires much more resources to produce, so wasting meat still has a significant impact on climate change (estimated to contribute to 20% of the carbon footprint of total food waste and loss) [4].

This catastrophic picture could be partially avoided, giving rise to many positive effects: in fact, eliminating global food waste would save 4.4 million tonnes of CO_2 a year (the equivalent of taking one in four cars off the road) [6]; also if one-quarter of the food currently lost or wasted could be saved, it would be enough to feed 870 million hungry people [2]. In the end, reducing food waste is the third most effective way to address climate change [9].

Food waste problems are also due to people's disinformation. In Europe, estimates show that up to 53% of consumers don't know the meaning of "best before" labeling, and 60% of consumers don't know the meaning of "use by" labeling [7] [8]. We, as consumers, can have a direct impact on the food waste problem by paying attention to our own behavior. In this sense, our device, EXODIA (EXpired foOD Intelligent Alert), wants to ease customers' attempts in controlling and reducing food waste. EXODIA consists of a small device to be placed in the refrigerator capable of detecting goods close to the expiration date: once it has acknowledged these items, it alerts the customer via an acoustic and visual signal whenever he opens the fridge. All this information is then stored in an app that the user can interact with: it sends a notification of the almost-expired goods and it allows the user to keep track of the products still present inside the fridge, in order to develop a sustainable criterion to do groceries.

II. Related works

Because of the impact of food wasting, a lot of effort has been put in order to find innovative solutions. Moreover, the ever-increasing diffusion of connected devices (the so-called Internet of Things), made possible the development of different kinds of "smart" objects such as fridges and other electrical households. In this sense, several companies tried to apply the concept of IoT to help people reduce food wasting using different approaches. Big companies, such as LG and

Samsung, because of their economic availability, managed to develop the whole refrigerator structure, exploiting systems like cameras and object recognition algorithms in order to keep track of expiration dates and food management. Other solutions concern the development of smartphone applications which require more interaction with users; the aim of this software, as it will be clarified later, is the same though. Finally, a good compromise between these two cases consists in small devices, like EXODIA and others, that represent an improvement in terms of diffusion, cost, and user-device communication. The way these devices get information and manipulate it differs one from the other: some of them exploit chemical and spectroscopic analysis and some others use imaging technologies. In the following subsections three of these solutions will be analyzed: the purpose is to briefly understand their working principle and what are the main advantages and drawbacks, so to comprehend how EXODIA collocates itself among them.

A. Samsung Family Hub^{TM}

Samsung Family Hub^{TM} is the first smart refrigerator Samsung has realized. The fact this device belongs to the smart refrigerators category means that it can connect to the cloud via Wi-Fi. While specific features can vary depending on the model, the units generally allow users to scan the inside of the fridge to see its contents, check remotely that the doors are closed, and determine if repairs are needed. The Family Hub does have some AI capabilities that take advantage of its placement. The three built-in cameras can analyze the contents of your fridge (as long as the cameras can see the items) and offer up recipe and meal plan suggestions based on what ingredients you have. For our purpose, it is very important to point out another updated feature which is the ability to manage expiration dates: the fridge scans the food labels using the cameras and pops up an alert when your milk is about to go bad. These features are still limited in their functionality, but this type of intelligence in our appliances does feel like a solid step toward the smart kitchen of the future. Moreover, the price of this device constitutes a major drawback, which is around $2000-4000. In addition, there is a potential risk of privacy leakage that the image taken by the camera contains the user's personal information (user's face, appearance, etc.).

B. Best Before - Food Tracker

Best Before-Food Tracker is an application that allows the user to manage and track his food. In this software, it is possible to add products manually, as well as their expiration date and other information. The application offers then a series of features:

- Product management by category;
- Product management by storage location;
- Notification to remind you to eat products before the expiry date or after opening.

For these reasons (the latter is the most important one) the solution via application represents a good approach in terms of user-friendliness. On the other hand, it requires a constant and responsible interaction of the user: he must check for updates whenever new items are added to the fridge. In this sense, despite the app being free, the user must put a lot of effort to manage his own groceries.

C. Smarter FridgeCam

FridgeCam by Smarter is a small device made of an intelligent camera that turns a normal refrigerator into a smart one. Through this camera, and thanks to an object and image recognition algorithm, the device can collect the expiry date from the items' labels, recognize the goods inside the fridge, and put them into a groceries list when they are going to finish. The cost of FridgeCam is modest, but the ability of the camera is limited to the objects placed in front of it.

Summarizing, it is worth noting each solution has its own abilities and defects. EXODIA tries to take the best from each one, attempting to keep a very low price, reduce to user interaction and assure a wide range of use.

III. Proposed Solution

After the analysis of the related works, it is time to introduce EXODIA and the concept behind its realization.

A. General Architecture

EXODIA presents itself as a small box made of biodegradable plastic (PLA), within which all the sensors are placed, meant to be used in everyday life. To achieve the optimal value of comfort use, it is necessary to place the device inside the refrigerator: whenever the user buys new items to be put in the fridge or consumes them, he is supposed to scan the products, thanks to the barcode scanner implemented in the device, so that a list of groceries can be memorized or updated. Thanks to this and other features that will be better clarified in the following sections, EXODIA can send an alert message which occurs whenever the user opens the fridge. The aim is to notify him about the amount of time that elapsed from the purchase date. To fulfill the objective, EXODIA has been developed dividing its architecture into some modules that can be treated separately. As shown in Fig. 1, the main component of the device is the Microcontroller, which is connected to all the other sensors. An external data logger shield is integrated over the Arduino Board to allow the storage of data on a removable memory (SD card). It is also equipped with a Real Time Clock that allows the Microcontroller to work with the proper date and time. The GM65 2D Barcode Scanner represents the principal sensor, even in terms of costs (about €20). The remaining modules, like the Presence Detecting, are realized via standard components, such as a photoresistor, LCD screen, LED, and buzzer. Their total current consumption is minor than 50 mA, while their estimated cost for medium-scale production is very low (about €2). Considering the Microcontroller too, for medium-scale production the average price of EXODIA is around €15 for a low-scale production.

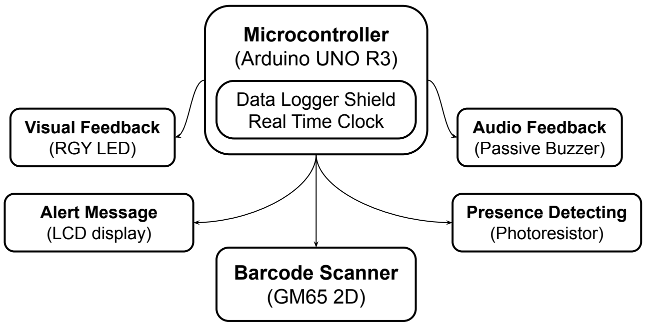


Figure 1: Schematic diagram of EXODIA's architecture.

B. System Specification and Requirements

Let's now see in detail what are the main aspects and requirements that describe EXODIA.

1) Functional Requirements:

- **Barcode Scanning** This is the core feature of our device: EXODIA can provide high-fidelity barcode recognition so that the device can extract information about the name of the product scanned and the category it belongs to so that it can be estimated the proper amount of time that can pass by before it spoils. Product scanning is the only manual operation that the user is supposed to do. It is worth noting that this operation has two purposes: adding new items to the list and removing them when they are consumed. Furthermore, this operation is made easier thanks to the fast response and angular resolution of the sensor.
- **Presence Detection** The device needs to know when the user is opening the fridge to choose properly the right time to send the alert message. To do this, a system based on light detection is used: the light exploited for this is the one that turns on inside the fridge whenever it is opened. Indeed, this feature is implemented in all refrigerators, and it is the easiest and cheapest way to detect the presence of the user.
- **User Interface** The alert message sent by the device must be as clear as possible. For this reason, an LCD screen is implemented in the device to show, through a written message, which product is going to spoil and the time spent by the item inside the fridge too.
- **Audio and Visual Feedback** For the same purpose as the one mentioned before, audio and visual feedback are used to alert the user. The audio feedback consists in a short beep signal that occurs only if inside the fridge there are products that are going to expire until products are not removed from the list. The visual one is made of three colored LEDs: a green light is shown if all the products are still good to be conserved; a yellow one occurs at the first alert message for the product and a red light when too much time has passed by.
- **Phone Connectivity** It is possible to connect the device to the smartphone via Bluetooth to manage the list of items inside the fridge and also receive a notification whenever a product is going to spoil.

2) Non-Functional Requirements: As the previous arguments suggest, the functional requirements EXODIA must satisfy bring a series of natural advantages that nowadays are required by most devices. First of all, the *ease of use* is for sure one of the main purposes that is fulfilled by minimizing the user interaction with the device and improving the communication media between them. Then also very low *cost and energy consumption* are the strength of EXODIA, which is achieved by relying on already implemented technologies (i.e. the light system in the fridge and the exploitation of barcode protocols). Thanks to these two characteristics, EXODIA can be used on all the different types of fridges available.

C. Meta-Algorithm

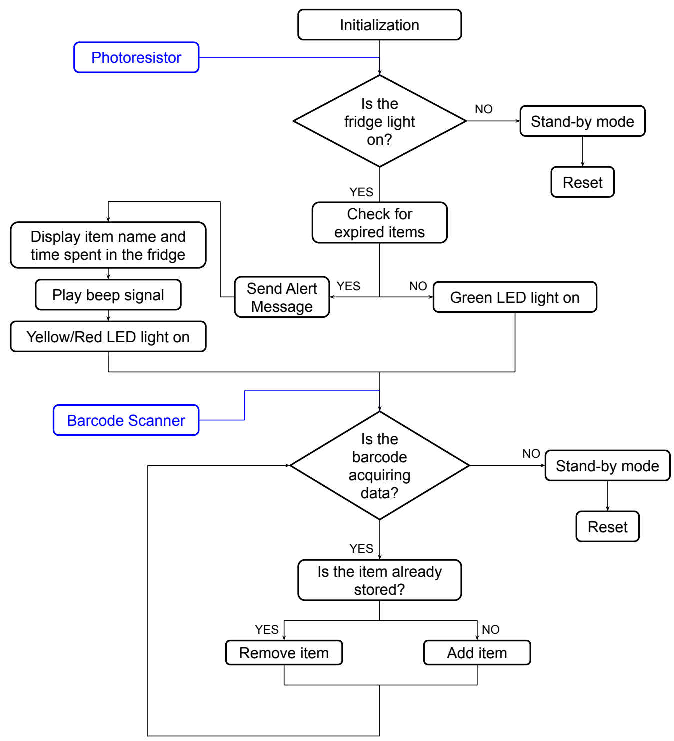


Figure 2: Flowchart representing the main EXODIA functions.

1) Barcode manipulation: One might now wonder why EXODIA does not alert the user by exploiting the expiry date information like many of those included in the products discussed in the previous section. That is because EXODIA retrieves information only from the barcode associated with every product. The barcode management system is provided by a nonprofit organization called GS1, which has developed over the years different kinds of protocols to codify the information to promote the exchange of goods. Unfortunately, the barcode protocol used nowadays to codify the purchasable items, the EAN-13 protocol (rarely it is used the EAN-8), does not contain the expiration date. Nevertheless, the decision to base

EXODIA on a barcode scanning process is given by the reasons explained before (III-A). For these reasons, it revealed to be necessary to find a different way of using the barcode.

2) Flow chart: Fig. 2 summarizes the basics of the algorithm implemented in EXODIA to satisfy its purpose to alert the user. Briefly, the starting process of EXODIA is the initialization, where all the variables of the algorithm are defined. As soon as the user opens the fridge, the photoresistor sends a signal to the Microcontroller; before any other operation, the list of items stored in the fridge is scanned to check for expired items. In case they are found, the system activates the alert messages process, using as output devices the LCD, the Y/R LED, and the active buzzer. In case all products are still good to be conserved, the green LED light turns on. After that, the device waits for a signal from the barcode reader: if it occurs, it will determine if the barcode has already been stored in the memory. Depending on the result, it will remove/add the item from/to the data storage.

IV. Experimental Results

In this section, there will be analyzed the major technical specification concerning the prototype of EXODIA realized.

A. Prototype

Figure 3: Prototype layout.

As told previously, the core of the device is an Arduino UNO R3 with an ATMega328P processor. Being its local memory too small for our purpose (32 KB of flash memory), it has been revealed to be necessary to implement the board with an external Data Logger Shield equipped with an SD card slot (16 GB). A Real Time Clock is also present in the shield, to collect data regarding the time of registration of the products. The output sensors implemented in this prototype are:

- **Active Buzzer**: it is used to emit an alert sound at a resonance frequency of (2000±300) Hz, and it works with a current consumption of 30 mA, and in a temperature range from -19°C to 45°C.

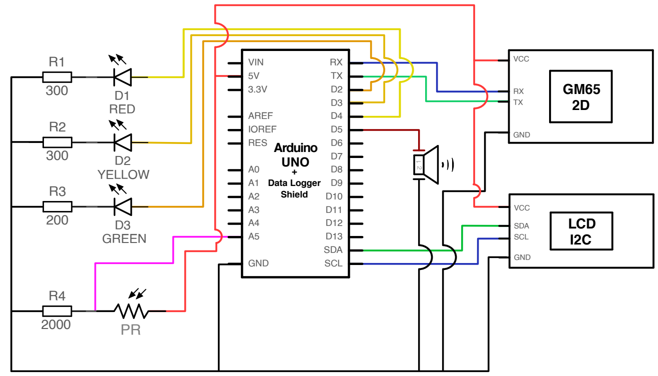


Figure 4: Circuital configuration of the device.

- **Photoresistor**: it is used to detect the fridge opening. Its implementation exploits a voltage divider with a 2kΩ resistor.
- **LED**: 3-color LED are used as a visual status message. In this case, resistors are used to implement the circuital part too.
- **LCD Screen**: as before, it is used to give the user visual feedback. The screen is composed by a 16x2 matrix of liquid crystals and uses an I2C communication interface. The current consumption of the screen is about 200 mA.

In the following, the input sensor of the device is described.

1) Barcode reader: The component that represents the strength of EXODIA is the barcode reader. The one implemented in this prototype is a GM65 2D Bar Code Reader. The sensor has been initialized defining the operation mode and other, that are summarized in Tab. I. The scan area of the

Table I: GM65 2D Barcode Scanner settings.

Settings Name	Setting Value
Baud Rate	9600 bps
Interface	UART
Break Time	2000 ms
Lighting	OFF
Prompts Tone	UP
Tail	Close

sensor (tested in an environment with a 250 lx brightness) is 34°, with a maximum detecting distance of 25 cm. The current consumption of the scanner depends on the operating mode: in the case of a continuous scan, it is about 160 mA, while in Standby Mode it drops to 30 mA. The bias applied to the sensor is estimated to be around 4.2-6 V.

In the end, the device is equipped with a 3D-printed external case, made by a Creality Ender 3Pro printer. The material used is PLA filament, for a total weight of 112 g.

B. Experimental results

After the description of the prototype in terms of sensors and features included, it is worth testing the implementation of the code, that has been developed following the algorithm illustrated in Fig. 2. In order to provide a concrete result about the efficiency of the code behind EXODIA, several experiments have been performed. In the following, the results are summarized and interpreted.

1) Confusion Matrix on Expiration Alert: The first kind of analysis that can be carried out is a statistical one to estimate the accuracy and precision of the expiration alert message. 100 products have been registered in the local storage and it has been saved the LCD message in case of expiration. The results of this experiment are collected in the confusion matrix shown in Tab. II. Also, from the confusion matrix, it is possible to derive some relevant quantities that are collected in Tab. III.

Table II: Confusion Matrix.

	Expired	**Not Expired**
Expired	50	1
Not Expired	1	48

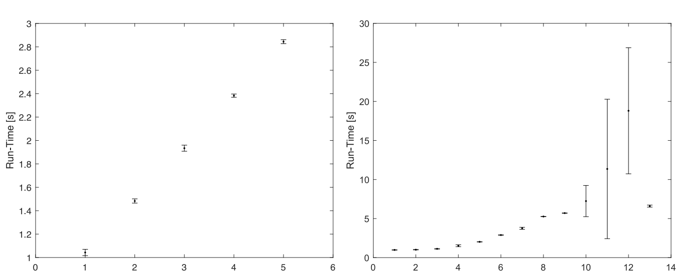
Table III: Relevant Quantities from analysis of confusion matrix.

Quantities	**Values**
Accuracy	98.0%
Precision	98.0%
F_1 Score	98.0%
Sensitivity	97.9%
Specificity	97.9%

2) Responsivity: The second part of the experiments consisted of the adjustment of the code in terms of time to analyze files stored in the SD memory. In fact, it is necessary that this value of time results smaller compared to the approximated time a person spends with the fridge opened. To adjust the time, it has been considered that, on average, the fridge will be open for about 5 seconds. It is worth noting, though, that it is sufficient for the device to react within this time for the first alert message: the following ones are negligible, because the user is supposed to stay longer once he has received the first message. Moreover, it is important to give an estimate of how the time of response depending on the number of items stored in memory and the number of products stored in the fridge. After the adjustment procedure, a set of 20 measurements have been carried out, and, considering a variable number of items, the results in terms of mean and standard deviation are shown in Fig. 5 and Fig. 6.

As predicted, the time employed by the device to check for the expiration of registered products is strongly dependent on the numbers of items store in the fridge and on the local database. Furthermore, as can be easily seen in Fig. 5b in the case of 13 products in the database a random error occur during the execution of the program that lead to an higer run-time and standard deviation.

Futher considerations after the analysis of the results have lead us to reconsider the implementation of the code. In fact, the previous version of the code included also the whole procedure of I/O instructions. It is common knowledge that these kind of processes are responsable for most of the memory overloads, which results in a larger runtime. To avoid this issue, the whole



(a) 5 products in Database. (b) 13 products in Database.

Figure 5: Code Run-Time in function of the items storage.

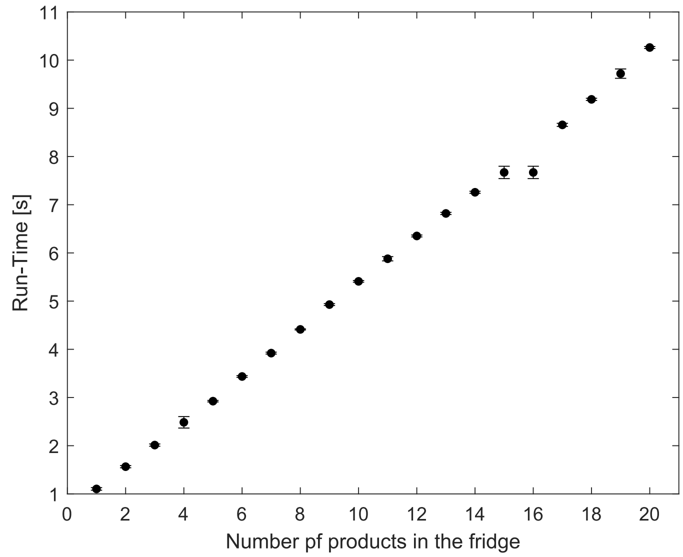


Figure 6: Code Run-Time in function of the items storage (20 products in Database).

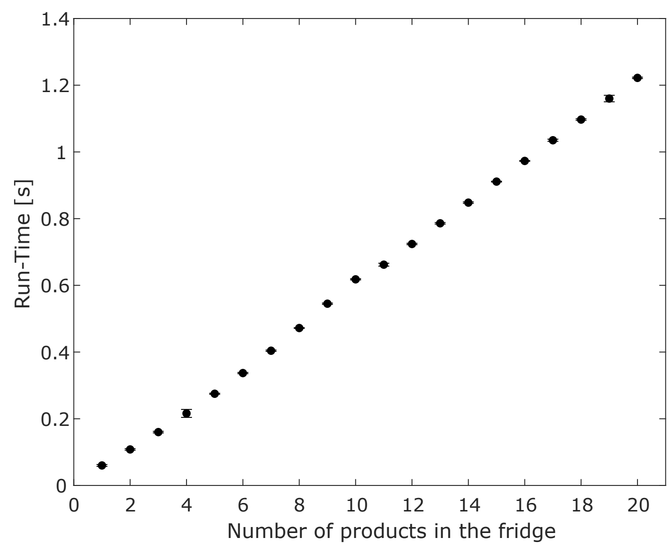


Figure 7: Code Run-Time in function of the items storage after code modifications.

procedure of the programm responsable of alerting the user has been reviewed, moving the I/O instructions out of it, and deleting all the unnecessary output messages (used during the debugging). The results are shown in Fig. 7, and it is clearly shown how this thin adjustment improved greatly the efficency of the device.

V. Conclusion

To conclude, let us recall what it has been done in this work: after having a better understanding of the food waste problem, several solutions related to our work have been analyzed, which resulted in pointing out that our product, despite all, represented the perfect compromise in terms of costs and ease of use; then, the description of EXODIA and his prototype followed, and all these information have been supported with the results of some experiments that have been performed to test the reliability of the device and its actual usefulness.

The prototype of EXODIA though, as it has already been stressed out in IV-A, does not represent the peak performance result of the original idea. Some improvements must be implemented:

- The first one is surely the management of items, which, in a better optimized product, would be performed exploiting cloud storage (instead of the SD local memory). This powerful tool would also result in the development of a mobile application, a secondary feature that would surely improve the user-friendliness of EXODIA, as already explained in III-B1;
- The employment of a constantly updated database of products, not economically accessible for the prototype realization (since those databases already exist, but they are created by private companies), and yet negligible in terms of cost when it comes to low/medium scale production;
- The development of an alternative barcode protocol, so that the expiration date is included. As it has been pointed out in III-C1, the modern protocol used by GS1 to generate barcodes takes the expiration date into account only for packaging unit (using the GS-128 protocol), while all the other units are labeled using the EAN-13 or EAN-8 protocol. The sooner this situation is reached, the better for EXODIA, which will have direct access to expiration date instead of a qualitative “best-before”.

Let us take now the results of the experiments that have been performed into account: as it has already been explained, under the proper adjustment, it has been possible to optimize the run-time of our device, in order to possibly manage a bigger and bigger database of products. The fact that these results have been achieved only by optimizing a prototype makes possible to say that EXODIA, despite its prototype nature, shows the ability to counter the problems we analyzed in I. Moreover, let’s consider all the aspects pointed out above in the paper. As discussed in detail in III-A and III-C, because of the working principle and the Meta-Algorithm implemented,and the ease of use together with the low costs of production and consumption, as well emphasized in III-A again, we believe that EXODIA would certainly be able to secure itself a place in the market.

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