RECODIFY – ENVIRONMENTAL MONITORING EMBEDDED SYSTEM

By

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This thesis is the result of my own work, and it has not been previously submitted for a degree at any other higher education institution. To the best of my knowledge and belief, this dissertation contains no material previously published or written by another person except where references are made. I responsibly declare that this is a true copy of my thesis, as approved by my thesis committee and the Graduate Studies office of Hellenic Mediterranean University of Crete.

Michail Angelos Lasithiotakis, 2021

Abstract

This thesis presents Recodify an Environmental Monitoring Embedded System (EMES) that can monitor, store, and analyze environmental data as well as calculate energy consumption in a specific environment.

Recodify consists of a microcontroller development board, sensors, and modules. We have designed and implemented a standalone appliance using a microcontroller, that can measure various environmental variables such as Temperature, Humidity, Light, Sound, Carbon Monoxide and Ozone levels as well as Current consumption. It has a build in motion detection and a relay module that gives us the ability to remote control the appliance. It can also support two types of connectivity using Wi-Fi and GSM protocols. Our standalone appliance can work as a unit or as part of a grid of appliances. In the case that we have the opportunity to equip a target environment, such as a room or floor with our device we could create a smart ICT grid of appliances. In a larger scale, we could monitor an entire building or even a building complex.

Furthermore, it aims to monitor spaces, analyze the collected data, determine and designate environmental spaces, in which human activities could be harmful. More specific, it can be used at world cultural heritage and archaeological places, building, constructions where allowance of human intervention is prohibited or very limited. Collecting and analyzing data could help us estimate the environmental consequences of human actions.

Once the appliance, gets connected, it starts collecting data from the environment. All data are transferred to the application server with timestamp and unique device ID. The data could be accessed by any authorized user through our dedicated software.

Our embedded system can be managed with the use of our Recodify application. It is a Web based application that provides central management abilities. It supports continuously monitoring with real-time graphs. Authorized users could observe current sensors values,

compare them with chronological order, and manage device settings and functionality of the appliance(s).

Moreover, through the Recodify application the user can: (a) run statistically diagnostics and analysis with the use of past and present data, (b) manage grid nodes and (c) intervene with the grid nodes (appliances).

Περίληψη

Η παρούσα διπλωματική εργασία παρουσιάζει το Recodify, ένα ενσωματωμένο σύστημα περιβαλλοντολογικής παρακολούθησης (EMES) που μπορεί να παρατηρεί, αποθηκεύει και να αναλύει περιβαλλοντολογικά δεδομένα, καθώς και να υπολογίζει την ενεργειακή κατανάλωση σε συγκεκριμένο περιβάλλον.

Το Recodify, αποτελείται από μία προγραμματιστική πλακέτα εξοπλισμένη με μικροεπεξεργαστή, αισθητήρια και εξαρτήματα. Έχουμε σχεδιάσει και υλοποιήσει μια αυτόνομη συσκευή χρησιμοποιώντας έναν μικροεπεξεργαστή που μπορεί να μετρήσει κρίσιμες περιβαλλοντολογικές μεταβλητές όπως θερμοκρασία, υγρασία, φωτεινότητα, τα επίπεδα του ήχου, του μονοξειδίου του άνθρακα και του όζοντος, καθώς και την κατανάλωση ηλεκτρικής ενέργειας. Διαθέτει ενσωματωμένο ανιχνευτή κίνησης και διακόπτη που μας δίνει τη δυνατότητα για τον απομακρυσμένο έλεγχο της συσκευής. Μπορεί να υποστηρίξει δύο πρωτόκολλα επικοινωνίας Wi-Fi και GSM. Η συσκευή μας μπορεί να δουλέψει ως αυτόνομη μονάδα ή ως μέρος ενός πλέγματος συσκευών. Στη περίπτωση που έχουμε την δυνατότητα να εξοπλίσουμε ένα στοχευμένο περιβάλλον, όπως ένα δωμάτιο ή ένας όροφος, με την συσκευή μας μπορούμε να δημιουργήσουμε ένα έξυπνο δίκτυο συσκευών (smart ICT grid). Σε μεγαλύτερη κλίμακα θα μπορούσαμε να παρακολουθήσουμε ένα κτίριο ή ακόμα και ένα συγκρότημα κτιρίων.

Επιπλέον, στοχεύει στην παρακολούθηση χώρων, την ανάλυση των δεδομένων που έχουν συγκεντρωθεί, καθώς και στο να καθορίσει και να προσδιορίσει τους περιβαλλοντολογικούς χώρους, στους οποίους οι ανθρώπινες δραστηριότητες μπορεί να είναι επιβλαβής. Πιο συγκεκριμένα, η συσκευή μας μπορεί να χρησιμοποιηθεί σε παγκόσμιας πολιτιστικής κληρονομιάς και αρχαιολογικούς χώρους, κτίρια, περιοχές όπου κρίνεται η ανθρώπινη παρέμβαση απαγορευμένη ή πολύ περιορισμένη. Η συλλογή και ανάλυση δεδομένων θα μπορούσε να μας βοηθήσει να εκτιμήσουμε τις περιβαλλοντικές συνέπειες των ανθρώπινων ενεργειών.

Μόλις η συσκευή συνδεθεί ξεκινάει η συλλογή των δεδομένων από το περιβάλλον. Όλα τα δεδομένα μεταφέρονται στο διακομιστή της εφαρμογής με χρονική σήμανση και με το μοναδικό αναγνωριστικό της συσκευής. Τα δεδομένα μπορούν να είναι προσβάσιμα από οποιονδήποτε εξουσιοδοτημένο χρήστη μέσω του λογισμικού μας.

Το ενσωματωμένο μας σύστημα μπορεί να διαχειριστεί με τη χρήση της εφαρμογής Recodify. Είναι μια εφαρμογή βασισμένη στο Web που παρέχει δυνατότητες κεντρικής διαχείρισης. Υποστηρίζει συνεχώς την παρακολούθηση με γραφήματα σε πραγματικό χρόνο. Οι εξουσιοδοτημένοι χρήστες θα μπορούσαν να παρατηρήσουν τις τρέχουσες τιμές των αισθητήρων, να τις συγκρίνουν με χρονολογική σειρά, να διαχειριστούν και να ρυθμίσουν τη συσκευή και τη λειτουργικότητα της.

Επιπλέον, μέσω της εφαρμογής Recodify, ο χρήστης μπορεί: (α) να διεξάγει στατιστική διάγνωση και ανάλυση με τη χρήση παλαιών και σημερινών δεδομένων, (β) να διαχειρίζεται κόμβους δικτύου και (γ) να παρεμβαίνει στους κόμβους του δικτύου (συσκευές).

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Dedication

My bottomless appreciativeness for their love and many years of supporting goes to my precious mother, Aikaterini and to my beloved father George. So countless thanks for being patient, always next to me and encouraging me during my entire journey in life. Also, I would like to express my gratitude to my brother Nikolas for his persistence that I should participate in the postgraduate process. So, a monumental thank to my family for believing in me when I did not do so myself.

Dedicated to the person who was the source of inspiration for me and left early from life

My beloved father George

Chapter 1: INTRODUCTION

Human life is inseparably bounded with natural environment. It is a crucial factor that affects the balance of the ecosystem. Our ecosystem consists of both living organisms and non-living elements. Aiming to coexist in harmony, living organisms seem to interact, among themselves, with the natural environment. This coexistence is a major field of research in natural, human and environmental sciences. For the scientific community living organisms are defined as the biotic factors and the non-living are defined as the abiotic factors. Thus, the structure and the functionality of the natural environment depends on biotic and abiotic factors.

The biotic factors distinguished in three categories. Producers are the organisms that can generate their own energy, in our ecosystem these are the plants. Consumers such as humans, animals, and insects, which feed on plants or other organisms and the decomposers the known fungi and bacteria which are feed on the decaying organic matter and convert it on abiotic components. On the other hand, soil, water, wind, solar radiation, light, sound, temperature, humidity, minerals and compounds such as oxygen, ozone, carbon monoxide and dioxide, liquid petroleum gas and organic compounds, such as proteins, carbohydrates, ketones and vitamins compose the abiotic factors [1]. In this biogeochemical cycle, energy is the key component of life. Plants produce energy with the use of abiotic factors. Humans and animals, as biotic factors, consume other organisms or plants in order to generate their energy then the fungi and bacteria decompose the residues, back to abiotic factors. This vicious circle of life declares the importance of biotic and abiotic factors in our ecosystem.

The bidirectional interaction between the biotic and abiotic factors is extremely fragile. Despite the fact that the limits of our ecosystem are not clear enough, these complexes set of interactions can be affected. A change or a removal of one of these factors can lead the entire system to collapse. Among the biotic factors, consumers, and especially humans are the major threat to our ecosystem [2]. Nature, air and water pollution, global warming, climate change, ozone depletion, acid rain, the extinction of the species, genetic modifications are the result of human impact to the ecosystem. The disposal of the industrial, toxic, chemical and radioactive waste produces an unfriendly-to-life-environment. Overproduction has exhausted the hitherto known assets of the environment, while human intervention in shaping life conditions has changed its image and disturbed its balance, thus the planet's resources have suffered immeasurable wasting [3].

The Greek Constitution considers “the need to actively protect the environment and planning in a sustainable manner to be an obligation of the State (article 24). In this way environmental protection is placed within the constitutionally protected human rights. This principle guides all legal approaches to the matter, legislative and case law. At the same time, as also set in the Greek Constitution, the State must secure social peace and must plan with the aim to ensure economic and regional development and take all necessary measures to utilize all sources of national wealth (article 106). Both, environmental protection and economic development, being in need for protection, they must co-exist as envisioned by the principle of sustainable development” [4]. According to the most recent press release of The Hellenic Statistical Authority (ELSTAT) the waste volume that have been generated during the 10-year period, escalated from 33.3 million tons, in 2004, to 69.7 million tons, in 2014. The percentage distribution of waste has increased two times, approximately 109% [5].

Globally, government agencies, individual organizations, universities, political parties and ecological groups are trying to handle this problem. Technology evolution acts as a major ally in this battle. Even though technology is the primary cause of environmental pollution, since it’s the key to material processing which turn into waste, it may eventually provide us solutions to our environmental disturbances. The imbalance of the natural environment strongly affects human existence [6]. Thus, scientific communities over time are developing new models and techniques to monitor, analyze and control it. Providing us all the means in order to identify the source of environmental problems, collect environmental data and examine current methods for possible alternatives. The process that is used to characterize and monitor the quality of an ecosystem usually referred as Environmental Monitoring, in abbreviation EM. Many researchers have implemented Environmental Monitoring Systems (EMS) that involve industrial, municipal, and environmental use. The core of an Environmental Monitoring System is the data. The continuous sampling of abiotic factors such as pollutants in soil, atmosphere and water can detect and determine vital issues and changes in the behavior of biotic factors [7].

The main objective of an Environmental Monitoring System is to assess the state of the natural environment in the area which falls, optimize the design of spatial management measures, application and future evaluation and redefinition of the various management practices to be implemented. Environmental monitoring, combined with an implementation of an alert system, contributes to identifying the main threats.

1.1 Purpose and Objectives

Nowadays, an increasing sense of environmental awareness is developing. There is a growing demand for new technologies that should detect and quantify the sources of pollution immediately. This dissertation will present a new environmental monitoring system, namely Recodify, that can monitor, store and analyze environmental data as well as calculate energy consumption, in any number of environments. The purpose of this system is to provide an environmental monitoring tool that can help us understand the natural environment, in which human activities could be harmful. Recodify aims to determine, describe and record ambient space's conditions and provide appropriate intervention means to enhance environmental conditions. In details it will monitor areas, analyze data and intervene depending on the data analysis' results. Furthermore, due to its non-intrusion design philosophy it is appropriate for use at spaces where human intervention is restricted or very limited such as world cultural heritage sites and archaeological places.

Depending on concrete application environmental monitoring could lead to many practical advantages such as data gathering, decision making and prediction. Nevertheless, there are three major objectives in each environmental monitoring process. First is the collection of the meaningful and relevant, to the environment, data. Second, is to estimate the changes in levels of the pollutants and third, is to alert or provide recommendations for improvement. Once these objectives have been achieved, we can improve the state of environment as well as to prevent or suspend disasters and health hazards.

1.2 Volume Overview

This dissertation is structured in seven chapters. Chapter 1, Introduction, provides the purpose and the objectives of this thesis. Chapter 2 presents the motivational theories and factors, which are combined for this dissertation. Chapter 3 discusses, in detail, the state of the art and the related work in the topic of environmental monitoring. Chapter 4 presents the Recodify system design providing the architecture model and unified modeling language diagrams. Chapter 5 introduces the Recodify system implementation describing the device, the web application, and the database that our system uses. Chapter 6 presents in detail a use case scenario of Recodify in real life situations. Chapter 7, this final chapter concludes the dissertation and discusses the results and the future work.

Chapter 2: MOTIVATIONAL THEORIES & FACTORS

This chapter discusses the two factors that motivate the research undertaken in this MSc thesis. Firstly, there is a dearth of research on the use of Information and Communication Technology on predicting changes in abiotic factors that affect our ecosystem. Secondly, there is a need to enhance the Wireless Sensor Network intervention in Internet of Things architecture. The following four sections discuss the motivational theories driving the research reported in this thesis and its potential benefits.

2.1 Information and Communication Technology

Information and Communication Technology, in abbreviation ICT, generally refers to the state-of-the-art technologies, analysis, storage, processing as well as communication of information. Information is assigned to data which can be recorded, organized and interpreted within a context. Communication is typically the transfer of ideas and among persons through different systems, devices, or media, such as computers, smartphones, or internet etc. Technology is defined as design, modification, adjustment and management of tools, techniques, methods, systems, or machines for the purpose of solving problems or achieving in a less time period [8]. The fundamental concept of ICT comprises of different communication devices or applications. It is a global phenomenon which organizes and control human activities that combines the Information and the Communication technologies [9].

The importance and positive influences of ICT can be seen in various areas such as education, health, environment, training, employment, business, military, or government. The role of ICT in society is further explained with the help of various applications. These applications enable humans to communicate with each other with the use of a computer or a smartphone through the internet. The most significant achievement of ICT is the computer which has gained a boundless influence in our society. Computer and Internet are inseparably bounded together. Through the internet people can improve their interaction with the whole world which can be beneficial.

There are many advantages, using Information and Communication Technology in society. One evident benefit is communication since information is transmitted all over the world without restrictions. ICT improves the cost-effectiveness and productivity of any business assisting employees to communicate with customers or partners and to prepare or transmit documents and files [10]. ICT provides a connection link between different cultures exchanging ideas and educating both sides. It also provides new job position since information technology requires software, hardware, and web developers as well as computer scientists to evolve telecommunications. Last but not least, ICT has a crucial role in education, giving new technologies such as e-learning and digital classrooms, encourages students to collaborate and improve their skills.

On the other hand, using ICT has obvious disadvantages in society. Using the computer systems and robotics in industrial sector increase the unemployment rate, since companies replace human resource to save money. Social media, communities and forums provide users the ability to spread information quickly to others without confirmation of its truth disposing users to misinformation and mislead. Users’ mental and physical health is affected since they adopt violence behavior that enhance cyber bulling and depression. Another detrimental effect of ICT is digitizing personal data compromising users’ privacy and security issues [8].

2.2 Wireless Sensor Networks

Wireless Sensor Network, in abbreviation WSN, is a key component which enables ICT convergence to be realized. In Computer and Telecommunications science, Wireless Sensor Networks have become a leading area of research. Sensor nodes can sense and detect the changes of abiotic factors in any number of environments to forecast disasters before they occur. It is a distribution of several devices, generally battery-powered and wireless infrastructure, equipped with sensors that perform a collaborative measurement process [11]. Wireless sensors can be used where wire-line systems cannot be deployed.

The Wireless Sensor Network architecture consists of numerous nodes, gateways, and its software. Each node consists of several sensors that are connected to a microcontroller and a power supply unit. Nodes' size and cost constraints have as result energy, memory, computational power, and communication bandwidth restrictions. Using the proper WSN communication topology, each node is connected to each other or direct to a gateway, which provides a node-grid interconnection, where data are collected, processed, analyzed, and presented using a dedicate software. Depending on the environment, the selection of the WSN's type variates [12]. There are five main types that can be deployed including terrestrial, underground, underwater, multimedia, and mobile WNSs [13].

There are many advantages on Wireless Sensor Networks. The ease of use, WSNs are released with dedicate user-friendly software. The lack of internet infrastructure, these networks could stand without internet connectivity. The nodes' scalability, the ability to extent on a larger scale by adding new nodes to the hub. The nodes' mobility, the ability to address failures of the hub, the heterogeneity of its nodes and the ability to withstand in harsh environmental conditions are some of strong characteristics of a Wireless Sensor Network [11] [14]. On the other hand, there are disadvantages of a WSN include the power harvesting, since they have batteries with a finite time, the little storage capacity, the low processing power and the short communication range, that consumes a lot of power [15] [16].

2.3 Internet of Things

Internet of Things, in abbreviation IoT, is a communication network for a variety of devices, home appliances, cars, and any other object that incorporates electronic media, software, sensors and network connectivity to allow connection and data exchange. More simply, IoT's philosophy is to connect all electronic devices to each other in a local network or to the internet [17]. IoT involves everything that can be connected to the internet, and it contains among the other technologies, the Wireless Sensor Networks. As a subset of IoT these WSNs works as the bridge that connects the real world to the digital. With the use of WSNs, Internet of Things can “sense” real world’s parameters, such as abiotic factors and make meaningful interpretation and even make decisions based on the sensed data [18] [19].

The Internet of Things architecture consists of four total layers. These main layers are the Hardware, the Gateway, the Data Process and the Software layer. Each one of them can be detected in any IoT implementation. The lower layer, Hardware layer, consists of two components sensors and nodes. The Gateway layer, establish the connection link between the nodes. The Data Process layer, analyzes, stores and prepare the collected data, and finally, the Software layer integrates a user interface which provides all the functions needed to present the data and perform a task [20] [21] [22].

There are many advantages, using Internet of Things in our daily life. On financial aspect, IoT improves the cost-effectiveness and productivity of any business. The provided automation process is replacing human intervention with the precision of multi-functional computing systems. One evident benefit is the easily access to data and information through its network of devices around the globe. IoT can save amount of time by managing humans’ everyday tasks. The more the information provided, the easier it is to make the right decision [23].

On the other hand, using IoT has obvious disadvantages in everyday lives. Nowadays, each device is connected through the internet, which increases the privacy and security issues of an IoT architecture. Leakage of data in third parties may have catastrophic consequences. The complexity of these networks, that contains billions of devices, can be affected and force entire system to collapse [24]. In today’s tech-driven world, each task is being automated. As a result, the human resource is being reduced and replaced with computational systems, affecting employability [25] [26].

Despite the crucial disadvantages, a recent Gartner's report estimates that, there will be 20 billion internet-connected "things", growing at a rate of 32% per year [27]. The applications of IoT are numerous, since it is a flexible technology that is capable to adjust itself in any environment. Many companies on the Internet of Things field are adopting this technology to facilitate, improve, enhance, automation and control internal processes. The most trending case of IoT use is smart homes and their related products. They promise to save homeowners' time, energy, and money as well as to provide convenience and security. Smart cities with smart grids and buildings, are another example of IoT use. They provide an infrastructure of renewable energy production, reducing the emissions and enhancing the sustainability of the city [28]. Another topic of interest is the wearable devices. These small and portable devices are equipped with an appropriate hardware and dedicated software in order to collect data about users that can be used in entertainment and health care [20]. The Industrial internet with smart factories and farms provides an advanced use of IoT. Automation systems in these processes can reduce the cost, heavy labor, tedious tasks and sources' wasting. It creates a controlled environment where tasks are done with more accuracy, precision and speed [29]. IoT is affecting the global economy. Providing us the Smart economy, with smart retail and supply chains, it establishes new business models improving their productivity and efficiency and encourages the commitment between customers and business [27].

2.4 Smart Grids

More than a hundred years ago, our needs for electricity gave birth to current electric grid. Powe plants were built around communities. Most of the houses had small energy demands like a couple of bulbs and small appliances. The power grid architecture was designed for power plants to deliver electricity directly to houses. This restricted single direction interaction weakens grid's p ability to meet the demands of the 21st century.

The Smart Grid is and intelligent, digitized energy network delivering electricity in an optimal way from source to consumption [30].

It provides a bidirectional communication where electricity and the information can be exchanged between the power plant and houses. It is an expanding grid of technologies and tools that coexists in order to manage and control the network. This Smart Grid enables new communications and automations to be integrated providing more stability and reliability to the grid. This Smart Grid implementation aims to change the hitherto power infrastructure, providing corresponding solutions consumers’ electricity needs [31]. The smart grid can be considered as a modern electric power grid infrastructure for enhanced efficiency and reliability through automated control, high-power converters, modern communications infrastructure, sensing and metering technologies, and modern energy management techniques based on the optimization of demand, energy and network availability [32]. The smart home communicates with the grid and enables consumers to manage their electricity usage. Inside the smart home, a home area network connects smart appliances, thermostats, and other electric devices to an energy management system. Smart appliances and will adjust their run schedule to reduce electricity demand on the grid at critical times. These devices can be controlled and schedule over the web or even a smartphone [33].

Chapter 3: STATE-OF-THE-ART & RELATED WORK

In this chapter we present a range of wireless sensor networks (WSN), smart electricity grid of appliances and Internet of Things (IoT) applications, such as health-care wearable technologies, industrial and building applications, disaster and pollution management and environmental monitoring systems. In more detail, we cite the relevant work that is developed in global scale as well as in Greece, on real-time, ambient-space-conditions monitoring, visualization, and appropriate intervention means. Specifically, we highlight the main features, as well as advantages and disadvantages and we analyze key factors such as data capturing, storing, data visualization, sampling times and precision of each sensor, the response time of databases and finally the presence of a user interface.

3.1 Range of WSN Applications

The applications of WSN are widespread including smart buildings, transportation and logistics, precision agriculture and animal tracking, intelligent sensor networks, weather prediction systems, physical security and surveillance, healthcare and medical diagnostics, smart grids and energy control systems, industrial and environmental monitoring [34] [35]. In agriculture Wireless Sensor Networks used for monitoring, temperature measuring, irrigation system and water supply measuring. WSN helps the farmer to produce the crop with high quantity and reduce the cost of yield [36]. This technology can be installed, with no harm to environment, on soil moisture monitors, to allow farmers to instantaneously access information on the actual soil moisture needs of their fields. Farmers can then use wireless technology to switch off their irrigator remotely to adjust to the crops' water needs [37]. In military application WSNs used for intrusion detection, target surveillance, communication systems, habitat monitoring, chemical sensing, infrastructure security and inventory [38]. In electric power industry the implementation of smart grids uses the WSN as a communication system. WSN is applied in condition-based maintenance, smart metering, smart-home, distributed bus protection of power networks and disaster prevention [39].

In the following subsections we will present some applications of the Wireless Sensor Network in Health Care, Industrial and Building Management, Disaster and Pollution Management and Environmental Monitoring Systems in global scale as well as in Greece.

3.1.1 Wearable and Health Care Monitoring

Wearable technology is the most common implementation of Wireless Sensor Network. Smart watches, fitness trackers and other bracelet wearable can be characterized as nodes that can track position and daily steps, exercise and fitness levels, heart rate, and even sleep schedules of the user. Rapid technology evolution could provide us solutions in the healthcare industry, specifically in hospitals. Medical employees use health care practice supported by electronic devices and information and communications technologies [28]. The combination of technology and health care gave birth to e-Health which includes electronic medical records, electronic prescriptions, remote monitoring, and health knowledge management. In the e-health context, wireless body sensors are small biomedical devices that are placed on the human body or are hidden under clothing to keep a remote monitoring of patient vitals and conditions, to increase efficiency of treatment and to reduce time gathering health data to make an early diagnosis [40].

Another application of WSN involves health and safety products to be available to any employ. In a company with thousands of employees, health and safety devices needs maintenance or replenishment and that requires significant amount of time to continuously check that their health and safety systems are maintained according to legislation requirements [41].

3.1.2 Industrial and Building Applications

In almost every field of industry production and building management, Wireless Sensor Network is the key element for all application scenarios.

Systems such as [42], [43] and [44] present building management solutions that can provide significant advantages in order to face some unexpected scenarios in the operating conditions. Living in a smart building often makes also significant demands on the occupants who are required to drastically change some of their habits This versatility may optimize users experience, reduce the energy consumption, improve the air quality and manage the environmental impact during building lifespan.

From industrial point of view, there are numerous applications of WSNs. Agriculture implementations such as [36], [45] and [46] improving the quality and productivity. They propose a system for each step of agricultural cycle, from the growth to the harvest and the storage of a crop. These activities include loosening the soil, seeding, special watering, moving plants when they grow bigger, harvesting and storing them in conditions to last more.

Michael J. O’Grady and Gregory M.P. O’Hare propose a smart farming models focused on providing the agricultural industry with the infrastructure to leverage advanced technology including big data, the cloud and the Internet of Things (IoT) for tracking, monitoring, automating and analyzing operations [47]. O. Debauche et al, focused in honeybees monitoring with the use of an IoT implementation. Honeybees are important crop pollinator which plays a significant role in the ecological system and the global industrial crop [48].

In industrial manufacturing, Agnieszka Radziwon et al. proposed a unified definition of a smart factory concept and its potential applications. According to authors view, the smart factory is a manufacturing solution that provides flexible and adaptive production processes that will solve problems arising on a production facility with dynamic and rapidly changing boundary conditions in a world of increasing complexity [49]. The WSNs that applied in the industrial manufacturing must be capable of rapidly adapting, to change, and support the flexibility and the responsiveness that system requires [50].

3.1.3 Disaster and Pollution Management

Alongside population growth, increasing environmental pollution is one of the greatest challenges facing us today and will entail scientific, political and social consequences around the world [3]. As K. Bakker et al stated, “environmental pollution is the introduction of contaminants into the natural environment that cause adverse change. Pollution can take the form of chemical substances or energy, such as noise, heat, or light. Pollutants, the components of pollution, can be either foreign substances/energies or naturally occurring contaminants. Pollution is often characterized as point source or nonpoint source pollution” [51]. As defined in [52], “the major forms of pollution include air pollution, light pollution, litter, noise pollution, plastic pollution, soil contamination, radioactive contamination, thermal pollution, visual pollution, and water pollution”.

Wireless Sensor Networks can’t stop disasters from happening, but can be very useful for disaster preparedness, such as prediction and early warning systems. In this way WSNs can compensate for a poor human infrastructure that puts any ecosystem in a particularly vulnerable position. In research filed there are numerous of IoT implementations base on WSNs [53]. For each pollution form, there is a research with a counter measure in order to predict, monitor and control the disaster.

Panu Maijala et al. presented an autonomous and a low-cost sensor implementation with a connection to a cloud service that monitor the environmental noise by separating between the target and interfering noise sources and implementing this approach to the sensor level [54]. Authors in [55], focus their work on a survey with particular emphasis on water quality. Various WSN based water quality monitoring methods suggested and analyzed, considering their coverage, energy and security concerns. Since indoor air pollution has become a serious issue affecting public health, Oluleke Bamodu et al, propose a low-cost system to monitor the thermal and humidity conditions in the indoor environment. Their analysis concludes that appropriately monitoring and reporting on indoor environment conditions helps to ensure appropriate application of control measures that leads to efficiency energy management [56].

3.2 Environmental Monitoring Systems

Environmental sensing has been the basic WSN application, since WSN appeared in industrial processes. Environmental Monitoring System is one of the most compelling industrial IoT applications driving operational transparency and efficiency. Across a variety of industries such as manufacturing, mining oil and gas, and agriculture, monitoring and managing environmental conditions such as air quality, water quality and atmospheric hazards is critical to prevent adverse conditions that may impact production process, product quality, equipment and worker safety [57]. However, unlocking the power of environmental data requires the sensor network enabled by robust, scalable and cost-effective connectivity. Wireless Sensor Networks are the ideal choice for connecting ambient sensors providing the extensive coverage and indoor penetration needed to cover vast areas and reach previously inaccessible locations [58].

Environmental Monitoring system is one of the tools in environmental engineering. It combines the process and the activities needed to take place, to characterize and monitor the quality of environment. It can detect improvements or degradation in the health of ecosystems in which human activities carry a risk of harmful effects. The environmental monitoring combined with enforcement ensures proper functioning of environmental protection measures prescribed for development activities. It also allows the early identification of potentially significant effect.

S. Bisoi et al. [59], presented an implementation of a wireless sensor network, namely iSENSE, which fulfills the common requirements of most monitoring applications The iSENSE architecture provides a platform for sensor data collection, storage and visualization, enabling the abilities of remote environment monitoring system.

All the above projects adopt the most common WSN architecture, following the OSI model. Physical Layer provides the communication channel, sensing and signal processing. Data link Layer provides channel sharing (MAC), timing, and locality. Network Layer includes adaptive topology management and topological routing. Transport Layer includes data dissemination and accumulation, caching, and storage. Finally, Application Layer, provides application processing, data aggregation, external querying query processing and external database.

3.3 Environmental Monitoring Systems in Greece

Greece's rich natural environment is a key factor in country's economy and provides many ecosystem resources such as drinkable and irrigation water, food; habitat for biodiversity, tourism and recreation, etc. but is constantly under increasing pressures due to rapid urbanization, industrial and agricultural escalation, inefficient energy generation and tourism expansion. Humans, animals, air, water, soil, forests, coasts, protected areas and sensitive ecosystems are experiencing serious environmental problems due to unplanned and careless development over the last 50 years [60].

Individual companies in Greece, such as [61] and [62], focus on developing real life environmental hardware and software solutions and providing specialized environmental consultation services. In research field, Mr. P. Papageorgas et al. presented the architecture of Polytropon based on Wireless Sensor Networks. It is an open-source scalable platform for the smart grid, that aims at the remote energy monitoring of appliances in real-time using web technologies. The Polytropon platform is designed as a research tool for experimenting with the various hardware and software components that can be integrated in the nodes [63].

3.4 Requirements of an Environmental Monitoring System

Implementing an Environmental monitoring tool has to comply with several requirements. Regarding the architecture of Wireless Sensor Network implementation, this subsection presents the demands of each approach starting with the measurement requirements, node requirements, gateway requirements, cloud infrastructure requirements and user interface requirements [64].

Measurement requirements The measuring instrument must be capable of completing the measurement task adequately. Long-term stability. The long-term stability of a measuring instrument is crucial for ensuring high process reliability at all times.

Node requirements The node must be autonomous, so the device operates independently and energy-wisely. It must provide reliability in order to prevent packet loss and it must provide flexibility in order to be able to add, move or change nodes, depending on the requirements.

Gateway requirements The keep-it-simple principle in these cases is the most common way, collect the information and send them through the Internet to dedicate cloud infrastructure.

Cloud infrastructure requirements The cloud must be able to gather the proper information from multiple gateways and visualize them with proper form to the end-users (measurement unit /time). Cloud must be able to grand access to database stores for the authenticated nodes and users. It must provide access to the data distributed over the web application including an optimal way to query and fetch the relevant information from the database.

User-side requirements A web-based application must be provided with a user-friendly interface. It must have an authentication clearance mechanism in order to login to the application. It must provide a mechanism to query metrics as per their dimensions. It must provide the collected data to the user or visualize them with proper graphs. User must have the ability to manage or intervene through his nodes.

Therefore, these requirements are essential when deploying a WSN in order to implement a stable monitoring system [65]. As defined in [34], nodes have to manage the resource limitations like power consumption, limited computation power and memory. bandwidth constraints and measurement reliability. Architecture limitations are application dependent and depend on the monitored environment.

In the following chapter, comparing related work with our approach, we implement a node design with low-cost hardware and a compact structure [66]. Each node can work individually, and store collected data to a real-time database. A web-based application has been developed supporting continuously monitoring, node management and intervention, data visualization and an alert mechanism to notify users when sensors detect anomalies. In the following section we are going to present our system design architecture and pilot development.

Chapter 4: RECODIFY: THE SYSTEM DESIGN

This chapter present the analysis, the design and the development of the Recodify system. It is divided in two main subsystems, a) the recodify web-based application and the recodify device. Both of them interact with the same real-time database to authenticate users, save and retrieve data (Figure 1).

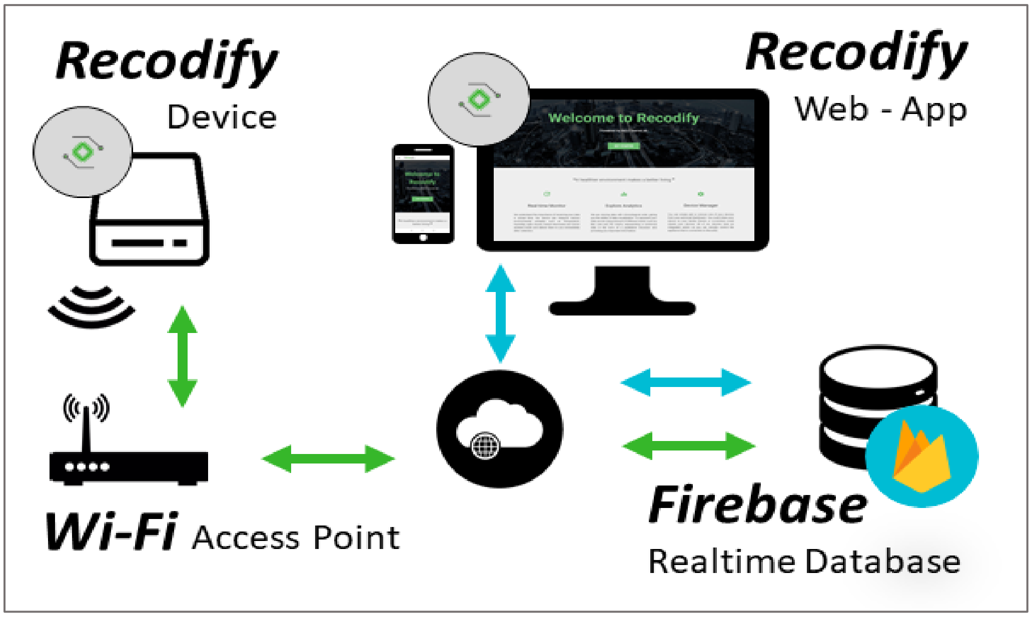

Figure 1 - The Recodify System

4.1 Architecture Model

The Client-Server model is a multitier development structure that exchange information between two parties, the data providers, called servers and the data requesters, called clients. In this bidirectional architecture when the client request for data, servers accept the requests and reply with corresponding data back to clients. The Recodify system structure is based on Client/Server Architecture. It consists of three main constituents: a) the software that controls Recodify and is implemented with Web-based technologies, b) an embedded, in Recodify, NodeMCU Microcontroller, and c) a repository for all necessary data that is implemented with Firebase. The web-based application acts as a client that sends requests to the NodeMCU platform and to the Firebase database which acts as a server.

4.2 Class Diagram

Recodify's static structure diagram, that describes the structure of its system by showing the system's classes, their attributes, operations (or methods), and the relationships among objects, is presented as follows (Figure 2).

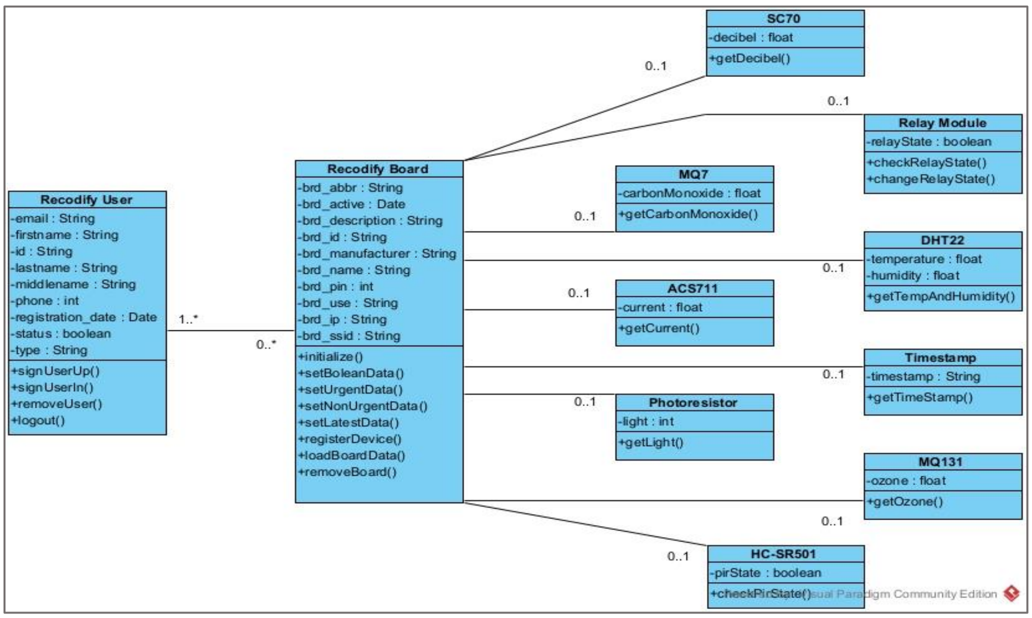

Figure 2 - Class Diagram

4.3 Use Case Diagram

The following subchapter presents the basic use cases and their diagrams which describe the functionalities of the developed system (Table 1 - Use Case & Scenarios). Those use cases revealed the required functions that had to be implemented in the system and led the development of the web-platform. A user when he is successful logged in, can navigate at the dashboard page from where he can monitor his devices.

Table 1 - Use Case & Scenarios

Use Case	Scenarios
Register a New Device	Sign In Register a New Device
Remove a Device	Sign In Remove a Device (required: Register a New Device)
Explore Analytics	Sign In Monitor Device (required: Register a New Device) Explore Analytics
Remove Common User	Sign In (required: Administrator) Delete User

One basic procedure of the system is the device registration (Figure 3). A singed-in user can register a new Recodify device through his dashboard, where an add button is available. By clicking this button, a form is popped up with the required fields. The user must fill the MAC address and the PIN code of the device. A system mechanism will validate user's input data, if they are correct the Recodify device will be available in user's dashboard. From there user can monitor the device and explore further analytics. Common users can also manage their devices from their profile page. On the other hand, administrators from the same page can manage common users and their devices.

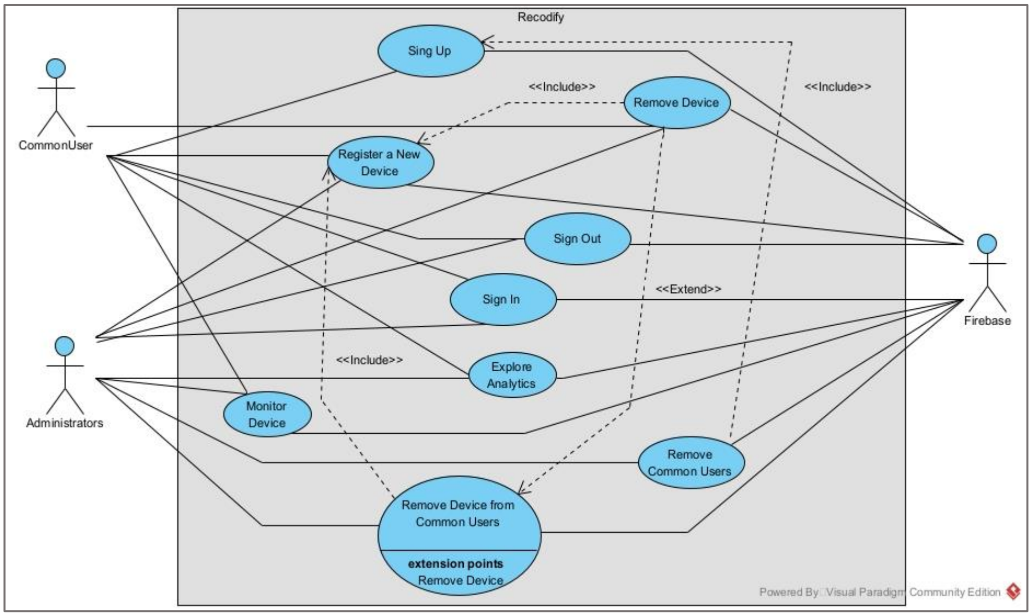

Figure 3 - Use Case Diagram

4.4 Sequence Diagram

In the following diagrams describe the sequence of the procedures that are available to user in order to fully access the web application capabilities. Loading the main page on Recodify’s web application, user can register a new account to Recodify service. Once the registration process complete, user can sign into his account. The interface provides a form with certain fields. The username and the password have to fulfilled correctly in order firebase validation mechanism accept his request. If the credentials are correct the user will be redirected to his dashboard, otherwise if firebase reject his request, he will be informed about the error that occurred and the fields of username and password will be reset (Figure 4).

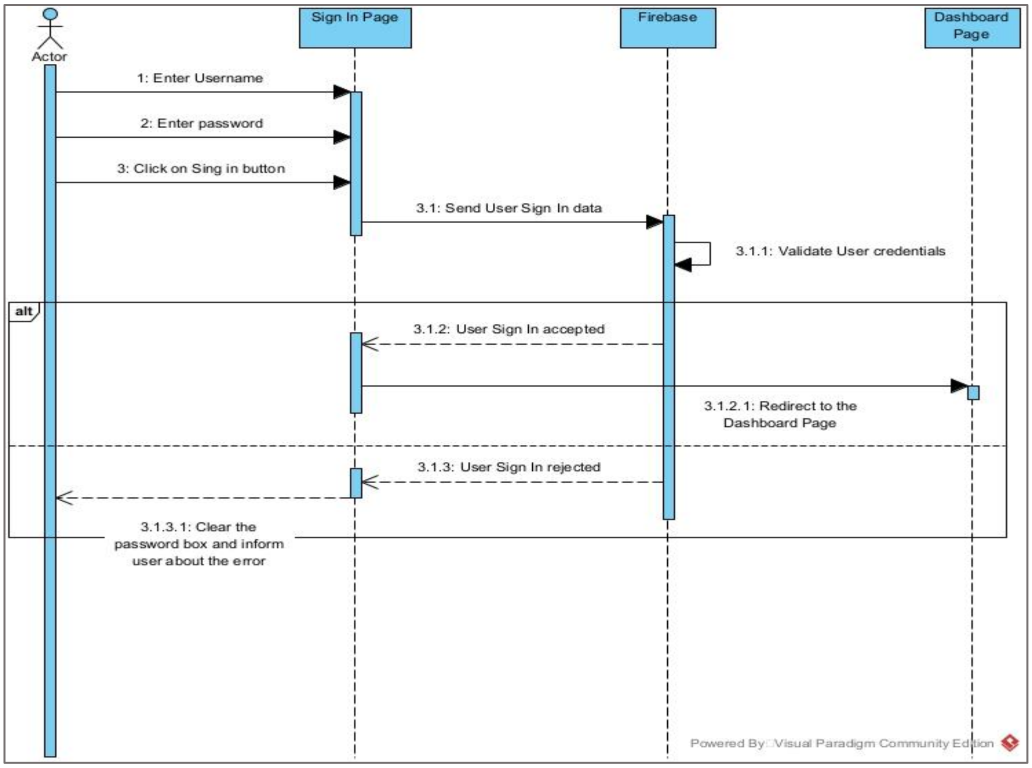

Figure 4 - Sign In Sequence Diagram

Once the sign-in procedure completes, user will be redirected to his dashboard. On this page user can register his first device to his account. Using the add "+" button a form with certain fields will appear. The MAC Address and the PIN code have to fulfilled correctly in order firebase validation mechanism accept the device registration. If the credentials are correct the popped-up form will close and the device will be appeared to his dashboard, otherwise if device registration rejected, user will be informed about the error that occurred and the fields of MAC address and PIN code will be reset (Figure 5).

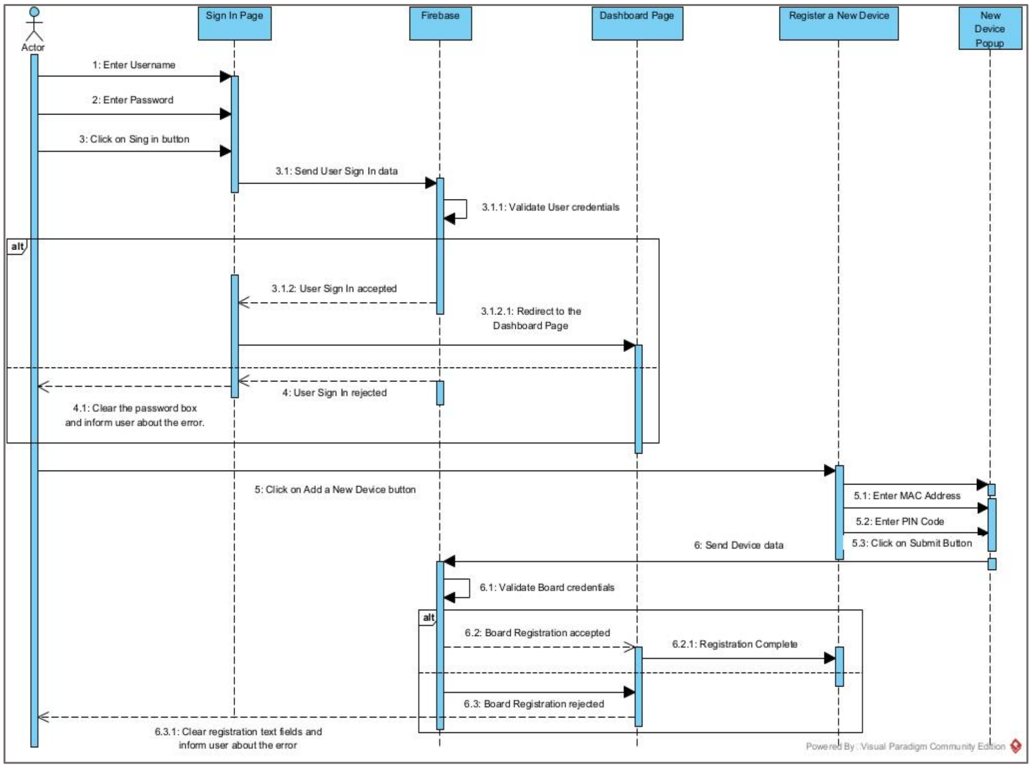

Figure 5 - Register a New Device Sequence Diagram

Assuming that user has logged in our service and at least one device is already registered to his account, user can manage his devices. On Profile page, under the Recodify Boards section, all user devices are listed. Using delete icon, user can remove the selected device. A pop-up will appear asking for delete confirmation. By submitting the delete request the device will be removed from user’s dashboard. As long as the PIN code remains the same, user can always add this device back to his account or shared it with another user (Figure 6).

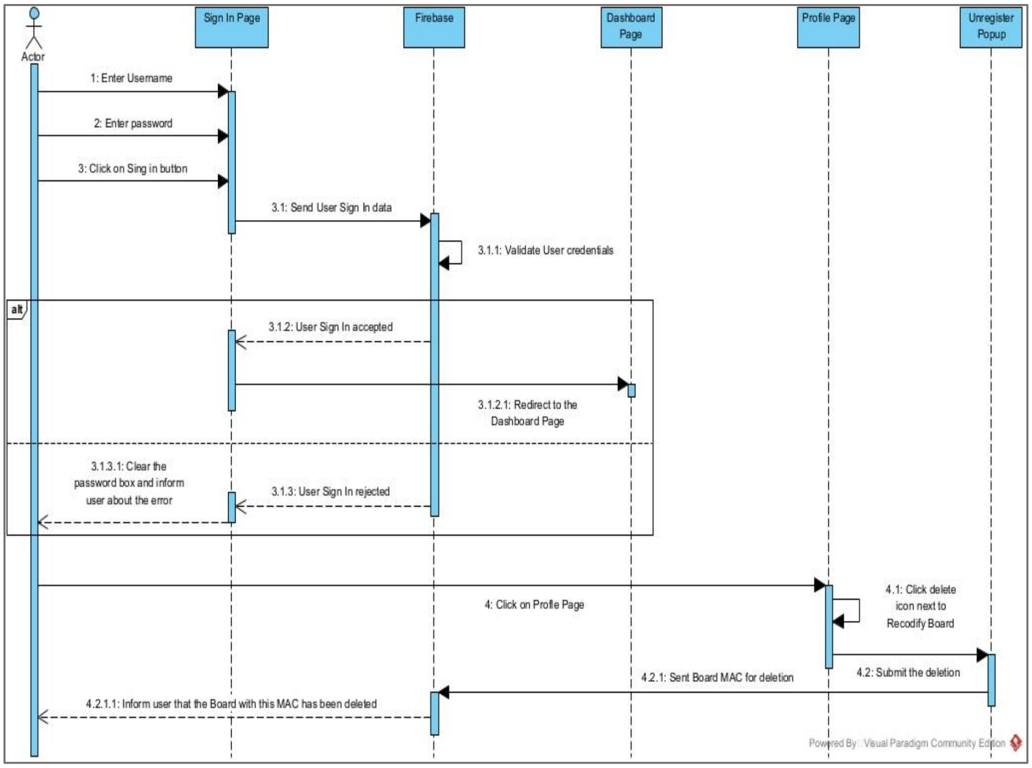

Figure 6 - Remove Device Sequence Diagram

When the user registers a device, he can monitor in real time the data that it captures. In order to monitor data in a specific period of time, he has to use the explore analytics button. A form with certain fields will appear, user has to select the starting date and time, the ending date and time and which sensors and modules he wants to visualize. By submitting the form, a client-side mechanism will collect all data matching users’ conditions and will present the results back to user, with a proper graphical presentation (Figure 7).

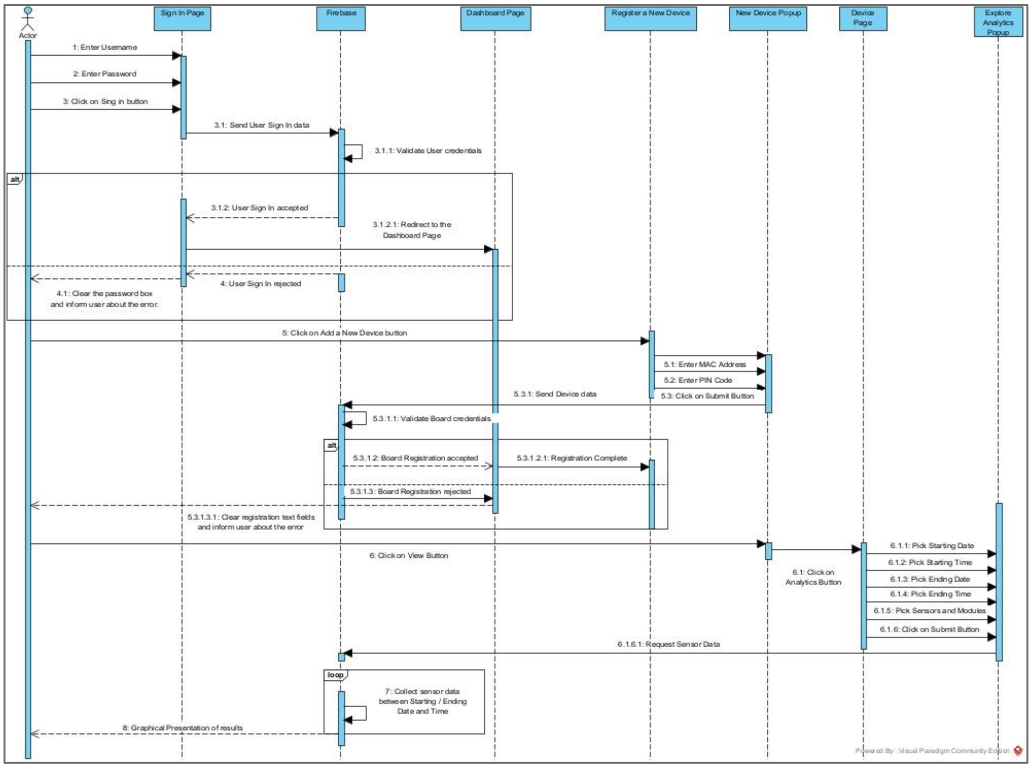

Figure 7 - Explore Analytics Sequence Diagram

Chapter 5: RECODIFY: THE IMPLEMENTATION

We have designed and implemented a standalone system that can monitor, record and visualize environmental data as well as calculate energy consumption in specific areas. Our Recodify system development process encloses both software and hardware engineering aspects. In the next sections, we elaborate on hardware and software design and implementation approaches.

The Recodify device can monitor and control critical ambient conditions like temperature, humidity, air quality, noise to improve quality control and optimize energy consumption. All ambient data with a specific time stamp and push them to the Firebase for future use and hooks them with a unique ID i.e., the device's MAC address. Authenticated users, using the Recodify Web-App, can observe only the device(s) that belong to them and monitor readings from the physical quantities or abiotic variables in real-time or visualize them with chronological order using graphs. Furthermore, they can intervene to connected appliances and devices in order to enhance space's environmental conditions. In the following section we present both hardware and software Recodify system's implementation [67].

5.1 Recodify Device

To implement a WSN application we need to comply with the OSI model requirements as stated at Chapter 4. Physical Layer provides the communication channel, sensing and signal processing. Data link Layer provides channel sharing (MAC), timing, and locality. Network Layer includes adaptive topology management and topological routing. Transport Layer includes data dissemination and accumulation, caching, and storage. Finally, Application Layer, provides application processing, data aggregation, external querying query processing and external database.

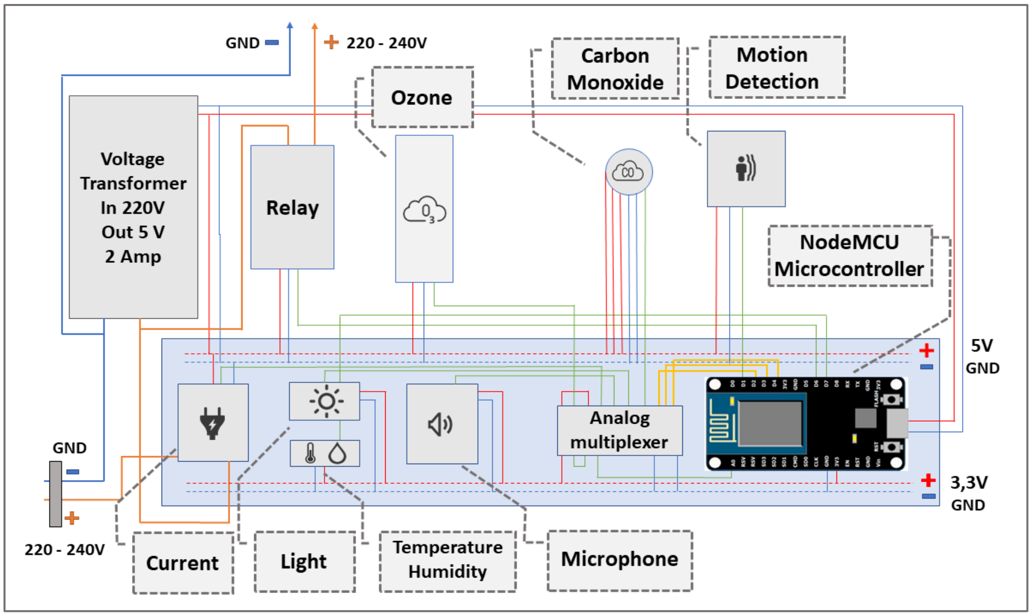

Figure 8 - Recodify device

Recodify device consists of several hardware components such as microcontroller, modules and sensors. The core of our device is NodeMCU, a developer programmable platform from Espressif Systems with integrated Wi-Fi module (ESP8266).

The prototyping hardware (Figure 8) that we used is a circuit board, and as manufacturer states, "it is functioning as a dual in-line package (DIP) which integrates a USB controller with a smaller surface-mounted board containing the MCU and antenna. The choice of the DIP format allows for easy prototyping on breadboards. The design was initially based on the ESP-12 module of the ESP8266, which is a Wi-Fi SoC integrated with a Tensilica Xtensa LX106 core, widely used in IoT applications". The core of Recodify device, NodeMCU, was created shortly after the ESP8266, on 13 Oct 2014, when Hong committed the first file of NodeMCU-firmware to GitHub [68].

Our standalone device will work as a unit or as a part of a grid of appliances. Within the case that we are able to equip a target surroundings - area, like a room or floor, with our device we may produce a smart ICT grid of appliances. In an exceedingly larger scale, we are able to monitor a complete building or even a building complex.

5.1.1 Microcontroller

The Recodify device uses the NodeMCU development kit version one, as known as version 0.9, which includes an integrated Wi-Fi System on Chip (SoC). NodeMCU introduced the Lua based firmware for the ESP8266 Wi-Fi SOC from Espressif [69], in October 2014. Two months later they developed NodeMCU board which integrated the ESP-12 module and released it to the Open-Source Community. Nowadays, the term NodeMCU essentially refers to the firmware rather than the related development kit. Both the firmware and board designs are open source. The NodeMCU development kit is a low-cost platform that offers stability and many features, characteristics that makes its’ popularity growing among the hardware community. Despite that, due to resource limitations, users need to choose modules compatible to their project and customize the firmware to their needs, the use of NodeMCU board can be found in numerous IoT applications.

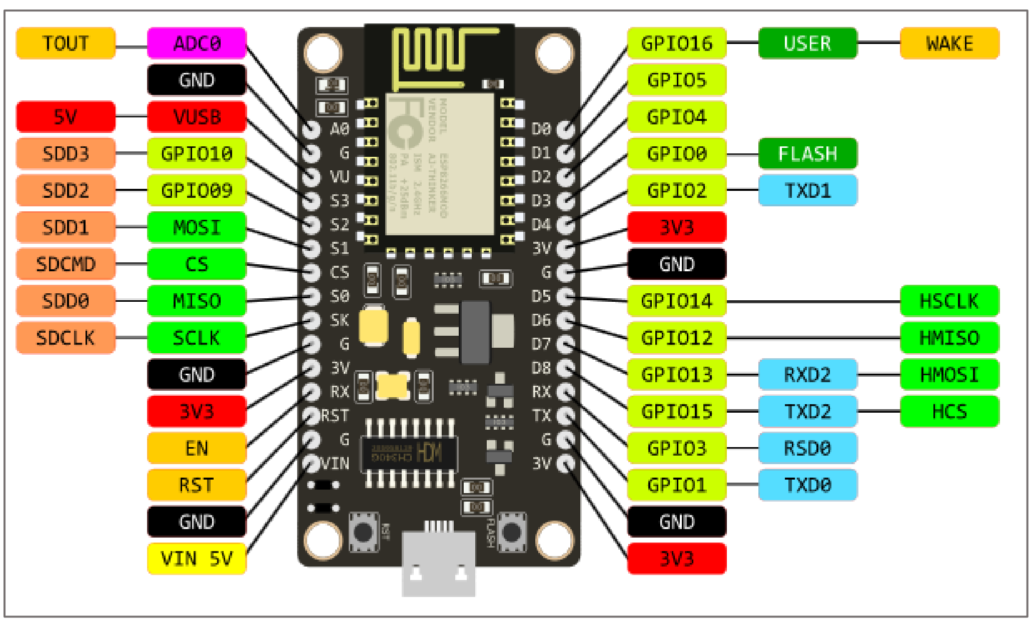

Figure 9 - Node MCU Microcontroller

The NodeMCU (Figure 9), as Espressif Systems Ltd. states, integrates "a L106 32-bit RISC microprocessor core based on the Tensilica Xtensa Diamond Standard 106 Micro, which achieves extra low power consumption and runs at default frequency of 80 MHz that reaches a maximum clock speed of 160 MHz. It has 128kB internal RAM which consists of 2 KiB instruction RAM, 32 KiB instruction cache RAM, 80 KiB user-data RAM and16 KiB ETS system-data RAM. It supports IEEE 802.11 b/g/n Wi-Fi with integrated TR switch, balun, LNA, power amplifier and matching network as long as WEP or WPA/WPA2 authentication for secured networks". As the operating voltage range of NodeMCU is 3 to 3.6 Volts, the board is equipped with an LDO voltage regulator to keep the voltage steady at 3.3 Volts. It can reliably supply up to 600mA, of which 80mA are being used during RF transmissions. The output of the regulator appears to three pins of the board and labeled as 3V3. These pins can be used to supply power to external components. The ESP8266 NodeMCU has total seventeen (17) GPIO pins located as pin headers on both sides of the development board. These pins can be assigned to all sorts of peripheral duties, including a10-bit Analog to Digital Conversion channel (ADC), a Universal Asynchronous Receiver-Transmitter (UART) interface, a Pulse-Width Modulation (PWM) output, SPI, I2C and I2S interfaces. Another useful feature of NodeMCU platform is that its' Real-Time Operating System (RTOS) and Wi-Fi stack allow 80% of the processing power to be available for user application programming and development.

The main reason NodeMCU was preferred for the implementation of Recodify besides its' low cost, was the amount of libraries, that were compatible with the selected components of our device. NodeMCU's Open-Source Community maintains library stability and provides developer support. Another factor for choosing this platform was its' integrated Wi-Fi module that efficiently established our needs for internet connectivity. Finally, NodeMCU's low energy consumption was considered a big asset due to the high consumption of all the sensors and modules that were going to be plugged in on it. On the other hand, using this platform presented three major limitations. As stated above the NodeMCU provides only one Analog to Digital Conversion channel which indicates that it can support only one analog sensor. In addition, the restriction of 600mA and the lack of 5 Volt output supply could not meet the requirements of Recodify. However, work around solutions will be presented in the following sub-chapter.

5.1.2 Sensors and Modules

Recodify’s main objective, as it has already been stated in previous chapters, is to monitor, store and analyze environmental data. In order to record the abiotic factors, substantial amount of sensors, such as Temperature, Humidity, Carbon Monoxide, Ozone, Luminance, Noise, Current and Motion, were connected to the main core. To ensure that all the sensors could be connected and work simultaneously and also to establish intervention, a voltage transformer module, a relay and an analog multiplexer, were introduced to the implementation.

Regarding sensors, Recodify includes a DHT22 sensor to record Temperature and Humidity, a MQ131 semiconductor for Ozone measurements, a MQ7 semiconductor for Carbon Monoxide, a HC-SR501 (PIR) for motion detection, an ACS711 Linear for Current consumption, a MAX4465 microphone to measure Decibel levels, and a photoresistor LDR for Luminance, as shown in Table 2- Sensors technical information.

Table 2- Sensors technical information

Name	Type	Interface	Voltage	Current	Sensitivity
DHT22(AM2302)	Humidity	Digital	3.3-5.5 V	1mA	2-5% RH
	Temperature				±0.5% C
MQ131	Ozone	Analog	5V	220mA	Rs (200ppb O3)/Rs(air) ≥ 2
MQ7	Carbon Monoxide	Analog	5V	150mA	Rs (300ppm CO)/Rs(100ppm) ≥ 0.5
HC-SR501	Motion Detector	Digital	5-20V	65mA	110°cone and 3-7 meters
MR003-009.2	Current Consumption	Analog	3.3-5V	5.5mA	110mV/A
MAX4465	Microphone	Analog	3.3-5.5 V	6mA	2.2kΩ
LDR	Luminance	Analog	3.3-5.5 V	28mA	proportional to Resistance

DHT22 (AM2302) is one of the most popular and high precision digital sensors which provides calibrated temperature and humidity measurements. It can connect to digital IO pins of NodeMCU, as well as other microcontrollers. DHT22 delivers temperatures between -40°C and +80°C and humidity between 0% to 100%. The temperature accuracy is ±0.1°C (maximum). Its' operating voltage ranges between 3.3 to 5.5 Volt [70].

MQ131 is a compact Ozone Gas measurement sensor, that can be used with NodeMCU and other microcontrollers. It is equipped with a wide range sensitivity to ozone which is able to detect ozone concentration up to 1000 ppb in ambient air. Its' operating voltage is 5 Volt, and its' analog output provides a voltage (0-5 VDC) that increases with increasing ozone concentration in the air [71]. The tin dioxide (SnO_2) is the sensor's sensitive material, that has a low conductivity (high resistance) in clean air environment and reacts in the presence of ozone (O_3), dichlorine (CL_2) and nitrogen oxides (NO_x). In order to measure the ozone levels, we had to use the documentation datasheet to calibrate the sensitivity characteristic curve of MQ131 (Figure 10).

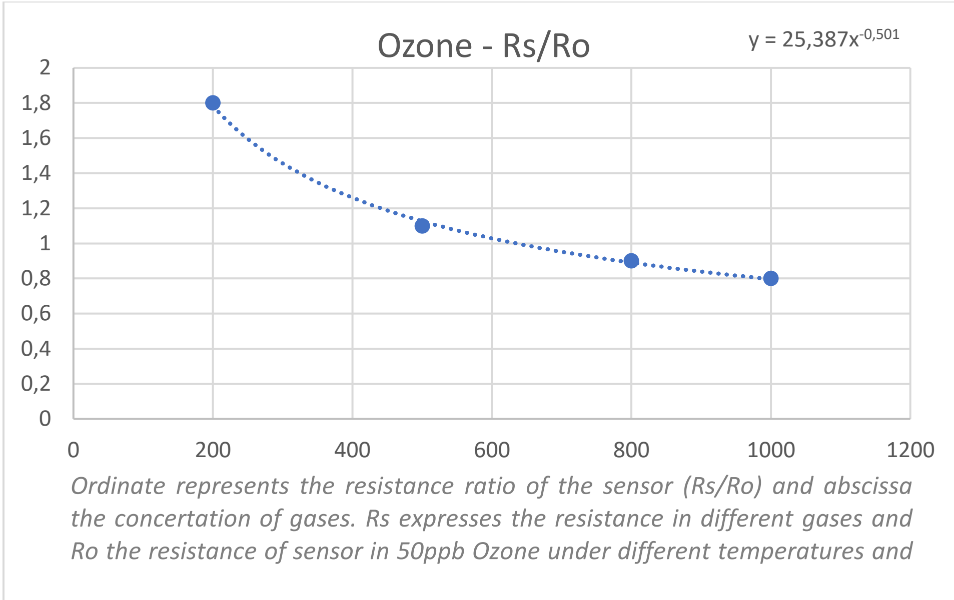

Figure 10 - Ozone - Sensitivity characteristic curve

MQ7 is a semiconductor sensor, suitable for sensing Carbon Monoxide concentrations (ppm) in the air. As manufacturer states "Tin Dioxide (SnO_2) sensitive layer, measuring electrode and heater are fixed into a crust made of plastic and stainless-steel net. The heater provides necessary work conditions for work of sensitive components" [72]. This sensor can measure CO concentrations ranging between 20 to 2000 ppm. The MQ7 has a high sensitivity and quick response time. Its' operating voltage is 5 Volt, and its analog output provides a voltage (0-5 VDC) that increases with increasing carbon monoxide concentration in the air. In order to measure the carbon monoxide levels, we had to use the documentation datasheet to calibrate the sensitivity characteristic curve of MQ7 (Figure 11).

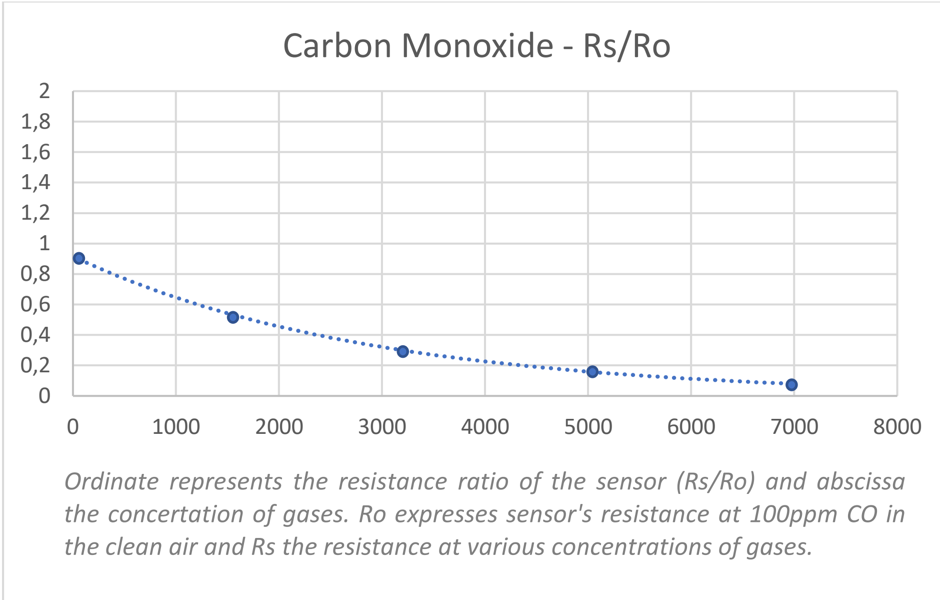

Figure 11 - Carbon Monoxide - Sensitivity characteristic curve

HC-SR501 (PIR) consists of a pyroelectric sensor which generates energy when it is exposes to heat. When a human or an animal body gets in the range of the HC-SR501, approximately three (3) to seven (7) meters, it will detect the movement because the body emits heat energy in a form of infrared radiation The Passive Infra-Red sensor, in abbreviation PIR, is not using any energy for detecting purposes however it absorbs the energy given off by the other objects. The sensor also consists of a specially deign cover named Fresnel Lens which focuses the infrared signals, with a sensing range of 110°, on the pyroelectric sensor [73].

MR003-009.2 as Allegro states, it "carries the ACS711 ELECTRIC-12B-T hall effect-based linear current sensor, which offers a low-resistance (~1.2mΩ) current path. The sensor operates at 3.3V (up to 5V) and its analog voltage output has a sensitivity of 110mV/A centered at 1.65V (if powered at 3.3V) with a typical error of ±1% and a 100kHz bandwidth. Optimized bidirectional current range is from -12.5A to +12.5A, but its robustness allows survival of the device at up to 5× overcurrent conditions. Top silkscreen shows the direction that is interpreted as positive current flow" [74].

MAX9814 is a low-cost, high-quality microphone amplifier with automatic gain control (AGC) and low-noise microphone bias. The device features a low-noise preamplifier, variable gain amplifier (VGA), output amplifier, microphone-bias-voltage generator, and AGC control circuitry. The low-noise preamplifier has a fixed 12dB gain, while the VGA gain automatically adjusts from 20dB to 0dB, depending on the output voltage and the AGC threshold. For our implementation, we chose MAX9814 as a decibel meter, in order to capture sound levels only, without violating users' privacy or threatening any personal information [75].

LDR (Light Dependent Resistor), is a resistance which depends on the amount of light falling on it. A typical structure for a photoresistor uses an active semiconductor layer that is deposited on an insulating substrate. Contacts are then placed either side of the exposed area. LDRs have a sensitivity that varies with the wavelength of the light applied and are nonlinear devices. The peak sensitivity wavelength is about 560-600 nm which is in the visible part of the spectrum [76].

To ensure that all the sensors could be connected and work simultaneously and also to establish intervention, we had to incorporate several modules to our device. A voltage transformer module, a relay, and an analog multiplexer were included to Recodify, in order for the implementation to be whole and functional.

CD4051B - NodeMCU provides only one Analog to Digital Conversion channel which indicates that it can support only one analog sensor. A workaround to this problem is to expand the analog inputs of the microcontroller with the use of a multiplexer module. The CD4051B is a single 8-Channel analog multiplexer, and it works similar to an 8-way switch that can be controlled using digital voltages. Thus, we had to generate the appropriate signals on NodeMCU to route the voltages appropriately and then take a reading through the unique analog port [77].

Relay – Recodify has a build relay module (SRD-05VDC-SL-C) which gives its’ users the ability to remote control interconnected appliances through a web-based application. A relay is an electrically operated switch that can be turned on or off, letting the current go through or not, and can be controlled with low voltages, like the 3.3V provided by the NodeMCU pins. Thus, users can efficiently intervene on the interconnected appliances’ power state [78].

Voltage Transformer – Recodify uses a Voltage Transformer module for a proper operation of its components. It is a universal phone charger circuit that it is integrated in Recodify and converts the input 220 - 240V to 5V providing 2000 mA at 50Hz. It supplies with power the NodeMCU microcontroller and sensors which have a minimum operating voltage of 5V and satisfies our needs of current consumption, since the NodeMCU covers only 600 mA. It is important to mention that the voltage source is connected in a parallel sequence to the NodeMCU and several other components such as the relay module, Ozone, Carbon Monoxide and PIR sensors [79].

5.1.3 Sketch – Unit of Code

Recodify software is separated into two different parts. The first refers to sketch that is uploaded to microcontroller and the second one refers to Recodify Web-App. Both were developed with different Integrated Development Environment (IDE) and different programming languages.

From the microcontroller aspect, we use the Arduino IDE with several development libraries which expand our capabilities. The Arduino IDE is a cross-platform application (for Windows, macOS, Linux) that is written in functions from C and C++. It is used to write and upload programs to Arduino compatible boards, but also, with the help of third-party cores, other vendor development boards, such as ESP8266 [80].

In Recodify's microcontroller sketch, nine libraries were imported (ESP8266Wifi, WiFiUdp, NTPClient, TimeLib, Time, SimpleTimer, Firebase_ESP_Client, DHTesp and MQ7) in order to capture data from sensors, to create a timestamp with Network Time Protocol (NTP), to establish the connection with the Internet and the Firebase and push all the recordings to our database. Interval timers were used, also, to separate the data in two main categories, urgent and non-urgent. Variables such as temperature, humidity, luminance are categorized as non-urgent since they barely change every half hour. On the other hand, the remaining variables declared as urgent, e.g., consider the importance of prediction and prevention on a Carbon Monoxide poisoning. Finally, sole formulas and algorithms were used to map and transform sensor readings to readable data. The source code that is uploaded in the Recodify's microcontroller could be accessed in our GitHub repository [81].

5.2 Recodify Web Application

Figure 12 - Web Interface Mockups

Recodify's web-based application is responsive on any type of device giving multimodal accessibility to users such as personal computers, laptops, tablets or smartphones. Recodify's user interface mockups were firstly designed in a sketchbook (Figure 12) and then implemented using proper development tools and editors. The final user interface was slightly changed due to reported usability issues. In the following subsections we will present the technologies that we used to implement the web application of Recodify.

5.2.1 Vue JS Framework

From the aspect of our web application, Vue.js handled our needs. It is a progressive JavaScript Framework which provides us with all components we need to create a single page application to support our Recodify device [82]. With the use of real-time database, we achieved a continuous monitoring. Recodify’s registered users can observe connected and active sensors’ values, compare them in chronological order using graphs and manage the device settings and functionality of their appliance(s). In detail, the user can utilize Recodify software to: (a) run statistical diagnostics and analysis in respect to time, (b) manage the grid of Recodify nodes and (c) control the Recodify inner connected appliances functionality. Once the Recodify-device gets connected, it starts collecting data from the environment. All data is transferred to the application server with timestamp and unique device ID. The data is accessed only by authorized users through our dedicated web-based software.

Vue JS is a JavaScript framework for building front-end UIs in view we can start simple and then progressively add in the tools and features that we need to build a complex web application. At its core it provides a way to build components that encapsulate data or state in our JavaScript and then connect that state reactively to a template in HTML. We call these components declarative views because the same data inputs will always produce the same output in the visual UI. When we declare data on this data object it links or binds it to the HTML on the template above when the value of the data changes the component will automatically rerender or in other words it is reactive, and the framework does a ton of work under the hood to make sure that this process is performance across a huge component tree. We can work with this data in the template thanks to views HTML based template syntax we can interpolate a value for expression using double braces and we also have a variety of directives to control the behavior of the HTML based on the data. We can use v-if to only render an element when the value on the right side is truthy and then we might have a fallback element after that that is only rendered when the values are false with velse. We can make the application interactive by listening to events using the v-on directive. We can listen to an event on an element then run some code to handle that event on the right side. We can do that directly in the template or define a custom method and the components methods object. The method has access to our reactive data and that means all we have to do is change the value of the data and the component will automatically rerender.

5.2.2 Vuetify a Material Design Framework

Vuetify is a complete User Interface Framework develop on top of Vue.js. The primary goal of Vuetify is to provide all the necessary tools to the developers in order to build responsive, rich, pleasant and expansive web applications. It is based on the Material Design specifications with hundreds of crafted UI components, and it is easy to use unlike to other Frameworks. Whether it is on a phone, table or desktop computer, Vuetify takes a mobile first approach to design, which means any application is fully responsive in any provided screen resolution.Vue.js was initial release in 2014, and it has become one of the most popular JavaScript Framework in developers' community. Reusable components and modules creation are the main reasons for this popularity among the developers. User Interface Libraries are collections of these modules that implement a specific style guideline to achieve this primary goal. Vuetify is developed precisely as indicated by Material Design specification with each component carefully crafted to be modular, responsive, and performant Vuetify has an active development cycle and is patched weekly with improvements, responding to community issues and reports [83].

5.3 NoSQL Database

When people use the term "NoSQL database", they typically use it to refer to any non-relational database. Some say the term "NoSQL" stands for "non-SQL" while others say it stands for "not only SQL." Either way, most agree that NoSQL databases are non-relational, and they do not store data in rows and columns. Based on their data model, non-tabular databases come in a variety of types. They provide flexible databases used for big data and real time web applications. One of the advantages of a NoSQL database is that it handles a lot of data quickly. Another advantage it’s data model, which is extremely flexible. In relational tables like MySQL and PostgreSQL we have to structure data in a predefined schema, create the database and the tables, define the datatype of each field and its’ constrains. On the other hand, NoSQL handles unstructured data since there is no data structure and tables. The most crucial advantage is scalability, it uses horizontal scaling, instead of vertical scaling that relational databases use. There are four types of NoSQL databases, document such as MongoDB and Firebase, key-value stores like Redis and Couchbase Server, wide-column such as Apache Cassandra, and graph like Neo4J. A common misconception is that non-tabular databases do not store relationship data well. NoSQL databases can store relationship data differently than relational databases do. Firebase is a Backend-as-a-Service (Baas) [84]. It provides developers with a variety of tools and services to help them develop quality apps, grow their user base, and earn profit. It is built on Google's infrastructure. Firebase is categorized as a NoSQL database program, which stores data in JSON-like documents. Alexander Dufetel, the product manager of Firebase stated that “the Firebase Realtime Database, with its client SDKs and real-time capabilities, is all about making app development faster and easier. Since its launch, it has been adopted by hundreds of thousands of developers, and as its adoption grew, so did usage patterns. Developers began using the Realtime Database for more complex data and to build bigger apps, pushing the limits of the JSON data model and the performance of the database at scale”.

Ambient data is constantly measured, recorded and collected by the Recodify device via the sensors and sent online, in real-time to the database using the Wi-Fi access point. Recodify uses Google’s cloud-hosted database called Firebase which provides a secure and real-time access to our data. Firebase provides a real-time database and backend as a service. The service provides application developers with an API that allows application data to be synchronized across clients and stored on Firebase's cloud.

Chapter 6: RECODIFY: USE CASES & SCENARIOS OF USE

Recodify, aims to monitor spaces, analyze recorded data, and characterize environmental areas, in which human activities, of any kind, might be destructive or damaging. Furthermore, due to its non-intrusion design philosophy it can be used in spaces where human intervention is restricted or very limited such as world cultural heritage sites and archaeological places. Monitoring, recording, and analyzing data can assist us in estimating the consequences of human actions in such spaces.

Chapter 6 is discussing about Recodify system in a case study. Through a scenario system’s functionality is being presented. Each section describes a certain procedure that a user must follow to fully make use of system’s capabilities. The exhibit of a greenhouse planting is designated for this purpose.

6.1 Representative Scenario

To illustrate the concepts described so far and to provide insight to our system we will describe a representative scenario emphasizing the main aspects of our system. The reference scenario is summarized in Exhibit 1.

Exhibit 1: *Mr. Michalis is a farmer at Heraklion of Crete. He has his own greenhouse full of vegetables. This time of year, he is planting tomato plants. As a farmer he knows that tomatoes thrive from May to October, but he wants to grow tomatoes indoors, all year long, for his family. The low temperatures and the animals are harmful for his plants. To keep them safe, Mr. Michalis needs to remotely monitor the ambient conditions. We assume that he has in his possession a Recodify device placed in the greenhouse which is interconnected with an ozone mist device. We also accept that this greenhouse area provides us a wireless network, with internet connectivity. In this context we will present how the Recodify system can handle his needs.*

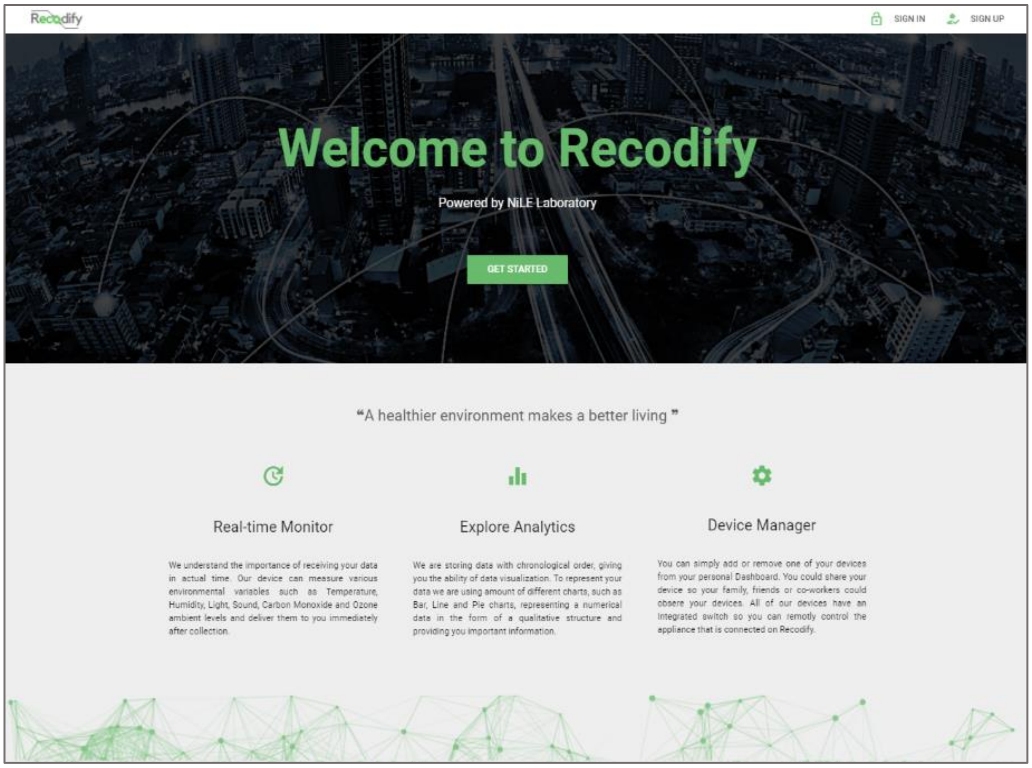

Figure 13 - Home page

Mr. Michalis should first visit Recodify's web-based application (https://projects.nile.hmu.gr/recodify) in order to sign-up using the "Get Started" or the "Sing-Up" button (Figure 13). This page also presents several information about the Recodify and Laboratory that supports it.

6.2 User Registration

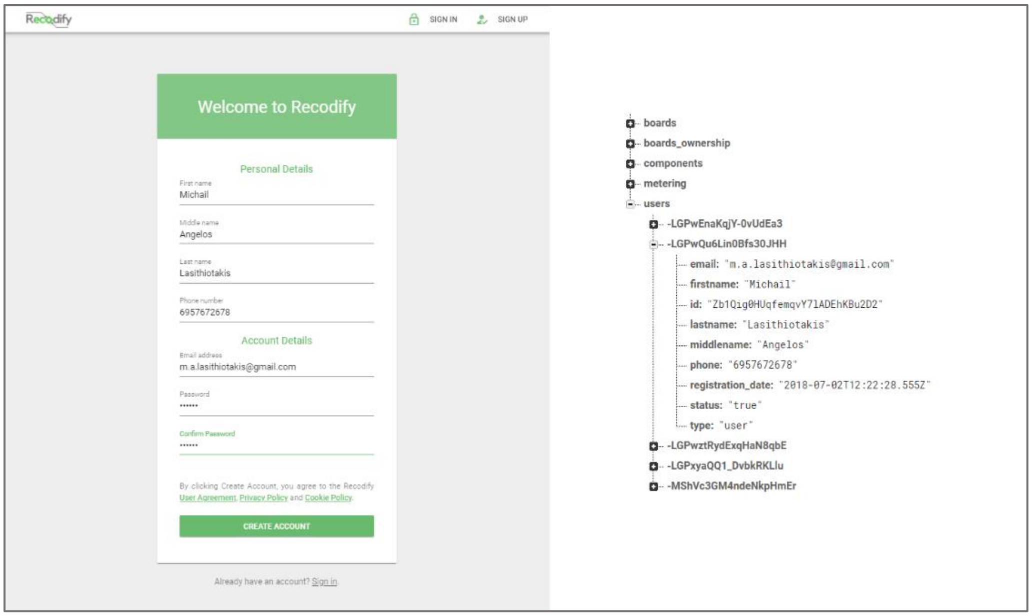

Figure 14 - User registration

Using the buttons, we mention above the Sign-up form is displayed to Mr. Michalis. There are two sections that he has to fill up, personal details such as First name, Middle name which is optional, Last name and a phone number. These details are needed in order for the seller/developer to contact with him in order to make firmware updates or to alert user. The other section is the account details that Mr. Michalis has to fill up to register in Recodify Service. An email, a password and a confirmation password will be needed in this section. Once the required fields are filled up and User agreement, Privacy Policy and Cookie Policy has been approved, Mr. Michalis can now create a new account. His data are stored in Firebase with a specific order. In addition to the data that Mr. Michalis provided, a unique ID for the user, a registration date, an account type and status is created for his account (Figure 14).

There are two types of users in Recodify application. The common users with limited privileges and the administrator users who have full access to the Recodify System.

6.2.1 Common Users

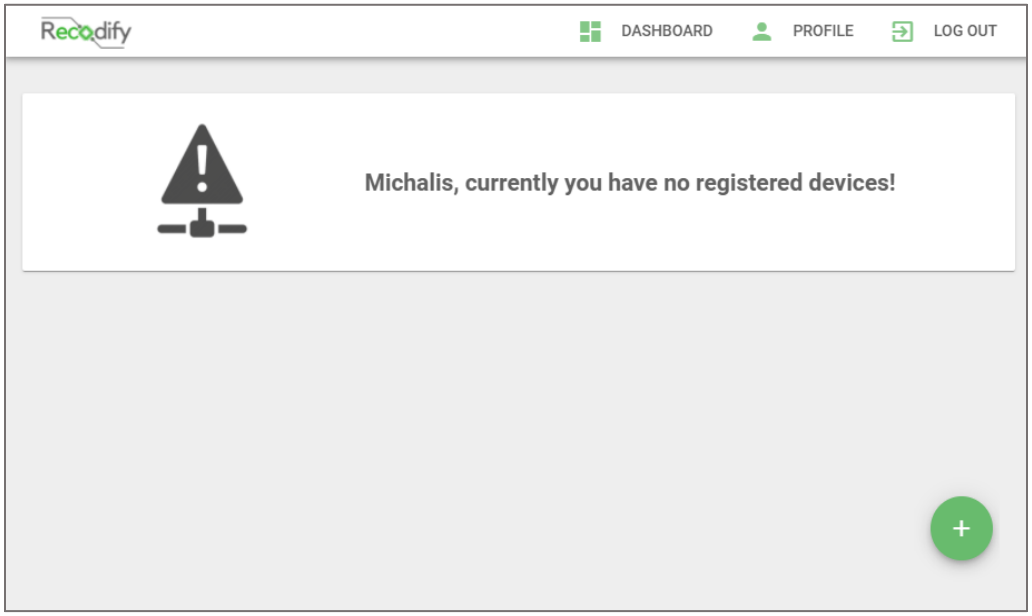

Figure 15 - New user home page

Once Mr. Michalis complete his registration, the web application redirects him into his Dashboard and sets his status true, as a logged-in user. Since he is a new user, he does not have any registered devices. In that case he can register a new one using the add button “+” in bottom right conner of his dashboard page. Since his account type is marked as user, he can navigate to his dashboard, his profile or logout from his account (Figure 15).

6.2.2 Administrators

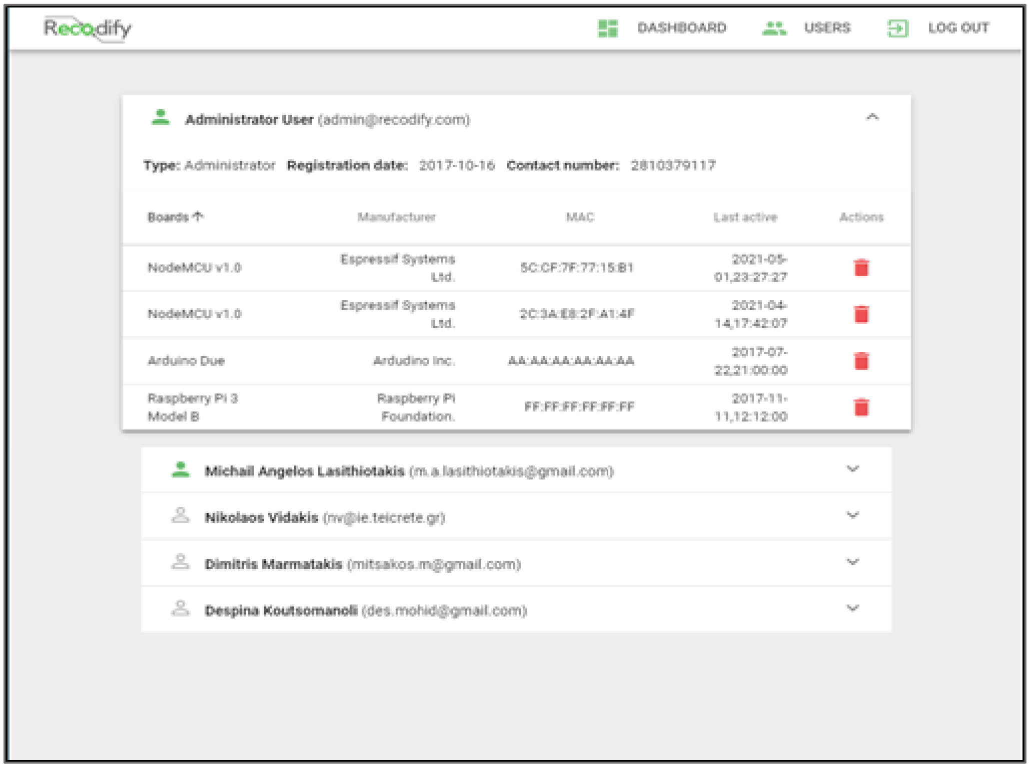

Figure 16 - Administrator's home page

On the other hand, administrators have access to users list where all users of Recodify System are displayed (Figure 16). Active users are labeled with a green icon and inactive user with a fade gray icon. With users list administrators can visualize which user owns which device, who shares his device with another user, which hardware version each device has, its' MAC Address and when it last booted. From that list, administrators can delete any common user account or any of their devices.

For each Recodify device registered to a user, it also registers to administrator's account. From their dashboard, administrators have full access to all Recodify devices and their data. They can also, intervene and interact with the devices that are interconnected to.

6.3 Sign In, User Profile and Log out

Once Mr. Michalis is registered and he wants to enter on his account he can visit again the Recodify's page and use the Sing in button this time. Use his credentials, email and password that he used in registration form, he can now log in to his account (Figure 17).

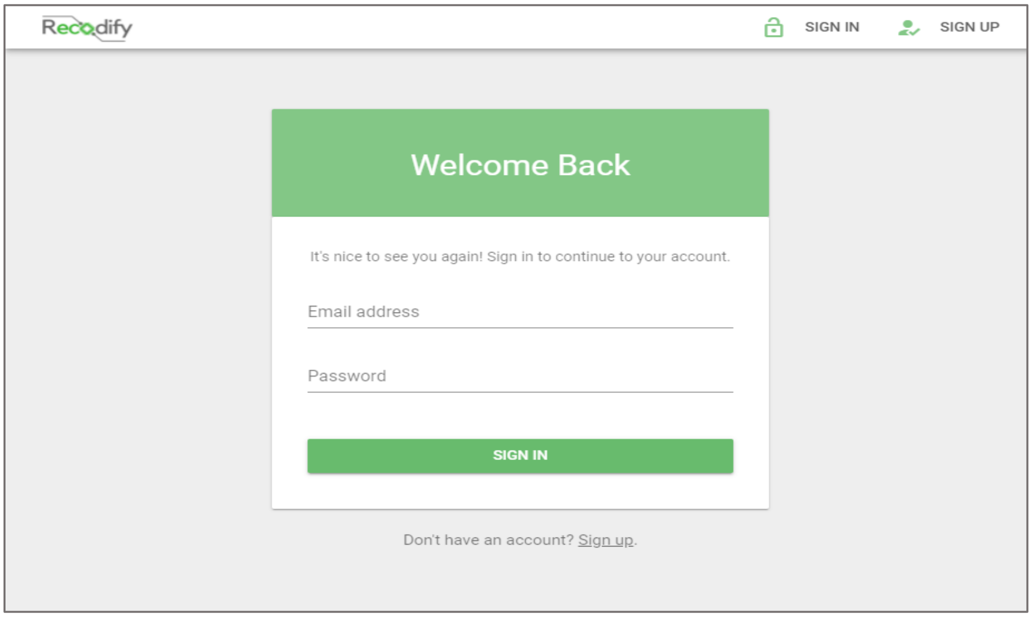

Figure 17 - Log in page

A validation mechanism will check the given credentials and will inform user if any error occurred. In User profile page, his personal information is being displayed. If Mr. Michalis had any Recodify device registered or shared to his account, it should be displayed in Recodify Boards section. This section also provides the ability to remove any of user devices using the proper action button (Figure 18).

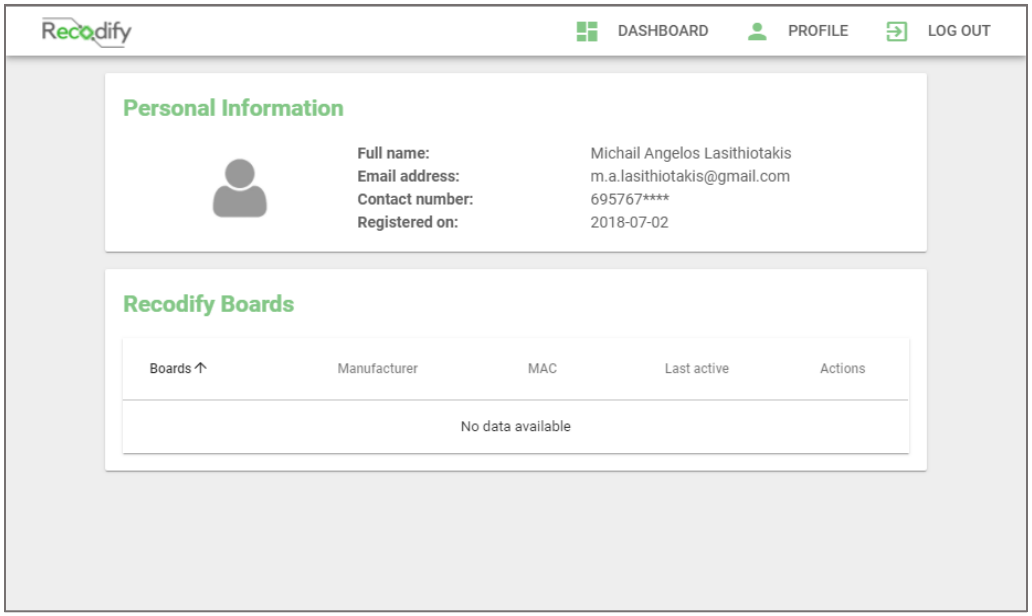

Figure 18 - User's profile page

6.4 Adding a Recodify Device

In order for Mr. Michalis to explore the Recodify hardware device sensors analytics and to find out in detail the conditions in his greenhouse he must first register a new device. Using his dashboard and by pressing the add button a pop-up form will appear asking for a MAC Address and the PIN code of his device (Figure 19).

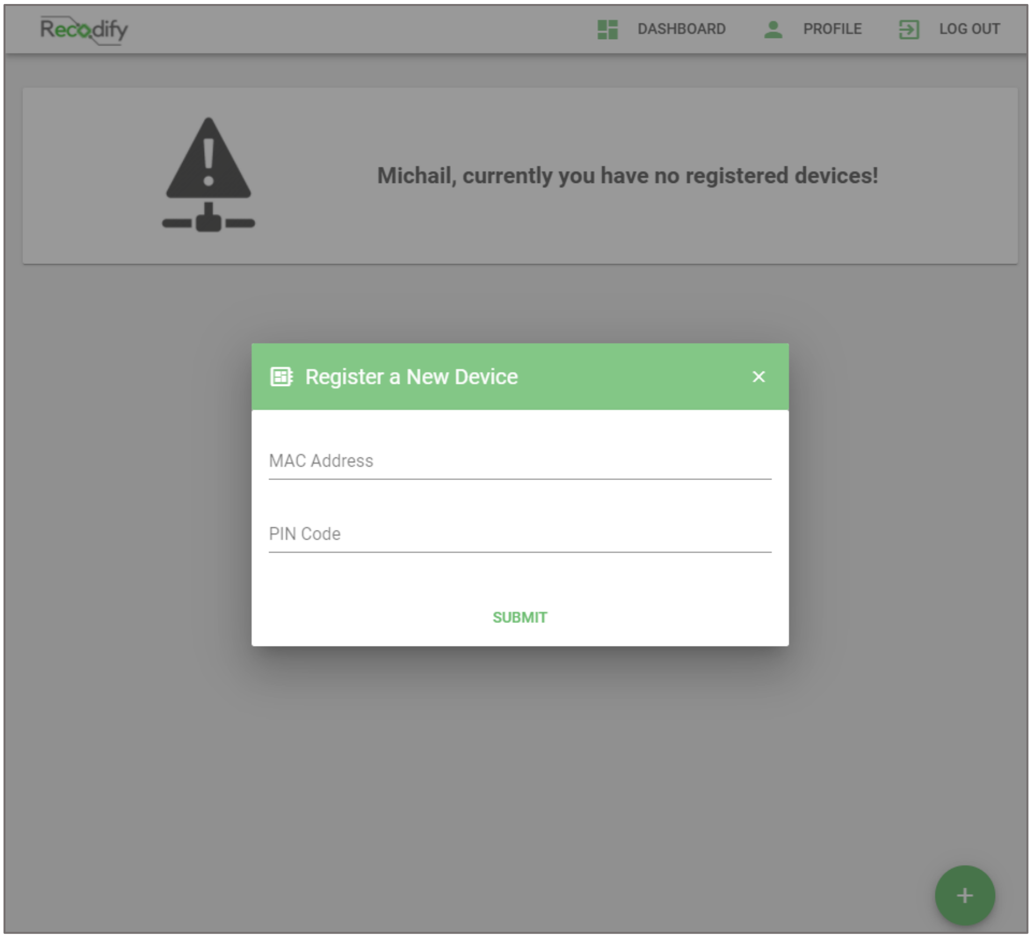

Figure 19 - Register a new device

The MAC Address is the unique identification for each device and the secret PIN code is defined inside the developer's script (Figure 20). These are the credentials of the device in order to register to his account and can be given only from the seller.

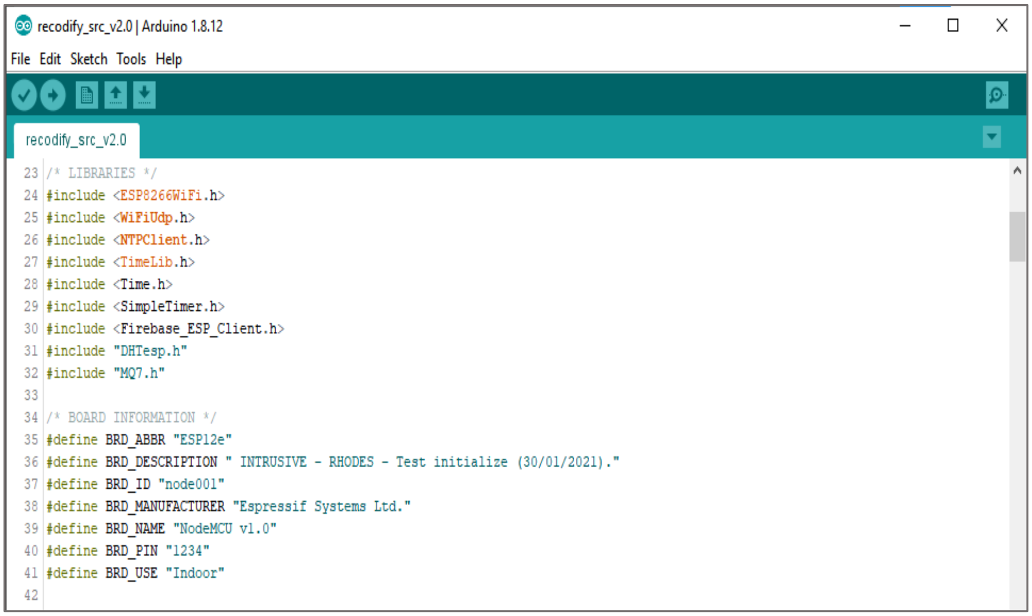

Figure 20 - Recodify sketch

Once the Recodify device is setup and initialization processes starts it registers itself in Firebase database. Board information such as abbreviation, description, id, manufacturer, name, pin, board use, MAC address and the IP Address are register to a unique node of database. By submitting the given MAC address and secret PIN code a system mechanism will validate these credentials and the Recodify device will be added to his dashboard, otherwise if any error occurred the user will be informed.

6.5 User's Dashboard

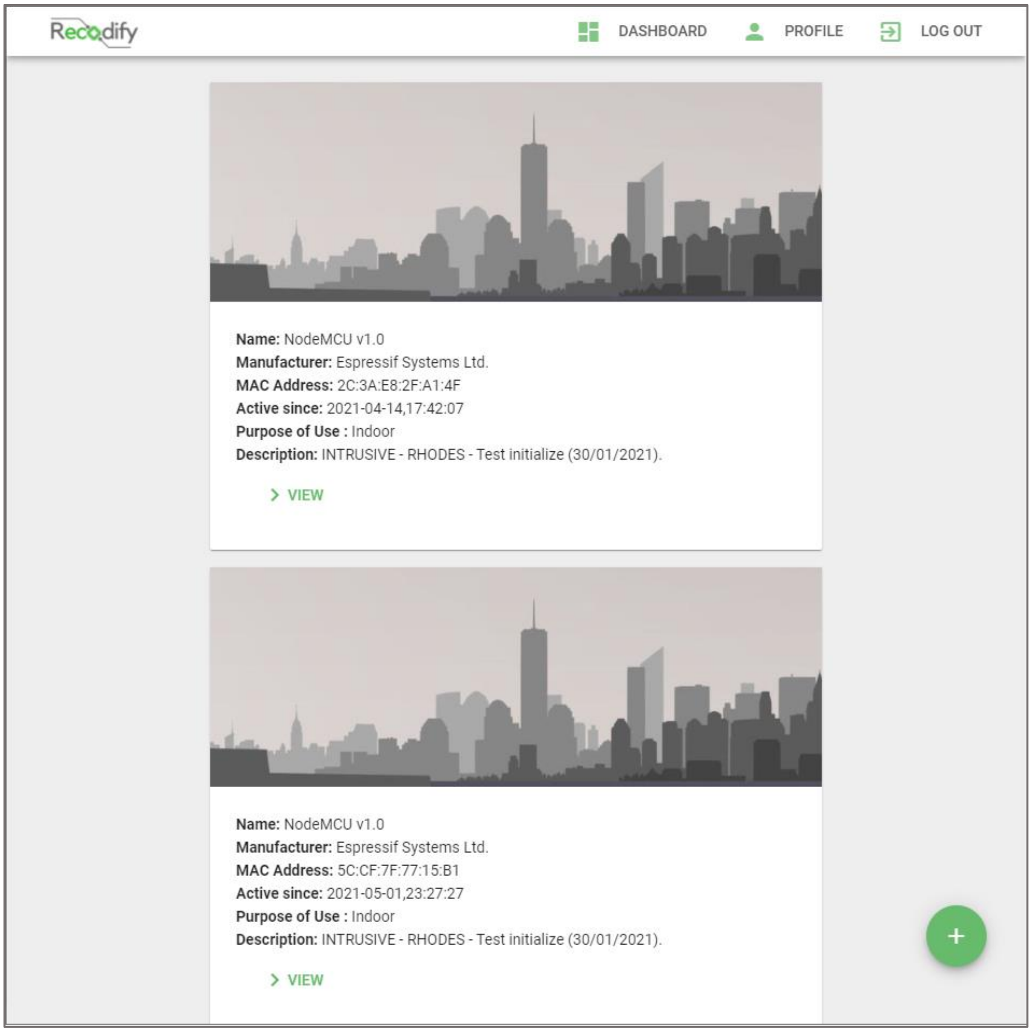

Figure 21 - User's dashboard

When device registration complete, the new device will appear in his dashboard with all its' information (Figure 21). Dashboard page supports endless-scroll and Mr. Michalis can add unlimited devices to monitor. In this page also includes the devices that are shared with him. Since he added two devices, they are now appearing also in his profile under the Recodify Boards section where he can manage them.

6.6 Monitor a Recodify Device

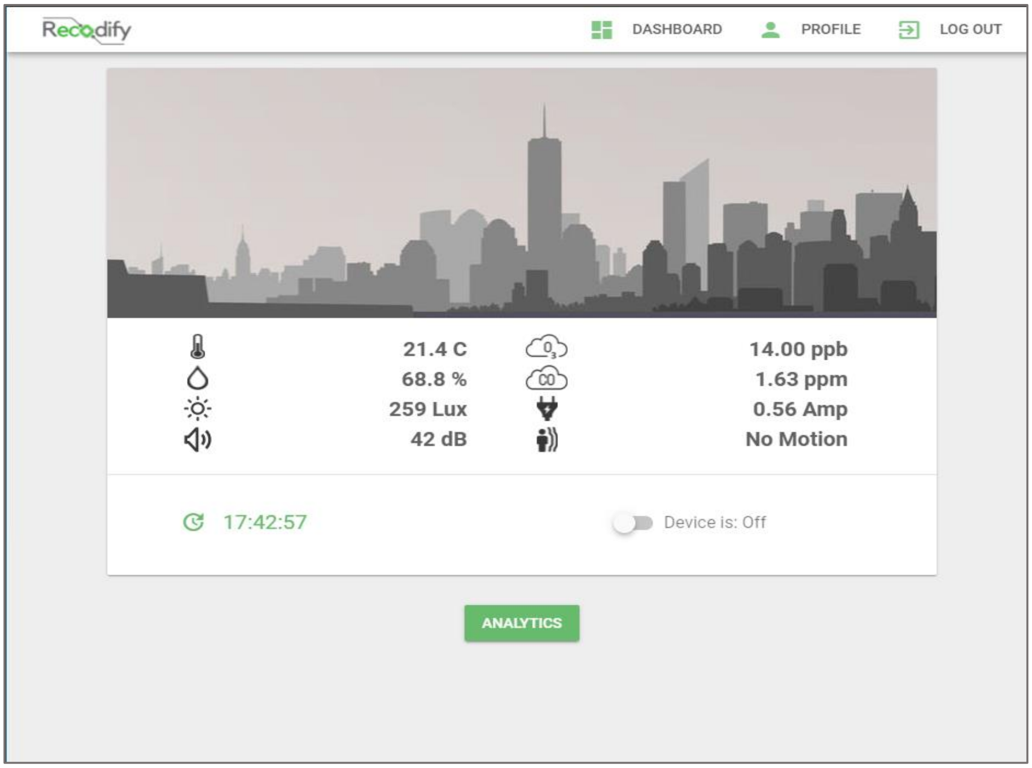

Figure 22 - Monitor a Recodify device

To monitor a Recodify device Mr. Michalis can press the View button in the device of his choice. The Web application will redirect him to the page of the selected device (Figure 22). The Recodify device can simultaneously monitor eight sensors in real time. Every few seconds it collects data such as ambient temperature, humidity, luminance, sound level, ozone carbon monoxide, current consumption and motion detection. On intrusive devices there is also an on-off switch, located next to the timestamp on the bottom, that controls the interconnected device, in Mr. Michalis example the interconnected device is an ozone mist. All these crucial for his greenhouse data are collected for each device separately, stored to Firebase and can be accessed from any computer or smartphone device.

6.7 Explore Device Analytics

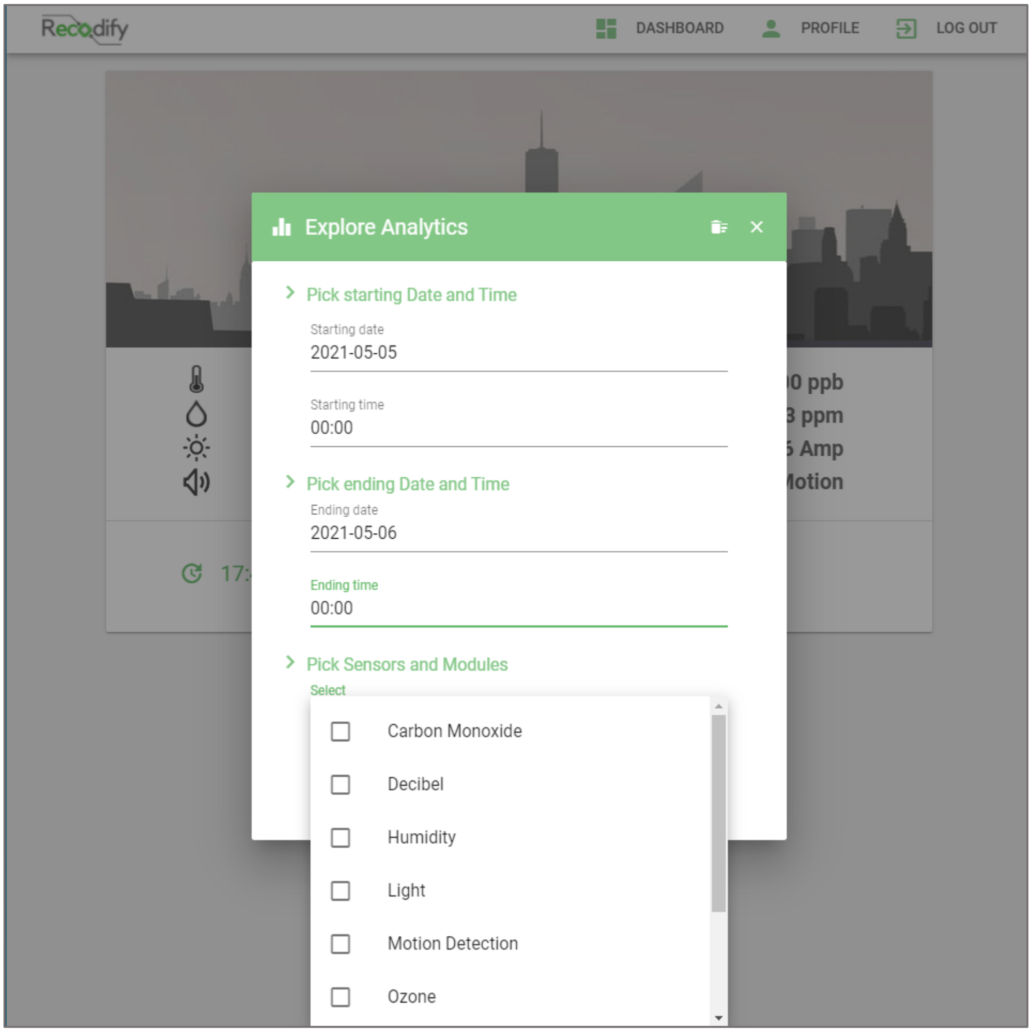

Figure 23 - Explore device analytics

As we mentioned the data are store in Recodify’s database and they can be accessed for more detailed analysis. By pressing the “Analytics” button a pop-up form will appear to Mr. Michalis (Figure 23). There he has to select a specific range of date and time, the starting and the ending point of the analysis, and the sensors that he wants to exam. For our exhibit Mr. Michalis selected a period of one day (05/05/2021 00:00 due to 06/05/2021 00:00) and he selected all the sensors that are available on his device. By submitting this form the web application will draw all the requesting data from this specific range from the database and visualize them with graphs (Figure 24, Figure 25, Figure 26, Figure 27).

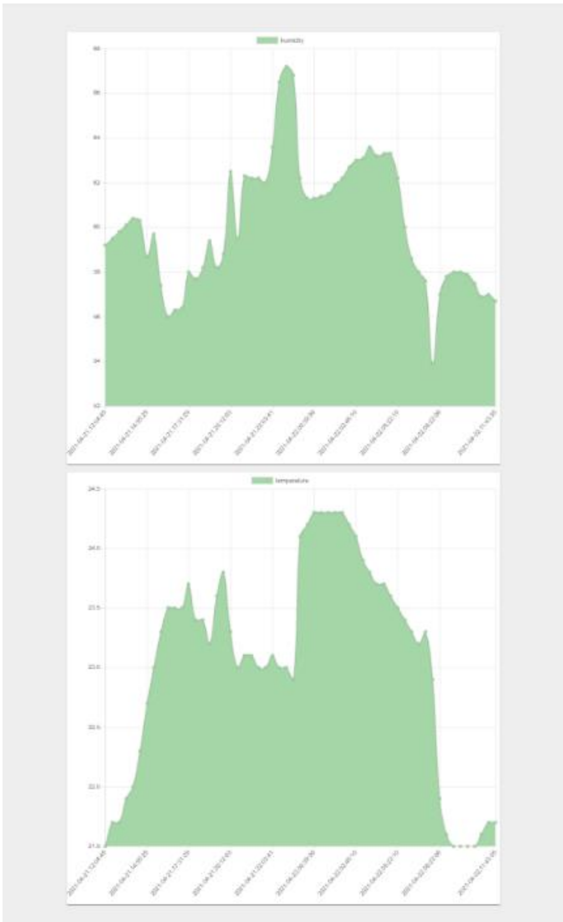

Figure 24 - Humidity and Temperature

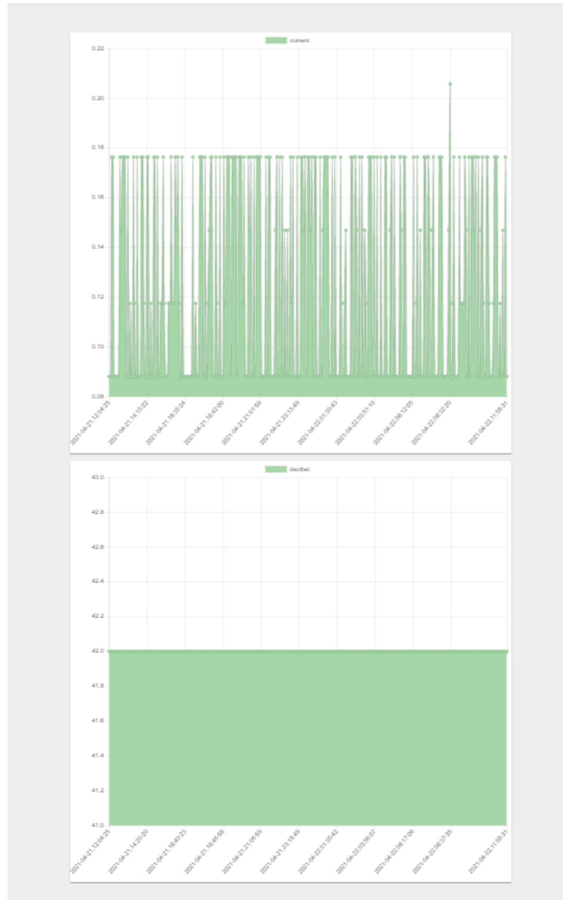

Figure 25 - Current and Decibel

The user can use the Recodify device to monitor the ambient Temperature, Humidity, Carbon Monoxide and Ozone levels that are important for the protection of his vegetables. Low temperatures slow down breathing and to some extent, aging, Very low temperatures can cause damage due to cold. Optimum fruit and vegetables preservation temperatures vary depending on the species.

Combining data from deferent sensors he can obtain a detailed image of his greenhouse. E.g., If the ozone levels were lower than the normal, we could assume that the greenhouse covering plastic was damage by an animal or the greenhouse door left open by someone. Either way we can crossover our data with decibel levels and motion detection for that specific period of time. Since the ozone levels are critical low, it is necessary for Mr. Michalis to take an action by turning the interconnect ozone mist device on until it restores the ozone levels back to normal.

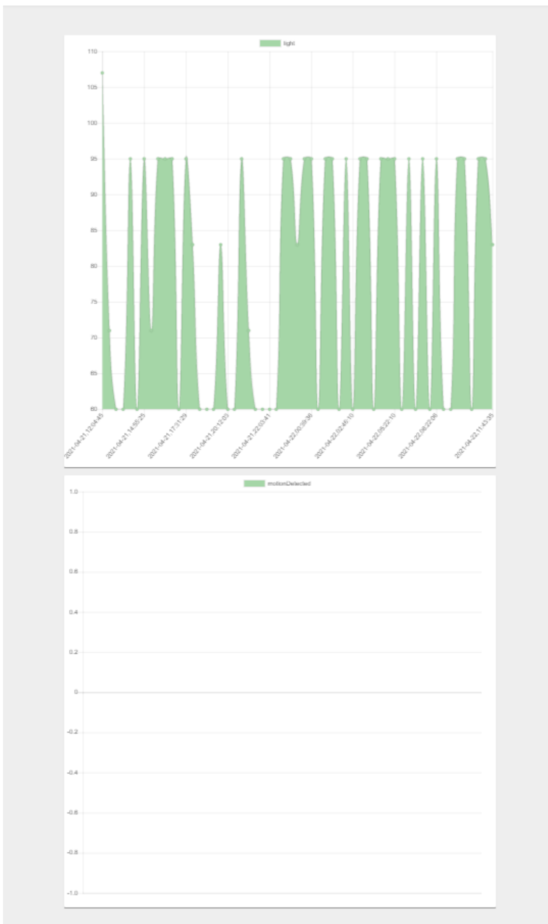

Figure 26 - Light and Motion detection

Figure 27 - Carbon Monoxide and Ozone

Chapter 7: RESULTS, CONCLUSIONS & DISCUSSION

7.1 Summary

The Recodify hardware and software was presented in this thesis. Our approach is based on two fundamental technologies namely the WSN and IoT. The proposed system has inner connected appliances and various sensors such as Temperature, Humidity, Carbon Monoxide, Ozone, Light, Noise, Current and Motion detector, providing us with data that is able to illustrate space’s environmental conditions. Our system, and specifically the collected data can be used, as raw data, from other research disciplines to create prediction, determination and designation models for preventing ecological disasters in environmental spaces with human activities. In that respect, Recodify can be useful in places where allowance of human intervention is prohibited or very limited. An exhibit was presented testing our device in real-life situations to handle the needs of a greenhouse vegetables from deterioration.

7.2 Future work

In the future, a design that is equipped with solar panel and internal battery supply, supporting device portability, will be implemented. To ensure the continuous data logging we will enhance our hardware with a real time clock (RTC) and storage device (SD) module saving our data offline with a proper order in case of internet connection lost. With the use of a GPS module, we could provide new features in our Recodify application such as tracking capabilities for all devices. Furthermore, Recodify will be tested in real life condition in order to extract more experimental results. Finally, we will improve the procedure of adding a new Recodify to user’s dashboard with QR tags and mobile scanning mechanism.

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