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INTERNET OF THINGS SYSTEM FOR ENVIRONMENTAL MAP ACQUISITION

Andrei Bragarenco[*], ORCID: 0000-0003-0405-5378,
Galina Marusic, ORCID: 0000-0002-2984-2055

Technical University of Moldova, 168, Stefan cel Mare Bd., MD-2004, Chisinau, Republic of Moldova
Corresponding author: Andrei Bragarenco, andrei.bragarenco@mib.utm.md

Abstract. The paper discusses the importance of contemporary electronic systems with the focus on the development of distributed electronic equipment. In this context the devices, potentially members of an Internet of Things (IoT) network, are part of a complex distributed electronic system organized in an IoT network dedicated to solving a specific problem. The paper proposes a concept of a distributed electronic system, consisting of a sub-components collection of the electronic devices placed on specific Cartesian coordinates. Furthermore, it is presenting a case study of the operation for a distributed electronic system, which is scanning environmental parameters such as temperature, humidity, CO_2, noise, brightness, or others. The proposed system consists of a set of electronic devices equipped with sensors for measuring the environmental parameters and communication modules to send the data collected to the IoT type network. The system stands for an analogy of a camera where every pixel collects environmental data at specific coordinates, where the collected pixels construct a 2D image, the uncovered areas are obtained by interpolation from the nearest sensors. As a result, a 2D image is obtained, which represents a map of the specific area in the selected parameter, such as the temperature distribution map, brightness, CO_2, motion, noise, or another parameter, depending on the type of sensors available on the scanning devices. Based on this concept, a prototype of a distributed electronic system, interconnected via an IoT network, was developed, following the ZigBee technology. It is capable of collecting 2D images of a predefined area in several parameters such as temperature, brightness, CO_2, motion, noise, simulating a "video" camera on these parameters.

Keywords: *autosar, architecture, device, electronic, environment, IoT, layer, map, network.*

Introduction

The Internet of Things (IoT) represents a network or system of physical objects - devices, buildings, automobiles, household items and other electrical and mechanical units, biological, chemical and optical systems incorporated with electronics, software, sensors, and the network connection, allowing these devices to communicate with each other and exchange data. Thus, this system allows us to monitor the status of these devices, to remotely control them, program their behavior, and obtain notification messages for certain target events.

A short history of IoT

The concept of an intelligent network of devices appeared in 1982 at Carnegie Mellon University, where a Coca-Cola sales car became the first general-purpose device connected to the internet, which could report when the bottles were sold and if the drink has cooled [1]. In 1991 Mark Weiser in his paper "The Computer of the 21st Century" [2] discussed a modern vision of the concept of the Internet of Things, which was further developed in the paper "From The Internet of Computers to the Internet of Things" by F. Mattern and C. Floerkeimer [3].

In 1994 Reza Raji described this concept as "sending small packets of data to a large number of nodes in a network in order to integrate and automate as many things as possible, starting with things from home to whole plants [4]. The concept of the Internet of Things became famous in 1999 through the Auto-ID Center1 at MIT and other various media publications. The popularization of the identification of objects using radio frequencies (RFID2) was also proposed. Thus to any object can be attached an RFID tag, which consists of an antenna with a microprocessor and little memory for the storage of the unique identification code so that any food item, device, clothing can be uniquely identified with the help of a radio transmitter-receiver system.

Besides RFID, other technologies such as bar code, QR code are used. According to the latest OECD report in 2015, the number of online IoT devices is growing continuously, so South Korea has about 37.9 devices per 100 people.

The Internet of Things technology has various applications and offers enormous opportunities for continuous development and implementation of these systems. Thus, Gartner Inc expects about 26 billion Internet-connected devices by 2020 [5], and ABI Research raises this figure to 30 billion [6], a figure well beyond the world's population. These integrated devices with limited processing and memory resources have practical applicability in many systems, starting with the acquisition of data from natural ecosystems and ending with smart house systems, factories, nuclear power stations, and others. These systems can be used not only for data collection but also for different processes monitoring.

Some IoT solution examples

Among the examples with an enormous potential of IoT systems can be considered:

- Intelligent shopping systems - can monitor items purchased for different users by analyzing the social profile and building recommender systems to give custom future offers, based on criteria such as the place where certain items can be purchased, the most reasonable price, the best quality.
- Smart Fridge - incorporation of smart devices and the network connection of a refrigerator. Some solutions are already existing, such as Samsung[7]. The smart refrigerator allows users to always be up to date with the available products.
- Data acquisition systems in the environment on large surfaces - this is a vast area of use of these devices used to monitor parameters such as temperature, humidity, the concentration of different types of gas, vibrations in the earth's crust, wind speed and many others. That allows performing statistical analysis, weather forecasts, qualitative assessment of the ecosystem, all directly online on a web page or on any smartphone, accessible in the all-around world (with access to the internet).
- Coordination of activities - IoT systems can be used for enterprise management to identify when employees enter or leave the office, and calculate their total working

time, or on a larger scale, monitoring the activity of individuals to manage the human resources efficiently. Another application of this method can be regulating traffic jams. For example, the creation of a network of devices to identify cars and the vehicle flow can be used to calculate and redirect the flow in real-time using various mathematical models. That allows us to minimize congestion and increase efficiency.

- Medical systems – IoT devices can be integrated into various medical devices. As an example could serve an embedded system of biological sensors that monitors blood pressure, by creating the ECG diagram over time, acquiring data on unique biochemistry, hormonal status, and more.
- Smart House – incorporation of smart devices in the home and household devices, with various applications at hand such as:
  o Video monitoring
  o Monitoring the total and individually consumed energy of each device
  o Data acquisition of the room temperature, the concentration of diverse types of gas in the air.
  o Fire safety and alarm systems
  o Connecting and disconnecting remote devices

It can be noted that the concept of the Internet of Things brings many opportunities for application development. Some of the solutions are not yet implemented in practice. This fact gives today's technology an enormous potential, and a lot of solutions and implementations are expected to emerge. That will lead to a tremendous impact on all aspects of human life. Notably, along with their wide acceptance, this type of system will become increasingly affordable.

The development in the time of the various applications of the Internet of Things is represented in Figure 1.
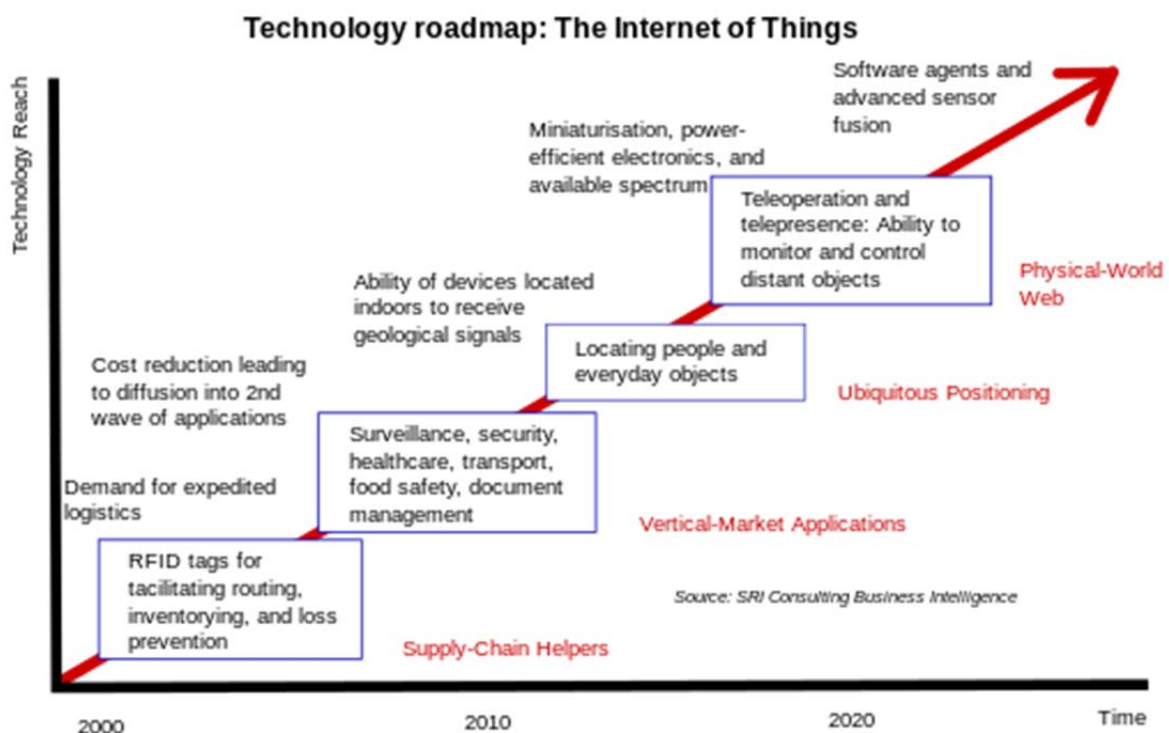

Figure 1. Development of IoT technologies in time [8].

IoT System main component overview

The essential components of an IoT system for the full functioning of data collection and control devices through the Internet are:

- The object - the physical entity to be controlled and to gather data. It is usually a device, which has an electronic communication interface or other methods by which data can be collected and over which various control mechanisms can be exercised.
- Microcontroller - a microprocessor with integrated chips used to carry out the program of control, along with data collection, processing, and transmission to further components.
- Gateway - a sophisticated device whose purpose is to collect data from multiple objects (via microcontrollers), logically aggregate, processing and transmit it for storage and processing to the Internet network.
- Internet - the global data transmission network, which, from the IoT perspective, allows us to monitor and control devices remotely.
- Client - the interface through which the user with internet access can communicate with the devices, either from a computer, smartphone and so on.
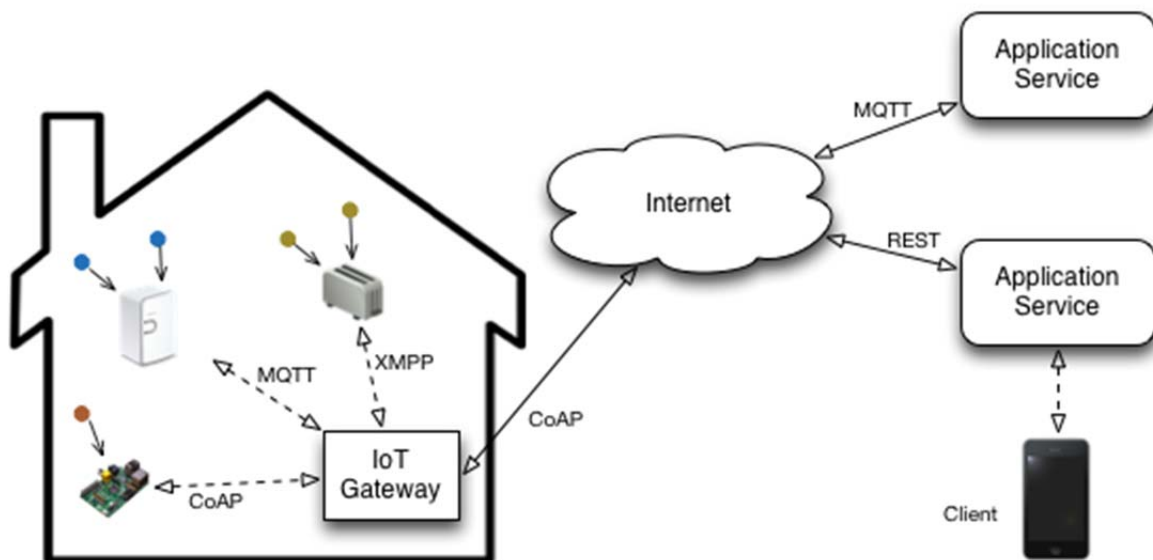

Figure 2. The main components of an IoT system [9].

IoT systems are subject to two main constraints to be feasible: cost and performance. This induces a wide range of requirements and principles regarding the IoT systems, targeting their design and organization, and these are:

- Identity - each device must be uniquely identified. This assumption is trivial for the correct function of these types of systems.
- Security - devices must securely transmit data, using authorization mechanisms. Security is tremendously essential for many aspects of the system: starting from system functioning to users' data privacy and protection rights to users' safety and even life.
- Independence and interoperability - devices must be independent. If one device is out of operation, it must not have a decisive influence on the operation of another device. They must also communicate through a well-defined and standardized protocol to ensure the interchange and interoperability of the devices.

- Low power consumption - this is an essential criterion for small data acquisition devices. Low power consumption will ensure long battery life, thus ensuring cost efficiency.

Communication protocols requirements

Depending on the application, there can be a wide range of requirements for data transmission. That can be achieved through several communication protocols based on the purposes and subject conditions. Some examples of requirements for communication are provided in table 1. As can be seen, in all applications, security represents the essential task. However, many applications have different needs regarding the required latency or speed of transmission, so IoT systems must be compatible. Regardless of the technologies and methods applied in a system, each application should be able to communicate efficiently to all the other components.

In many cases, the security of transmission is not crucial, for example, audio and video transmission should have low latency and high transmission speed, but if some information is lost on the road, this is not critical, and that is why IoT systems must support different protocols, including TCP / IP, UDP. For example, using the UDP protocol, there is no retransmission of messages to detect transmission errors, so in a high-noise environment, the messages will not be relayed many times, so the tape will be used very efficiently, which is not valid for the TCP in this case. There are also higher-level protocols such as SSH (Secured SHell) or HTTPS (HyperText Transfer Protocol Secure), and these can be used to ensure the security of data transmission by using encryption.

Table 1

Communication requirements for applications

	Latency	Communication speed	Security	Power consumption	Communication quality
Biomedical systems	Middle	High	High	Middle	High
Automotive	Low	Middle	High	Middle	High
Audio transmission	Low	High	High	Middle	Middle
Video transmission	Low	High	High	Middle	Low
Home appliances	High	Low	High	Middle/ High	Middle

In this paper, we present the architectural principles and the concept of building an electronic device part of an IoT system, which contains the generic components such as sensor, actuator, user interaction, communication, database, and power management.

The basic functionalities within the system are presented, and these are data acquisition, conditioning, processing, diagnostics, and reactions.

At the application level, a system is built for collecting environmental parameters from different devices of an IoT system. Its novelty is that it acts as a distributed electronic device. Based on the acquired results, a map of the environment is obtained in the selected parameter.

Materials and methods

For the design of the proposed system we have used several basic notions regarding the conceptual and architectural design of the systems of an IoT type network, presented in this paper, as well as the use of ZigBee networks.

An Internet of Things (IoT) network can also be viewed as part of a complex distributed electronic system, in which the network replaces the wired connections for signal transmission, Figure 3.
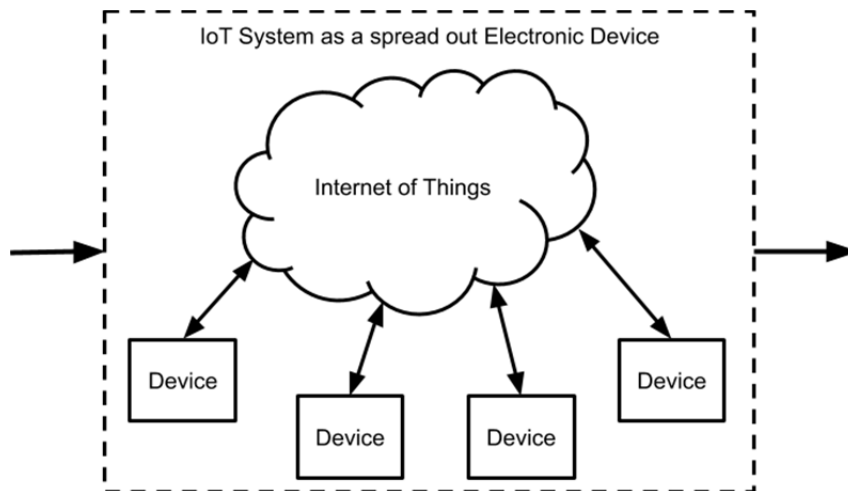

Figure 3. Spread out electronic device with IoT type interconnections.

System level-wise, we abstract from any implementation details, either mechanical, electrical, software, or of any other kind. We only consider the system as a set of components and the distribution of transfer function among them.

The generic architecture of an IoT device

Certain functionalities of the system can be viewed as generic components, which usually are present in standard systems. These components contain problem-specific functionalities. Examples of such components can be Acquisition, Actuation, User Interaction, Communication, Database, Power Management, Basic Software, and Operating System components, Figure 4.

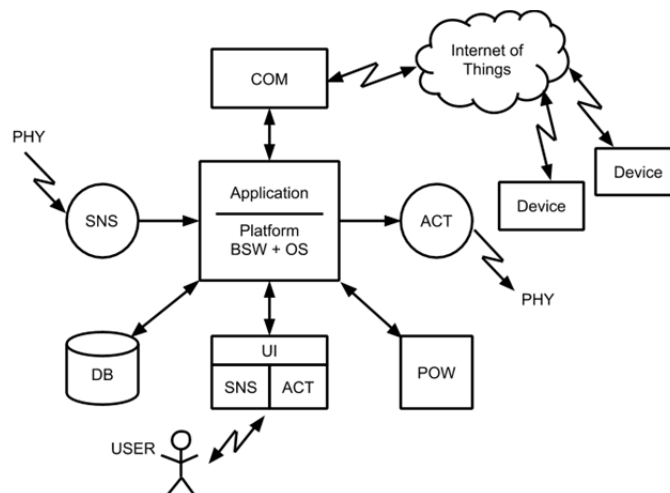Considering all the assumptions, we propose the following architectural diagram of an IoT connected device:

Figure 4. The generic architecture of an IoT Device.

Figure.6 includes two aspects. The first one consists of interaction parts, which are the environment and the communication network between the user and the devices. The second aspect consists of the components that are part of the device structure. These are Sensors, Actuators, User Interaction, Database, Power Management, Communication.

AUTOSAR Layered architecture

An excellent example of a well-defined architecture is the AUTomotive Open System ARchitecture (AUTOSAR) concept that is the basis for the development of the new modules in automotive systems and stands for the newest worldwide automotive trend. AUTOSAR standard defines the reference architecture and method for the development of automotive software systems and supplies the language (metamodel) for their architectural models. It also specifies the architectural modules and functionality of the middleware layer known as Basic Software (BSW).[10]

The concept is abstracting the electrical equipment through a specific layer called Runtime Environment (RTE) so that the application (ASW) does not consider the type of equipment or the location of the required resources. The duty of ensuring the necessary functionalities and connectivity is transferred to BSW Figure 5.
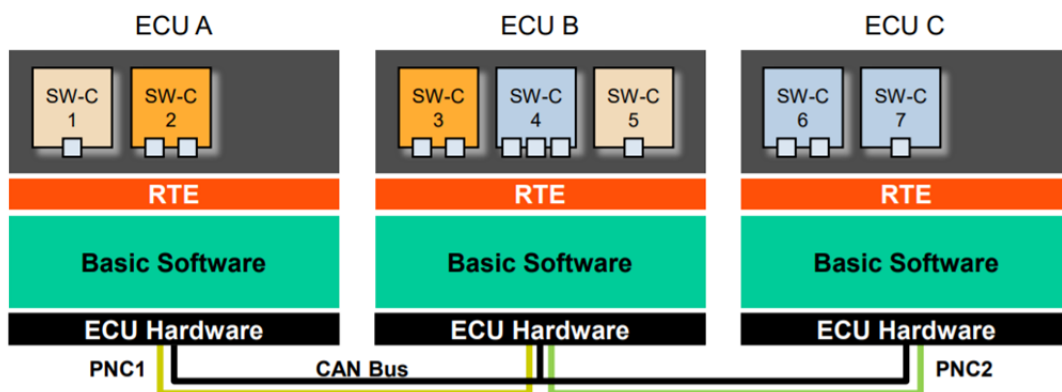

Figure 5. AUTOSAR component interaction concept [10].

Inspired by the AUTOSAR concept, it is proposed that the components of the Sensors and Actuators class, including the User Interaction that in the AUTOSAR architecture, are part of the Application Layer, to be generalized in a group so-called Extended Software (ESW). That provides an abstraction for most of the generic architecture components proposed in this work.

ZigBee network communication

For the project presented in this paper, ZigBee technology was chosen.

ZigBee is a specification defined in IEEE 802.15.4 for a range of communication protocols intended for a large number of devices (up to ~ 65000) in a network, with low power consumption so that the devices can operate for a long time using only one small power source, such as a battery. The basic topology of the ZigBee network is mesh, but it can operate on other types of networks such as star or tree. The essential advantage of ZigBee is its low power consumption, efficient bandwidth usage, and is an ideal solution for IoT, but the most significant disadvantage is the higher cost of the devices at the moment, which is mostly due to the license required to produce them. ZigBee typically uses 2.4 GHz radio, integrating everything with microcontroller and memory for storing instructions and

data, using as few analogs and more digital floors as possible to minimize power consumption. The high cost is due to the requirements of the process of validation of ZigBee systems and their qualifications.

The standard transmission rate is low, somewhere 250 kbps for 2.4 GHz at a 10-20 m distance.

The current ZigBee protocols support two modes of network operation, with active and passive radio base.

In the active one, the routers periodically transmit radio signals to confirm their presence in the network, so that the nodes can be in sleep mode in the intervals between the beacon signals, thus reducing the power consumed. In those with passive beacons, a channel with the CSMA / CA protocol is always used, so routers do not transmit beacon signals, but require the nodes to be active.

This has a disadvantage because of high energy consumption, but the essential advantage is the possibility of using heterogeneous networks in which some devices always transmit and others very rarely. See Figure 6 for the network conceptual diagram.
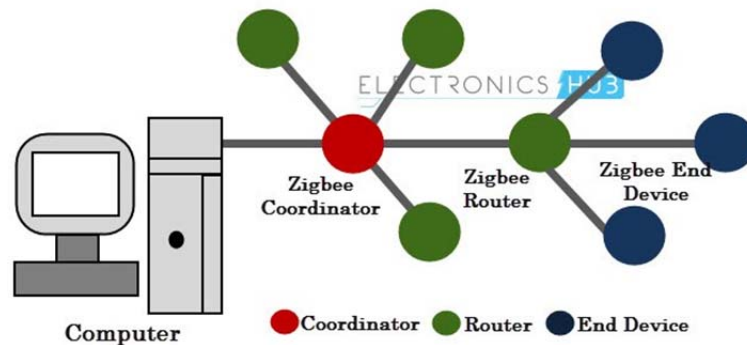

Figure 6. The ZigBee network and its components [11].

Results and discussions

Within the research works a system was designed for monitoring the environment according to the parameters of temperature, humidity, presence detection, brightness, noise, CO_2 detection.

For the system architecture definition, the concept of a layered architecture organized in stacks was used. This will allow better project organization, as well as the reuse and extensibility of the system components.

System Concept

The purpose of the system is to collect environmental data from devices located at different geographical coordinates.

The data will be stored on a server dedicated to the system, with the possibility to view the data both on display from the component of the server device, and also accessed through the Internet from a web page, hosted by the dedicated server. The system-level architecture is shown in Figure 7.

Each of the devices is responsible for the data collection in the area where it is located, and the data will be processed by other systems for which this data is of interest.

In the application analyzed in this paper, the data are collected in order to achieve a climatic variation on various parameters.

However, it is possible that this data can be used for other purposes, such as performing a reaction to intervene in the area of interest.
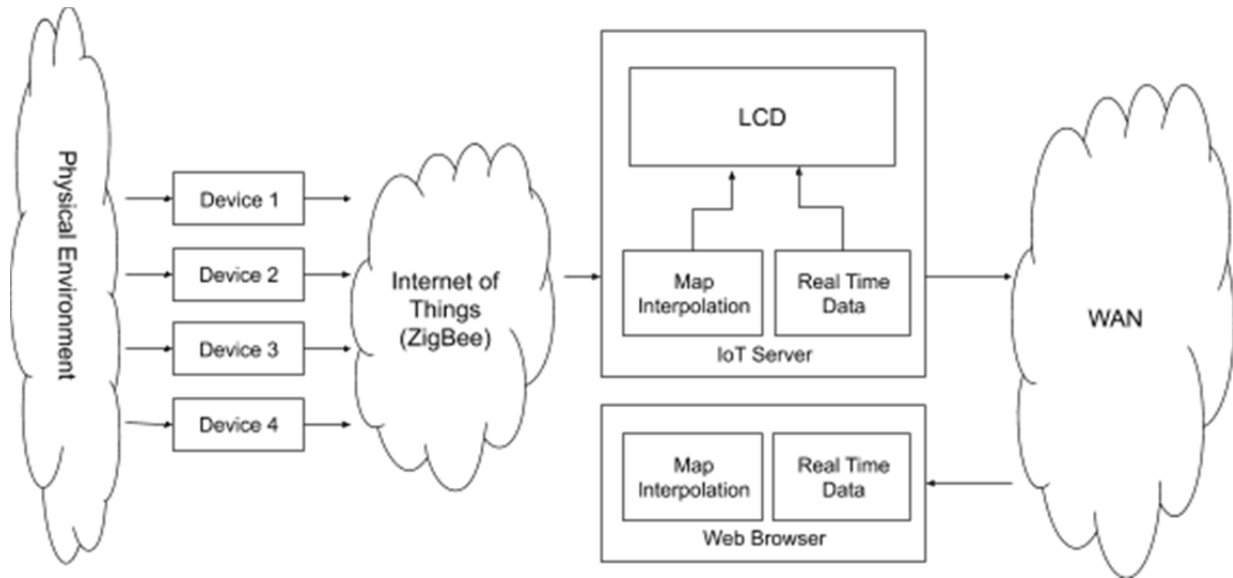
Figure 7. The general architecture of the system.

Acquisition devices

Following the System Architecture, the Devices were designed according to the principles described in the previous section.

Structurally, each component of either sensor or communication will be realized as following the concept of the generic component present in this work. Respectively, each of the components has a stack divided by layers, which provides the application with many services through the RTE interface. As a whole, the device will have the following structure shown in Figure 8.
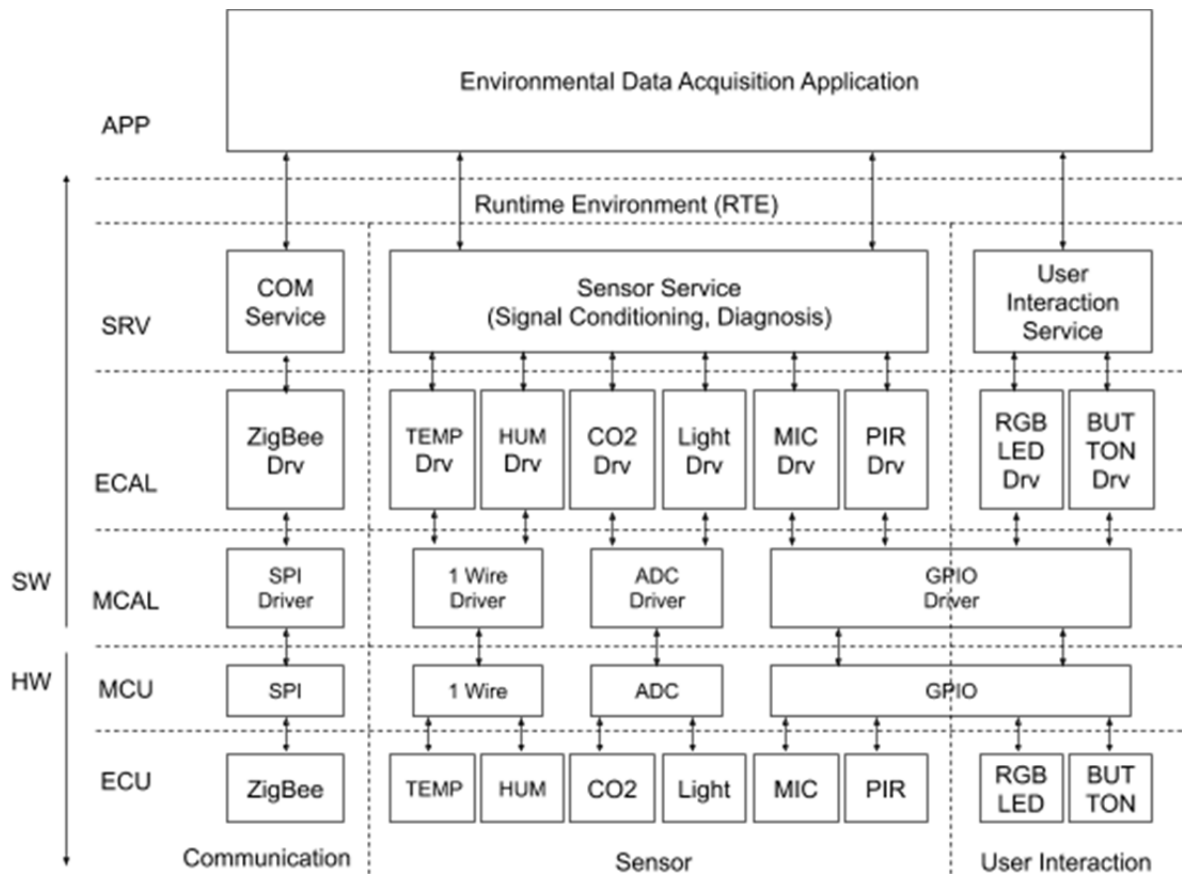

Figure 8. Layered architecture of the IoT device.

Functionally, devices collect data about the environment and transmit it to the IoT network. On the control side, minimal functionalities are realized, the environmental diagnoses are signaled sequentially to an RGB LED, where each of the eight primary colors indicates a threshold diagnosis on a specific parameter. The button on the device has the function to send an identification signal, used to configure the system

The data flow and the control signals are presented in the functional diagram of Figure 9.
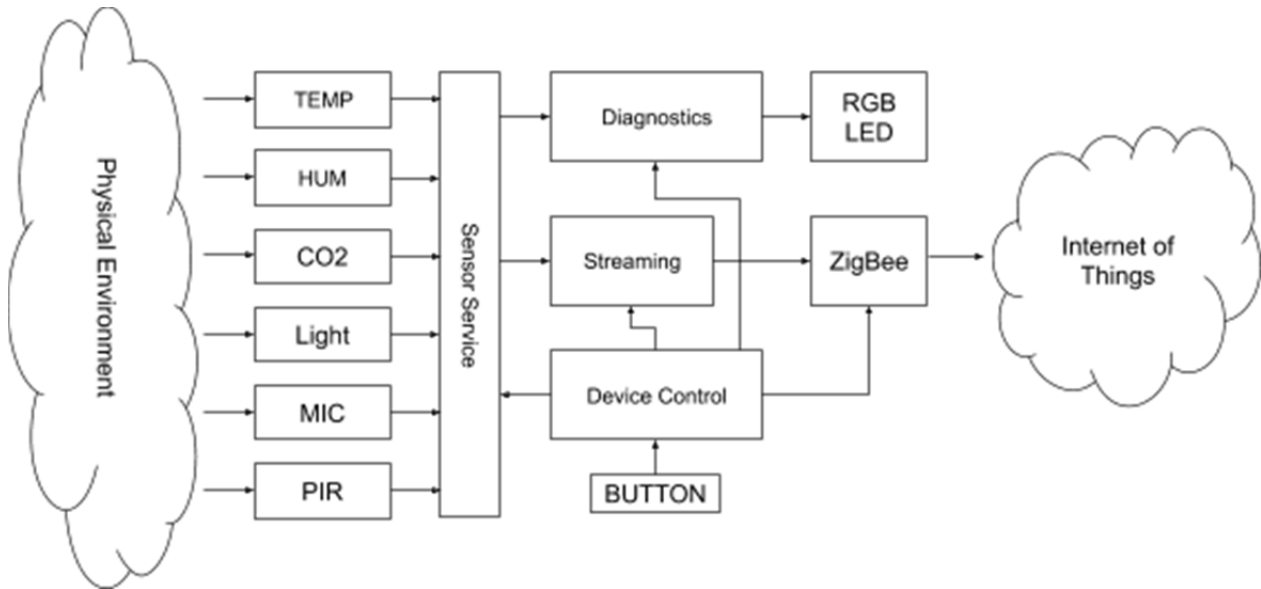

Figure 9. Functional & dataflow diagram for the IoT device.

Devices are built for low-cost reasons. From the electrical point of view, devices contain a minimum collection of components - sensors, low-cost microcontroller, ZigBee communication mode, button, RGB led. These constraints require that the conditioning functions be performed in the software domain.

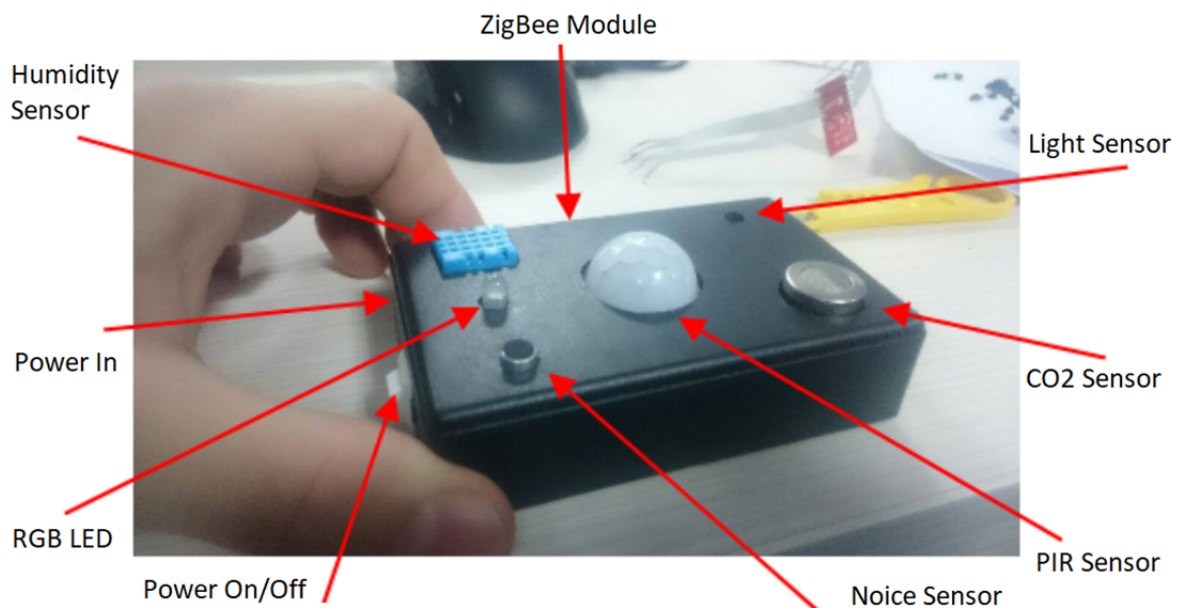For the demonstrations, a prototype was built and is presented in Figure 10.

Figure 10. IoT device prototype for environmental data acquisition.

Acquisition server coordinator

In the implementation presented in this paper, the acquisition server through the Zigbee network works as a ZigBee Coordinator (ZC), the central node in the network, from which all the devices connected to the network are accessible.

Structurally, the implementation is a complete system, especially on the part of sensors connectivity due to the architectural concept, where the sensor services abstract the sensor components. In the case of the acquisition server, the data flow from the sensors is directed through the communication module, and respectively the data requests from the sensors are replaced with requests to the network. From the application point of view, the data access from the service layer through the RTE, the sensors are seen as if they are part of the given equipment.

In Figure 11 is presented the system architecture of the coordinating server, including the representation of the lower level of the sensor stack, along with the linkage between the sensor services and the communication services.
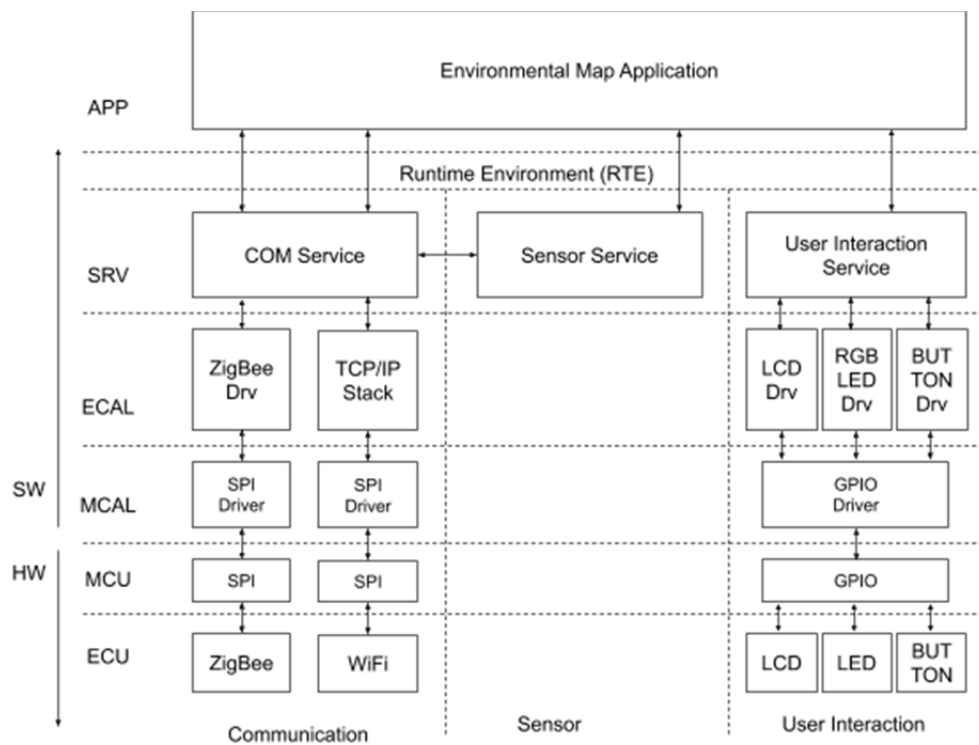

Figure 11. Layered architecture of the IoT server.

Another feature of the server for acquiring environmental data through the ZigBee network is that it can communicate with the regular Internet network through the WiFi network. In the architecture, it can be observed that the TCP / IP communication stack with all the components for the LAN / WAN access is included among the communication components. Functionally, the coordinating system, as it can be seen in Figure 12, does implement the data flow from the network of interconnected devices through the ZigBee technology to the Global Network with local functionalities for data representation in an interpolation map and real-time monitoring of a selected sensor.

Due to the sensor abstraction in the sensor service layer, the application uses the data from sensors as if it would be directly connected to the equipment on which it runs. It implements the concept of Distributed Electronic Circuit, which is proposed in this paper.

By accessing the Global Internet Network through WiFi, the coordinator server acts like a Gateway connecting the IoT network through the ZigBee technology. That performs the acquisition services outside the acquisition network as well.
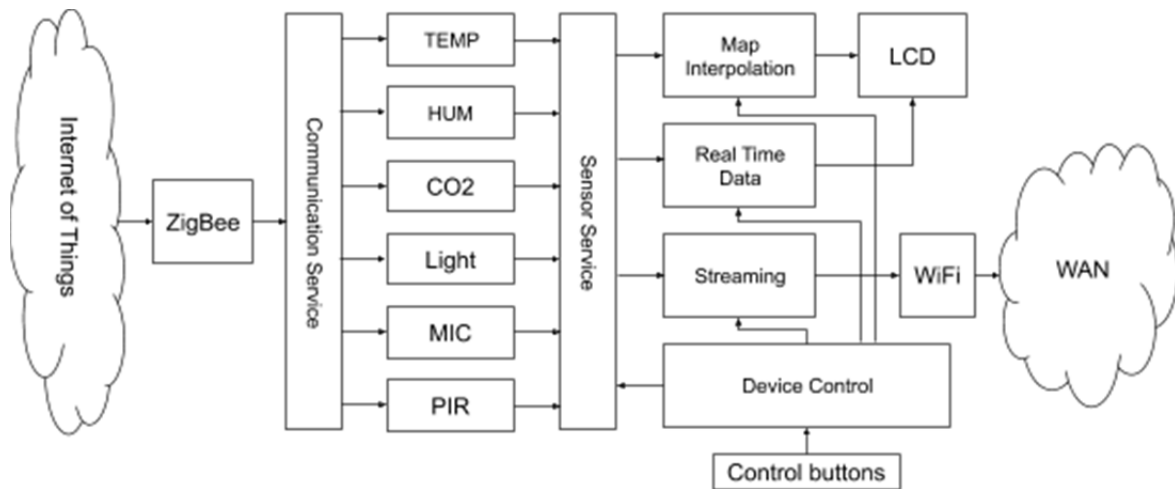

Figure 12. Functional & dataflow diagram for the IoT server coordinator.

The implementation of the prototype for the Coordinating Server was implemented on a development board, which has onboard different types of Wireless connections. Besides the fact that the processor has a moderate performance, on this platform the entire architecture mentioned above was realized according to the principles described in this paper, the functionalities of interaction with the user, the interpolation of the map, and a Web server, to access the data from the global network, Figure 13.
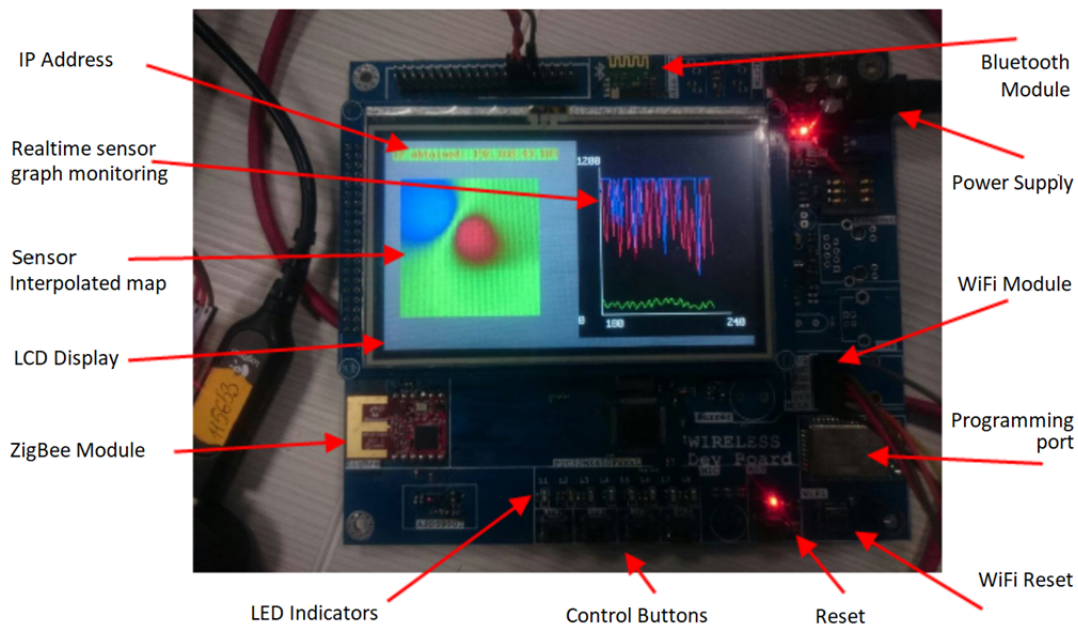

Figure 13. IoT server prototype for snvironmental data acquisition.

Web service

For the prototype phase, the web service on the coordinating server provides a simple page, duplicating the functionalities realized in the interaction with the user on the equipment running the Server for selecting the visualized parameter, and real-time monitoring of the data from the selected sensor, Figure 14.
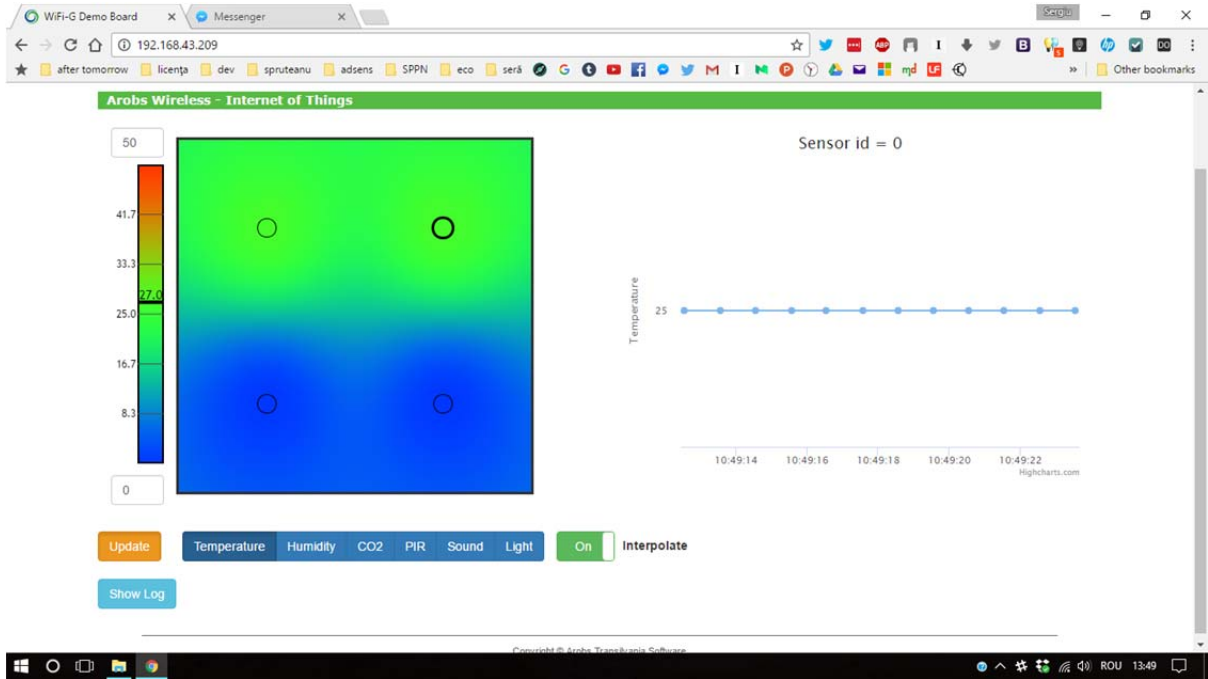
Figure 14. Web service for environmental data acquisition.

Interpolated map on a parameter layer

Each of the devices engaged in the acquisition of environmental data is located at specific physical coordinates of the environment, providing information about the collected environment collected from the area in which it is located. Referring to the idea of constructing an environmental map in the specific parameter, we encounter the problem that the collected information defines only specific discrete points in the area of interest.

In order to achieve a continuity of the environment map, a 2D interpolation was applied using the weighted arithmetic mean method. That is, each indefinite point is calculated based on the other defined points, the weight of the value of each being proportional to the inverse of the distance, proximity to this point. In this way, based on the values collected from the network devices, and the scan line method, the non-coverage areas are restored by neighbor sensors Figure 15.
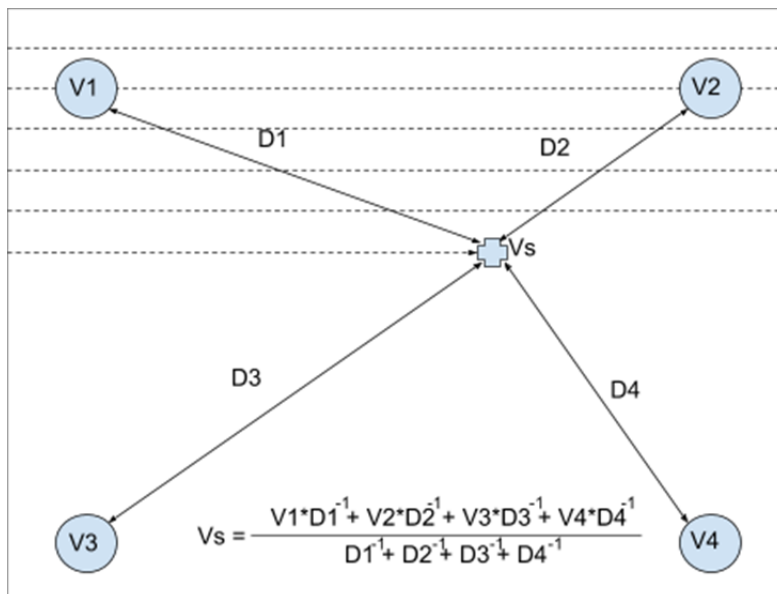

$$Vs = \frac{V1 \cdot D1^{-1} + V2 \cdot D2^{-1} + V3 \cdot D3^{-1} + V4 \cdot D4^{-1}}{D1^{-1} + D2^{-1} + D3^{-1} + D4^{-1}}$$

Figure 15. Interpolation method for 2D map building.

The given approach is a relatively simple method for obtaining a map on a satisfactory accuracy. For greater accuracy, it would be necessary to increase the number of acquisition devices, but also the choice of a more sophisticated method of interpolation calculation, which would increase the performance requirements of the data processing device and display the map.

Tools and methods

For the realization of the system there were used the design tools with free licenses. The IDE used is Eclipse, GCC compiler, GIT versioning system. The implementation was done in the C language for the embedded systems methodology. For the server was used the methodology of implementation with Javascript.

System operation

The operating mode with the system is a simplistic one. The setup consists of the acquisition devices distribution in the coordinates of interest, and the registration of the coordinates in the system on the device as a transmitted parameter and on the coordinating server.

From the user interface of the Coordinating Server, the parameter layer for visualization on the map can be selected by control buttons, as well as the device for viewing the data in real-time.

Similar is the operation mode from the web page provided by the Coordinator server.

Applications and Use cases

Typical applications for the use of this system are monitoring an area for environmental monitoring purposes and detecting special situations. Each of the monitoring layers provides information specific to the parameter on which it monitors. As a typical application, the security of a room can be analyzed. So:

The PIR sensor layer will track the authorized or unauthorized access in a designated area as well as the moving track of an object in the area.

The temperature monitoring layer will provide the temperature distribution map, from which can be extracted information about the temperature drops due to an open window, or the signaling of excessive temperature due to a fire source.

The brightness layer will provide with information about the level of light in the room, which can be used to ensure the working norms from the point of deviation of the amount of light needed for human activity, to detect defects in the lighting, as well as to identify situations in which somebody forgot to turn off the light for energy saving.

The noise layer will detect if the environment complies with the legal norms from noise, but also detect specific incidents such as breaking the glass or falling objects.

The CO_2 sensor layer will be used for the detection and monitoring of air quality in the area of interest, as well as signaling potential sources of fire or excessive smoke, for example, unauthorized smoking in the rooms.

The humidity layer can be used to monitor the quality of the environment to ensure working standards for in-room staff.

It is also possible to merge the mentioned layers in order to provide specific diagnoses and to detect more complex situations. For example, a fire can be detected by the CO_2 sensors, luminosity, temperature, and humidity, a closer analysis of these parameters could give more detailed information about the incident.

In case of detection of certain irregularities, it will be signaled with a report about the situation that will contain which parameter is detected, the coordinates, and proposals for solving the problem.

Conclusions

By the concepts presented in this paper, a methodology and design process was established that resulted in a modular system. It was proposed the reuse of the designed and applied components to the processing of a specific signal also for the other signals. This principle allows even the existing system to be extended to other parameters of interest, by adding a sensor and configuring the system to treat the signal source, similar to the existing ones.

A study was performed in order to identify a generic method for a system definition based on layered principle for a Spread out the electronic device as an IoT system.

A generic architectural concept was proposed for a device definition, as well as a layered architecture for a sensor actuator component was defined that will be developed continuously for so called Extended Software (ESW) stack components as the extension for an AUTOSAR like architectural concept.

An acquisition system was developed for Environmental map Acquisition, following the proposed methodology, the same will be developed for the Actuator part, for Industrial Internet of Things (IIoT) system concepts where devices are collaborating for executing an industrial process.

An interpolated map, 2D image, obtained from a collection of devices distributed on specific coordinates.

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