AN APPROACH CPS FOR THE SMART MONITORING OF INDUSTRIAL SYSTEMS

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ABSTRACT

Process monitoring is an important element for the long-term reliable functioning of any automated system. In fact, monitoring system is constituted of sensors installed in the physical system, in order to analyse, observe and control production systems in real time. In network, these sensors may interact with one other and with an external system via wireless communication. With recent advances in electronics, tiny sensors have appeared. Their low cost and energy consumption allow them to perform three main functions: capture data, provide information and communicate it via sensor network. In this paper, we had interested to the Cyber-Physical System (CPS) and Prognostics Health Management (PHM) domain; The CPS is one of the most important advanced technologies, it connects the physical world with the cyber using a communication layout. In other side, PHM has become a key technology for detectingfuture failures by predicting the future behaviour of the system.

KEYWORDS

Internet of Things (IoT), Cyber-Physical System (CPS), System of Systems (SoS), Cyber-Physical System of Systems (CPSoS), Wireless Sensor Network (WSN), Prognostic and Health Management (PHM), fog computing.

1. INTRODUCTION

We are fast approaching three centuries since the beginning of the original industrial revolution, which began around 1760. This is also called industry 1.0, which was based on the “Mechanization” resulting from the invention of the steam machine. It was followed by the second “mass production” using electricity and the third "digitization" using electronics and computers, marking the dawn of the fourth industrial revolution that brings us to the Internet of Things and Cyber-Physical Systems [1]. The Internet of Things (IoT) has recently become increasingly important [9]. It concerns, with more or less blurred boundaries, the massive connectivity of objects, such as sensors, telephones, or more generally objects previously disconnected. Within the factory of the future, also considered as an intelligent factory, Cyber-Physical System (CPS) will allow communication between people, machines and products [2]. As they are able to acquire and process data, they can self-control certain tasks and interact with humans via interfaces. Indeed, even a relatively simple machine can significantly increase its value if it is equipped with an appropriate on-board system for controlling and processing the device's information.

The purpose of this paper is to evaluate the contributions of the Internet of Things (IoT) to the monitoring of industrial systems, to propose a system monitoring methodology using the connected objects and finally illustrate our proposal on a case study such as the monitoring of a wind farm.

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2. System Monitoring

Monitoring is only one module of a complete process that allows a machine to operate with safety, productivity and quality criteria even in case of failure. As machine maintenance technology emerged, diagnostic and prognostic progressively crossed all fields. Nowadays, there are many types of professional instruments, such as sensors, counters, controllers and calculation devices, to diagnose a certain machine. These instruments can be used to acquire and analyse signals from a machine or process.

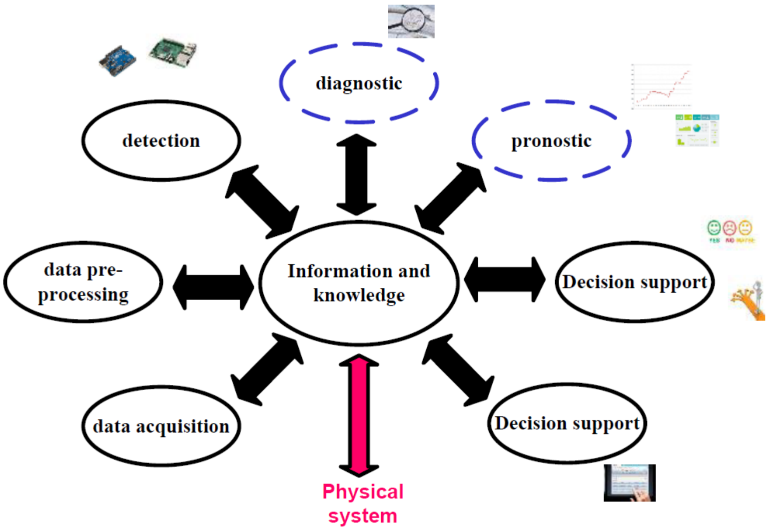

Figure 1. The main dimensions of the PHM [3]

Prognostic and Health Management (PHM) presents our application context; it aims to provide users with an integrated view of the health status of a machine or global system [16]. PHM consists of several dimensions as illustrated in Figure 1: data acquisition, data pre-processing, detection, diagnostic, prognostic and decision, except that we will limit ourselves to a few steps. Our approach is to use the different technologies of the industry 4.0 for system monitoring, and to do so, we must first define these different concepts.

3. State of the Art

After defining what system monitoring is, we will now examine what the Internet of Things consists of and then study how these two approaches can be coupled.

3.1. Internet of Things

Internet of Things (IoT) presents all physical objects equipped with information processing capacity and network connectivity to communicate with other entities: Objects, network, humans [6].

The Internet of Things aims to make it possible for things to communicate with one another, so that they can communicate with other things and users. These are integrated interconnections of various electronic devices and a fusion of two technologies: wireless connectivity and intelligent sensors [8]. With recent advances in low-power microcontrollers, these new things are easily and inexpensively connected to the Internet [15].

3.2. Machine to Machine

Machine to Machine (M2M) is a technology that allows communication between machines without human intervention. M2M is a general term, as it does not specify specific wireless or wired networking, information and communication technologies.

This general term is particularly used by business leaders. Indeed, in M2M, four phases are involved [7]:

1. Data collection
2. Data transmission
3. Evaluation of the data collected
4. Response to the machine based on the evaluation

Machine to Machine has a wide range of applications such as industrial automation, logistics, smart grid, smart buildings, health, monitoring and security defense, automobile and transportation, etc. M2M is therefore considered an integral part of the Internet of Things and brings several benefits to industry and business [17].

3.3. Wireless Sensor Network

Wireless Sensor Network (WSN) presents the set of autonomous sensors distributed in space to cooperatively monitor and transmit their data via the network to a central location [11]. They are currently used for the real physical environment without monitoring to measure many parameters.

3.4. Cyber-Physical System

According to Bergweiler [18], the best way to represent a Cyber-Physical System (CPS) is to describe it as "systems that integrate computing and communication capabilities with monitoring and control of entities in the physical world". These systems are generally composed of a set of network agents. One of the characteristics of a CPS is that its architecture is heterogeneous, as shown in Figure 2: a system that integrates electronics and software: sensors and actuators and has communication capabilities [4] [5].

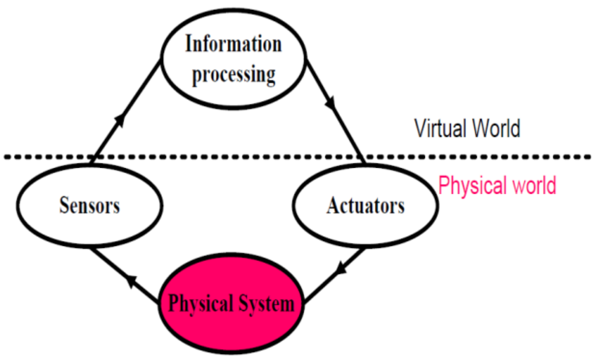

Figure 2. Principles of Cyber-Physical Systems operation

Cyber-Physical Systems perfectly integrate computation with physical processes and provide abstractions and modelling, design and analysis techniques for the integrated whole. CPSrequires computer and networking technologies to encompass not only information, but also physical dynamics. Embedded computers and networks monitor evaluate and control physical processes based on feedback control, where physical processes affect the computation process and vice versa. Within a Cyber-Physical System, the virtual world generally presents the digital twin of the real object. In fact, this twin is a way to introduce static objects into the digital world. Therefore, the result is an intelligent maintenance system that detects potential problems within the system and refines or solves the process before it becomes a problem.

3.4.1. System of Systems

Very often, we are in the systemic approach. So, a complex object is rather than a System of Systems. A System of Systems (SoS) brings together a set of cooperating systems for a task that none of the systems can accomplish on its own [10]. Each constituent system keeps its own management, goals and resources while coordinating within the SoS and adapting to meet SoS goals.

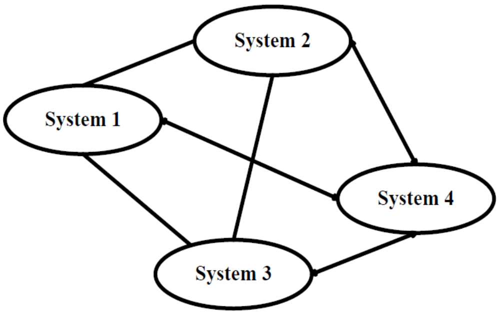

Figure 3. Architecture SoS

3.4.2. Cyber-Physical System of Systems

The combination of these SoS with Cyber-Physical Systems forms CPSoS: Cyber-Physical Systems of Systems: these are Cyber-Physical Systems that represent the characteristics of System of Systems as illustrated in Figure 4: large physical systems, often distributed in space, with complex dynamics [10].

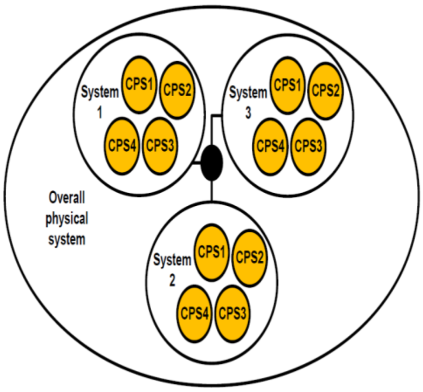

Figure 4. Architecture CPSoS

These systems allow distributed control, supervision and management and have features suchas: partial subsystem autonomy, dynamic reconfiguration of the entire system over different time scales, continuous evolution of the entire system during its operation and the possibility of emerging behaviors.

Cyber-Physical Systems of Systems can include components that are not themselves cyber-physical, for example, computer systems that manage the entire system consistently, the conceptis slightly broader than that of Cyber-Physical Systems, implying that each component of the overall system is a CPS.

3.5. Synthesis

The Figure 5 illustrates the transition of Machine-to-Machine sub-assemblies, Wireless Sensor Networks and Cyber-Physical Systems to the Internet of Things. The Internet of Things is therefore an evolutionary form of the existing ubiquitous sensor network and Machine-to-Machine (M2M).

Through these definitions, we have presented the state of the art relating to the differentconcepts of this paper in order to highlight the most appropriate methods and techniques in the field of the Internet of Things.

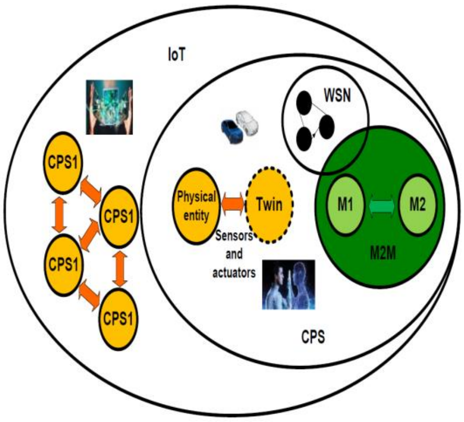

Figure 5. Synthesis diagram of IoT subsets

4. The Different Architectures

Several architectures have been cited in the scientific literature: IoT, M2M [17] and 5C by Lee dedicated CPS [19].

In the IoT architecture, a construction of object meshes exists to develop increasingly intelligent systems at long distances. Thus, real-world objects transmit and receive information. The IoT architecture is made up of 3 levels: objects, fog and Cloud.

Fog level: this technology processes data from the Internet of Things locally by using clients or devices close to users to perform a substantial amount of storage, communication, control, congregation and management [14]. Finally, the fog is a new cloud paradigm designed specifically to meet the requirements of the Cloud [20].

Cloud level: cloud is a metaphor for describing the web as a space where computing has been predominant installed and exists as a service; data, operating systems, applications, storage and processing power exist on the web ready to be shared [12].

So, our contribution consists in proposing an architecture that accurately describes an intelligent monitoring method for industrial systems.

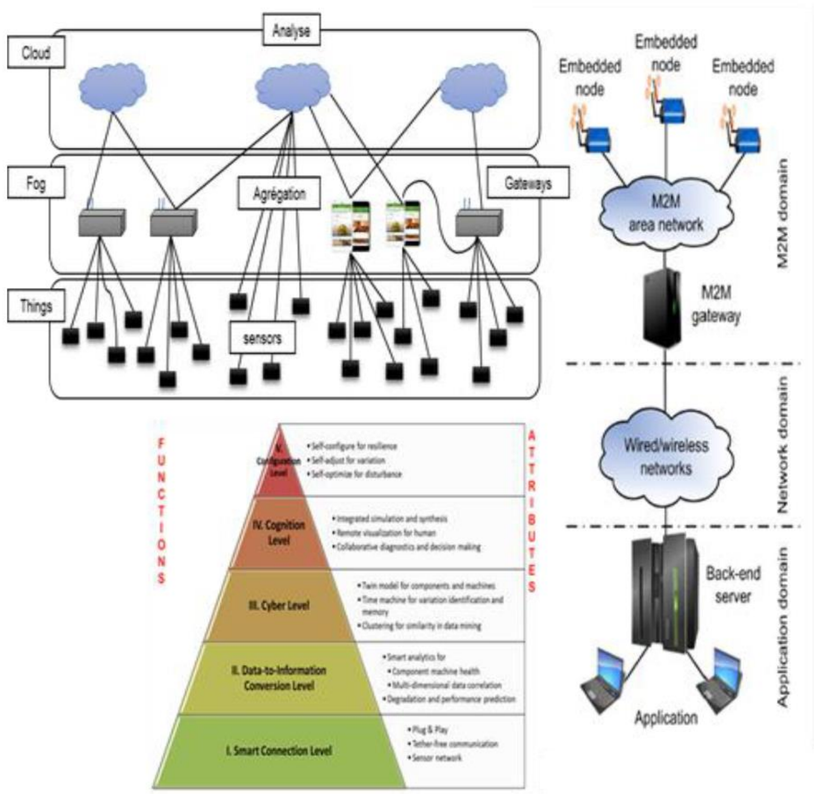

Figure 6. The different architectures

5. DISTRIBUTED INTELLIGENT SURVEILLANCE ARCHITECTURE

As illustrated in Figure 7, a Cyber-Physical System (CPS) can be modeled as a closed system loop representation. In fact, there is a similarity between the two; we also differentiate two levels when we consider a communicating object: the object itself (level 0) and the instrumented object (including communicating elements) (level 1).

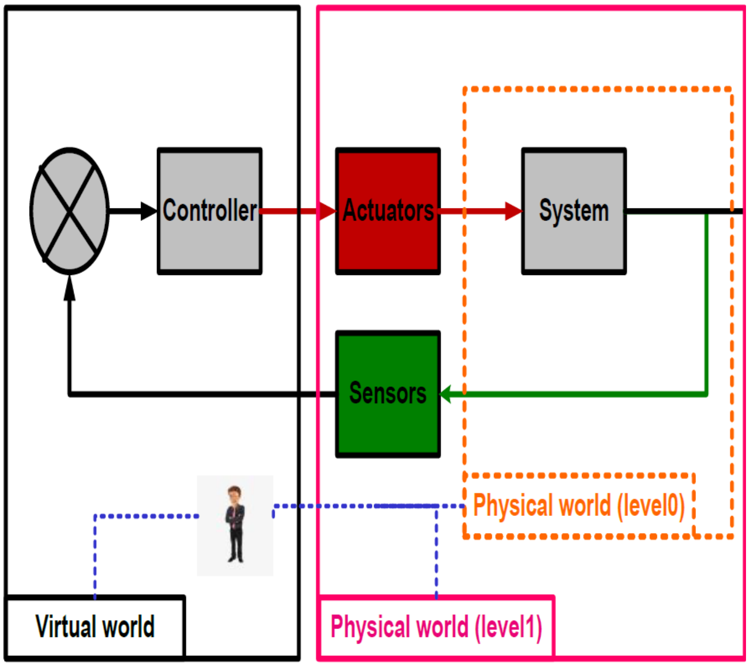

Figure 7. Closed-loop model of a CPS

Information is constantly transmitted from the physical world to the virtual space through sensors; the latter are used to collect incoming data which is then stored at the virtual world level for appropriate processing and calculation. Once this processing is completed, a generation of response actions per actuation is necessary for the good of the system. Note that this data processing is carried out at the network level through the infrastructure equivalent to fog or Cloud depending on whether we are on a local network (controlled by our equipment) or global (use of Internet, less secure networks).

5.1. Wireless Smart Node Network

In order to offer industries, the ability to monitor and control machines without any manual intervention, we have proposed a new intelligent solution based on Internet technologies for objects and Fog computing. This important solution becomes clearly necessary when dealing with a considerable number of geographically separated machines. The detailed architecture of our system is illustrated in Figure 8. As the latter illustrates, the architecture we propose is composed of three main parts which are:

The physical world: also composed of two levels; level 0, which represents the monitored system and level 1 which presents the instrumentation part, i.e. the equipment used to connect and communicate with the virtual world.

The virtual world: represents our contribution at three levels: monitoring, detection and decision support.

Fog computing: it is the infrastructure in which the virtual world is hosted.

This new surveillance architecture is characterized by intelligent wireless communication enabling a distributed, communicating and above all autonomous system.

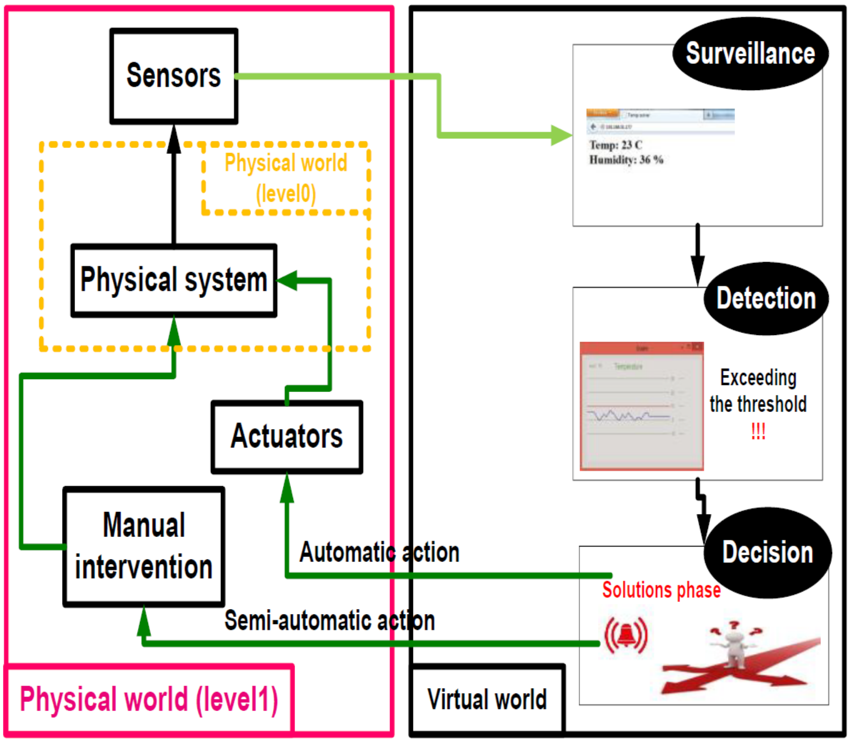

Figure 8. Proposed architecture

Wireless communication allows you to have us own processing and analysis capabilities thanks to the processor and local storage space thanks to the ROM memory. Indeed, a node is either a microprocessor or a microcontroller with wireless communication capabilities associated with sensors or actuators.

The main goal of the proposed system is to demonstrate cyber-physical systems applied to system monitoring, i.e., to build an interface for monitoring, failure detection and decision support of a system via a wireless sensor network.

In fact, the nodes of our network are distributed and wirelessly linked such that each node has processing capabilities allowing problems to be detected.

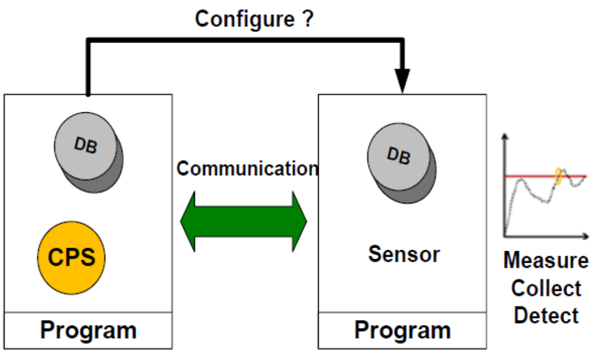

Figure 9. Example of two nodes

Let's take the example of two nodes as shown in Figure 9: the first has a CPS and the second a temperature sensor, each with a database and a program, and they are in remote communication. The sensor does three things in general: it picks up (each point = one measurement), collects and finally processes.

Data collection is not random, it is necessary to think of different scenarios that allow an intelligent distribution of decision-making responsibilities: knowing how often to collect, at what interval, at a specific request...Then, detecting any threshold overrun and therefore ensuring monitoring.

5.2. Architecture Topology

A global Cyber-Physical System (CPS) is considered to be the root of a tree that dissociates intoa set of nodes: each node has a sub-CPS that itself is formed by leaves as shown in Figure 10, so each upper level of the tree is master of the lower-level elements.

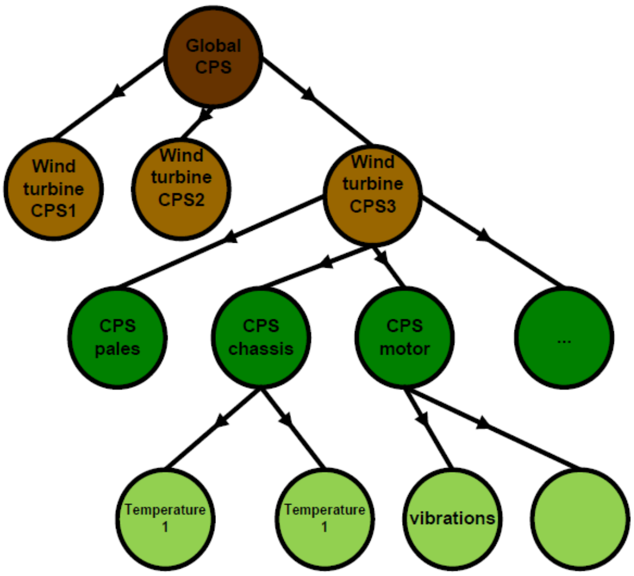

Figure 10. Tree diagram of a CPS

This tree structure allows a better localization of things and therefore the recovery of data. For example, the subdivision of a global CPS into an engine CPS and a chassis CPS allows the manufacturer to recover the operating states of the latter: temperature values as well as vibrations for the engine.

6. ARCHITECTURE PROTOTYPING

Wind energy has increased nowadays due to the proliferation of wind farms and their operation on the electricity grid by providing the electricity grid with clean and low-cost resources. As a result, there is an increasing need to establish remote monitoring of wind turbines that arehighly dependent on providing real-time safety data through a wireless connection.

The objective of our strategy is to monitor a wind farm and detect failures in order to extend the life of the turbines and thus increase productivity.

One solution is to remotely monitor a wind farm on the Internet to perform supervision, control and data acquisition tasks.

6.1. Selected Materials

The previously proposed architecture was evaluated by using a number of connected industrial devices to simulate a monitoring system. This set was composed as shown in Figure 11, a wind farm consisting of three mini-wind turbines equipped with the different modules, an anemometer which is a device for measuring wind speed, it is equipped with a mechanical sensor that rotates according to the wind power and therefore the rotational speed of the propeller is proportional to the wind speed, also a router which is a device capable of managing a small network and distributing an Internet connection to all devices connected on our "fog" network, so it is a Wi-Fi station allowing wireless devices to connect to the networks to which the router is connected and finally, a Raspberry Pi.

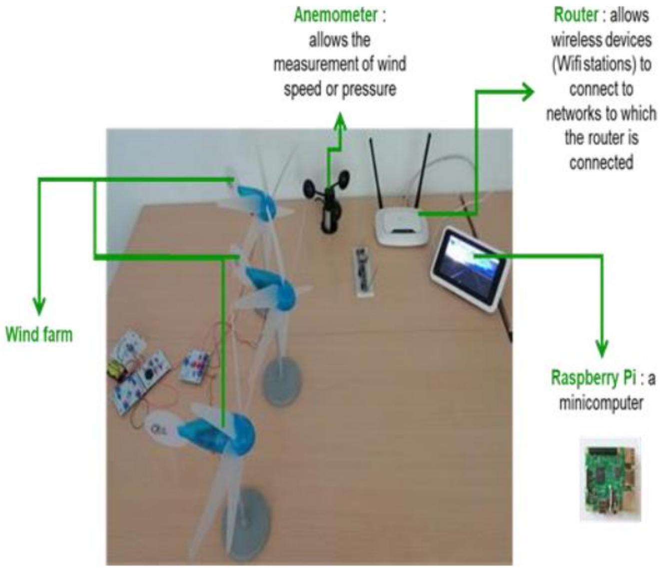

Figure 11. Selected materials

6.1.1. Arduino ESP32

Is a microcontroller designed by Espressif Systems, a Chinese company based in Shanghai. This microcontroller (figure 12) is a stand-alone Wi-Fi network solution and is also capable of running stand-alone applications. It can interface with other systems to provide Wi-Fi and Bluetooth functionality via its SPI/SDIO or I2C/UART interfaces.

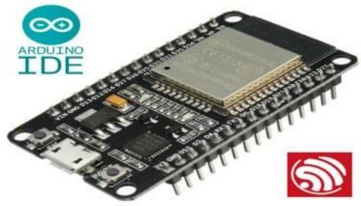

Figure 12. ESP32 [21]

6.1.2. Raspberry Pi

(Figure 13) is a Linux-powered computer and is a preferred choice for Internet of Things applications since it runs on a complete kernel and has direct interfaces such as Ethernet for wired Internet as well as USB ports to connect to Wi-Fi.

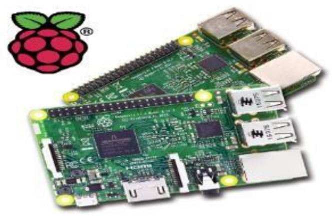

Figure 13. Raspberry PI

6.2. Data Collection

In our prototype, we used mainly two types of nodes: basic nodes and complete nodes as shown in Figure 14.

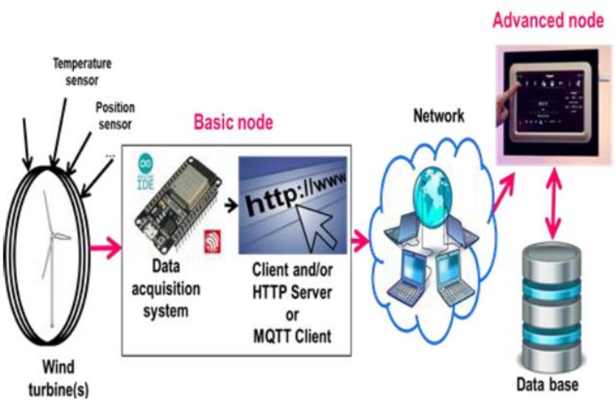

Figure 14. Data collection architecture

6.2.1. Basic node

Basic nodes contain essentially communication protocols and microcontrollers that act as a data acquisition system or are also known as data loggers; they are information systems that collect, store and distribute information. These base nodes are our server, so other systems can connect to them. Then it goes into the network. Thus, the base node can be programmed in two modes: client or server [13].

Client mode: after having correctly wired our assembly, and chosen the appropriate IDE libraries, we programmed the sensor in client Wi-Fi mode. After compilation, opening the serial console at a frequency of 115200 bauds gives the information captured by the sensor as shownin Figure 15.

Figure 15. Serial monitor

Server mode: to make things easier, we have installed the Arduino JSON library. Indeed, JSON (JavaScript Object Notation) is a popular data exchange format, a light text-based open standard designed for the exchange of human-readable data. It has been derived from the JavaScript scripting language to represent simple data structures and associative arrays, called objects. Despite its relationship with JavaScript, it is language independent, with analysers available for many languages.

Figure 16. Serial monitor

The serial console displays as shown in Figure 16 the IP address of our ESP32 (in our case 192.168.0.101) and there any person connected to the same local network (FOG-AP) canretrieve the information received by the sensors. So, we can see the server start and initialize its server socket on which it listens for incoming connections. When a connection arrives, it begins to execute its request-response loop.

6.2.2. Complete Node

Aggregation: the purpose of data aggregation is to eliminate redundant data transmissions and thus improve network life. Therefore, data aggregation represents the way data is collected at sensor nodes and the routing of packets across the network.
User interface: the system developed was tested on a wind farm formed by low-power mini- wind turbines.

The user interface allows online monitoring with the goal of early defect detection preventing major component failures, facilitating a proactive response, anticipating the final shutdown of the physical system, minimizing downtime and maximizing productivity by analyzing measurements collected continuously on different types of sensors.

A user interface can be composed of several parts. For example; a part allowing the configuration of data collection. In addition, you can change the URL from where the data originates, starts data collected or even edit the period of time when the information is collected. The second part, for example, displays the values coming from the HTTP server of the monitored physical system; another part displays the evolution curves of the various monitored parameters as well as threshold values allowing the detection of any deviation from normal and thus warn the user to intervene either through an automatic action through actuators or through asemi-automatic action. Thus, the user interface allows you to display the instant control parameters of:

- The power and frequency delivered by the wind farm. In our case, we will have the power generated by the park.
- Wind speed, direction and the rotational speed of the wind turbine blades. Indeed, whenthe speed is too high, the wind turbine must be put out of service in order to avoid any damage.
- The vibrations
- The outside and inside temperature of wind turbines
- Cumulative production in 24 hours
- The state of wind turbines: either in production, starting or stopping.

Even then, we provided an image from a camera to visualize in real time the operation of the wind turbines and finally a link to current weather conditions.
Thus, the main objective of this project is achieved through the implementation of the previously proposed architecture.

The results obtained are very acceptable for remote monitoring and data acquisition. Data acquisition can be performed for all variables at an interval as small as one second, allowing accurate modeling of climatic phenomena and wind turbine operation.

7. ILLUSTRATION OF MONITORING SCENARIOS

The objective we had set ourselves was to be able to process the following 4 scenarios, which allowed us to think and design the tree architecture presented above.

7.1. Excessive Speed

Each wind turbine, regardless of the wind speed for which it has been designed, has a minimum wind speed below which it does not produce appreciable electricity and a maximum wind speed above which it must stop to avoid damage to the mechanical parts. Therefore, excessive wind can cause a wind turbine's rotation to run wild. Above a certain speed, the blades can be damaged. The anemometer is then used to detect the wind direction and speed and if the control system realizes that these speeds are high, it sends signals to the braking mechanisms to stop the wind turbine to prevent damage and therefore acts as an actuator.

7.2. Phase Failure

The rotor of each wind turbine is formed by a set of blades; it allows the conversion of the mechanical energy provided by the rotation of these blades into electrical energy. Indeed, the rotation of the rotor varies the magnetic field flux: when the north face of the rotor rotates, it causes a change in the coil pole, i.e., this pole then becomes a south pole. And conversely, when the south face of this magnet meets this same coil. This variation in magnetic field flux resultsin the production of electrical energy. The higher the rotor rotation speed, the greater the variation in magnetic field flux and therefore the greater the production of electrical energy. So, in our monitoring scenario, the phase failure of a wind turbine causes the rotor to lock, stopping power generation and the system fails.

7.3. Network failure

Communication becomes impossible, there is no more interface, no more parameters to monitor.

CONCLUSIONS

Through this project, we have succeeded in setting up a communication network in a wind farm that allows remote access to the devices connected to this network within the "fog computing" and therefore real-time monitoring of the system status.

This intelligent, efficient and robust monitoring strategy reduces maintenance costs and ensures production continuity. Indeed, it allows early detection of electrical or even mechanical defects, preventing component failures, minimizing downtime and maximizing productivity.

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