An IoT Approach for a Smart Maintenance

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***Abstract*—The Internet of Things (IoT) can be defined as an intelligent pervasive environment, based on a continuing proliferation of intelligent networks, wireless sensors and a massive data centers; the basic idea of IoT is that, virtually every small or large physical thing in this world can be a computer connected to the Internet. There are many fields of research on IoT technology with a wide number of application domains. In this paper we had interested to Industry 4.0 and Prognostics Health Manager (PHM) domain; Industry 4.0 is a name for the current trend of automation and data exchange in manufacturing technologies. It includes cyber-physical systems, Internet of things, Cloud Computing and Cognitive Computing. In other side Prognostics Health Manager offers significant benefits for industrial maintenance which is one of the main factors of production process. We have proposed a new smart multitenant solution based on IoT and cloud computing technologies which makes an industrial environment connected, and enhanced with a system offering a Web Application (Dashboard) to monitor, supervise and control an important number of machines geographically separated; the importance of such system become clearly necessary when dealing with a large industrial environment.**

Keywords*—*Internet of Things (IoT); Cloud Computing; Smart maintenance; PHM; MQTT Protocol; Monitoring; Remote Control;

I. INTRODUCTION

The Internet of Things is a computing concept that describes the idea of everyday physical objects being connected to the internet and being able to identify themselves to each other. Some of the worldwide leaders in information technologies like Cisco, claims that Internet of Things will change everything including ourselves, and justify their statement by mentioning the impact that the Internet already has had on education, communication, business, science, government, and humanity. IoT can be defined also as a global, invisible, ambient networked computing environment built through the continued proliferation of smart sensors, cameras, software, databases, and massive data centers in a world-spanning information fabric The basic idea of the loT is that virtually every physical thing in this world can also become a computer that is connected to the Internet. IoT currently is one of the most interesting topics in information and communication technology that it has many visions and can be applied in almost any domain.

Industry 4.0 creates what has been called a Smart factory. Within the modular structured smart factories, cyber-physical systems monitor physical processes, create a virtual copy of the physical world and make decentralized decisions. Over the Internet of Things, cyber-physical systems communicate and cooperate with each other and with humans in real time, and over the Internet of Services, both internal and cross-organizational services are offered and used by participants of the value chain [3]. Prognostics and Health Management (PHM) has emerged as a key enabling technology to detect upcoming failures [1] by predicting the future behavior of the system as well as its Remaining Useful Life (RUL) [2] and take appropriate decisions to maintain it in time. In this work we have proposed a solution in order to implement a smart industrial environment which offer in real time a prognostics and health management system.

This paper is organized as follows: the prognostics and health management (PHM) domain is presented in Section II. The proposed smart PHM IoT solution is detailed in Section III. In Section IV, the system functionality is illustrated, and finally, the illustration of the implemented solution results are presented in Section V.

II. PROGNOSTICS AND HEALTH MANAGEMENT (PHM)

A. PHM Architecture

Prognostics and health management (PHM) is a key process for Predictive Maintenance (PM) which consisting of seven modules shown in Fig.1 involving data acquisition and processing, fault detection and diagnostic, fault prognostics and decision support. A brief description of each module is given as follows [4]:

- Data acquisition : Is the process of gathering and storing digital data from sensors or transducers.
- Data processing : The acquired data are processed to extract, reduce and select relevant features and indicators that can provide information on the behavior of the system, the presence of anomalies and the evolution of the degradation.
- Condition assessment : This module deals with the classification and the detection of the states of the system. It can be assimilated to fault detection.
- Diagnostic : This module focuses on the detection, isolation and identification of faults causes.
- Prognostic : The aim of the module is to predict the failure before it occurs as well as its RUL.
- Decision support : Its main function is to recommend the optimal decision of maintenance actions or other

alternatives. Particularly, decision phase is based on RUL estimates.

- Humane Machine Interface (HMI) : This module could be built into a regular humane machine interface.

Fig. 1. PHM Architecture.

B. Prognostic approaches

The prognosis is carried out by various methods that can be classified into three main approaches. The PHM community proposes three approaches [5]:

1) ***Prognostic Based on Models:*** The methods proposed in this approach are based on the use of an analytical model can be a set of differential or algebraic equations obtained by using traditional laws of physics to represent systems dynamic behavior and degradation phenomenon [6].
2) ***Prognostic Guided by Data:*** The methods developed in this approach aim to transform the raw monitoring into relevant information. In addition, it handles the behavior models to inform the evolution of the systems degradation in order to predict its RUL. In fact, these methods are based on two phases: the first phase conducted offline to understand and learn the behavior of degradation (the learned model) and the second phase conducted online to estimate the state of the systems current health and predict its duration of operation before failure [5]. The data-driven approach uses a variety of data modeling tools. Most of these tools come from the field of artificial intelligence. Neural networks [10] and neuro-fuzzy networks [11] are the most used ones.
3) ***Hybrid approach:*** This approach uses model-based approaches and Data-driven approaches to estimate the current state of the system and to predict its RUL. Moreover, it benefits the advantages of the two previous approaches, consequently, with their disadvantages [5].

C. Discussion

After our study of recent IoT related works, we have noticed that in order to propose an IoT solution of any domain we should ensure the next points:

- A system to supervise or to monitor in real-time our environment to get detailed information about it status, in order to choose which decision to make.
- Choosing the appropriate architecture layers [18] according to the system functionality.
- Selecting the appropriate communication protocol for the proposed architecture.
- Securing the information to keep them safe from hacking (stealing, data corruption . . . etc).

III. Proposed Solution

After studying some IoT application domains, we have interested to industrial area problems, precisely on PHM. We have proposed a new smart solution based on IoT and cloud computing technologies in order to offer industries the ability to monitor and to control machines without the need to manually intervene. The importance of such a system become clearly necessary when dealing with a considerable number of machines geographically separated.

The detailed proposed architecture of our system is illustrated in Fig.2.

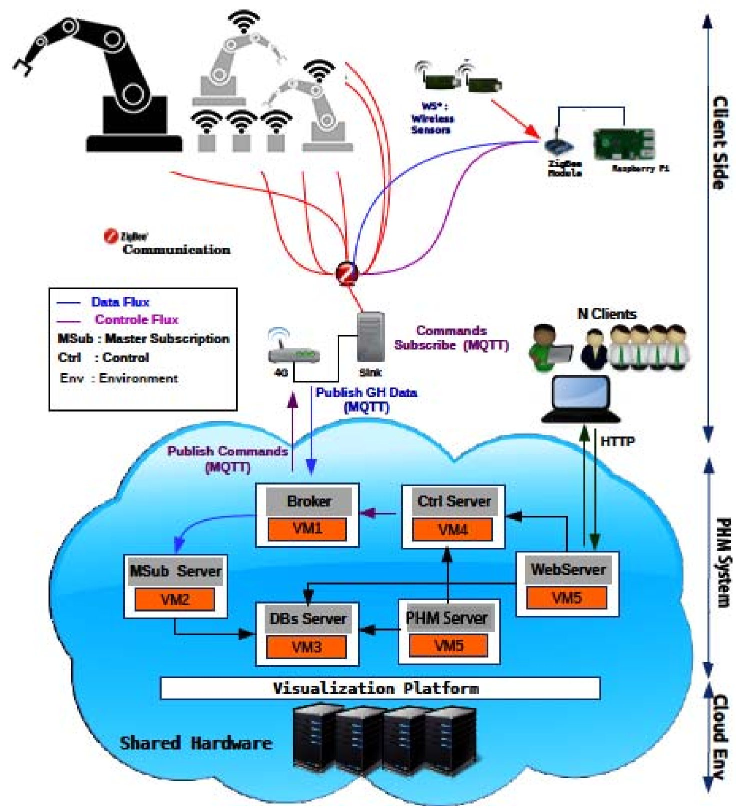

Fig. 2. Detailed Proposed Architecture of our System.

As illustrated in Fig.2, our proposed architecture is composed of three principal parts which are:

- **Client-Side:** represents the monitored machines and the used equipment in order to connect and to communicate them with the PHM System.

- **PHM System:** represents our proposed six cloud servers which are dedicated to collect the received data from the machines sensors, also to remotely control the machines.
- **Cloud Environment (CE):** is the cloud computing infrastructure in which PHM System is hosted; it also represents the classic cloud computing environment.

A. Client-Side

1) Principal Components: In order to connect each machine we needed the C_n electronic components presented in Table I.

TABLE I. CLIENT-SIDE COMPONENTS

Component C_n	Description
Sensors	depending on the type of the machine
Principal Sink	Connect all the intermediate sinks to Internet
Intermediate Sink or Micro-controller (Raspberry Pi + ZigBee)	Connect and manage all sensors and machines
Gateway	LTE router (G4/3G): connect the industry to the Internet
Electronic Relay	To command machines

2) Deployment and Functionality: The presented client-side components are deploying as follow:

1) We have placed the wireless sensors inside each machine.
2) Intermediate_Sink (Micro-controller: Raspberry Pi) [17]: it has two tasks, the first one is gathering environment data from wireless sensors before sending them over ZigBee communication to the principal sink; the second task is controlling the Actuators with GPIO (General Purpose Input Output) board and relay module.
3) Principal_Sink (Sink Server): It has also two tasks; the first one is to collect data from the intermediate sinks and to send them using the MQTT protocol to the Cloud PHM System. The second task is receiving the control commands from PHM_System and retransmitting them to the appropriate intermediate sink.
4) The Gateway: 3G/4G wireless technologies connected to the principal sink.

B. PHM System (Cloud Provider-Side)

1) Principal components: In order to efficiently manage the functionality of the proposed solution, we have separated our proposed PHM System into six Virtual Machines (VMs) servers (roles), which are presented in Table II.

TABLE II. PHM SYSTEM COMPONENTS

VM servers	Role
MQTT	Broker Server. It has two roles: Monitoring and Remote control management. 1) Monitoring: Receive MQTT publisher messages from the Principal_Sink and sending them to MSub_Server which mange and affect them to the appropriate subscriber client. 2) Remote command: Receive control messages from the Control_Server and distribute them as MQTT publisher messages to the appropriate Principal_Sink subscribers.
Master Subscription Server (MSub Server)	Manage all MQTT messages types and save data over the the Databases_Server.
Databases Server (DBs Server)	Save and manage data of MSub_Server, PHM_Server, and Web_Server.
Web Server	Used to host our developed cloud SaaS.
Control Server (CtrlServer)	Receives user commands sent through our proposed SaaS (Software as a Service) web interface (Web_Server) as a manual control, also the automatic commands sent from the PHM_Server, after that the Control_Server publish the commands as MQTT messages through the Broker_Server to the distined Principal_Sink.
PHM Server (PHM_Server)	Responsible of evaluation the RUL of machines

IV. SYSTEM FUNCTIONALITY

In this section we will explain the working of PHM IoT Monitoring System; in order to better understand its functioning we will present some related UML diagrams.

The UML use case diagram in Fig.3 shows the principal actors in our system (Client, PHM System Provider, Cloud environment Provider) and explains the actions that can be done by each of them.

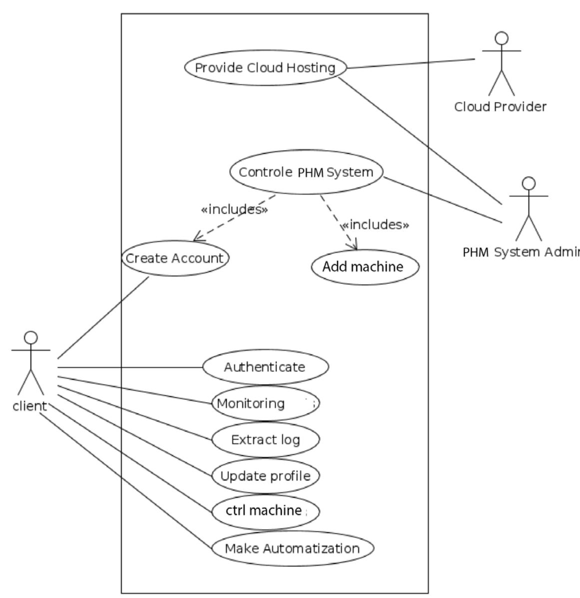

Fig. 3. UML use case diagram of our system.

V. IMPLEMENTATION

To implement our solution we have used several hardware and software tools which are:

A. Hardware tools

- Sink (Advanticsys SG1000): is an 802.15.4 Ethernet gateway device that acts as data concentrator for wireless sensor networks. [15]
- Wireless sensors (MAXFOR XM1000): new generation of mote (sensors) modules, based on T̈elosB̈technical specifications. [16]
- Raspberry Pi 3 Model B: is a credit card-sized computer. Due to its small size and accessible price; it was quickly adopted by tinkerers, makers, and electronics enthusiasts for projects that require more than a basic microcontroller (such as Arduino devices).
- Sainsmart 4-Channel 5V Relay Module: is a 5V 4-Channel Relay interface board, which able to control various appliances, and large current equipment. It can be controlled directly by Micro-controller (Raspberry Pi, Arduino, 8051, AVR, PIC, DSP, ARM, ARM, MSP430, TTL logic etc). [7]
- Cloud Computing Platform: we have hosted our PHM_System in a Cloud Computing environment of Synchromedia Laboratory [12] in order to get best results.

B. Software tools

- Python as our programming language since it has a wide collection of frameworks.
- Open source Eclipse Mosquitto broker, which implements the MQTT protocol that provides methods of carrying out messaging using a publish/subscribe model; this makes it suitable for İnternet of Thingsṁessaging for such low power sensors or mobile devices like smartphones, embedded computers or microcontrollers (Arduino, Raspberry ...etc).[13]
- Python Paho-MQTT: this package provides a client class which enable applications to connect to an MQTT broker to publish messages to subscribe to topics and to receive published messages. [8]
- Python Cryptography Toolkit: is a collection of cryptographic algorithms and protocols including both secure hash functions (such as SHA256 and RIPEMD160), and various encryption algorithms (AES, DES, RSA, ElGamal, etc.). We have used AES through this package in order to secure our MQTT messages.
- Web.py: is a web framework for Python.
- Python Dataset: toolkits that provide a simple abstraction layer for database access; it removes most direct SQL statements without the necessity for a full ORM model. Essentially, the databases can be used like a JSON file or NoSQL store. Database contents can be exported using a sophisticated plain file generator with JSON and CSV support. Exports can be configured to include metadata and dynamic file names depending on the exported data. The exporter can also be used as a command-line tool, datafreeze. [14]
- Corona SDK [9]: is a framework that empowers developers to create 2D games and apps for mobile, TV, and desktop. It has the ability to generate apps for smartphone systems like android and iOS by using the same source code. We have used corona SDK in order to develop an android App for our web App.
- Monitoring dashboard: illustrated in Fig.4 and Fig.5, it represents the developed web application (SaaS) which allow clients to both supervise and control their machines.

Fig. 4. SaaS (web application) interface.

Fig. 5. PHM dashboard.

VI. Conclusion

The Internet of Things has been growing at an increasing rate leading to an important revolution in industry, environment and society which presents a huge impact that will change human life. Despite the challenges that may face this technology such as security, privacy and horizontal integration between services, this has not stopped its expansion in contrast factors such as the cheap cost of equipment (like sensors and microcontrollers ... etc). Furthermore, the support of the open source community in the form of open standards and libraries has given a boost to this technology. PHM is yet another domain which can benefit a lot from this revolution.

In this paper, we have designed and implemented a new smart multitenant solution based on IoT and Cloud Computing technologies for a smart maintenance. This solution offers cloud services in order to monitor, and to control remotely their industrial machines any time and everywhere. Beside this, it resolves efficiently the management problem of big number of machines through the presented SaaS (web application).

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