System based on sensor dots for monitoring smart buildings

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***Abstract*—The environmental impact of the buildings is poorly monitored or null so that most of the buildings in cities suffer from sick building syndrome. Alternatives to monitor the health of buildings are few, expensive and difficult to deploy. the present work proposes a design of a complete solution not only to monitor the health of the building but also to register parameters that allow to get a LEED certification. The design of a low-cost remote terminal unit called sensor dot is proposed as base of the system, the same concept can used for deploy any kind of sensor or control unit. The communication of the sensor dot is based on a simplified message passing model that can be adapted to any transport network, which could extend the applications beyond the control of buildings. The results obtained from the proposed prototype make it comparable with existing commercial solutions**

***Index Terms*—Sensor dot, Embedded processor, LEED, IoT, Transport network**

I. Introduction

Every building during its useful life generates impacts on its environment: 70% of the world's energy goes to buildings in human settlements, 50% of the energy is used for air conditioning, 30% of the buildings suffer the syndrome "sick building" [1] in addition to contamination by garbage and wastewater that these buildings produce. In many cases nobody know about that impact because the building has not monitoring systems and the cost to implement one is high. Exist solutions that proposed low cost solutions but only include single o few variables [2].

Leadership in Energy and Environmental Design (LEED) is one of the most popular green building certification programs used worldwide [3]. LEED performance is a group of category areas that need sensors information to evaluate different factors of quality of the building to give a certification. The information of the sensors need to be available on cloud to analyze the health of the building and keep the certification.

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The sensors are the main source of information for the management of smart buildings. The easy way to deploy and manage them in buildings not designed to be manageable is one of the main problems to solve. A Smart Object framework encapsulate: identification, sensor technologies, embedded system, networking, and Internet-based information infrastructure [4]. A sensor dot is defined as an smart object with power autonomy, ease of management and at a cost low enough to be reusable or disposable, some of sensor dot could even have basic control functions.

We propose a complete solution of a management system for buildings that includes the architecture of different sensor dots, a main controller and a management system that remotely records the necessary information to be able to certify LEED performance categories. The work is described in four parts: the first presents the general model of the entire solution, the second the details of the architecture and the hardware used, third the communication model and the information management strategy, in the final section the results of the deploy and a set of final conclusions is presented.

II. System model

Figure 1 shows the overview of the system and includes three types of basic components: the sensor dots, the controller and the management application. Sensor dots are connecting by on-chip wireless [5] WIFI with the controller and this in turn connects to a private cloud via Internet both networks are independent. Different kind of sensor dot collect the information and send to the controller. The management App receive from cloud the information deploys it in real time and can execute some actions over the dots. The cloud store the values of all sensor and process historical graphs that could be show in the management App.

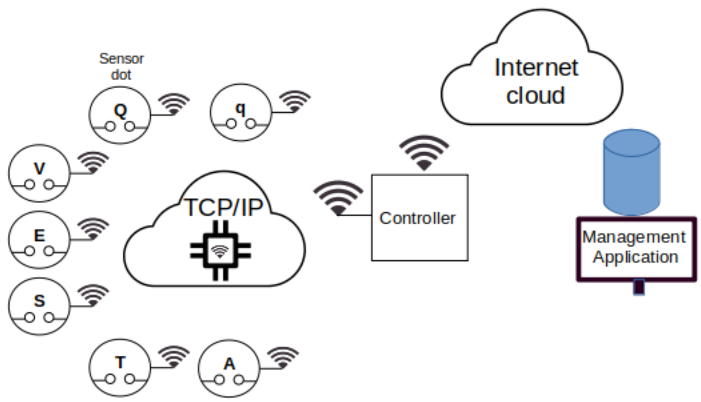

Fig. 1. System general concept.

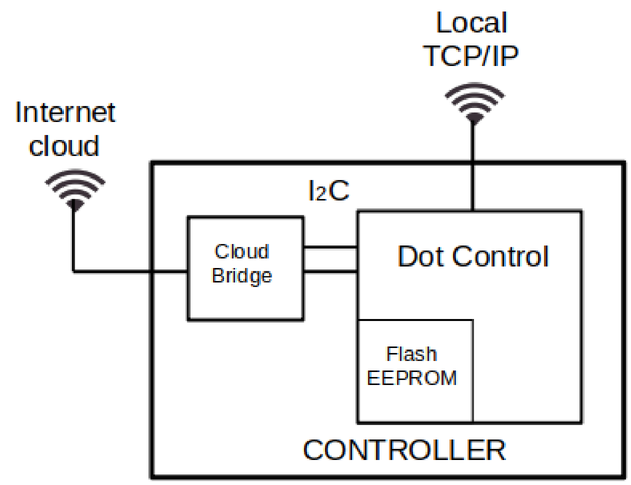

Fig. 2. Controller Functional design.

The controller regulates the addition and elimination of the sensors automatically in addition to managing the status of each of them. For a lower power consumption the communication of the networks is not always on, then the information is send it triggered by event. if no event happens, the controller start a update to the cloud for regular periods.

A. Controller functional design

Figure 2 show the functional design of the controller. This module focus mainly to management the sensor dot and as gateway communication to update the variables to the cloud. Two separate embedded TCP/IP network are using, first connect with sensor dots and second with Internet. With this topology it maintains the connection with dots even if Internet connection is inactive.Two embedded controllers are used to separate the two functions of the module they communicate with each other using I2C. The dot control manages the addition, identification, update of the information and removal of the sensor dots using a lightweight message exchange process [6] on the TCP / IP channel. All the information is recorded in a local non-volatile memory in case of loss of connectivity or energy power so that it can be recovered once it has been re-established maintaining the integrity of the topology and its information.The cloud bridge embedded is responsible for communication, which is established only when there are relevant changes in the operation or to maintain a keep-alive of all grid.

B. Sensor dots functional design

We define a sensor dot as a low cost simple unit of instrumentation and control with monitoring, processing, control, communication and power autonomy capabilities. The unit could be deployed easily to measure different kind of environmental variables to control the healthy of the buildings. Each sensor dot is attached to a controller that provide it a unique ID that could be reused if the module fail, change or is retired. A star logic topology is used to connect the units over a TCP/IP transport network using a simple message passing structure to exchange information with the controller. Figure 3 show the general functional design of the sensor dot the different between one or other is in the monitoring and control capabilities. For this work were designed seven kind of sensor dots: energy [7], power outlet, switch, environmental variables (Temperature, humidity and CO2), volatile organic compounds (VOC) [8], incoming and outgoing flow [9] but the base design could be used for other variables. The main component is the processor based on Internet of thing embedded system with complete capabilities to process the raw data of the instrumentation unit, record it on non-volatile memory, connect with all modules using a I2C bus and exchange information with the controller trough TCP/IP wireless network. Firmware is optimized with hardware interruptions to reduce power consume and long the life of the battery. OLED screen allow users have local access to variables is lighting only for short times when push button is pressed show the data for a few second and going dark again to reduce the power consumed. The instrumentation unit is responsible to get the information form sensor, that could be simple as a power switch or complex as a ASIC, depend on it some configuration task are required which are included on the processor firmware. Only when variables change their are recorded and send to the controller just the last value is saved and replaced with each change, historical record important for LEED certification can access in management application. Some sensor dots need control action for example change the set point of temperature room or off/on power outlet these task are executed by control unit. For future develop this unit could be used to start local alarm in case of variables up thresholds established by user.

C. Communication model

The communications module usually is that it consume the highest percentage of processor resources and consequently more energy approximately 80% for embedded systems. Most buildings, regardless of their purpose, have availability of wireless connections, so taking advantage of these resources is the most viable option for sensor dots. Despite the existence

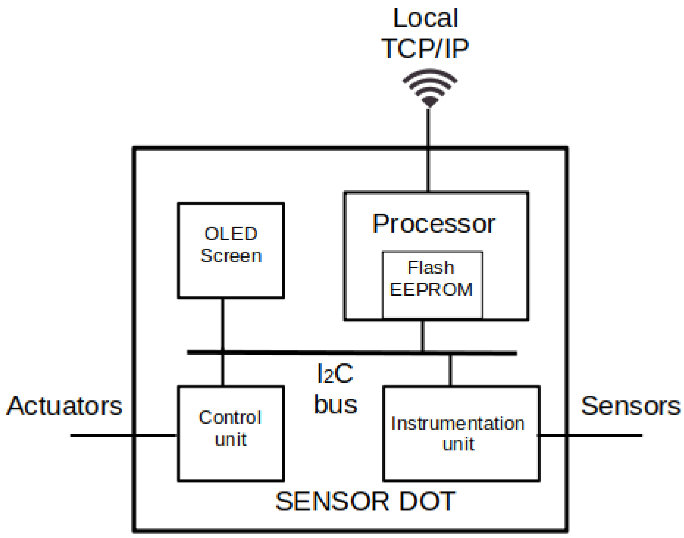

Fig. 3. Sensor dots functional design.

of many message passing protocols [10], an own alternative is proposed with a simplified header that facilitates the incorporation, management and removal of the sensor dots. Figure 4 shows the structure of the message consisting of 23 bytes of plain text which are sent in a single message that requires a single response using a TCP transport channel. The first two fields identify the origin and destination of the message and use 4 bytes to define each component. Figure 5 shows the structure of the identifier. Array is a field defined by the user at the time of configuration of the controller to represent the group of sensor dots manage by single controller, the structure can support till 254 arrays. Kind is a character to identify the type of sensor dot or controller. Table 1 show the character defined for each modules developed. Correlative is character to identify individually sensor dots the value ”00” is reserved for the controller, the space and white character are not available to be used, the rest of character are assigned randomly by the controller. A routine in the controller ensures that no correlative is repeated besides defining the mechanism for the reuse of the identifiers. The field type represent the kind of messages that exchange controller and sensor dot. For the complete communication we define five type of messages identified by a letter. Heartbeat (H) is a periodic messages that sensor dots send to controller for indicate that their are active in grid. If the controller do not receive a heartbeat messages or another kind before 30 minutes, the sensor dot will be declared inactive and the information will send to the cloud. A sensor dot could be inactive only by 30 minutes more after this time the controller erase its record and the ID could be reused. Advertisement (A) is a type of message used when a new sensor dot want to join to the group, the payload include the kind of sensor and the controller build a new ID with this information, stores the ID in non-volatile memory, informs about the new ID to the cloud and response to the dot with the new ID with what it will become active. If a sensor dot is inactive for more than 30 minutes it should starts this process by pressing the control button to re-join the group. Retreat (R) message is used when a sensor dot leave the group by maintenance or malfunction, the message trigger by press a control button, the controller receive the message, erase the ID of the sensor dot and pass the information to the cloud then the ID could be reused. Update (U) messages is used by the sensor dot to inform that variable changed its value, the message is triggering asynchronous, controller receive, store and update the information to the cloud. Check (C) messages is used only by the sensor dots with capabilities of control to verify if the cloud wish change any condition or control variable. This message is similar to heartbeat but with information in the response for update the control information in sensor dot.

D. Application management

To obtain the certification of healthy buildings it is necessary to have data records for periods of time established by the regulations applied [11] [12].

Application management used for this purpose, need a basic database to keep the historical data and present over a simple interface for process of analysis. To reduce cost our solution bind a Google account and use a spreadsheet as a database to record all the information received from the sensor dots. The data es processed and passed to Google Charts for create live graphics that can get for the application management. The application is web-based and with support for Mobile platforms include the basic functions of configure, management, display, backup and restore. All the transaction use REST model [13] and JSON to connect the data with the Internet of thing embedded processor.

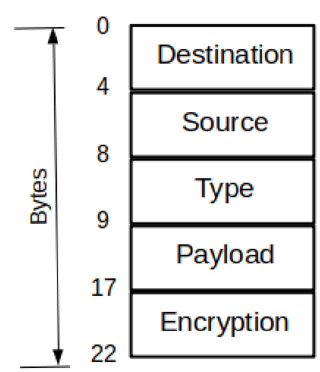

Fig. 4. Message Structure.

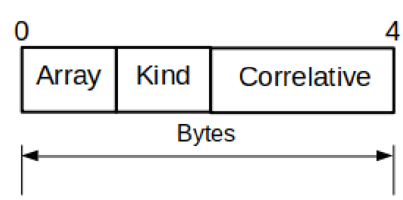

Fig. 5. ID Structure.

TABLE I
KIND OF SENSOR DOTS

Character	Kind of dots
"C"	Controller
"E"	Energy
"S"	Switch
"T"	Power outlet
"A"	Environmental variables
"V"	Volatile organic compounds
"Q"	Incoming flow
"q"	Outgoing flow

III. Implementation

For the deployment we are using low cost embedded chip and Internet of Thing controllers that include a basic cloud service for inter exchange of limited number of variables without cost. Some proprietary APIs are used to connect variables from the cloud service of the IoT modules to user account Google Cloud. All firmware was developed using processing and wiring languages, optimizing the routines with interruptions to reduce the power consumption.

A. Embedded processors

Two main embedded processor are used for deploy the modules: Particle Photon/P1 and ESP8266e, first include the cloud service then is the base for the controller module and the second no, then is used for the sensor dots.

The controller is made with Photon/P1 [14] [15], that is a tiny single board based in STM32F205RGY6 32-bit ARM Cortex-M3 microcontroller with the Broadcom BCM43362 Wi-Fi chip. Include 1Mb of flash memory that the controller use for store the ID of each active sensor dots furthermore controller firmware. The controller design use two processor to separate the wireless network for Internet access and the network to connect sensor dots because the functions used for link the cloud take the full control of the processor and for flapping connections the sensor grid could be down frequently. The second processor keep the exchange of information with sensor dots while the Internet connection return, for update the data in the cloud.

All types of sensor dots are based on ESP8266e [16] IoT processor that self-contained Wi-Fi networking capabilities, extra low power consumption and reaches a maximum clock speed of 160 MHz. The Real-Time Operating System (RTOS) and Wi-Fi stack allow 80% of the processing power to be available for user application programming. The ESP32e modules include enough processing power and flash memory to processes at the edge and store the variables before to send their to the controller and keep full operational the sensor dot even without controller connection.

A TCP service provide the mechanism of communication between controller and sensor dot. A server-client model is used for messages passing protocol, the role of server is activated in Photon/P1 and the client in ESP8266e. The sensors could be deployed over a LAN VLAN or MAN or even over VPN with independently security policy.

B. Sensors

A basic component of the sensor dot is the module to measure the variable we plan monitoring. There are a lot of low cost sensors for different variables, sensors that can connect via digital, analog or serial communication port are selected for easily interface with embedded IoT. For some dots a ASIC is connected with sensor to get more variables, that's the case of energy sensor dot. Table II show a resume of the most important sensors used to deploy the entire system.

TABLE II
RESUME OF SENSORS USED

number	Description
CCS811	Low-power digital gas sensor for Volatile organic components [17]
DHT11	Humidity and Temperature Sensor [18]
SCT-013	Split core current transformer [19]
ADE7753	Single-Phase Multi-function Metering IC [20]
YF-S201	Hall effect water flow sensor [21]

The calibration and processing of all variables are develop by firmware on embedded IoT before to send them to the controller.

C. Cloud data inter-exchange

The processor used for the controller design include a cloud services but only for limited number of variables and functions. So for save historical records that space on cloud is insufficient. A Google cloud service have enough space for high volume a data and include a lot of application for processing then bind the system with that kind of service is the best way to resolve the limitation.

A subscribed streams of Server-Sent Events is used for pass the information received in space limited cloud service to make visible the data for Google cloud. The variables are synchronized with IFTTT (If This, Then That) [22] Applet so all of them can now connected with any applications available in Google Cloud. The figure 6 show the full data inter-exchange implemented for the entire variables.

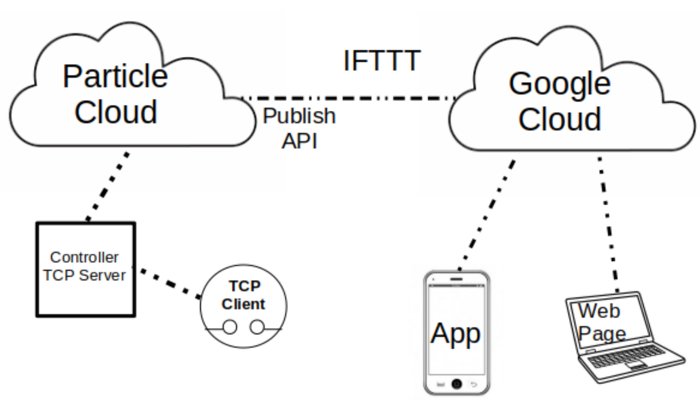

Fig. 6. Data inter-exchange.

The value of a variable is collected by sensor dot and processing at edge before to send it. The sensor dot start a

TCP connection single messages with the controller for pass the information. The controller connect with Particle cloud, generate a event based condition on variable, so the variable is pass to the Particle Cloud and this is now visible for subscribe service. With IFTTT the Google cloud is subscribed to variable visible in Particle Cloud. The variable is stored, processed and displayed using different Google Apps. At last a user interface multi-platform connected with a personal account can show the variable to the end user.

RESULTS AND CONCLUSIONS

Figure 7 show a prototype of three sensor dots without a final case. The simple way for deploy and its communication model allow integrate the data with software solution like proposed in other related works [23] [24].

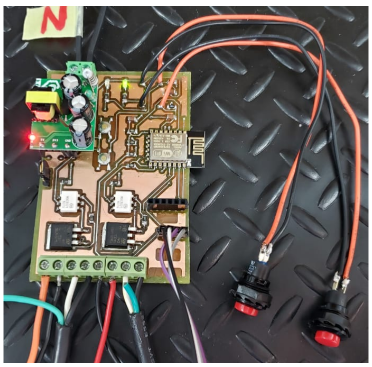

Fig. 7. Switch(a)

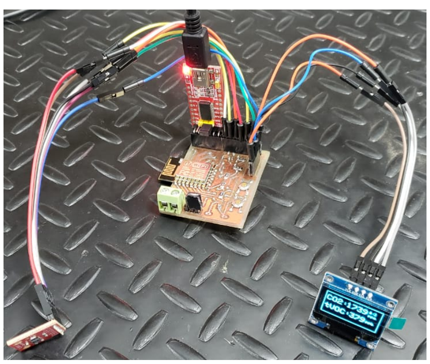

Fig. 8. VOC(b)

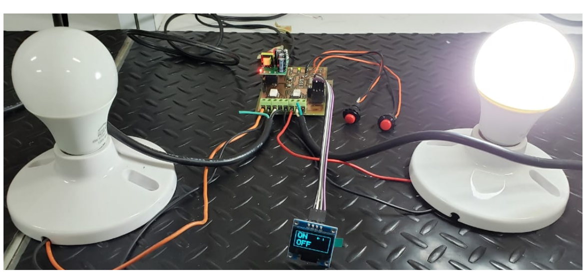

Fig. 9. Power outlet(c)

Only a appropriate interface connector is needed to bind the data or use a model of agents [25] integrated inside the sensor dots. The information collected by sensor dots was comparable with the data measure of different commercials equipment with a error less than five percent. The cost of system proposed is low than many solution for smart sensing and no need to pay licence for cloud service and software. Sensor dots could be a alternative for industrial RTU and with basic modification can be connected with other industrial field device and add smart capabilities to unconnected components of old industrial process. The information collected can easily be accessed not only by the user but also by the organizations in charge of auditing the certification for buildings such as LEED. The solution was deploy in few room and was compared with the information of already LEED certified building. There are not significantly differences found.

For future works we will develop the security for the passing messages strategy proposed and test the sensor dots on industrial plants. A tiny dc-dc circuits will be add to sensor dots for a energy harvester and will tested with a RF interface communication to enhance the reach a probe for other application in remote place where WIFI are not available

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