STUDY AND DEPLOYMENT OF SENSOR NETWORKS AND THE INTERNET OF THINGS IN THE GDL SMART CITY

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Abstract—The objective of this work is to propose the design and deployment of sensor networks and the Internet of Things (IoT) in the Guadalajara Smart City. Initially, all project development was conducted at the Living Lab in the Smart Cities Innovation Center at the CUCEA University of Guadalajara (UDG). Once the first sensor networks are functional, the goal is to transfer the experience to the first Intelligent Building Complex, which will be created by the Guadalajara (GDL) downtown Ciudad Creativa Digital (CCD) project. Many modules with sensors will record information, creating open data sets, including: zone temperature, atmospheric pressure, luminosity, pollution components (such as carbon dioxide and nitrogen oxide), green area humidity and water consumption. Thus, the main contribution of this work is the development of sensor networks for the GDL smart city, as well as supporting the production of datasets to empower the data analytics and visualization of the IEEE Smart Cities working group in the GDL.

Index Terms— Internet of Things, Smart Cities, Arduino, Sensor networks, Smart Building

1 Introduction

IT is important to describe the knowledge areas involved in the Smart Cities (SC) project. Figure 1 shows where this project is located among some of the concepts involved in the SC, creating the need to describe and contextualize each one.

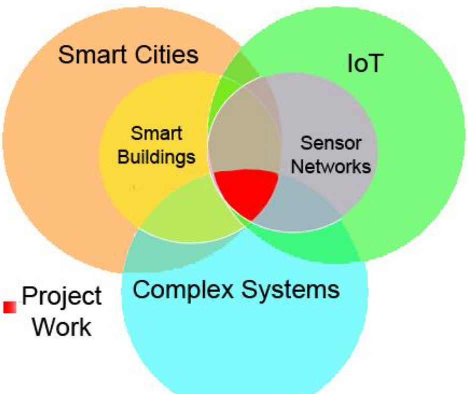

Fig. 1. Areas of knowledge for Smart Cities

There is no formal definition of a smart city, but it is possible to describe its purpose. As this document addresses Information Technologies (IT), the perspective of a smart city will be presented using information and communication technologies. Today, IT provides solutions and is used by every person around the world. In SC, there has been an increase in the population that is easily noticed by observing how cities have grown over the past decade. As a consequence of this growth, urban areas now contain more of a city's population, meaning that more resources are wasted and more pollution is generated. If we envision how this will affect us in the coming years, cities will not be environmentally friendly. A Smart City offers the assurance that it will properly manage community resources with the help of an IT infrastructure gathering information from the environment. This means that decisions in critical areas, such as locations with more air pollution, can be made to increase the quality of life for people via the proper use of technology.

One of the challenges in the Smart Cities initiative is related to coordinating and supporting the IoT. With this in mind, it is important to examine how many objects are connected at the same time to the Internet and how many will be connected within six years. Mukhopadhyay [1] determined that by 2020, there will be 50 billion items and a population of 7.6 billion residing in cities, generating a huge amount of online traffic every day. Moreover, communication creates the need for an infrastructure where it is possible to manage the resulting data flows, as well as storage, in every city.

In this context and as an example, we introduce the Smart City of Padova, Italy. The city government created a system to use all public streetlights as a sensor network connected to the Internet. This system operates the light system and includes other sensors to monitor the different levels of pollution in the air and the local weather. An analytical team then works to provide information to citizens to create alerts in the most polluted areas of the city and to support actions to improve the quality of the environment. [2]

Sensors networks and the IoT are strongly related, but

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there are still many definitions and discrepancies in the field. Technically, the idea of the IoT is to connect everything, people and objects, through the Internet. With this idea in mind, there is the possibility that everything in a persons house could be connected, making it possible for the refrigerator to buy all the food a person needs while they are at work. Initially, the IoT requires a hardware structure. This structure can be built with sensor networks or technologies such as Radio-Frequency Identification or Near Field Communication. This project will work with sensors only. These networks, such as the ones in the Padova Smart City, will monitor components of the environment and, at the same time, actuators (devices that affect the environment) will interact in a closed loop with the sensors, creating sensor-actuator networks. Thus, it should be possible, for example, to reach the correct temperature in a room efficiently from an energy consumption standpoint. However, software and standards are needed to handle this network to support the billions of sensors that need to be simultaneously connected, creating a relationship between the hardware and the software. These networks are meant to be implemented not only in the city infrastructure, but also inside a building, creating the concept of a Smart Building (SB). This concept has been used since the 1970s and consists of implementing devices inside a building to control the energy resources in an efficient manner [3], [4], [5], [6] and [7].

Moreover, complex systems are used to model the collective behavior of a system and examine how each device interacts within the environment, which is precisely what sensor networks do. As the number of components in the system grows, the system becomes more complex and organization and emergent behaviors are needed [8], [9].

With all these concepts together, we can begin to discuss the purpose of the project we propose for the GDL Smart City Sensor/Actuator Network. Everything working together creates something known as the Service. The definition of the Service is not different from that of a normal service, it is a thing that people interact with and may be as simple as a panel at the bus stop that displays the bus schedule [6] and [10].

Finally, a motivation for this work is that GDL has been selected as a pilot project by the Institute of Electrical and Electronics Engineers (IEEE) in its Smart Cities initiative, in July 2013. This project proposes to have Masters Degree students develop experience in solving problems for Smart Cities to foster new talent and meet the Smart City Challenges. Furthermore, one of the reasons for the IEEE selection of GDL is because the local and federal governments are funding a project called Ciudad Creativa Digital (CCD). Additionally, local industrial ecosystems are interested, creating a significant chance for research of Smart Cities in GDL. Additionally, the CCD project requires a technology testing platform for Smart Cities innovation to allow the IEEE to connect with the UDG at CUCEA to create a Smart Cities Innovation Center (SCIC) and a Smart Cities Living Lab. SCIC, in partnership with industries such as IBM, Intel and HP, has the goal to support the innovation required for the development of Smart Cities and to create a pool of talent and experience in the near future in GDL. All of this provides motivation for this work in the field of the Internet of Things, Smart Cities and Complex Systems. [11]

2 Problems, limitations and goals

At the Living Lab of the Smart Cities Innovation Center in UDG, implementation of the first Smart Building is taking place. This living lab is installing an infrastructure of the Internet of Things to ensure greater energy and weather efficiency, as well as generating a better interface to communicate with the user's needs. Furthermore, the entire system, hardware and software together, will be a reference model for the city. The Living Lab is located on a campus that holds 20,000 students over 50 hectares, representing almost all of the dynamics of a city on a smaller scale. This is the reason for testing the first solutions at the Living Lab.

This problem will be solved using a sensor network controlled by Arduino programming boards to ensure an open system with high interoperability and the capacity for scaling and modularity. Arduino offers advantages to IoT thanks to a large collection of libraries that researchers have developed over many years. Additionally, this is an open-source electronics platform, allowing the program to adapt to the special needs and requirements of the project.

3 First approach for the sensor network

We are using Intel Galileo to control the sensors and actuators because of its capabilities associated with supporting the processing of a number of sensors and helping to analyze data prior to delivering it to online repositories. Furthermore, Intel Galileo has an included Ethernet port, which facilitates IoT solutions, unlike other Arduino boards, which require a plugin or extra hardware to use the Internet. This solution is expensive but offers more autonomy and intelligence for the initial testing of the sensor networks.

Intel Galileo will be connected to different sensors, as shown in Table 1. The sensors will retrieve information for the board so that Intel Galileo can detect errors and examine data integrity. Once the data is verified, the board will send the information to a server so it can be stored for future analysis.

One of the features that Intel Galileo possesses is the ability to use software developed for Arduino. We are working with the Arduino 1.6.3 Integrated Development Environment (IDE) to build software as easily as if we were programming an Arduino.

TABLE 1. Sensor characteristics.

Part number	Description	Measure purpose
TSL2561	Luminosity sensor	Lumens.
MPL115A	Temperature and Atmospheric pressure.	Celsius and kilo pascal.
MAX4466	Noise sensor	Decibels (dB)
YF-S201	Water flow	Water liters per hour.
DHT22	Humidity sensor	Humidity percentage

We have worked with these sensors and determined that a number of different issues exist. Figure 2 shows the protoboard used for the tests. Initially, when we tested the noise sensor, we found that we required an instrument to determine the real sound measured in the environment to perform the calibration. Then, when we tried to test the water flow sensor and realized that we first needed to build the infrastructure, as water leakages were affecting the measurement. Nevertheless, these issues are easily fixed. The humidity sensor represented a large compatibility issue, as it only works with the Arduino microcontroller. Intel Galileo does not have a microcontroller but rather a microprocessor. This makes it more difficult to use the inputs and outputs of the microprocessor's ports because the switch of a pin between the input to ouput takes longer than with a microcontroller, causing incompatibility with this sensor unless extra hardware is used. However, the luminosity and pressure sensors work perfectly with Intel Galileo. Furthermore, the pressure sensor also has a temperature sensor that is considered to be very accurate. All sensors were tested in the Living Lab at CUCEA UDG and some have been tested at the authors' own homes to check the calibration of the sensors.

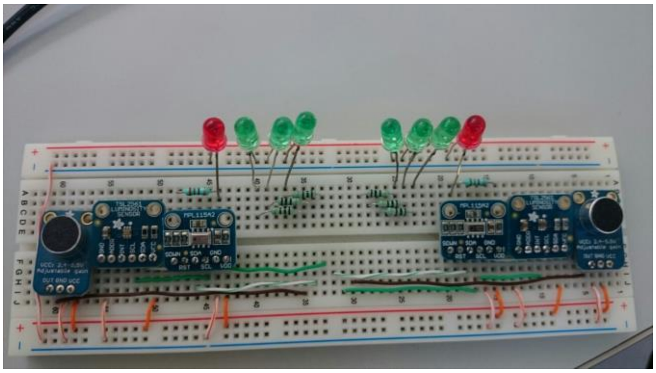

Fig. 2. Protoboard with light, noise, temperature and pressure sensors.

We have used the Arduino libraries provided from a repository recommended by the provider for the pressure and luminosity sensors. Regrettably, the library for the humidity sensor could not be used because of the hardware incompatibility. Additionally, we did not find a library for the noise sensor. Therefore, we created our own driver for it. For the other features such as the Ethernet and the Ports, we used the native Arduino libraries included with the IDE.

For sending data through the Internet, we used the Hyper Text Transfer Protocol (http) with the POST method to hide the information. We intended to use the Message Queue Telemetry Transport (MQTT) protocol but first identified an issue with the library compatibilities of the Intel Galileo, meaning that we cannot use this method at until we migrate all the work from Arduino to the Yocto Project (www.yoctoproject.org). This is actually one of the best features of Intel Galileo, and it must be used to take advantage of all its processing power. Therefore, for the time being, we are sending data to a local server through http, as other working groups require real measurements from our laboratory, and this is the fastest and easiest way to obtain records from all the sensors.

In order to start testing communication between the Galileo board and the internet repository, we used a website, www.freeboard.io (Fig. 3) that allows us to view all our data in real time using web services. This data is directly connected to another website, dweet.io, which is essentially Twitter for the Internet of Things, and allows our devices to posts updates on their states somewhere. The only important issue that has arisen during testing is that we cannot store the data using these sites. However, it was useful to check that our sensors were working and could communicate over the Internet.

The last and current step we are working on is the communication with a local server at the UDG Living Lab Server to start populating datasets using a non-relational database. This will allow us to create personal records and create our own tools to adapt to our needs in the future. However, it is important to define what protocols will be used. We will work with mongoDB, which is a non-relational database. We chose this database because it offers scalability and agility performance of large quantities of data, so that will not be an issue in the future.

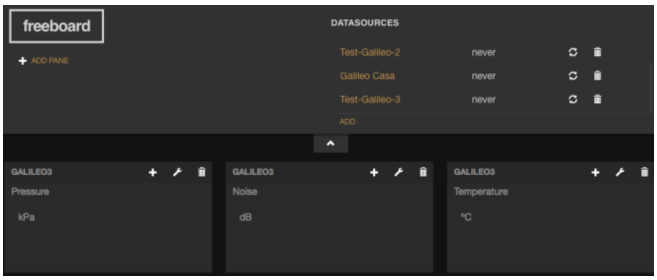

Fig. 3. Freeboard site for examining data from sensors.

4 Discussion and Perspectives

In conclusion, this project is a significant component of the entire sensor network that forms the base of the IoT. It is important that everything related to the data provided from the sensors is as accurate as possible, as other projects in the Living lab will be making use of the stored information. We will be focusing on state-of-the-art experimentation to fabricate the first prototype as soon as possible so that we can begin designing the network for the lab.

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REFERENCES

[1] S. C. Mukhopadhyay, Internet of Things, vol. 9. Cham: Springer Science & Business Media, 2014.

[2] A. Cenedese, A. Zanella, L. Vangelista, and M. Zorzi, "Padova Smart City: An urban Internet of Things experimentation," A World of Wireless, Mobile and Multimedia Networks (WoWMoM), 2014 IEEE 15th International Symposium on, pp. 1–6, 2014.

[3] A. van den Dobbelsteen, A. van Timmeren, and M. van Dorst, Smart Building in a Changing Climate. 2009.

[4] B. Morvaj, L. Lugaric, and S. Krajcar, "Demonstrating smart buildings and smart grid features in a smart energy city," presented at the Energetics (IYCE), Proceedings of the 2011 3rd International Youth Conference on, 2011, pp. 1–8.

[5] C. Perera, A. Zaslavsky, P. Christen, and D. Georgakopoulos, "Sensing as a service model for smart cities supported by Internet of Things," Transactions on Emerging Telecommunications Technologies, vol. 25, no. 1, pp. 81–93, Jan. 2014.

[6] M. Gigli and S. G. M. Koo, "Internet of Things: Services and Applications Categorization." AIT, vol. 1, no. 2, pp. 27–31, 2011.

[7] T. Gea, J. Paradells, M. Lamarca, and D. Roldan, "Smart Cities as an Application of Internet of Things: Experiences and Lessons Learnt in Barcelona," presented at the Innovative Mobile and Internet Services in Ubiquitous Computing (IMIS), 2013 Seventh International Conference on, 2013, pp. 552–557.

[8] M. Jensen, J. Gutierrez, and J. M. Pedersen, "Location Intelligence Application in Digital Data Activity Dimensioning in Smart Cities." Complex Adaptive Systems, pp. 418–424, 2014.

[9] S. P. Lau, G. V. Merrett, A. S. Weddell, and N. M. White, "StreetlightSim: A simulation environment to evaluate networked and adaptive street lighting," presented at the Wireless and Mobile, 2014 IEEE Asia Pacific Conference on, 2014, pp. 66–71.

[10] C. Harrison and I. A. Donnelly, "A Theory of Smart Cities," Proceedings of the 55th Annual Meeting of the ISSS - 2011, Hull, UK, vol. 55, no. 1, 2011.

[11] K. Pretz, "Guadalajara: Smart City of the Near Future" 13-Jul-2014. [Online]. Available: http://theinstitute.ieee.org/technology-focus/technology-topic/guadalajara-smart-city-of-the-near-future. [Accessed: 04-Dec-2014].

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