International Journal of Advances in Engineering and Management (IJAEM)
Volume 3, Issue 10 Oct 2021, pp: 168-173 www.ijaem.net ISSN: 2395-5252

On Design Rapid Prototyping and Testing of IoT Enabled Sensors Using Open Source Tools

Dr. Nandkishor M. Dhawale[1], Ms. Sneha A. Patil [2], Mr. Aditya R. Rajput[3], Mr. Kiran A. Shinde [4], Mr. Rohan S. Kulkarni [4], Mr. Nitesh R. Chavan[4]

[1]*Associate Professor, P.V.P. Institute of Technology Budhgaon, Sangli, Maharashtra.*
[2] *Assistant Professor, P.V.P. Institute of Technology Budhgaon, Sangli, Maharashtra.*
[3]*Student, Government College of Engineering, Karad, Maharashtra*
[4]*Student, P.V.P. Institute of Technology Budhgaon, Sangli, Maharashtra.*

Submitted: 25-09-2021 Revised: 01-10-2021 Accepted: 05-10-2021

ABSTRACT: The term IoT (Internet of Things) has recently become more relevant to the practical world largely because of the growth of mobile devices, embedded and ubiquitous communication, cloud computing and data analytics. The IoT application covers smart and healthy environments in various domains but not limited such as: agriculture, building, city, culture and tourism, emergency lifestyle, environment and energy, factory, supply chain, healthcare, retail, transportation, user interaction, etc. There is plenty of documented literature available in the internet and digital space (database) on IoT from knowhow, hands-on to its implementation and testing using both proprietary and open-source tools. However due to lack of availability of structured and complete set of instructions in the internet space, with special attention to several project activities including software and hardware development phases is exceptionally challenging to rapidly prototype and test an IoT enabled sensor device in timely manner. The objective of this paper is to demonstrate a project and document the complete structured set of instructions to research, design, rapid prototype and test a general purpose IoT enabled sensor device using open-source tools.

KEYWORDS: IoT, WSN, prototyping, 3D printing, design, embedded systems, temperature, humidity, sensors, hardware, Software, cloud, instrumentation, dashboard, AI, ML, data analytics

I. INTRODUCTION

The IoT concept was coined by a member of the Radio Frequency Identification (RFID) development community in 1999, and it has recently become more relevant to the practical world largely because of the growth of mobile devices, embedded and ubiquitous communication, cloud computing and data analytics. Internet of things is an internet of three things: (1). People to people, (2) People to machine /things, (3) Things /machine to things /machine, Interacting through internet.[1].

The IoT application covers smart and healthy environments in various domains but not limited such as: agriculture, building, city, culture and tourism, emergency lifestyle, environment and energy, factory, supply chain, healthcare, retail, transportation, user interaction, etc. In this context, it is possible that the level of diversity will be scaled to a number a manageable connectivity technology that address the needs of the IoT applications, are adopted by the market, they have already proved to be serviceable and are supported by a strong technology alliance [2]. Examples of standards in these categories include wired and wireless technologies like Ethernet, WI-FI, Bluetooth, ZigBee, GSM, and GPRS.

The term IoT (Internet of Things) has recently become more relevant to the practical world largely because of the augmentation of mobile devices, embedded and ubiquitous communication devices, cloud computing services and data analytic algorithms. With the IoT the communication is extended via Internet to all the things that surround us. It is much more than machine to machine communication, wireless sensor networks, sensor networks, 2G/3G/4G, GSM, GPRS, RFID, WI-FI, GPS, microcontroller, microprocessor etc. These are considered as being the enabling technologies that make "Internet of Things" applications possible [3].

There is plenty of documented literature available in the internet and digital space (database) on IoT from knowhow, hands-on to its implementation and testing using both proprietary and open source tools. It is also clear that IoT is not a single technology, but it is a mixture of different hardware & software technologies. It provides solutions based on the integration of information technology, which refers to hardware and software used to store, retrieve, and process data and communications technology which includes electronic systems used for communication between individuals or groups [4]. However, there is lack of availability of structured and complete set of instructions in the digital space, with special attention to conduction of several cost-effective project activities including software and hardware development phases. Therefore, it is exceptionally challenging for many instructors and students to practically teach and demonstrate on how to rapidly prototype and test an IoT enabled sensor device in timely manner.

The objective of this paper is two-fold 1) to demonstrate a simple approach on conducting IoT projects using cost effective means and 2) to document a complete and structured set of instructions to research, design, rapid prototype and test a general purpose IoT enabled sensor device using open-source tools.

II. LITERATURE REVIEW

The Internet of Things provides solutions based on the integration of information technology, which refers to hardware and software used to store, retrieve, and process data and communications technology which includes electronic systems used for communication between individuals or groups. However, there is a heterogeneous mix of communication technologies, which need to be adapted in order to address the needs of IoT applications such as energy efficiency, speed, security, and reliability [5].

IoT architecture consists of different layers of technologies supporting IoT. It serves to illustrate how various technologies relate to each other and to communicate the scalability, modularity and configuration of IoT deployments in different scenarios [6].

Smart device / sensor layer: The lowest layer is made up of smart objects integrated with sensors. The sensors enable the interconnection of the physical and digital worlds allowing real time information to be collected and processed. Various types of sensors are used to measure and monitor the environmental conditions when placed in their surroundings. For example; acceleration, color, humidity/moisture, light intensity, level, pressure, position, speed, and temperature are the most commonly known parameters to whom almost everyone is aware of.

Gateways and Networks: Massive volume of data will be produced by these tiny sensors and this requires a robust and high performance wired or wireless network infrastructure as a transport medium. Wired and wireless, switch, subnet, and routers working on TCP/IP protocols are some of the commonly known devices in this category. Where Ethernet and Wi-Fi are the most commonly known examples of Local Area Networks (LAN) of wired and wireless types respectively. Network Address Translation (NAT), Firewall, De-Militarized Zone (DMZ), Port Forwarding (FWD) are some the techniques implemented by the router device to handle security while connecting between devices in Wider Area Networks (WAN).

Management Service Layer: The management service renders the processing of information possible through analytics, security controls, process modelling and management of devices. Cloud services for data storage and processing are some examples of such management layers. Where, Google, Microsoft, Amazon, etc. are some commonly known examples offering such services to manage their proprietary or open source devices.

Application Layer: This is the layer where a human or non-human (robotic) user interacts between devices for monitoring, control or usage purpose. such layer can be implemented either as web based application irrespective to its operating system or it can also be implemented as a mobile device based application developed for android or iOS. The IoT application covers "smart" environments/spaces in all domains.

Based on literature it is clear that IoT has wide area of applications, it is not based on a single technology. It makes use of integrated hardware and software-based systems. There are different proprietary and open source tools available in the market to design and prototype IoT based devices depending on the target application required for industrial, commercial or domestic purpose.

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III. MATERIALS AND METHODS

3.1 Selection of the Product to be prototyped:

Based on literature and the stated objectives of this paper, hereafter we will demonstrate the steps we followed to design, prototype and test an IoT enabled device (product) to record and monitor environmental parameters such as Temperature and Humidity measurements in our surrounding space in timely manner.

The reason to choose prototyping such a product was based on the requirements set by our project sponsor as well as for the versatile applications and importance of measuring, monitoring and controlling temperature and humidity parameters in agriculture and food processing industries, which is the main type of industry in the region where our institute is set up. According to the additional requirements set by our sponsor the prototype must also offer geo-coded mobile data acquisition features and finally the development cost should be at the minimum.

Therefore the network layer was implemented using a readily available circuit board (SIM900A) based on Global System for Mobile Communications (GSM) Technology and the sensor layer was implemented using DHT21 (Temperature and Humidity Sensor) and Arduino based microcontroller hardware (prototyping board). Use of Global Navigation Satellite System (GNSS) Technology such as GPS receiver (Neo 6M) was used to record the geographical positions of the acquired data points in space.

To implement the full functionality of the product including its features and Interactive development environment (IDE) from Arduino was used to develop and program the arduino based microcontroller. Arduino based IDE's are free, and arduino offers low cost and readily available hardware and is based on open source Technology.

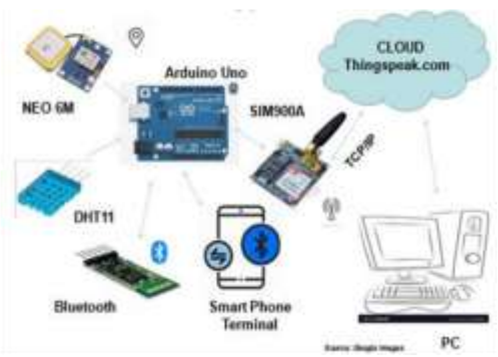

Figure 1. The conceptual block diagram of the IoT Enabled Temperature and Humidity Sensing Device

Usually use of open Source tool means no license is needed to develop, implement, test, distribute or sell products built on such platforms. To implement the cloud storage and application layer we used the cloud service from Thingspeak.com. Things peak is a proprietary cloud data storage and data analytics service provider from MathWorks Inc. However, it also offers limited free space options, depending on the size of data to be stored for a given time duration in months. Finally for troubleshooting and testing reasons a Generic Bluetooth device was used to enable communication features between smart phones and the prototyped device. Therefore the overall development cost were drastically reduced. Figure 1. Illustrates the conceptual Block Diagram of the proposed product to be prototyped and tested.

3.1 Proof of Concept (PoC)

Figure 2. Various activities involved during implementing the PoC

To implement the device as per the conceptual block diagram as shown in Figure 1, we decided to go ahead with building the PoC and test it. Various activities that were involved in this phase are shown in Figure 2. The activities included; purchase of on shelf components, assembly, discrete programming and testing, and build version 1.

3.2 Prototype

To develop the prototype and to protect the electronics, we went a step forward by placing the assembly inside an enclosure. The enclosure was initially implemented using a readily available Ice cream container made up of plastic. Special holes and grooves were made in the container to allow prototype interface with external world such as power and programming cables. However, in the later stage the enclosure was redesigned using a open source 3 dimensional (3D) Computer Aided Design (CAD) application called FreeCAD.

Later the enclosure design was printed in Polylactic Acid (PLA) material as a prototype using a low cost and readily available 3D printer from FLSUN. 3D printers from FLSUN are DIY type and are based on open source platform like

Arduino. For more details on working, materials and applications on 3D printers please refer to [7].

IV. COST

Table 1. Summarizes the costs of material

Sr. No.	Component Quantity	Unit Price* including shipping and handling charges in INR	Cost**
1	Arduino Uno	499 X 1	499
2.	Neo 6M	1100 X 1	1000
3.	SIM 900A	1100 X 1	1000
4.	DHT 22	800 X 1	700
5.	Jumper Wires	10 X 15	150
6.	Power Adapter	250 X 1	250
7.	Enclosure 3D Print	700 X 1	700
8.	9V Battery	50 X 1	50
9.	Purchase of SIM Card and monthly DATA Subscription	150 X 1	150
10.	Bluetooth device	200 X 1	200
11.	Miscellaneous Hardware	300 X ~	300
12	Arduino IDE	0 X 1	0
13	Cloud Data Storage	0 X 1	0
Total			4999/-

* - Unit price of components were slightly higher as compared to regular average due to the ongoing Covid-19 related pandemic situation, when this project was being conducted.

** - Costs exclude price of laptop computer, smart phone, testing tools and prototyping devices such as 3d printer, due to readily availability reasons.

V. RESULTS AND DISCUSSION

Figure 3 illustrates the implementation of the proof of concept (PoC). It follows the block diagram shown in Figure 1. The first 2 layers (Sensor and Network) was implemented by assembling the readily available components. The Arduino based Microcontroller board was programmed through Arduino's IDE installed on a read lily available laptop computer to implement the functionality as per the sponsors requirements.
Figure 4 illustrates the implementation of the partially prototyped product. All components are shown to be mounted on some base plates in tower mount configuration to reduce the total volume. However, some interference was detected between the power supply modules of the GPS and GPRS modules and their antennas. Therefore, a flat mount configuration was adopted in the final prototype as illustrated in Figure 5.

Figure 3. The implementation of the PoC.

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Figure 4. Partial implementation of the Prototype Product

Figure 5. Implementation of the final Prototype Product; (a) ice-cream container used as enclosure.

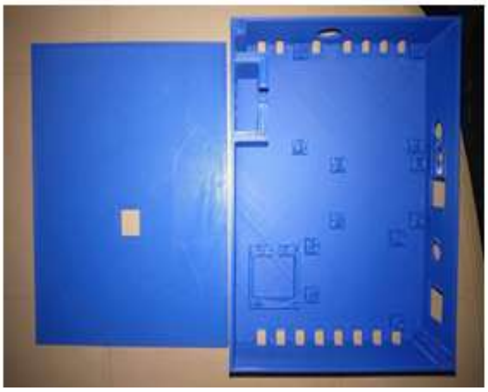

Figure 5. (b) Custom designed and 3D printed enclosure.

Figure 6. Illustrating the cloud storage and data analytic service (the third and fourth layers) of ThingsPeak.com also illustrating the data points of temperature and humidity as well as the geographical coordinates (latitude and longitude) in timely manner.

VI. CONCLUSION

In this research we identified the four layers of the IoT architecture. Using open source tools, we were able to successfully design, prototype and test the general purpose IoT enabled temperature and humidity sensing device (product). While implementing all the four layers of the architecture. Depending on the sponsor specifications/requirements we were able to add the geo-coded mobility data acquisition feature and we were able to build the prototype at minimum developmental costs. To protect the electronic components as well as to add aesthetics to the prototype (product) we used 3D Printing technology to rapidly design and print the enclosure as per the selected mounting or placements of all components. Therefore overall we were able to demonstrate a simple approach on conducting IoT projects using cost effective means and we were able to document a complete and structured set of instructions to design, rapid prototype and test a general purpose IoT enabled sensor device using open source tools.

ACKNOWLEDGMENTS

Authors would like to thank Mr. Prasant Prusty, Founder of Smart Food Safe Solutions Inc. Montreal, Quebec, Canada for partly sponsoring this project. Also, would like to extend their thanks to Mr. Shardul Karandikar, Proprietor of Fine Circuits, Madhavnagar, Sangli, Maharashtra, India, for his valuable guidance. Also, would like to thanks to the three internship students for their hard working contributions in various activities starting form research, to design, prototyping and testing

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