Comparative Study of Intelligent and Smart Development Platforms Employed for Internet of Thing's Applications

Ranvir A. Ghate[1], Shivaprasad K. Tilekar[2] and Sachin V. Chavan[3]

[1]Department of Electronics, MIT Arts, Commerce and Science College, Alandi(D), Pune
[2]Post Graduate Department of Electronics, S. M. Mahavidyalaya, Akluj, Solapur
[3]Department of Electronics, GH Raisoni College of Arts, Commerce and Science, Pune
Correspondence author: vipulaghate@gmail.com, t_shivaprasad@rediffmail.com

Article History: Received: 11 January 2021; Revised: 12 February 2021; Accepted: 27 March 2021; Published online: 23 May 2021

Abstract: The Internet of Things (IoT) describes the network of advanced microcontroller based embedded system having capability of connecting and exchanging data with other electronics devices and systems over the internet. The IoT applications are enabling the integration of internet or cyber world with the physical world. It provides the facility of interaction between human beings and computers with the millions of things, which are embedded system and other internet connected objects. The System on Chip (SoC) based processor development platforms are becoming extensively popular in development of different embedded systems and hence, IoT networks because of their low cost, ultra-low power, small size and ease in deployment. In this paper we investigated the many development platforms, such as Arduino Uno, Raspberry Pi, Beaglebone Black, Adafruit feather, etc., are made available by the vendors which is revolutionizing the IoT based embedded systems. This paper depicts review and survey of development platforms and different technologies for the development of the sophisticated and smart systems for numerous IoT applications. Therefore, extensive literatures survey has been carried out and studied, and provided a comparative solution to choose a relevant IoT development platform for various applications.

Keywords: Internet of Things (IoT), Processors, SoC, Embedded systems, etc.

1. Introduction

Internet of things (IoT) products are emerging paradigm, that connects many smart physical devices with each other to form a smart network, that stores and analyses the data on cloud to provide smart solutions to the users. On the extensive study and survey of the industries, such as sugar factory, alcohol industry, textile industry, food processing industries or the applications like smart homes, smart retail, smart cities, Industry 4.0, smart traffic management system etc, it is found that most of the applications are demanding a smart electronics system for high preciseness and reliability, smart control and smart decision-making scenario.

It is also found that some applications are using the wired networks for the measurement of parameters, data acquisition and controlling the process. The wired network ensures the complex wiring connections; it also exhibits electromagnetic interference in the transmission signal, difficulties in troubleshooting the problems, etc. Secondly, portability was also the biggest challenge in wired sensor networks, since these were always connected with the power outlets and network ports in order to function properly.

To overcome the drawbacks of Wired Sensor Networks (WSN) [1], smart WSN technology was also introduced, wherein any number of sensor nodes were deployed for collection of the different parameters, these sensor nodes are equipped with data processing circuits and will collect and transmit the data at the base station using short range wireless communication like Zigbee [2]. But it is found that, the WSN also has some limitations like data security, Power management, limited signal strength, etc. The line of sight or geological restriction will limit the area of the network. Therefore, to overcome the present-day problem of the industrial sector as well as different smart applications and to ensure wireless data transfer with high accuracy and reliability, implementation of the IoT based advanced electronic systems are preferred. IoT is the most trending and revolutionary innovation in today's world. Wherein most of the devices networked with the internet, can now connect and share the data as a smart device [3].

The IoT is adding true in many smart applications by connecting all the devices on the cloud, this cloud data let us allow remotely monitor, control and configure systems, and allows us to analyze the data on a unified platform. It gives the real time glimpse of everything from machine performance, industrial monitoring, smart homes, smart logistics and smart traffic management [4-5].

On extensive study, it is found that, many researchers are working in the field of IOT and also suggested the different architecture, platforms, applications, etc. in this field. Therefore, literatures survey has been carried out and studied, and provided a comparative solution to choose a relevant IoT development platform for various applications.

2. Literature Survey

Indeed, the Internet of things (IoT) is an emerging field of electronics, ensuring research of applied nature. The salient features of IoT motivate to undertake the research work in this field. According to the architecture of IoT, it consists of a thousand of self-organizing, lightweight internet enabled connecting devices, which are used to monitor physical or environmental conditions. For the deployment of IoT networks, smart sensors and data processing devices should have capabilities like strong security and encryption, less power consumption, compatibility with operating systems, data handling and storing, data acquisition and control, different wireless connectivity scenarios and most importantly, the cost effectiveness [6]. To get started with IoT project it is important to understand the IoT device characteristics and applications requirement. Since the IoT technology is rapidly developing it is necessary to have an advanced microcontroller SoC, which provides data processing and storage capacities [7]. The possibilities of deployment of IoT hardware and software are numerous but IoT hardware must be classified in to two categories wearable gadgets & devices and embedded systems & boards. Since last decades, Arduino enabled electronic hobbyists to make their own prototypes. The Mohammad Hoque et al have been designed the IoT based smart home security systems wherein, passive infrared sensors, also known as motion sensors temperature sensors, smoke sensors and web cameras are employed for security surveillance [8]. The Jie Lin et al have been reported the extensive survey and also investigated the fog/edge computing based IoT for many applications [9]. The Sobin have reported and presented the survey on technical challenges, such as security & privacy, interoperability, scalability and energy efficiency [10]. It is also observed that, different modules which are available in tiny sized has the ability to be programmed and deployed in to wireless networks [11]. The mentioned platforms or development boards are becoming part of our day-to-day activities. Some of the applications of IoT are smart homes, smart retail, smart cities, Industry 4.0 and smart traffic management system [10]. The advantages of proposing IoT networks are, it has widespread adoption in industries, intelligent infrastructure signalling, many wearable smart devices and smart factories. Since IoT facilitates novel products and services by reducing cost and improving the efficiency that enhances the utility of the existing systems [12]. The technical and economic constraints like development and support cost with the concern about data security and system security are the limitations of this technology [13]. The principles of IoT technology have a large impact on industries and organizations affecting business strategy, cost and risk management as well as architecture and network design. IoT processors or IoT development boards are having very important role in creating IoT network architectures [14].

3. Architecture of IoT System

There is no single or confirmed consensus over the architecture of IoT network, many researchers introduced different type of architectures based on layers like Three-layer, Five-layer and Six-layer architecture. However, the most common architecture is Five-layer architecture that includes perception layer, transport layer, processing layer, application layer and business layer [15], which is depicted in Fig. 1.

Whereas in perception layer sensors and smart devices are deployed, that gathers information and sends it toward network devices using different communication technologies, these network devices are part of transport layer. This layer transfers the information from the perception layer to the processing layer and vice versa through networks such as wireless, 3G, LAN, Bluetooth, RFID, etc. using network devices like gateways, routers and servers using protocols such as HTTP, MQTT, CoAP, etc. [10]. The processing layer is storing, analyzing and processing huge amounts of data or information that comes from the transport layer. It supports many technologies useful for IoT applications, such as databases, cloud computing and big data processing modules. The issues related with this layer are integration and authentication of the data transported in the network [16]. Application layer is responsible for client interaction with IoT objects and their environment by visualizing and analyzing the data, this layer sends action requests also to sensors and actuators in IoT network. This layer provides application specific services to user, many kinds of applications can be defined in this layer like smart homes, smart cities, smart factories, etc. [17]. Finally, the business layer controls and manages the complete IoT system including applications, business & profit models and user's privacy as well. Some researchers have discussed about six-layer architecture, where additional layer like monitoring layer is also included to explain the system in very fine manner [16].

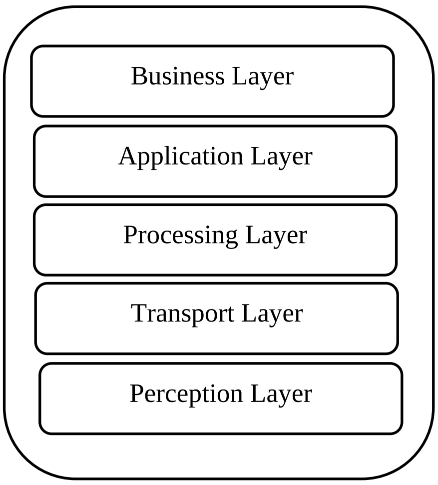

Figure 1. Five-layered structure of IoT architecture

4. Architecture of IoT Hardware Module

The Fig.2 depicts the architecture of connecting device or IoT platform [18-20] wherein, the processing unit which is a heart of the connecting device, connectivity Universal Serial Bus (USB) host, storages unit, memory unit, etc. present. The whole system of a connecting device is also known as an IoT development platform.

These hardware development platforms are available with connecting ports for loading programs, Operating System (OS) or updating firmware. These ports are USB or RJ45 type of ports, memory interfaces are embedded on board to connect memory devices for storing data. Processors with different computing capabilities are the core of the SoC systems [21-23], which processes on the data based on system program. The graphic unit and audio/video unit enhances the image processing and audio/video processing capability of the board, since these boards are utilized in many kinds of WSN and IoT applications [24-26].

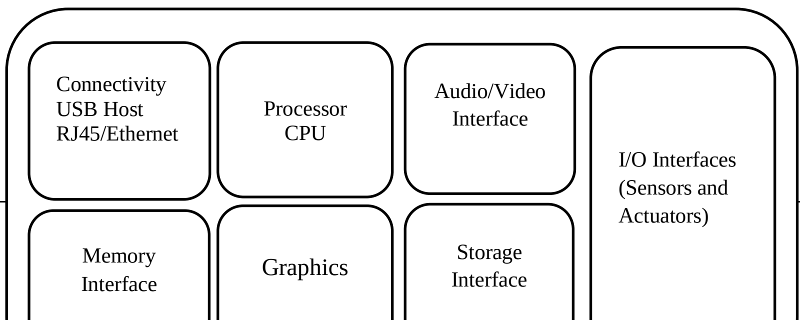

Figure 2. Internal architecture of typical IoT development platform.

Input/output interfaces are implemented on board, so that user can connect sensors, actuators and smart devices with the board. While choosing a relevant development platforms, user needs to understand the requirements of particular application and accordingly select the development platform based on parameters shown on the diagram, like connectivity options provided by the manufacturer, performance of processor in terms of speed, interfaces provided for audio and video, storage interfaces for the external memory, graphic processing capacities, amount of internal memory (EPROM) and number of input & output interfaces for connecting sensors & actuators. In this paper, comparative study of development boards like Raspberry Pi 3 model B, Arduino UNO Rev 3, Beaglebone Black and Intel Joule 570X has performed based on the mentioned parameters [6].

In following section, the comparative study of development platforms which are available for various IoT applications are elaborated. Input/output interfaces are implemented on board, so that user can connect sensors, actuators and smart devices with the board. While choosing a relevant development platforms, user needs to understand the requirements of particular application and accordingly select the development platform based on parameters shown on the diagram, like connectivity options provided by the manufacturer, performance of processor in terms of speed, interfaces provided for audio and video, storage interfaces for the external memory, graphic processing capacities, amount of internal memory (EPROM) and number of input & output interfaces for connecting sensors & actuators. In this paper, comparative study of development boards like Raspberry Pi 3 model B, Arduino UNO Rev 3, Beaglebone Black and Intel Joule 570X has performed based on the mentioned parameters [6].

In following section, the comparative study of development platforms which are available for various IoT applications are elaborated.

4.1. Raspberry pi 3

The Raspberry Pi is an open-source, Linux based, credit card sized computer board created by Raspberry Pi foundation in United Kingdom. Many generations of Raspberry have been released where all the modules consisting of Broadcom SoC [27-29] with an integrated ARM Controller (CPU) and Graphic Processor Unit (GPU). The Raspberry Pi 3 (Model-B) was released in 2016 replacing Raspberry Pi 2, it consists of a processor with 64-bit quad core and clock speed of 1.2 GHz Broadcom (BCM-2837) is provided on board. It also includes 802.1n Wi-Fi, Bluetooth and USB boot facility, 1 GB RAM available facilitates the user to utilize this board as a server in most of IoT Network configurations. The 40-pins of General-Purpose Input/Output (GPIO) are provided to interface different types of inputs and outputs from sensors and actuators in an IoT network. The 4 USB 2.0 ports are given as a storage interface. 100 base Ethernet in Pi can be used to connect with internet gateways [30-31]. There is no need to connect external antenna to Pi 3, its radios are connected to chip antenna directly soldered to the board [32-33].

4.2. Arduino Uno Rev 3

The Arduino Uno Rev 3 is an open-source microcomputer platform based on ATmega328P microcontroller which is flexible and easy to use hardware/software developed by Arduino.cc. It has

20 input/output pins for external hardware interface through which it can sense the physical or chemical parameters by receiving inputs from variety of sensors and control its surrounding like lights, motors and actuators. Out of 20 input/output pins 6 pins can be used as Pulse Width Modulation (PWM) output and 6 pins can be used as analog inputs. The Arduino UNO Rev 3 is the latest version with improved USB interface chip. It can cope up with many communication protocols that must useful in IoT applications. Arduino Uno Rev 3 is incorporated with 16 MHz on board resonator for generating a clock frequency for its operation. A dedicated USB boot loader is given for users to reprogram it. [32-34].

4.3. Beaglebone Board

The Beaglebone board is very famous among researchers, electronics hobbyists and embedded system enthusiasts because of its wide range of capabilities, which makes it a very powerful board for constructing various embedded systems. It has very flexible networking capabilities which supports many kinds of networking services like File Transfer Protocol (FTP), TELNET, SSH and the biggest benefit of its that, it can be used as a web server to publish webpage with lighttpd package. Beaglebone board can be remotely accessed by using VNC/MobaXterm based software. It makes the use of Linux file system which offers enhanced file security and has better capability of handling function calls compared to FAT32/NTFS file system. Beaglebone board provide support for variety of programming languages like C, C++, Python, Ruby, perl, JAVA, etc. Since it works on LINUX operating system this board becomes multitasking which processes multiple programs without affecting the performance. Beaglebone board is equipped with ARM Cortex A8/A15 processor technology that operates on clock speed of 720 MHz, 1 GHz and 1.50 GHz. Ethernet port with 10/100 RJ45 standard is available for all kind of network protocols and USB port for data sharing [35-36].

4.4. Adafruit Feather

Feather is a microcontroller board developed by Adafruit. Feathers are the main or mother boards of the system and daughter boards as a feather wing. Almost every board in the feather family makes use of ARM microcontroller that can be programmed with Arduino IDE environment. All feathers are having on board bootloader, that reduces the need of separate programmer device for loading the programs. 20 General Purpose I/O's for interfacing of external hardware and every I/O pin is able to source PWM output. Analog input and outputs pins are also given. Those feathers have 'Express' in their names are fully compatible with circuit python. [37]

Feathers or main boards are broadly classified in to five types as Basic Feathers, Wi-Fi Feathers, Bluetooth Feathers, Cellular Feathers and LoRa & Radio Feathers. Basic feathers are the boards without wireless connectivity and built-in data logger, this are simple boards and works great for those who don't need wireless network and data logging facility. Wi Fi feathers are introduced by Adafruit in 2012, most popular Wi-Fi feather from Adafruit is ESP8266 which contains 4 MB of flash and antenna. Feather nRF52840 Express is Bluetooth feather and its core & peripherals are similar with the other feathers. Cellular feathers can be used anywhere from the world, one can get access of SMS network, phone calls and Internet with GPRS. It has built-in geo location facility as it can communicate with cell tower. LoRa and Radio feathers having long range packet radio transceiver with built in USB and battery charging. It provides flexibility than Bluetooth LE Feathers and low power than Wi-Fi Feathers [38].

4.5. Intel Joule 570X

The Intel Joule 570x developer platform integrates a broad hardware and software ecosystem, allows developer to select OS from multiple operating systems to take advantage of different libraries. This platform features a quad core Intel atom T5700 processor operating at 1.70 GHz that burst up to 2.4 GHz, with 4 GB of on-board RAM and 16 GB of on-board embedded multimedia controller (eMMC) storage, minimizing the need of SD card. The 802.11ac Wi-Fi and Bluetooth 4.1 features Wireless connectivity for data transmission and reception. The multiple GPIO's are available for interfacing multiple sensors and devices. Serial Peripheral Interface (SPI) and Inter Integrated Circuits (I^2C) interfacing protocols are supported for peripheral devices. Joule board is expensive, but the advantage of using joule board is that, it is equipped with quad core processor that will be able to support 64-bit OS [39].

4.6. Thunderboard Sense 2

Thunder board Sense 2 is a product from Silicon Labs' developed as an excellent platform to get familiar with the energy friendly IoT devices. It is a multiprotocol kit containing EFR32™ Mighty Gecko 32-bit ARM cortex M4 Wireless SoC that operates on 38.4 MHz frequency with 1024 KB flash, 256 KB RAM and 8 Mbit of flash for Over the air (OTA) programming and data logging. The development kit is embedded with many sensors and peripherals that delivers SoC solution and can be useful in different application developments. The Thunderboard Sense 2 features total seven on board sensors that include relative humidity & temperature sensors, Hall-effect sensor, Barometric pressure sensor, UV index & ambient light sensor, indoor air quality gas sensor, 6-axis inertial sensor and MEMS microphone. Programming the Thunder board made easier with the MicroUSB port and SEGGER J-Link debugger, MSD programming facility, it has a 2.4 GHz ceramic chip radio antenna for communication, it also supports standard communication protocols like Zigbee, Low energy Bluetooth and Thread. 20 breakout pins are provided for connecting external hardware peripherals with I^2C, Universal Asynchronous Receiver and Transmitter (UART), SPI protocols or it can be used as GPIO's. Absence of Ethernet Port and Wi-Fi communication facility are the demerits of the Thunderboard. Free android and iOS app as a cloud analysis tool is provided to connect a smartphones or smart devices for sharing and analysis of real time data, which makes it great hardware development board for IoT applications [40].

4.7. DECA Board

The DECA Development board is built around the Altera MAX 10, The board can have a capability of availing re-configurability paired with a high-performance and low-power FPGA system that provides overall design protection features, onboard integrated Analog to Digital Converters (ADCs) and 32-bit microcontroller. The DECA development board is equipped with DDR3 memory, video/audio capabilities, networking/communication with Ethernet and many other facilities that promise interesting applications. The four different types of sensors like proximity/Ambient light sensor, humidity/temperature sensor, separate temperature sensor and accelerometer are also provided on board, which makes the board compatible for IoT applications. 2 FPGA (Field Programmable Gate Array) based ADC's are also given onboard [41].

4.8. Intel Galileo

Intel Galileo development board is developed and launched by Intel. To develop these boards, Intel technology has been combined with Arduino technology. So that, Arduino Integrated Development Environment (IDE) and libraries will provide smooth project development as well as easy to code interface for the programmers. The board uses Open-Source Technology like Linux OS along with Arduino Libraries. Basically, the entire ecosystem of Arduino is supported by Intel Galileo in terms of hardware and software [42]. Intel Galileo board makes use of a 32-bit Intel Pentium-class Quark SoC X1000 Processor as a CPU which operates with 400 MHz of clock. It is first generation board developed by Intel in compliance with Arduino Shields. Front end programming of this board can be achieved by Arduino IDE for sending code to the Board and easy interfacing. Till date, Intel Galileo has revised in different generations like Gen 1, Gen 2, where Intel Edison is also launched by Intel Corporation to support development. Galileo provides total 20 pins, where Pins 0 to 13 can be used as digital I/O pins and pins 0 to 5 can be used as analog inputs. Galileo also contains power header, ICSP header and UART port for data flow [43].

4.9. Particle Photon

The Particle photon is a fully-integrated IoT development prototype. The Particle has developed different versions like Photon, Electron and Particle Mesh. Where the Photon family boards work on Wi-Fi network. It's easy to use and powerful enough to get connected to the cloud. The board uses a Cypress Wi-Fi chip with a powerful STM32 ARM Cortex M3 microcontroller, which operates with clock frequency of 120 MHz on board 1 MB of flash and 128 KB of RAM is provided for the support of CPU. 18 Mixed-signal GPIO are given for interfacing much analog as well as digital type of peripherals. The board comes with free RTOS. The onboard Wi-Fi is supported with Broadcom BCM43362 Wi-Fi chip. The RGB LED on Photon board is used to give information about the mode of operation of the device. The colour of the LED and its blinking pattern indicates, which mode the device is operating in, like connected mode, OTA firmware update, looking for internet, connected with cloud, listening mode, cellular signal strength, network reset, cellular off, safe mode, Device Firmware Update (DFU) mode, firmware reset and factory reset mode. It has on board 9 pins or channels for PWM generation. The Photon also comes with all the standard peripherals for data communication including I^2C, SPI, UART, PMW, USB, CAN, ADC and (Digital to Analog Converter) DAC, but the Photon does not have the shield support like Arduino microcontrollers. Just like other microcontrollers the Particle Photon is also having cloud-base with the IDE and compiler being accessed over the cloud. But the compilation of program code is not the only cloud-based service; the feature of Photon is that it can be programmed remotely, this remote program capability allows the Photon to be built into a remote system and changing the codes easily by sending to it via the cloud. All Particle hardware is designed in such a way that it will ground up to work with the Device Cloud. [44-45].

Sr. No	**IoT Hardware Development Platforms**	**CPU/ Microcontroller**	**Clock Speed**	**RAM**	**Security**	**Communication platform**	**Supporting Protocols**	**Cost**

4.10. Intel Edison

Intel Edison is available in three variants as Intel Edison Module, Intel Edison with kit for Arduino and Intel Edison with Breakout Board. The Intel Edison module is a System on Chip (SoC) that includes an Intel Atom dual core, dual threaded CPU, which operates on the 500 MHz clock frequency and it also contains Intel Quark microcontroller capable of operating at 100 MHz This tiny sized board packs 1 GB DDR3 RAM and 4 GB eMMC Flash storage. For wireless communication it is equipped with integrated Bluetooth 4.0 LE and Wi-Fi. The Intel Edison has a 70-pin header connector which exports all the interface pins such as USB, GPIO, SPI, I^2C, PWM and many more. The Intel Edison can be programmed with this special version of the Arduino software. This device supports different type software platforms like Yocto Linux, Python, Node.js and Wolfram [46-47].

Table 1. provides quantitative comparison of all the discussed modules based on, its version, clock speed, RAM, Security features, communication platforms used, data transfer protocols. After extensive review of the above modules, it is observed that, Arduino UNO Rev 3, Thunderboard Sense 2 and Particle Photon are the low cost IoT hardware modules with limitations like low RAM capacity, less clock speed, limited communication protocols, absence of Ethernet connectivity and most importantly, no security features included. So, these modules are not preferable in complex IoT applications where extensive amount of data will be collected and analyzed. It is very difficult to maintain data security also with this type of modules. But for small and experimental purpose IoT systems these devices are most suitable.

On the other side Raspberry Pi 3 model B, Beaglebone Board, Adafruit Feather (Basic) and Intel Galileo are the modules with medium cost providing sufficient amount of RAM capacity, moderate clock speed, different types communication protocols, data encryption for enhanced

1.	Raspberry Pi 3 model B	Broadcom (BCM2837) ARM cortex A53,64-bit Quad core	1.2 GHz	1 GB	SSH, WPA2	Dual-band IEEE 802.11b/g/n/ac Wi-Fi, Bluetooth 4.2, USB 2.0, Gigabit Ethernet	I^2C, UART, SPI	Medium
2.	Arduino UNO Rev 3	ATmega328P	16 MHz	2 KB	Nil	USB-B port	UART, I^2C (TWI) SPI	low
3.	Beaglebone Board	AM335 x ARM Cortex A8/A15	720 MHz/ 1 GHz/ 1.5 GHz	128/ 256/ 512/ 2048 MB	WPA/WPA2	USB 2.0, 802.11 b/g/n 2.4GHz Wi-Fi and Bluetooth, HDMI	TCP, UDP, COAP and MQTT, UART and SPI	Medium
4.	Adafruit Feather (Basic)	ATmega32u4	8 MHz	2 KB	WEP, WPA and WPA2	802.11bgn-capable Wi-Fi, LoRa, Bluetooth LE, USB	I^2C, SPI, UART	Medium
5.	Intel Joule 570X	Intel atom T5700, Quad core	1.70 GHz	4 GB	Intel® AES-NI, WMM, WMM-PS, WPA, WPA2, and WPS2	11ac Wi-Fi with MIMO and Bluetooth 4.1, USB 3.0, HDMI	MPI CSI and DSI, I^2C, UART, I^2S	Very High
6.	Thunderboard Sense 2	EFR32™ Mighty Gecko 32-bit ARM cortex M4 Wireless SoC	38.4 MHz	256 KB	Nil	Zigbee, Low energy Bluetooth and Thread, MicroUSB	I^2C, UART, SPI	Low
7.	DECA Board	Altera MAX 10 10M50DAF484C6G	50 MHz	512 MB	Nil	10/100 Ethernet, USB 2.0, MAX 10 FPGA ADC SMA input, HDMI, BLE/Wi-Fi Cape Compatible with DECA	I^2C SPI and UART	High
8.	Intel	32-bit Intel	400	512	Nil	10/100Ethernet,	I^2C, SPI,	Mediu

	Galileo	Pentium-class Quark SoC X1000	MHz	KB		USB 2.0	UART and ICSP	m
9.	Particle Photon	STM32 ARM Cortex M3	120 MHz	128 KB	WPA/WPA2 encryption	802.11b/g/n Wi-Fi, USB	I^{2}C, SPI, UART, PMW, USB and CAN	Low
10.	Intel Edison	Intel Atom dual-core, dual-threaded CPU & Intel® Quark 100MHz microcontroller	500 MHz	1 GB	WPA2-PSK	USB 2.0, Bluetooth 4.0 LE, 802.11 a/b/g/n Wi-Fi	SPI, I^{2}C, RS232, UART	High

Table 1. Comparison of typical IoT development platforms.

security and different types of port connectivity for the data transfer. With these features, many small scale IoT applications can be constructed for small industries, home appliances, agriculture and healthcare etc.

Finally, Intel Joule 570X, DECA Board and Intel Edison are the modules with high cost but equipped with large RAM capacity, flexible communication protocols, different types of ports and high security features which makes these devices very useful in complex IoT applications, where a big amount of data collected and shared with the cloud services for the purpose of analysis. Smart cities, driverless car, industrial automation, wearable healthcare devices are the few applications of complex systems.

5. Conclusion

On literature survey and extensive study, it is found that, many researchers are working in the field of Internet of Things (IoT) and also suggested the different architecture, platforms, applications, etc. in this field. This also provided a comparative solution to choose a relevant IoT development platform for various applications by the investigators. This survey intends to describe technical specifications, advantages and limitations of SoC IoT development boards to develop a complete IoT ecosystem. A survey on all the IoT development boards helps in understanding the architecture, types of devices used on board, operating system supported by board, middleware and communication interfaces. According to the requirement of the hardware for an IoT ecosystem, various IoT development boards are discussed. A comparative overview of IoT OS, memory management, performance, power has been done. Basic communication technologies that are supported by IoT platforms has been described. Cloud computing as a base technology in order to operate and integrate with recent technologies such as big data. The technology of cloud computing refers to the processing power of the data at a central database. So different type of Clouds supported by IoT platforms are also studied extensively.

References

[1] Torres-Ruiz, Miguel Lytras, Miltiadis D, Mathkour Hassan, "*Innovative services and applications of wireless sensor networks: Research challenges and opportunities*", International Journal of Distributed Sensor Networks, Vol. 14(5), pp. 1-4, (2018).

[2] Hao Li and Zhuying Lin, "*Study on location of wireless sensor network node in forest environment*", Internation congress of Information and Communication technology, Procedia Computer Science 107 (2017), pp. 697-704, (2017)

[3] Dr. Sachin Chavan, Dr. Bhimrao Ladgaonkar and Mr. Ranvir Ghate, "*Monitoring Concentration of Alcohol Gas in Alcohol Generation Plant of Sugar Industry Using Wireless Sensor Network*", International Journal of Advanced Research in Electronics and Communication Engineering, Volume 7, Issue 1, pp. 55-60, (2018).

[4] Dr. Sachin Chavan, Sumayaa. C. Pathan, Suhas. N. Patil and Dr. Bhimrao Ladgaonkar, "*Design of Lm4f120h5qr Based Node for Wireless Sensor Network to Monitor Environmental Parameters of Polyhouse*", International Journal of Advances in Engineering & Technology, Vol. 8, Issue 3, pp. 314-328, (2015).

[5] Dr. Sachin Chavan, Dr. Bhimrao Ladgaonkar and Dr. S. K. Tilekar, "*Implementation of Sensor Network to Monitor Environmental Parameters of Preparatory Unit of Textile Industry*", International Journal of Advanced Research in Electronics and Communication Engineering, Volume 6, Issue 9, 1008-1012, (2017).

[6] P.P. Ray, "*Survey of Internet of Things architectures*", Journal of King Saud University-computer and Information Sciences, 30, pp. 291-319, (2018).

[7] Corentin Dupont, Massimo Vecchio, Congduc Pham, Babacar Diop, Charlotte Dupont and Sename Koffi, "*An Open IoT Platform to Promote Eco-Sustainable Innovation in Western Africa: Real Urban and Rural Testbeds*", Hindawi Wireless Communications and Mobile Computing, Volume 2018, Article ID 1028578, 17 pages, (2018).

[8] Mohammad Asadul Hoque and Chad Davidson, "*Design and Implementation of an IoT-Based Smart Home Security System*", International Journal of Networked and Distributed Computing Vol. 7(2), pp. 85–92, (2019).

[9] J. Lin, W. Yu, N. Zhang, X. Yang, H. Zhang and W. Zhao, "*A Survey on Internet of Things: Architecture, Enabling Technologies, Security and Privacy, and Applications*," in *IEEE Internet of Things Journal*, vol. 4, no. 5, pp. 1125-1142, (2017).

[10] C. C. Sobin, "*A Survey on Architecture, Protocols and Challenges in IoT*", Wireless Pers Commun **112,** 1383–1429 (2020)

[11] Ermi Media's, Syufrijal, and Muhammad Rif'an, "*Internet of Things (IoT): BLYNK Framework for Smart Home*", 3rd UNJ International Conference on Technical and Vocational Education and Training 2018, Volume 2019, pp. 579-586, (2019).

[12] Joshua E. Siegel, Sumeet Kumar and Sanjay E. Sarma, "*The Future Internet of Things: Secure, Efficient, and Model-Based*", IEEE INTERNET OF THINGS JOURNAL, VOL. 5, NO. 4, pp. 2386-2398, (2018).

[13] Sachin Kumar, Prayag Tiwari and Mikhail Zymbler, "*Internet of Things is a revolutionary approach for future technology enhancement: a review*", Journal of Big data, pp. 1-21, (2019).

[14] Cirillo F., Wu F.J., Solmaz G. and Kovacs E., "Embracing the Future Internet of Things", *Sensors, 19*, 351. (2019).

[15] Pallavi Sethi and Smruti R.Sarangi, "*Internet of Things: Architectures, Protocols, and Applications*", Hindawi Journal of Electrical and Computer Engineering Volume 2017, Article ID 9324035, 25 pages, (2017).

[16] Muhammad Burhan, Rana Asif Rehman, Bilal Khan and Byung-Seo Kim, "*IoT Elements, Layered Architectures and Security Issues: A Comprehensive Survey*", Sensors (Basel). 2018; 18(9):2796, pp. 1-37, (2018).

[17] Carlos Eduardo Pantoja and et.al, "*Exposing IoT Objects in the Internet Using the Resource Management Architecture*", International Journal of Software Engineering and Knowledge Engineering Vol. 29, Nos. 11&12, pp. 1703–1725, (2019).

[18] A.Gómeza, D. Cuiñasa,*, P. Cataláa, L. Xinb, W. Lib, S. Conwayc, D. Lackc, "*Use of Single Board Computers as Smart Sensors in the Manufacturing Industry*", The Manufacturing Engineering Society International Conference, MESIC, Procedia Engineering 132 (2015) pp. 153 – 159, (2015).

[19] G. Bedi, G. K. Venayagamoorthy, R. Singh, R. R. Brooks and K. Wang, "*Review of Internet of Things (IoT) in Electric Power and Energy Systems*", *IEEE Internet of Things Journal*, vol. 5, no. 2, pp. 847-870, (2018).

[20] Naufal Alee, Mostafijur Rahman, R. B. Ahmad, "*Performance Comparison of Single Board Computer: A Case Study of Kernel on ARM Architecture*", The 6th International Conference on Computer Science & Education, August 3-5, 2011, SuperStar Virgo, Singapore, pp. 521-524, (2011)

[21] Kumar Yelamarthi, Md Sayedul Aman, and Ahmed Abdelgawad, "*An Application-Driven Modular IoT Architecture*", Hindawi Wireless Communications and Mobile Computing Volume 2017, Article ID 1350929, 16 pages, (2011)

[22] Kanchan Warathe, Dinesh Padole, Preeti Bajaj, "*A design approach to AMBA (Advanced Microcontroller Bus Architecture) bus architecture with dynamic lottery arbiter*", 2009 Annual IEEE India Conference, pp. 1-4, (2009)

[23] Johnston, S. J., Basford, P. J., Perkins, C. S., Herry, H., Tso, F. P., Pezaros, D., Mullins, R. D., Yoneki, E., Cox, S. J., and Singer, J., "*Commodity single board computer clusters and their applications*", Future Generation Computer Systems, 89, pp. 201-212, (2018)

[24] T.K.Priyambodo, A.W.Lisan, and M.Riasetiawan, "*Inexpensive Green Mini Supercomputer Based on Single Board Computer Cluster*", Journal of Telecommunication, Electronic and Computer Engineering, Vol. 10 No. 1-6, pp. 141-145, (2018)

[25] Philip J. Basford, Graeme M. Bragg, Jonathon S. Hare, Michael O. Jewell, Kirk Martinez, David R. Newman, Reena Pau, Ashley Smith and Tyler Ward, "*Erica the Rhino: A Case Study in Using Raspberry Pi Single Board Computers for Interactive Art*", Electronics 2016, 5, 35, pp. 1-18, (2016).

[26] Kenneth C. Karamihan, Ivan Dave F. Agustino, Ronnick Bien B. Bionesta, Ferangelo C. Tuason, Steven Valentino E. Arellano, Phillip Amir M. Esguerra, "*SBC-Based Cataract Detection System using Deep Convolutional Neural Network with Transfer Learning Algorithm*", International Journal of Recent Technology and Engineering, Volume-8 Issue-2, pp. 4605-4613, (2019).

[27] Pritish Sachdeva and Shrutik Katchii, "*A Review Paper on Raspberry Pi*", International Journal of Current Engineering and Technology, Vol.4, No.6, pp. 3818-3819, (2014).

[28] J. Marot and S. Bourennane, "*Raspberry Pi for image processing education,*" *2017 25th European Signal Processing Conference (EUSIPCO),* Kos, 2017, pp. 2364-2366, (2017).

[29] Jaokar Ajit, "*Using Raspberry Pi to Teach Computing 'Inside Out'*." Educational Technology, vol. 53, no. 2, JSTOR, pp. 37–40, (2013).

[30] Mrs. Mikhal John, "*comparative study on various system based on Raspberry-pi technology*", International Research Journal of Engineering and Technology (IRJET), Volume 05, Issue 01, pp. 1486-1488, (2018).

[31] Anuradha Patel, Dr. P. Devaki, "*Survey on NodeMCU and Raspberry pi: IoT*", International Research Journal of Engineering and Technology (IRJET), Volume 06, Issue: 4, pp. 5101-5105, (2019).

[32] Sharu Bansal, Dilip Kumar, "*IoT Ecosystem: A Survey on Devices, Gateways, Operating Systems, Middleware and Communication*", International Journal of Wireless Information Networks, 27, pp. 340-364, (2020).

[33] Dr. Malti Bansal and Bani Gandhi, "*IoT Based Development Boards for Smart Healthcare Applications*", 4th International Conference on Computing Communication and Automation (ICCCA), pp. 1-7, (2018).

[34] Dinkar R Patnaik Patnaikuni, "*A Comparative Study of Arduino, Raspberry Pi and ESP8266 as IoT Development Board*", International Journal of Advanced Research in Computer Science, Volume 8, No. 5, pp. 2350-2352, (2017).

[35] Ali Raza, Ataul Aziz Ikram, Asfand Amin and Ahmad Jamal Ikram, "*A Review of Low Cost and Power Efficient Development Boards for IoT Applications*", FTC 2016 - Future Technologies Conference, San Francisco, United States, pp. 786-790, (2016).

[36] Anand Nayyar and Vikram Puri, "*A Comprehensive Review of BeagleBone Technology: Smart Board Powered by ARM*", International Journal of Smart Home Vol. 10, No. 4, pp. 95-108, (2016).

[37] V. Jeevana, R. Kapil Sundar, K. Pravin, S. Preethi and R. Karthik, "*Design of Intelligent Stick - Guide for the Blind*", International Journal for Scientific Research & Development, Vol. 6, Issue 01, pp. 2321-0613, (2018).

[38] Ricardo Toro, Jorge E. Correa and Placid M. Ferreira, "*A Cloud-Monitoring Service for Manufacturing Environments*", 46th SME North American Manufacturing Research Conference, NAMRC 46, Texas, USA, Volume 26, pp.1330-1339, (2018).
[39] Dexmont Pena, Andrew Forembski, Xiaofan Xu, and David Moloney, "*Benchmarking of CNNs for Low-Cost, Low-Power Robotics Applications*", RSS 2017 Workshop: New Frontier for Deep Learning in Robotics, pp. 1-5, (2015).
[40] Balz Maag, Zimu Zhou and Lothar Thiele, "*W-Air: Enabling Personal Air Pollution Monitoring on Wearables*", Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies, Vol. 2, Issue No. 1, Article24, pp. 24.1-24.25, (2018).
[41] Emekcan Aras, St´ephane Delbruel, Fan Yang, Wouter Joosen and Danny Hughes, "*A Low-Power Hardware Platform for Smart Environment as a Call for More Flexibility and Re-Usability*", International Conference on Embedded Wireless Systems and Networks (EWSN) 2019, At Beijing, China, (2019).
[42] Liu Jie, Hemant Ghayvat, S. and C. Mukhopadhyay, "*Introducing Intel Galileo as a development platform of smart sensor: Evolution, Opportunities and Challenges*", IEEE 10th Conference on Industrial Electronics and Applications (ICIEA), pp. 1797-1802, (2015).
[43] Anand Nayyar, Er. Vikram Puri, "*A Review of Intel Galileo Development Board's Technology"*, Int. Journal of Engineering Research and Applications, Vol. 6, Issue 3, (Part - 4), pp.34-39, (2016).
[44] Sergio Trilles, Alberto González-Pérez and Joaquín Huerta, "*A Comprehensive IoT Node Proposal Using Open Hardware. A Smart Farming Use Case to Monitor Vineyards*", Open-Source Electronics Platforms: Development and Applications, *7*(12), 419, pp. 1-32, (2018).
[45] I. Tarimer and S. Eren, "*An IoT application with particle card over cloud*", International Journal on Technical and Physical Problems of Engineering, Volume 10, Issue 36, Number 3, pp. 6-13, (2018).
[46] M. Vivek Kumar, V. Prabhu, Ravindra Gupta, M. Srijith and N Zainulabdin, "*IOT Based Home Automation using Intel EDISON Gen-2*", International Journal of Innovative Science and Research Technology, Volume 3, Issue 4, pp. 1-3, (2018).
[47] Zaid Hadi, Nasri Sulaiman, Izhal Abdul Halin and Nurul Amziah Md Yunus, "*Implementation of Image Enhancement Techniques Based on Intel Edison Platform*", 1st International Conference on Information Technology, Information Systems and Electrical Engineering, Yogyakarta, Indonesia, pp. 17-20, (2016).