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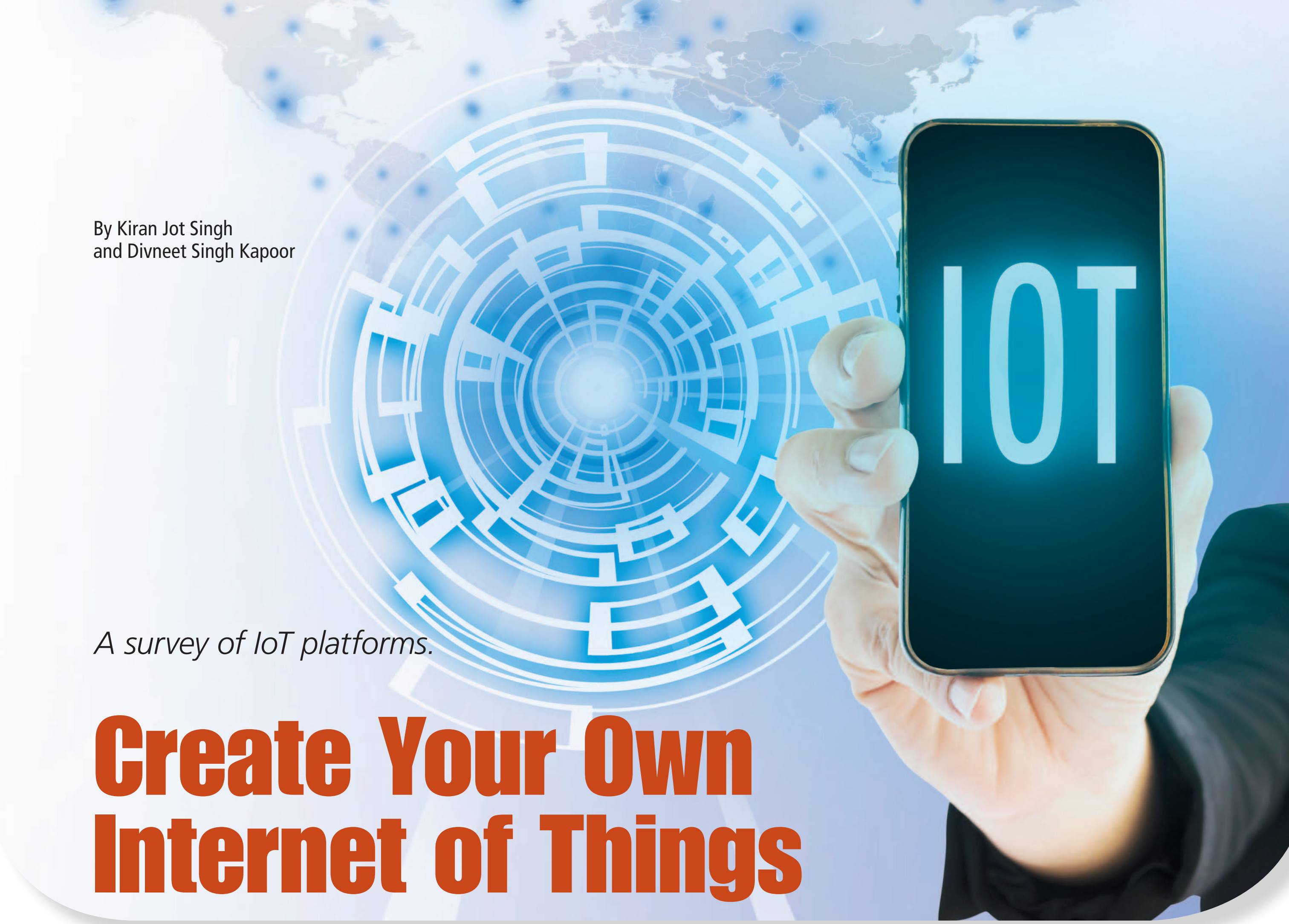
A survey of IoT platforms.

Create Your Own Internet of Things



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We live in the age of After Google (AG), where information is just one click away and talking just one touch away. The near future of the AG age is the Internet of Things (IoT), where physical things connected over a network will take part in Internet activities to exchange information about themselves and their surroundings. In other words, the IoT is nothing but a computing concept in which everyday objects with embedded hardware/devices are connected to a network or are simply online.

The IoT is developing tremendously day by day because of the continuous efforts of a wide community, stretching from hobbyists all the way to researchers. The IoT tends to have unlimited applications, as there are seemingly unlimited needs in every sphere of life. This being the case, consumers have found that either the available IoT-enabled products are not able to cater to the universe of people's requirements or there is no such product for a specific requirement. So consumers have started developing applications and products on their own by using open platforms. As the saying goes, "Necessity is the mother of invention." Thus, people have begun practicing the art of do it yourself (DIY) to develop customized IoT applications and products for their needs. To complement this DIY explosion, lots of boards, single-board computers, and embedded platforms have landed on the market, each offering distinct features.

In the not-so-distant future, everything in the home and workplace will have a unique Internet address and will be able to be controlled or monitored over the network. This will be possible only if the whole IoT community starts developing and deploying things, which makes DIY a crucial point in IoT development. DIY, however, is not just limited to personal laboratories. It has created many corporations that have flourished by keeping DIY projects as the soul of their finished products. One famous example is the close association between Apple employees and the Homebrew Computer Club. The members of the club developed a computer, the schematics of which were made open source, that provided Apple with a platform to make personal computers. On the whole, it was the efforts of the DIY community that made Apple one of the leaders in consumer electronics. Stories like this encourage

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Arduino offers a vast range of open-source boards capable of performing tasks from blinking an LED to publishing material online to handling heavy networking tasks.

people to develop and transform projects into products by themselves, which makes DIY essential for the IoT.

This article examines various IoT hardware items and software platforms and lists some interesting projects for each platform that can be undertaken by a beginner, hobbyist, student, academician, or researcher to develop useful projects or products, which will in turn empower the IoT to make this world better in terms of connectivity and service.

IoT HARDWARE

When it comes to IoT hardware, one can think of mobile phones as IoT devices, since smartphones have sensors, displays, and a unique address and are connected to the Internet. Regarding IoT devices, Paul Jacobs, former chief executive officer of Qualcomm, has said, "In the future, almost all things will be linked on the web, and mobile phones will act as hubs for IoT. So, IoT is nothing but the Internet linkage of smart objects and embedded systems other than mobile phones, with mobiles phones acting as access centers for IoT" [1]. The term *smart objects* referred to by Jacobs can be described as things or objects that are responsible for providing useful information on their interactions on a network. These objects can be deployed in a network via Bluetooth Low Energy (IEEE 802.15.4), Wi-Fi (IEEE 802.11), Ethernet (IEEE 802.3), or other communication standards.

The possibilities for IoT development in hardware and software are infinite. IoT hardware can be classified into two broad categories: 1) wearable devices and gadgets and 2) embedded systems and boards, as depicted in Figure 1.

In the wearable category, many preassembled standard hardware applications ranging from smart shoes to glasses are available. The scope of IoT development in this category is limited to software, where a DIYer can develop applications suitable only for a particular hardware item of a wearable gadget.

On the other hand, both the hardware and software aspects are open for developers under the embedded systems and boards category. The services provided by these systems and boards can be further classified into three subcategories: 1) device control, 2) data acquisition, and 3) application development. Device control includes monitoring of devices, security, and firmware updates. Data acquisition encompasses management and transformation at different layers of the IoT. Finally, application development includes analytics, event-driven logic, visualization, and application programming.

Discussed next are some of the most popular and advanced platforms and boards, which are becoming the first choice of any IoT developer for initial prototyping, creating smart objects, and developing projects and products.

THE ESP8266 WI-FI MODULE

ESP8266 (Figure 2) is a well-known Wi-Fi solution among hobbyists and students who want to add an edge of the Internet to their embedded projects. Two of its versions are preferred. First, there is the generic ESP8266 module [2], which is distributed

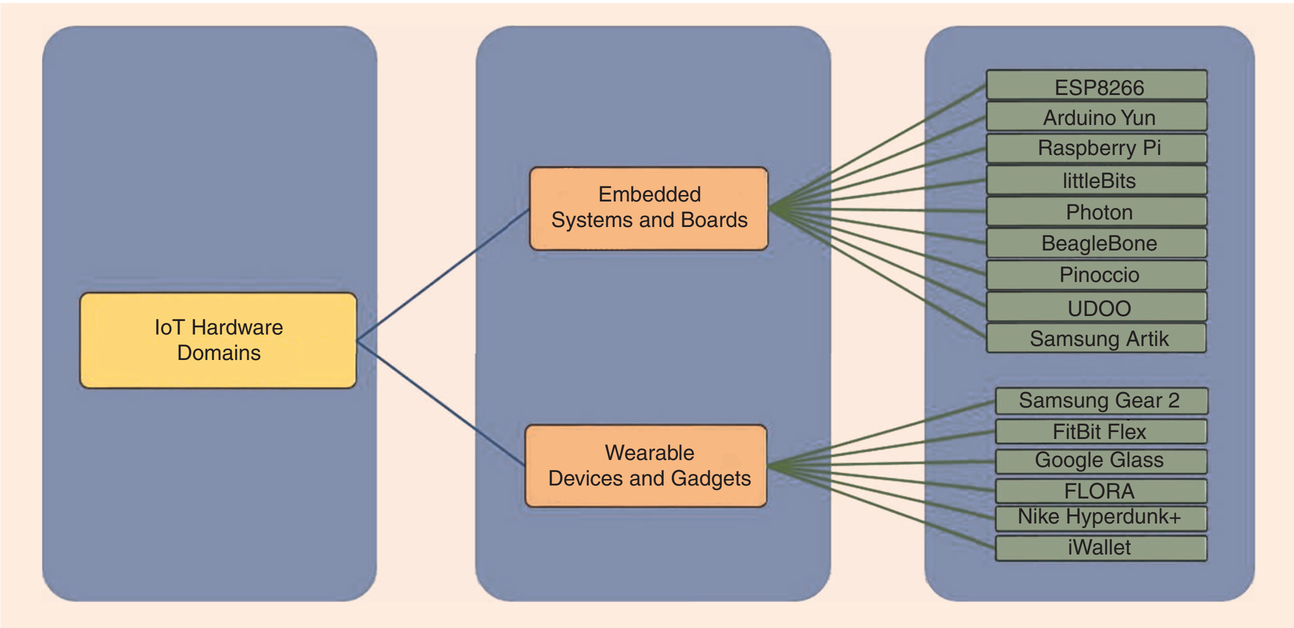

FIGURE 1. A classification of IoT hardware domains.

with a preprogrammed attention commands (AT) set and can be easily interfaced with various microcontrollers. It has 1 MB of flash memory, works on the 802.11 b/g/n protocol, and supports Wi-Fi Direct (P2P) and soft-access point. It comes with an integrated transmission-control protocol/Internet protocol stack and a self-calibrated radio-frequency antenna, which allows it to operate under almost all conditions. However, this module lacks 3-V to 5-V logic-level shifting.

The second module is the SparkFun Blynk Board [3], which is an ESP8266-based board with nine general-purpose input/output (GPIO) pins supporting serial-peripheral interface (SPI) and inter-IC (I2C) communication protocols. It has an onboard lithium-polymer (Li-Po) battery connector and charging port. It also comes with onboard Future Technology Devices International for reprogramming, red-green-blue light-emitting diode (RGB LED), analog-to-digital converter (ADC), and temperature and humidity sensor. It can automatically connect to Blynk Cloud and can be controlled with the Blynk app, which is available for both the iOS and Android operating systems. This module is a bit more costly than the first one. Many people have used these modules for fascinating projects such as Home Automation in the Cloud with the ESP8266 [4] and a solar-powered file server [5].

A new ESP-series module—the ESP32 [6], [7]—is set to arrive on the market. It will feature upgraded Wi-Fi that will support HT40 speed (150 Mb/s), Bluetooth Low Energy, a dual-core processor 2x Tensilica L108 clocked at 160 MHz, and peripherals such as capacitive touch, ADCs, digital-to-analog converters (DACs), I2C, universal asynchronous receiver/transmitter (UART), SPI, and pulsewidth modulation (PWM).

ARDUINO

Arduino offers a vast range of open-source boards capable of performing tasks from blinking an LED to publishing material online to handling heavy networking tasks. This is made possible through the Arduino software integrated development environment (IDE), based on processing.

Arduino has a broad range of boards, from simple 8-b microcontroller boards to products for wearables, IoT items, three-dimensional (3-D) printing, and much more. There is a large community of students, hobbyists, and researchers doing projects on Arduino boards and providing many tutorials, and support is available online. For supporting IoT applications, the company offers the Arduino Yun (Figure 3), with onboard Wi-Fi (IEEE 802.11 b/g/n) and Ethernet (IEEE 802.3 10/100Mb/s) [8]. It has an ATmega32u4 with a clock speed of 16 Mhz and an Atheros AR9331 (MIPS @ 400 MHz), which backs a Linux distribution called OpenWrt-Yun. The board has a micro-SD card slot, a USB-A port, seven PWM pins, 12 analog inputs, and a micro-USB connection.

The GPIO pins of the Atheros AR9331 are not accessible, as these are tied to the ATmega32u4. SPI is available only on the in-circuit serial programming (ICSP) header, which is supported by the SPI library. Hence, any shield that uses SPI and does not have a six-pin ICSP connector will not work with Arduino Yun.

Hobbyists have developed interesting projects [9] powered by Arduino Yun, such as a cat camera, a bathroom occupancy detector, an Internet-enabled football trophy, and many more. Arduino also offers the Genuino MKR1000 [10] with the capability of a SAMD21 Cortex-M0+ 32-b low-power ARM MCU and WINC1500 low-power 2.4-GHz IEEE 802.11 b/g/n Wi-Fi. It also includes a Li-Po charging circuit. It comes with Cryptochip for secure communication. Its I/O pins can withstand only 3.3 V, which necessitates the use of a logic-level shifter for 5-V devices.

Arduino is in the process of launching its much-acclaimed Arduino TRE board [11], which is based on the 1-GHz Sitara AM335x processor, suitable for computationally complex applications and algorithms, high-speed communications, telemetry hubs that gather data wirelessly from sensor nodes, and many other IoT-based applications.

RASPBERRY PI

Raspberry Pi 2 is a single-board computer that comes with a quad-core ARM7 800 MHz, a Videocore IV 250 MHz as a graphics processing unit, 1 GB of random access memory (RAM), 40 GPIO pins, four USB 2.0 ports, one Ethernet port, one HDMI connector, and one micro-SD card slot [12].

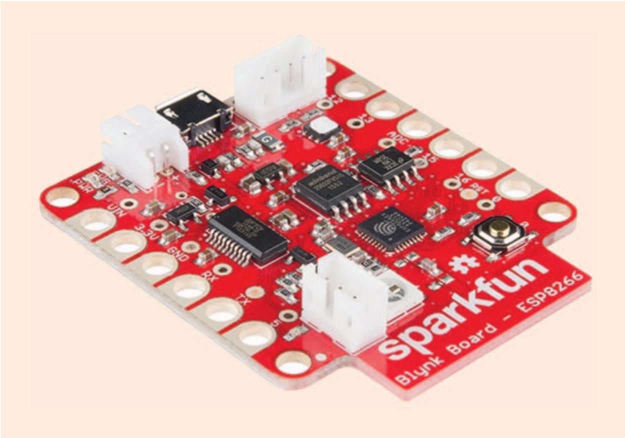

FIGURE 2. An ESP8266 Wi-Fi module. (Photo courtesy of SparkFun.)

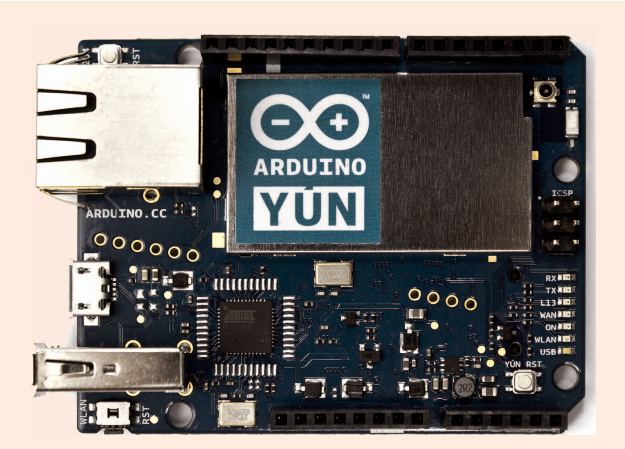

FIGURE 3. An Arduino Yun board. (Photo courtesy of Arduino.)

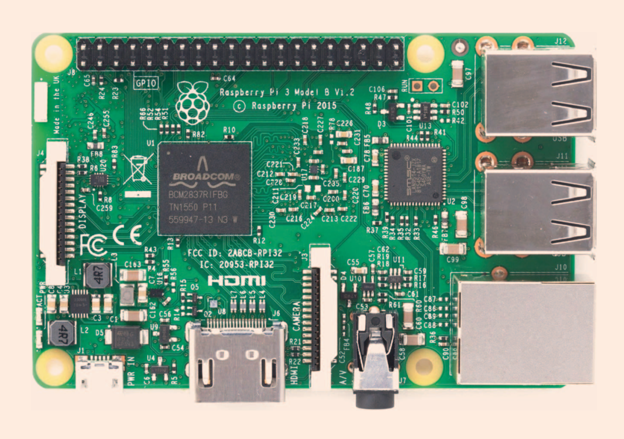

FIGURE 4. A Raspberry Pi 3 board. (Photo courtesy of Raspberry Pi.)

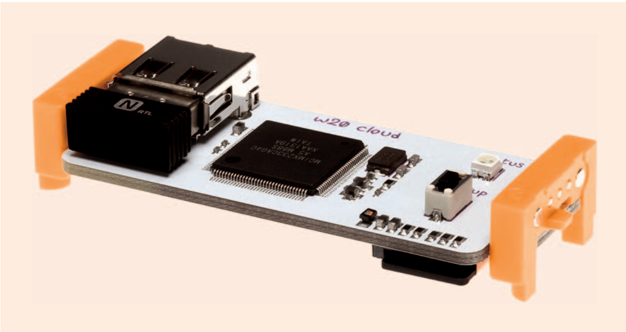

FIGURE 5. A cloudBit platform. (Photo courtesy of littleBits.)

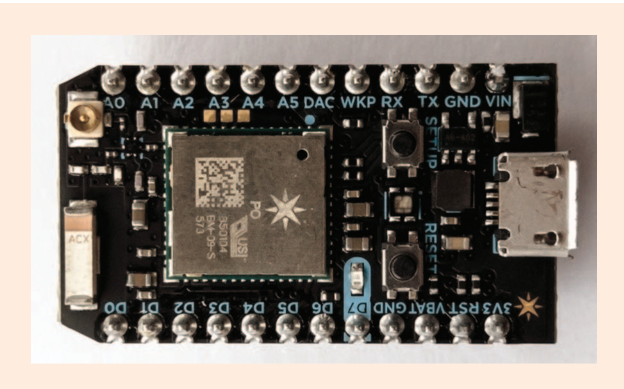

FIGURE 6. A Photon board. (Photo courtesy of Particle.)

The makers of Raspberry Pi also recently launched Raspberry Pi 3 (Figure 4), which they claim to be ten-times faster than Raspberry Pi 2. It is powered with a 1.2-GHz 64-b quad-core ARM Cortex-A53 CPU and has integrated 802.11n wireless LAN and Bluetooth 4.1. With the addition of onboard wireless LAN and Bluetooth capability, it will be even more useful for developing IoT applications [13].

Raspberry Pi can run many operating systems, including Raspbian Linux, Ubuntu Mate, and Windows 10 IoT Core. It also provides full support for such programming languages as C/C++, Python, and JavaScript. Best of all, the Pi community, as with Arduino, is huge, and software support is always assured. Raspberry Pi boards for IoT projects are an excellent choice. However, additional hardware is required for interfacing with analog inputs such as potentiometers, photocells, and joysticks, as ADC is not available onboard. Moreover, the board consumes slightly more power compared to earlier versions and gets a bit warmer when used in the overclocking mode for a longer time.

Developers using Raspberry Pi have come up with many intriguing IoT projects, such as Rebroadcast Internet Radio with a Raspberry Pi [14] and Raspberry Pi Internet Weather Station [15].

CLOUDBIT/LITTLEBITS

The company littleBits was born out of a movement focusing on open hardware. It comes with almost 60 interchangeable bits (modules) that are attached to each other magnetically in billions of possible combinations. It is the hardware through which anyone, irrespective of technical capability, age, or discipline, can create new things [16].

The cloudBit (Figure 5) is one of the 60 bits or modules provided by littleBits. It comes with a Linux-based system on a Freescale i.MX23 ARM926EJ-S processor with 64 MB of RAM. It makes use of an 802.11 b/g/n USB adapter for networking. Once cloudBit is connected to Wi-Fi, it starts sending data from other littleBits modules with 10-b precision to the cloud without a need for programming. Moreover, it is supported by many application program interfaces (APIs), particularly the if this, then that (IFTTT) app, for more customizations [17].

The ease with which every module can be magnetically attached to others makes it very popular among youth who are elementary electronics enthusiasts, and littleBits illustrates the rapid and effortless realization of such projects as Remote Pet Feeder and SMS Doorbell. [18].

PARTICLE PHOTON

Photon packs a 32-b 120-MHz ARM Cortex M3, 1-MB Flash, 128 KB of RAM, a Broadcom BCM43362 Wi-Fi chip, FreeRTOS, and 18 GPIO pins into about a 2-in package (Figure 6). Once it is connected to a Wi-Fi network, it can be programmed by Particle's Cloud IDE as well as through any ARM development environment locally. The programs can be stored and compiled in the cloud through Cloud IDE.

Also, Photon has the capability to automatically and continuously switch between internal and external antennas and select the best signal. It can support coexistence with Bluetooth and other external radios through three gold pads on the top side of the Photon PCB [19]. Photon is the result of a successful crowdfunded project on Kickstarter [20]. However, off-line tools for Photon are under development.

Interesting projects have been developed by DIYers through Photon, including a cloud data logger [21] and Wi-Fi Baby Monitor [22]. Many more can be found at Hackster.io [23].

BEAGLEBONE BLACK

BeagleBone Black is one member of the community-supported BeagleBoard platforms (Figure 7). It is powered by a TI Sitara AM3358 ARM Cortex-A8 processor running at 1 GHz, with 4 GB of onboard flash memory, 512 MB of DDR3L DRAM, and a 3-D graphics accelerator. It offers two 46-pin headers, an Ethernet port, and many more connectivity options. It supports the Debian, Android, and Ubuntu operating systems. It is an open-source board, as all of its schematics and bills of materials are available on its maker's website [24].

BeagleBoard claims to be able to boot Linux in under 10 s on BeagleBone Black. DIYers are exploring its capabilities through such projects as Debrew (a coffee bot) [25], a smart home energy monitoring and management system [26], and many more that are available at Beagleboard.org[27].

The BeagleBoard community is about to add one more feather to its cap with the launch of BeagleBoard-X15. It will be the top performer among all the BeagleBoards and will be powered with a TI AM5728 2 × 1.5-GHz ARM Cortex-A15, with 2 GB of DDR3 RAM, 2 × 700-MHz C66 digital signal processors, and additional connectivity options [28].

PINOCCIO

Pinoccio is a full-packed, open-source board to support the IoT that was floated on a crowdfunding website and successfully funded [29]. It comes with an Atmel ATmega256RFR2, 2.4 GHz using 802.15.4, Wi-Fi, a rechargeable Li-Po battery (550 mAh), 17 digital I/O pins, an SPI and I2C port, an onboard temperature sensor, and an RGB LED [30], [31] (Figure 8).

The single onboard controller chip houses a combination of an AVR 8-b processor and a 2.4-GHz transceiver for supporting wireless personal area network communications (IEEE 802.15.4), that is, ZigBee, Bluetooth, ISA100.11a, body area network, IrDA, Z-wave, and Mi-Wi [32]. It also supports wireless mesh networking without making use of the Internet. It can work on full power continuously for 27 h, and the developers claim it can work for years if the board is put to sleep and made to wake up when specific conditions are met [29]. Pinoccio is fully compatible with Arduino and can utilize its libraries for IoT project development. In addition, the Pinoccio HQ IDE provided by the makers gives a fully synced, real-time graphical user interface to monitor online/off-line Pinoccio boards, check their battery levels, set up their pin modes, and write scripts on them.

Although it is new to the market, people have started working on it and coming up with interesting projects such as Save the World, One Drop at a Time [33], and Music Controller [34]. More of these can be found at Hackster.io [35].

UDOO QUAD

UDOO QUAD is an all-in-one, open hardware-based, single-board computer with an ARM i.MX6 Freescale processor and an ATMEL SAM3X8E ARM processor (Arduino Due-compatible section) for Android, Linux, and Google ADK (Figure 9). It is, in general, a fusion of two worlds, as it combines the capabilities of both Raspberry Pi [36] and Arduino [37] on the same board [38]. It offers 76 fully available GPIO pins, an integrated Wi-Fi module, an Ethernet module, LVDS + Touch, and 1 GB of DDR3 RAM.

It is an innovative vision over existing frameworks, providing a boost to the DIY world and the IoT and is an excellent tool for prototyping. Because UDOO is new to the market, its support and tutorials are still building up, but people using it

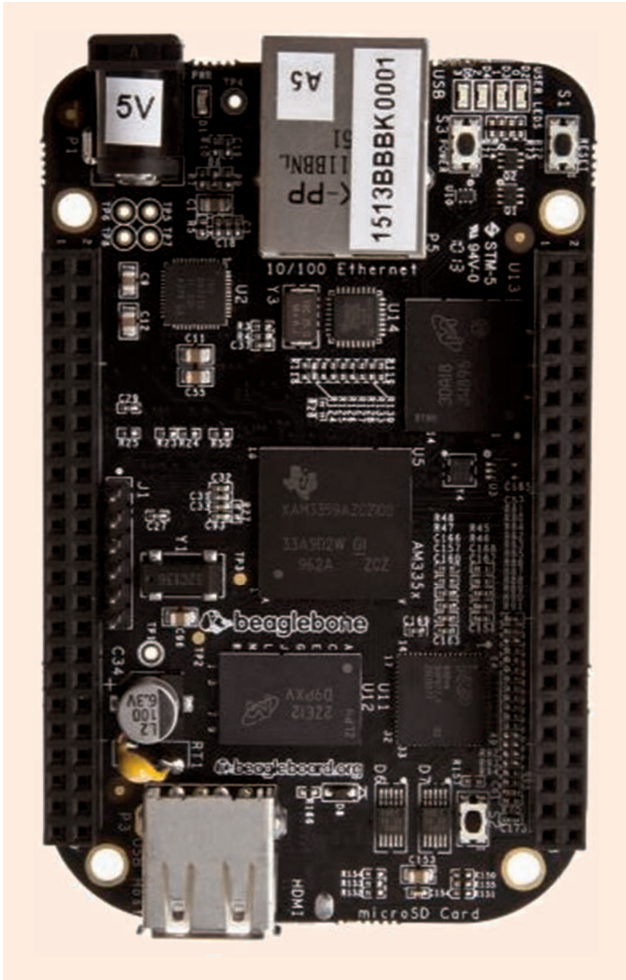

FIGURE 7. A BeagleBone Black platform. (Photo courtesy of BeagleBone.)

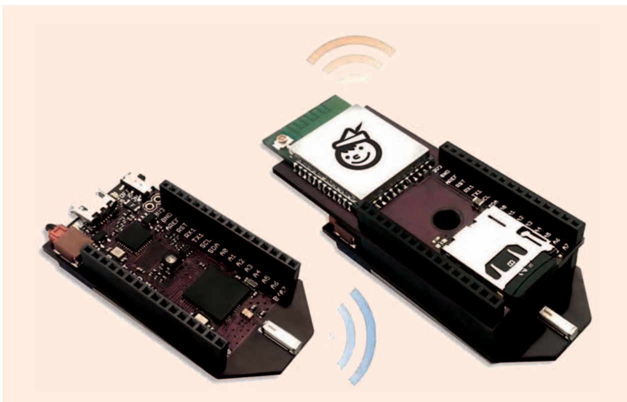

FIGURE 8. Two Pinoccio boards. (Photo courtesy of Pinoccio.)

The selection of a board or platform for prototyping a DIY IoT application, project, or product is a critical step.

have come up with intriguing IoT projects such as Baby Room Home Automation [39] and HomeController [40].

SAMSUNG'S ARTIK

Samsung has debuted in the IoT domain with three modules: Artik 1, Artik 5, and Artik 10 (Figure 10), which come in different sizes. Although development boards are available for them, the modules can also be directly deployed to develop a target product. The tiniest one, the Artik 1, comes in a 12-mm × 12-mm package and runs with a coin cell battery. It has a dual-core processor running at 250 MHz and 80 MHz, Bluetooth LE 4.0, an accelerometer, and a nine-axis motion sensor [41]. The Artik 5 comes with an ARM A7 dual-core 1-GHz processor, Bluetooth BLE, ZigBee, and 47 GPIO pins, with SPI, PWM, UART, I2C, and USB interfaces. It supports Arduino/Java/C/C++ as development environments. It also has a hardware video codec supporting various standards [42].

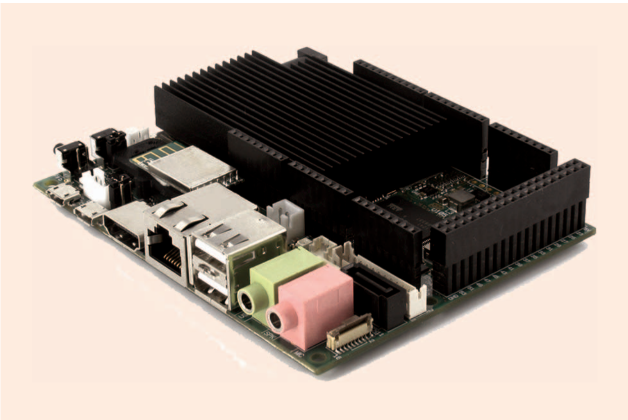

FIGURE 9. A UDOO QUAD platform. (Photo courtesy of UDOO.)

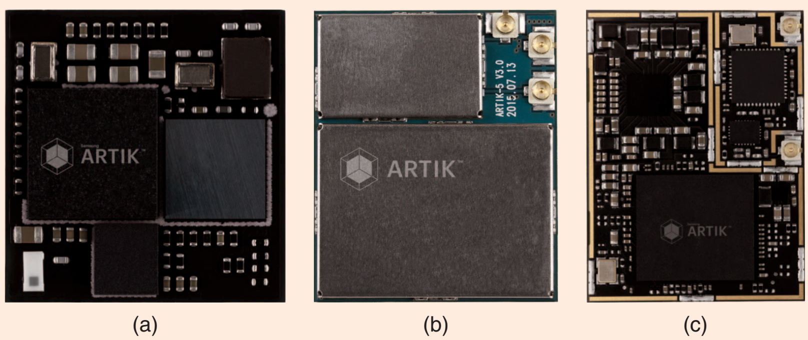

FIGURE 10. (a) The Artik 1, (b) Artik 5, and (c) Artik 10 modules. (Photo courtesy of Samsung.)

The top module is the Artik 10, which comes with ARM A15x4@1.3 GHz + A7x4@1.0 GHz processors with 2 GB of LPDDR3 + 16 GB eMMC memory in a package size of just 39 mm × 29 mm × 3.5 mm. It comes with a Yocto 1.6 (Fedora) OS and hardware audio and video codec for various standards. It has 51 GPIO pins with SPI, inter-IC sound (I2S), I2C, UART, USB, Bluetooth Low Energy, and many more interfaces. It also backs Open GL ES 1.1/2.0/3.0, DirectX 11, and Google RenderScript for graphics processing units [43].

Artik development boards are available on the market. Many tutorials, such as MQTT Message Broker and web page interfaces to Edge devices, can be found on the maker's website [44]. Citizens are also contributing to solving the California water crisis by making use of Artik development boards [45].

SELECTING THE OPTIMUM PLATFORM OR BOARD FOR IOT APPLICATIONS

Turning ideas into a concrete plan is the first step in an IoT project. Therefore, the selection of a board or platform for prototyping a DIY IoT application, project, or product is a critical step. In broad terms, three things must be taken into account in this regard: 1) specifications, 2) open API, and 3) open hardware. The project's specifications play a vital role in the selection of the hardware platform to be used for a particular IoT application. One must consider fundamental aspects such as the processor/microcontroller, clock speed, GPIO, ADC/DAC, connectivity (Wi-Fi, Bluetooth, or Ethernet), communication (e.g., I2C, UART, and SPI), and, last but not least, the price of the hardware board to be selected. A prior brainstorming session for the selection of a platform with a certain set of specifications for a particular application is always recommended.

Afterward, the key aspect that comes into play is Open API. To avoid being locked, it is essential for a DIYer to select an IoT solution that comes with open standards, community support, and open libraries. The use of readily available open libraries and support enables a DIYer to develop applications in less time with better resource utilization and efficiency, which is reflected in the overall development life cycle of a particular application.

Finally, there is open hardware, which becomes considerably important when someone has accomplished the initial prototyping and is ready to transform the project into a product. For marketed applications, one needs to design a customized, cost-effective hardware solution. A platform with open schematics and hardware support is always handy in developing an application and deploying the product. The specifications of the above-discussed boards are compared and depicted in Tables 1–3.

IoT SOFTWARE

Once a hardware platform has been selected, the next step is choosing the application software. The wide range of programming language support for application software—such as C, C++, and Python—boggles the mind of the DIYer with its seeming softwarization of the IoT. Normal questions a DIYer has are often about programming language foundations and specific layer or application area catering.

As the development of IoT hardware continues, learning programming languages such as C and C++ is a must. Additionally, for middleware applications and API development, learning Python, Java, NodeJS, and .NET is really helpful. Furthermore, for making front ends, languages such as HTML5, CSS3, Java, android software development kits (SDKs), and Javascript are the best options. Finally, understanding current practices in IoT technology and architecture and concepts, including representational state transfer (REST) API, Constrained Application Protocol (CoAP), and JavaScript Object Notation for Linked Data (JSON-LD), are very much required [46].

Many IoT software platforms are available on the market to simplify and speed up the process of product development. These platforms make real-world objects smart and talk back to the user through software layers on the Internet. These software platforms also provide such services as programming frameworks, machine-to-machine (M2M) integration, data and device management, security and storage, and protocol translation. The automatic generation of production-ready codes across multiple programming languages for hardware deployment is the pivotal role of these software platforms. Data management is a crucial aspect of IoT software development, which becomes easier with the use of APIs offered by these platforms. As an example, e-mails or text messages can be triggered via APIs when a specific event occurs in real-world objects. Moreover, these platforms offer cloud storage and continuous data analysis tools. So these platforms give the DIYer a head start for developing applications in a speedy

Table 1. A comparison of boards and platforms in terms of computing.

Features	Processor/Microcontroller	Graphics Processing Unit	Clock Speed	Size	Memory	RAM	Supply Voltage	Listed Price
SparkFun Blynk Board	Tensilica L106 32-b	No	26 MHz	51 mm x 42 mm	4 MB	128 KB	5 V via micro-USB/ Li-Po connector and charging circuit	US$29.95
Arduino Yun	ATmega32u4 and Atheros AR9331 (for Linux)	No	16 MHz and 400 MHz	73 mm x 53 mm	32 KB and 16 MB + micro-SD	64 MB DDR2	5 V via micro-USB	US$58
Raspberry Pi 3	Broadcom BCM2837 and ARM Cortex-A53 64-b Quad Core	VideoCore IV @ 300/400 MHz	1.2 GHz	85 mm x 56 mm	Micro-SD	1 GB LPDDR2	5 V via micro-USB	US$35
cloudBit	Freescale i.MX233 (ARM926EJ-S core)	No	454 MHz	55 mm x 19 mm	Micro-SD slot with 4-GB micro-SD	64 MB	5 V via micro-USB	US$59.95
Photon	STM32F205 120Mhz ARM Cortex M3	No	120 MHz	36.5 mm x 20.3 mm	1 MB	128 KB	5 V via micro-USB	US$19
BeagleBone Black	AM335x ARM Cortex-A8	PowerVR SGX530	1 GHz	86 mm x 56 mm	4 GB 8-b eMMC, micro-SD	512 MB DDR3	5 V via mini-USB	US$49
Pinoccio	ATmega256RFR2	No	16 MHz	70 mm x 25 mm	256 KB	32 KB	5 V via micro-USB/ Li-Po connector and charging circuit	US$109
UDOO	Freescale i.MX 6 ARM Cortex-A9 and Atmel SAM3X8E ARM Cortex-M3	Vivante GC 2000 for 3-D + GC 355 for 2-D (vector graphics) + GC 320 for 2-D	1 GHz	110 mm x 85 mm	Micro-SD	1 GB DDR3	12 V	US$135
Samsung Artik 10	ARM A15x4 and A7x4	Mali-T628 MP6 core	1.3 GHz and 1.0 GHz	39 mm x 29 mm	16 GB	2 GB LPDDR3	3.4–5 V	US$100

Table 2. A comparison of boards and platforms in terms of development environments and communication standards.

Features	Operating Systems Supported	IDE	Video Standard	Video/Audio Ports	USB Ports	Communication
SparkFun Blynk Board	No	Arduino, Blynk	No	No	No	I2C, SPI, UART
Arduino Yun	OpenWrt-Yun (based on GNU/Linux)	Arduino	No	No	1x USB 2.0	I2C, UART
Raspberry Pi 3	Raspbian, Windows 10 IoT Core, OpenELEC, OSMC, Pidora, Arch Linux, RISC OS, Ubuntu	C#, Python, Java, Scratch and many more	MPEG-2,VC-1,H. 264 AVC (1080p @ 30 fps)	HDMI 1.4 with CEC, 4-pole 3.5-mm connector, Raw LCD (DSI)	4x USB 2.0	1x SPI, 2x I2C, PCM/I2S, 1x UART
cloudBit	Customized Arch Linux ARM distribution	Cloud API, Arduino	No	No	No	UART
Photon	FreeRTOS	Particle Build (Online), Particle Dev (Local)	No	No	No	2x SPI, 1x I2S, 1x I2C, 1x CAN, 1x UART
BeagleBone Black	Debian, Android, Ubuntu	C++, Perl, Python, Cloud9 IDE	NEON software decoding support	Micro-HDMI	1x USB	4xUART, 2x SPI, 2x I2C, 2x CAN BUS
Pinoccio	No	Arduino, Pinoccio HQ (Online/ Off-line)	No	No	No	I2C, SPI, 2x UART
UDOO	UDOObuntu, Android, XMBC, Yocto, Arch Linux, OMV	Arduino	MPEG-2, H.264 (1080p60)	HDMI, Analog audio and mic jacks, LVDS + Touch	1x USB OTG, 2x USB 2.0, 1x USB to Serial	SPI, I2C, UART, CAN BUS
Artik 10 Samsung	Yocto 1.6 (Fedora)	Arduino IDE, Samsung SDK, C/C++, Java, Groovy	1080p @ 120 fps H.263/H.264/ MPEG-4/VP8 + MPEG-2/VC1 decoding	Four-lane MIPI DSI up to WUXGA, HDMI, one-channel PCM and two-channel I2S audio interface	1x USB2.0, 1x USB3.0	1x SPI, 6x I2C, 1x I2S, 3x UART

GNU: GNU's not Unix; OSMC: Open-Source Media Center; RISC OS: reduced-instruction-set computer operating system; CEC: consumer electronics controller; LCD: liquid crystal display; DSI: digital serial interface; PCM: pulse code modulation; CAN BUS: controller area network; NEON: Nonprofit Enterprise Online Network; XMBC: Xbox Media Center; OMV: Open-Media Vault; LVDS: low-voltage differential signaling; OTG: on-the-go; MIPI: mobile industry processor interface; WUXGA: wide ultra-extended graphics array.

manner. A basic classification of IoT software domains is presented in Figure 11.

IoT software platforms can be broadly classified into four types [47]. The first mainly focuses on the connectivity of devices via subscriber identification module cards, that is, telecommunication networks, termed *connectivity/M2M platforms*. The second classification is intended to provide processing power and hosting space for IoT applications and is termed *infrastructure as service platforms*. The third category is hardware-specific software platforms that are built for specific IoT hardware items. And the fourth classification caters to the consumer/enterprise software extensions that offer software packages and integration of IoT devices.

In addition to these four classifications, there are some hybrid IoT platforms that focus on multiple aspects, such as connectivity, integration, and the like. It is quite important for a DIYer to have a basic understanding of these aspects. In a nutshell, an IoT software platform can be divided into the architectural building blocks shown in Figure 12 [47].

Selecting an IoT software platform is a critical part of IoT product development. It is essential to know what IoT software platform will support a particular IoT hardware platform. The choice for selecting an optimal software platform will be driven by the instruments provided, specifically, the IDE for programming and the API available for access of data and notifications.

Furthermore, the efficiency of data management tools, such as desktop and mobile applications, dashboards, and the like, also makes the particular choice significant. Finally pricing, community support, and available documentation should also be considered in selecting a software platform. Table 4 compares IoT software platforms that are compatible with and support the various IoT hardware platforms discussed above and are either open source or offer free accounts.

GENERIC API DEVELOPMENT

In this era of sensor technology, scientific advancements have led to the miniaturization of sensors, which are available in various specifications and forms. One cannot imagine any smart IoT device or application without sensors. Because of the rapid increase in IoT sensors, data collection has become a tedious task for the DIYer. Putting sensor data on the web has so far been a slow and ad-hoc process. Moreover, hardware manufacturers are flooding the market with different platforms and sensors that may be incompatible. Dealing with this poses challenges in application and product development, requiring substantial technical expertise that may be more costly than the actual end product.

The ultimate goal of the IoT is to make all objects in homes and offices smart, so they can be controlled from anywhere in the world.

Another cost factor, one that can also slow the product development process, involves different APIs for different sensors. The independence to use any platform and sensor technology can be achieved by following a generic approach that reduces the work of data integration.

Possible solutions like the Semantic Sensor Network Ontology of the World Wide Web Consortium [46] have been established during the past decade. The latter emphasizes generic sensor API development, which in turn is increasing the speed of new sensors' web exposure and implementation process

Table 3. A comparison of boards and platforms in terms of connectivity.

Features	GPIO	PWM Pins	Analog Pins	ADC/DAC	Ethernet	Wi-Fi	Bluetooth	Camera Interface	Onboard Sensors and Display
SparkFun Blynk Board	9	3	1	10 b	No	IEEE 802.11 b/g/n	No	No	Temperature and humidity sensor, RGB LED
Arduino Yun	20	7	12	10 b	IEEE 802.3 10/100 Mb/s	IEEE 802.11 b/g/n	No	No	No
Raspberry Pi 3	26	2	No	No	IEEE 802.3 10/100 Mb/s	IEEE 802.11 b/g/n	Bluetooth 4.1 LE	CSI	No
cloudBit	No	No	No	No	No	IEEE 802.11 b/g/n	No	No	No
Photon	18	9	8	12-b ADC, 12-b DAC	No	IEEE 802.11 b/g/n	Yes	No	Real-time clock
BeagleBone Black	69	8	7	12-b ADC	IEEE 802.3 10/100 Mb/s	No	No	No	No
Pinoccio	17	4	8	10-b ADC	No	Wi-Fi Backpack IEEE 802.11 b/g/n	No	No	Temperature sensor, RGB LED
UDOO	76	13	12-ADC, 2-DAC	12-b ADC, 12-b DAC	IEEE 802.3 10/100 Mb/s	IEEE 802.11 b/g/n	No	CSI	No
Artik 10 Samsung	51	2	6	Six-channel	No	IEEE 802.11 b/g/n	Bluetooth 4.1 LE	1x two-lane MIPI CSI, 1x four-lane MIPI CSI up to 23 MP still, 8 MP @ 30 fps	No

fps: frames per second.

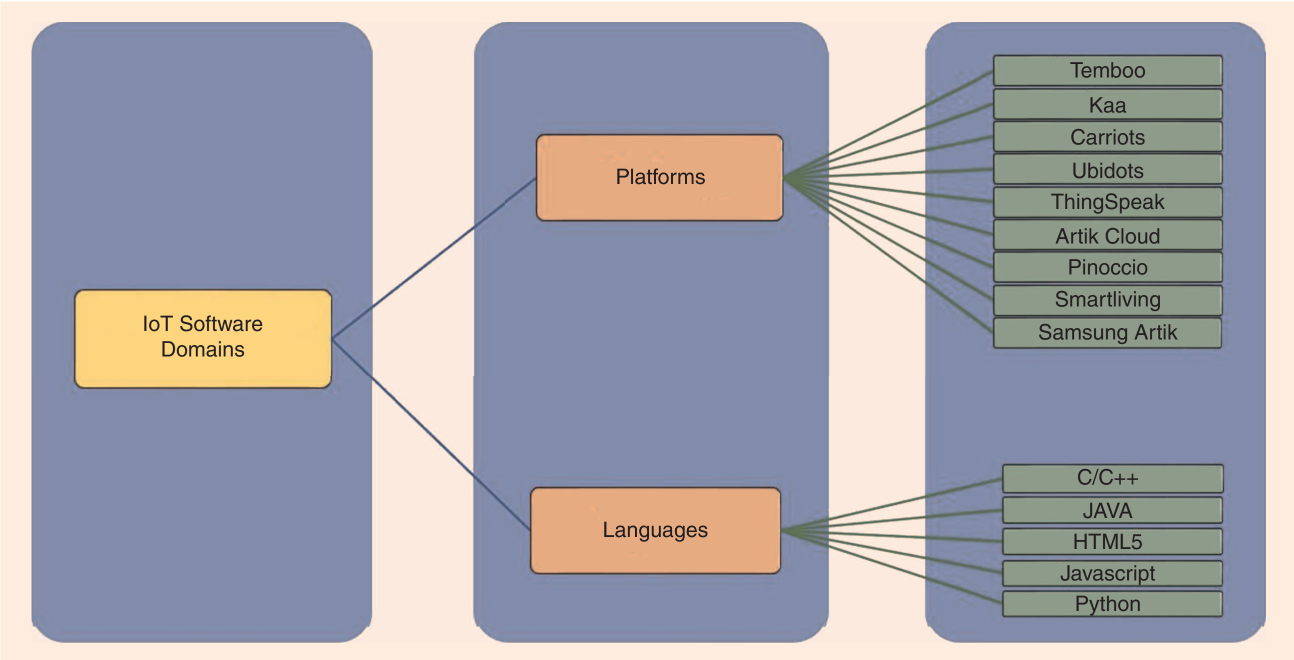

FIGURE 11. A classification of IoT software domains.

streamlining. A few points that need to be considered by a DIYer in developing a generic API include the following.

- A generic API should provide a unified framework for different categories of sensors, encapsulating such key parameters as sensor state, sensor reading, initiating a sensor, stopping a sensor, error handling, time stamp, and event management.
- A provision for sensor autodiscovery, configuration, and basic data processing should be considered.
- Heterogeneities of transmission procedures, data modeling, and formats should be addressed on a syntactical and structural level.
- Security and privacy issues are a huge concern, as sensor reading will be shared by many applications and platforms. So a proper assessment needs to be made in designing a generic API.
- The DIYer should develop a low-cost alternative with the ability to handle different hardware and sensors manufactured by various vendors, to achieve web integration, and to have the capacity to execute on commonly available computing devices.

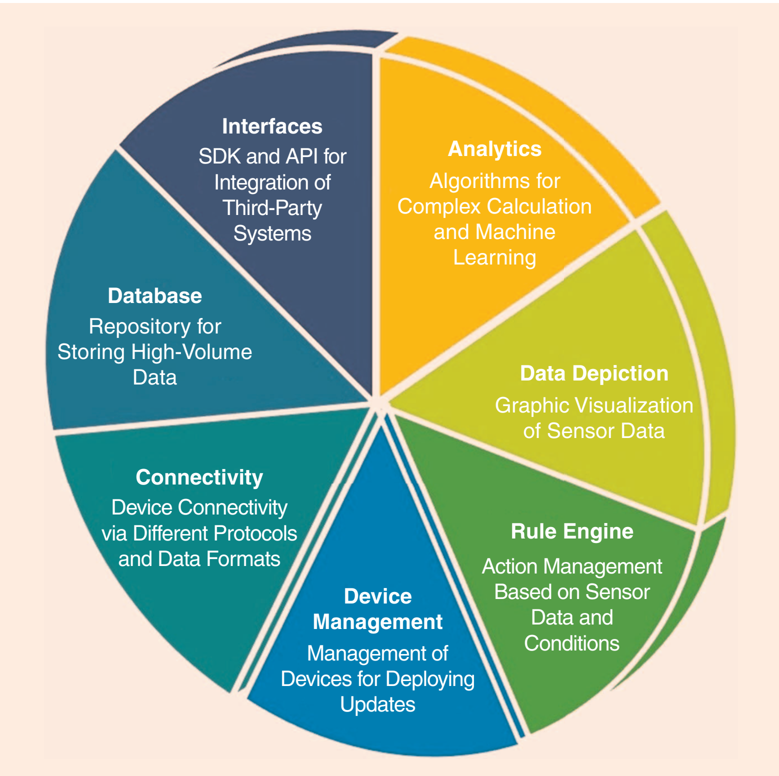

FIGURE 12. The architectural building blocks of IoT software platforms.

CONCLUSION

The ultimate goal of the IoT is to make all objects in homes and offices smart, so they can be controlled from anywhere in the world. This can eventually be achieved by building interest and awareness among people to empower the IoT movement. DIY and the IoT are multidisciplinary streams in which individuals work on various aspects of hardware, software, and design. In this article, we have mostly discussed open-source boards and platforms that can be utilized by DIYers for developing IoT projects, as a lot of support is available online. However,

Table 4. A comparison of IoT software platforms.

IoT Software Platform	Integration	Protocols	Analytics	Visualization	Pricing	Hardware Platform Supported
Temboo [48]	REST API, XML, JSON	MQTT, CoAP, HTTP	Microsoft Power BI, Google BigQuery	Streaming, dashboard, mobile app	Free account or other paid plans	Samsung Artik, Arduino, Texas Instruments
Kaa [49]	REST API, Web UI, JSON	MQTT, CoAP, XMPP, HTTP	Hadoop, mongoDB, Oracle, Cassandra, Spark, Couchbase, CDAP	Administration UI, dashboard, mobile app	Open source and free	Intel Edison, BeagleBone, Raspberry Pi, Econais, LeafLabs, Texas Instruments
Carriots [50]	REST API, XML, JSON	MQTT, HTTP	Microsoft AZURE, IBM, Ducksboard, Nibodha	Dashboard, mobile app	Free account or other paid plans	Arduino, Raspberry Pi
Cayenne [51]	REST API, JSON, XML	MQTT, CoAP	Real-time analytics within dashboard	Dashboard, mobile app	Free account or other paid plans	Raspberry Pi
Ubidots [52]	REST API, JSON, XML	UDP, HTTP, MQTT, CoAP	Distimo, Google Analytics	Dashboard	Free account or other paid plans	Arduino, Raspberry Pi, Spark Core, Microchip WCM, Adafruit FONA
ThingSpeak [53]	ThingSpeak API, JSON, XML	HTTP, MQTT	MATLAB	MATLAB, dashboard, mobile app	Open source and free	Arduino, Particle Photon and Core, Raspberry Pi, Electric Imp
Leylan [54]	Device API, Physical API, Type API	HTTP, MQTT, OAuth 2.0	IFTTT (third-party apps)	Web app, IFTTT (third-party apps)	Open source and free	Arduino Yun, Raspberry Pi, Electric Imp, Spark Core, Netduino, Texas Instruments
The ThingBox [55]	Node Red	HTTP, MQTT	Emoncms	Emoncms	Open source and free	Raspberry Pi
Smartliving [56]	REST API, JSON	HTTP, MQTT, Stomp	Real-time analytics within dashboard	Dashboard, mobile app	Free	Arduino, Raspberry Pi, Intel Edison, LoRa
Artik Cloud [57]	REST API, JSON	HTTP, MQTT, CoAP, Websocket	Supported by many third-party service providers	Dashboard, mobile apps and many third-party apps	Free account or other paid plans	Arduino, Raspberry Pi, Samsung Artik
Wyliodrin[58]	Wyliodrin API, JSON	HTTP, MQTT	Real-time analytics in dashboard and supports R programming	Dashboard, mobile app, Google Chrome app	Free account or other paid plans	Raspberry Pi, Intel Galileo, Intel Edison, UDOO, BeagleBone Black, Arduino

UI: user interface

selecting a board is not an easy task. This article provides a kick start toward selection of the best possible boards and platforms for initial prototyping and finally for commercialization and cost-effective hardware solutions. Furthermore, there is a discussion of IoT software platforms compatible with the described hardware platforms. We also examine generic API development for interfacing with sensors and actuators for better IoT application and product deployment. In a nutshell, DIY empowers everyone to make their own IoT.

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