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COMPARATIVE ANALYSIS OF PROGRAMMABLE DEVICES WITH ANALOG AND DIGITAL INPUTS AND OUTPUTS

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Abstract: *In the present article, single-board programmable devices suitable for control of automation processes are considered. A comparative analysis of specific models of the most common single-board computers, suitable for this purpose.*

Key words: *single-board programmable devices, Arduino, Raspberry, BeagleBone*

INTRODUCTION

Development of single-board programmable devices began in the beginning of the century and entered all areas of life very rapidly. In recent years, there are two main directions in the application of single-board computers - building high-performance, computing clusters [1] and management of functional subsystems. Measurement stands are a complex structure composed of interconnected subsystems. In the present article, single-board programmable devices suitable for control of automation processes are considered [2,3]. A comparative analysis of specific models of the most common single-board computers, suitable for this purpose.

COMPARATIVE ANALYSIS

For the purpose of automation, we need to choose a device with the following features:

1. Small size
2. Minimal power consumption
3. Several digital I/O
4. Several analog I/O

Since the number of devices falling in this category is almost infinite, we decided to limit our analyses to these three devices: Arduino Uno rev3, Raspberry Pi 4B and BeagleBone Black rev. C.

All three devices are open source, have a size of a credit card, offer programmable GPIOs, several standard communication ports (UART, I2C, USB, LAN) and have the ability to connect to a screen (or a touchscreen) to create a user interface.

I. Arduino Uno rev 3

The Arduino UNO [4] is the best board to get started with electronics and coding. If this is your first experience tinkering with the platform, the UNO is the most robust board you can start playing with. The UNO is the most used and documented board of the whole Arduino family.

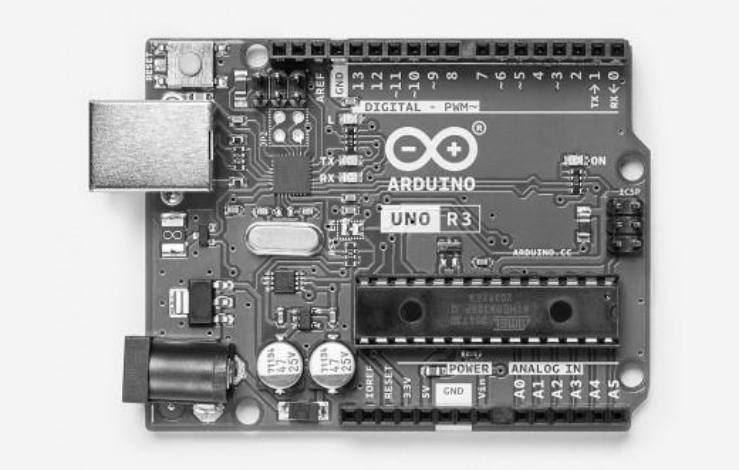


Fig. 1. Arduino Uno rev3

Arduino Uno is a microcontroller board based on the ATmega328P. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz ceramic resonator (CSTCE16M0V53-R0), a USB connection, a power jack, an ICSP header and a reset button (Figure 1). It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with an AC-to-DC adapter or battery to get started. You can tinker with your Uno without worrying too much about doing something wrong, worst case scenario you can replace the chip for a few dollars and start over again. "Uno" means one in Italian and was chosen to mark the release of Arduino Software (IDE) 1.0. The Uno board and version 1.0 of Arduino Software (IDE) were the reference versions of Arduino, now evolved to newer releases. The Uno board is the first in a series of USB Arduino boards, and the reference model for the Arduino platform; for an extensive list of current, past or outdated boards see the Arduino index of boards.

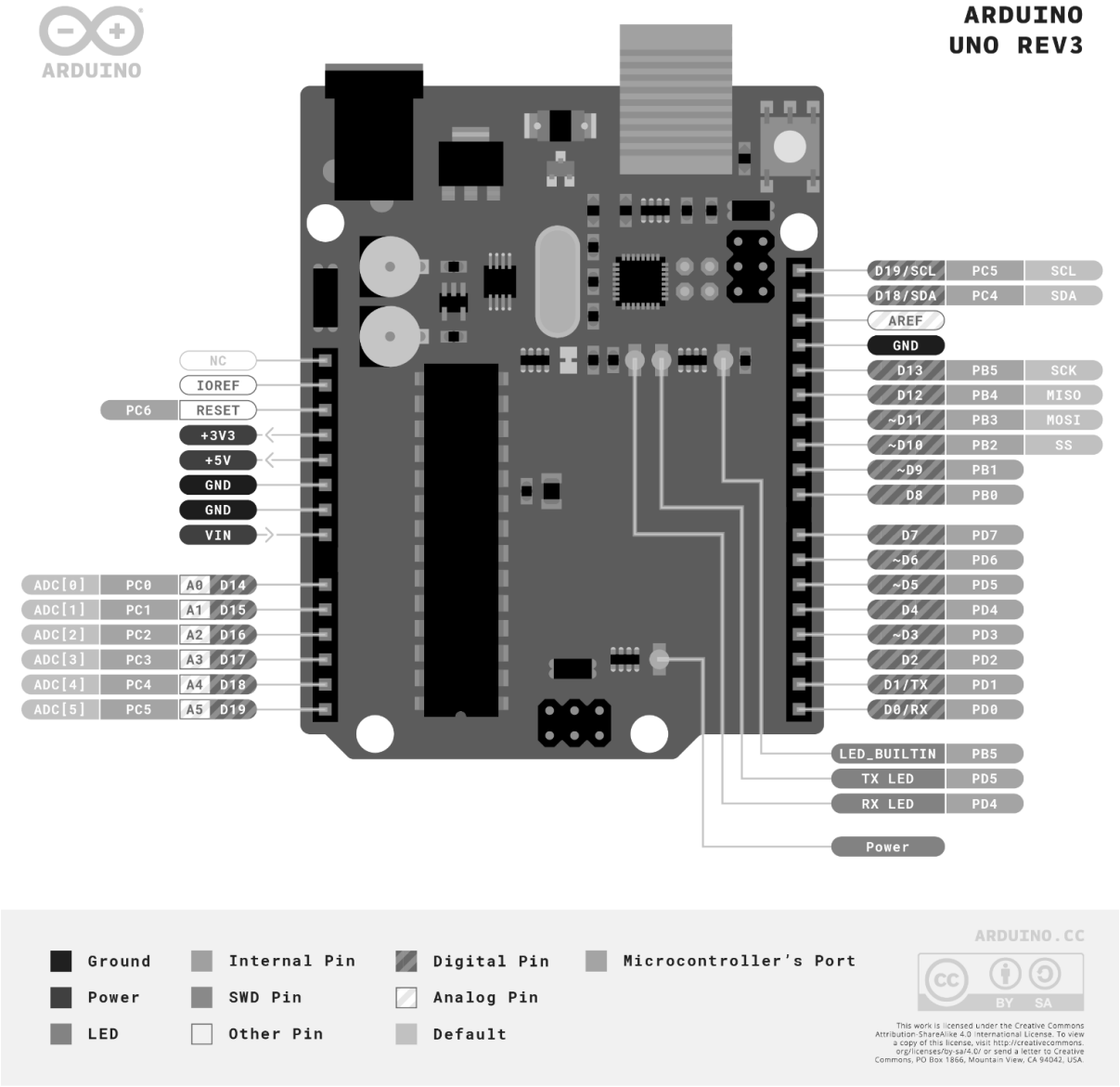


Fig. 2. Arduino Uno rev 3 with GPIO

This Arduino model has been successfully applied to various control systems [5].

II. Raspberry Pi 4B

Raspberry Pi (paɪ) is a series of small single-board computers (SBCs) developed in the United Kingdom by the Raspberry Pi Foundation in association with Broadcom. The Raspberry Pi project originally leaned towards the promotion of teaching basic computer science in schools and in developing countries [6]. The original model became more popular than anticipated, selling outside its target market for uses such as robotics. It is widely used in many areas,

such as for weather monitoring, because of its low cost, modularity, and open design. It is typically used by computer and electronic hobbyists, due to its adoption of HDMI and USB devices.

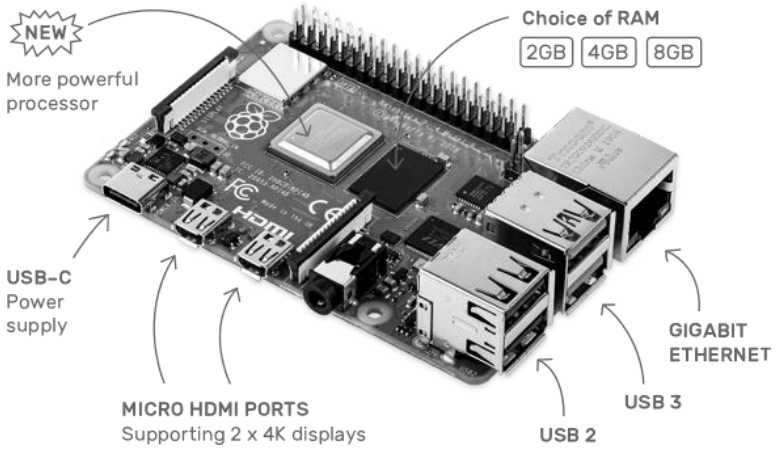


Fig. 3. Raspberry Pi 4B

The Raspberry Pi is one of the best-selling British computers. As of May 2021, more than forty million boards have been sold. Most Pis are made in a Sony factory in Pencoed, Wales, while others are made in China and Japan.

Processor speed is 1.5 GHz for the Pi 4; on-board memory up to 8 GB available on the Pi 4. Secure Digital (SD) cards in MicroSDHC form factor (SDHC on early models) are used to store the operating system and program memory. The boards have four USB ports. For video output, HDMI and composite video are supported, with a standard 3.5 mm tip-ring-sleeve jack for audio output. Lower-level output is provided by a number of GPIO pins, which support common protocols like I^2C. The B-models have an 8P8C Ethernet port and the Pi 4 has on-board Wi-Fi 802.11n and Bluetooth (Figure 3).

The Raspberry Pi 4 uses a Broadcom BCM2711 SoC with a 1.5 GHz 64-bit quad-core ARM Cortex-A72 processor, with 1 MB shared L2 cache. The interrupt controller on this SoC is compatible with the ARM Generic Interrupt Controller (GIC) architecture 2.0, providing hardware support for interrupt distribution when using ARM virtualisation capabilities.

The BCM2711 chip that we use on Raspberry Pi 4 can address up to 16GB of LPDDR4 SDRAM, so the real barrier to our offering a larger-memory variant was the lack of an 8GB LPDDR4 package.

The default operating system image uses a 32-bit LPAE kernel and a 32-bit userland. This allows multiple processes to share all 8GB of memory, subject to the restriction that no single process can use more than 3GB. For most users this isn’t a serious restriction, particularly since every tab in Chromium gets its own process. Sticking with a 32-bit userland has the benefit that the same image will

run on every board from a 2011-era alpha board to today's shiny new 8GB product.

But power users, who want to be able to map all 8GB into the address space of a single process, need a 64-bit userland. There are plenty of options already out there, including Ubuntu and Gentoo.

Not to be left out, a new version was released - an early beta 64-bit operating system image. This contains the same set of applications and the same desktop environment that you'll find in the regular 32-bit image, but built against the Debian arm64 port.

Both the 32-bit and 64-bit operating system images have a new name: Raspberry Pi OS. As the community grows, they want to make sure it's as easy as possible for new users to find our recommended operating system for Raspberry Pi.

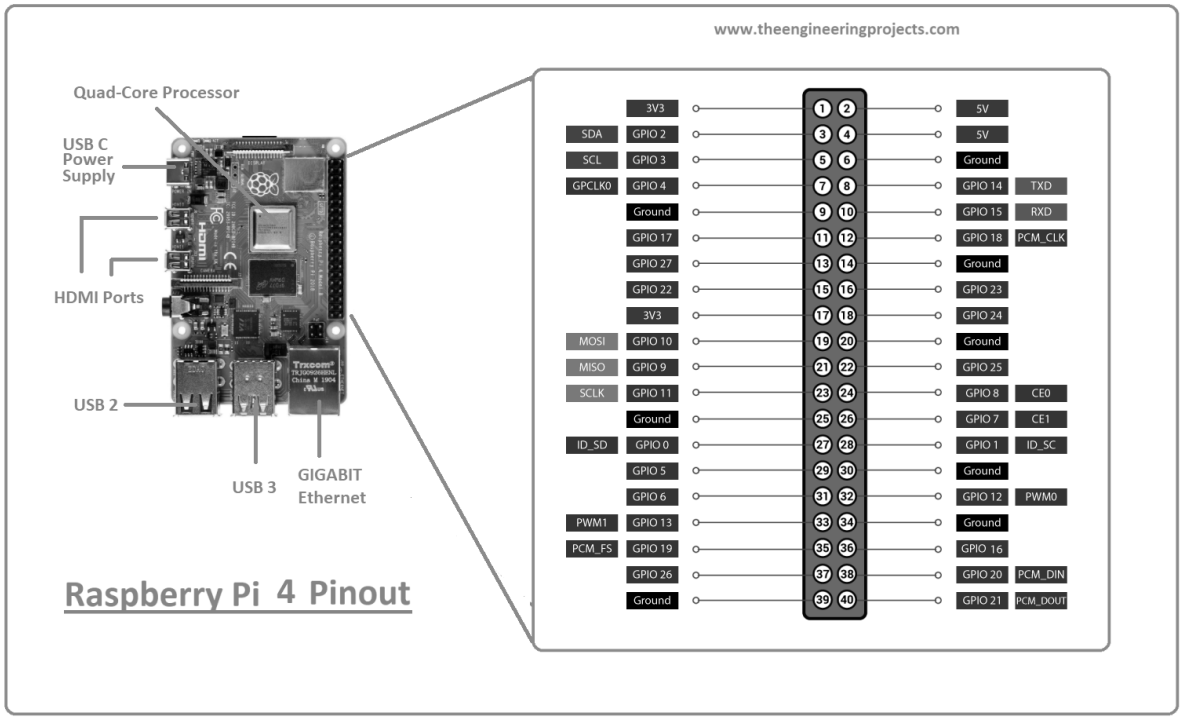


Fig. 4. Raspberry Pi 4 with GPIO

This Raspberry Pi model has been successfully applied to various control systems [6].

III. BeagleBone Black rev C

BBB could be used in one of three modes:

1. Standalone machine – when a HDMI monitor is plugged to microHDMI video output port and the USB host port is connected to a mouse and keyboard (either via USB hub or a wireless dongle) BBB could run as a

desktop machine. Currently supported maximum video resolution is 1280x1024 pixels (source - github.com/beaglebord/beaglebone-black/wiki). With its 1 GHz dual-core Sitara processor BBB can host some up-to-date OS. List of OS for BBB is published here – elinux.org/BeagleBone_Operating_Systems

2. Server mode – the BBB is connected to a router via 10/100 Ethernet LAN port. Then it could be accessed either via a local LAN network or via Internet. The BBB can run a server, for example TightVNC server.
3. Tethered to a PC. Every BBB is delivered with a USB to microUSB cable. By connecting the USB end of the cable to a computer and the microUSB end of the cable to the USB Client port of the BBB, BBB is connected as a storage device to the computer.

The real power of the BBB comes with learning and prototyping with electronics. It has embedded two 46 pins expansion headers that provide extensive I/O capabilities. Through them a developer has access to up to 65 digital GPIOs, 8 PWM and 4 Timers, 7 analog inputs (1,8 V), 4 UARTS and 1 TX only ports, 2 I2C ports and 2 SPI ports. The advanced developers can make use of 2 built-in 32-bit 200 MHz Programmable real-time unit (RTU) processors (Figure 5).

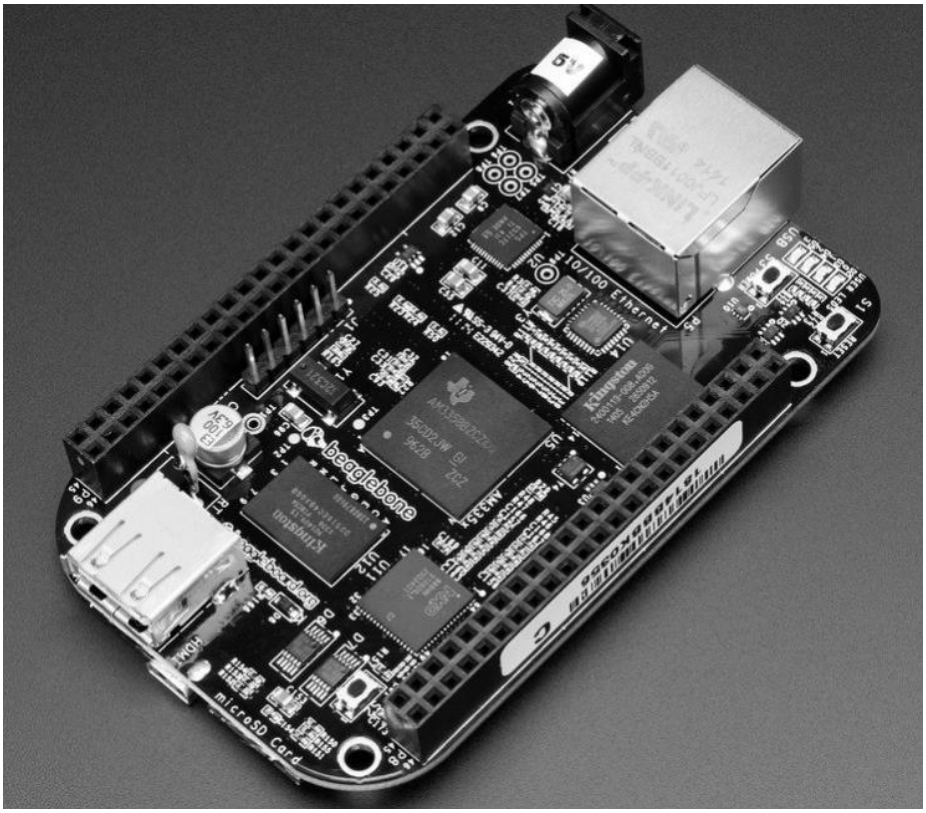


Fig. 5 BeagleBone Black rev. C

A serial debug port is provided via UART0 port on the processor with a single 6 pins header. In order to use it a USB-to-TTL adapter is required. Also for SW development and debugging purposes exists an option for a single 20 pin CTI JTAG header. This header is not supplied with the board and to be used a connector must be soldered on the board. Then a various type of JTAG emulators could be used.

The BeagleBone Black is an excellent tool to start if one is new to the electronics but is also a great tool for advanced users offering a greater speed, computational power and variety of different inputs and outputs for numerous devices. One can use BBB just to make the first steps in electronics simply by making a LED blinking or dimming while the more experienced can develop a complicated projects like underwater robot-camera, home automation server etc.

The people who deals with electronics divides on two major types: one that likes programing and other that is into hardware. The BeagleBone Black offers something for both. It comes with an IDE called Cloud9 – a great tool for programing and developing software. For those who are not comfortable with the IDEs BeagleBone Black offers a simple editors like NANO and VIM. They can be used to create text file that later can be either compiled as an executable files or used as a program by signaling to the shell that this is a program file when calling it.

BeagleBone Black comes with preinstall compilers for C and Python. Also if the user is familiar with the Linux Secure Shell he or she can use it for programming and addressing the inputs/outputs of the board. If this isn't enough one can use HTML, Java, PHP and any other programming language. Not only that but a user can reuse a code written for other computers and other BBBs.

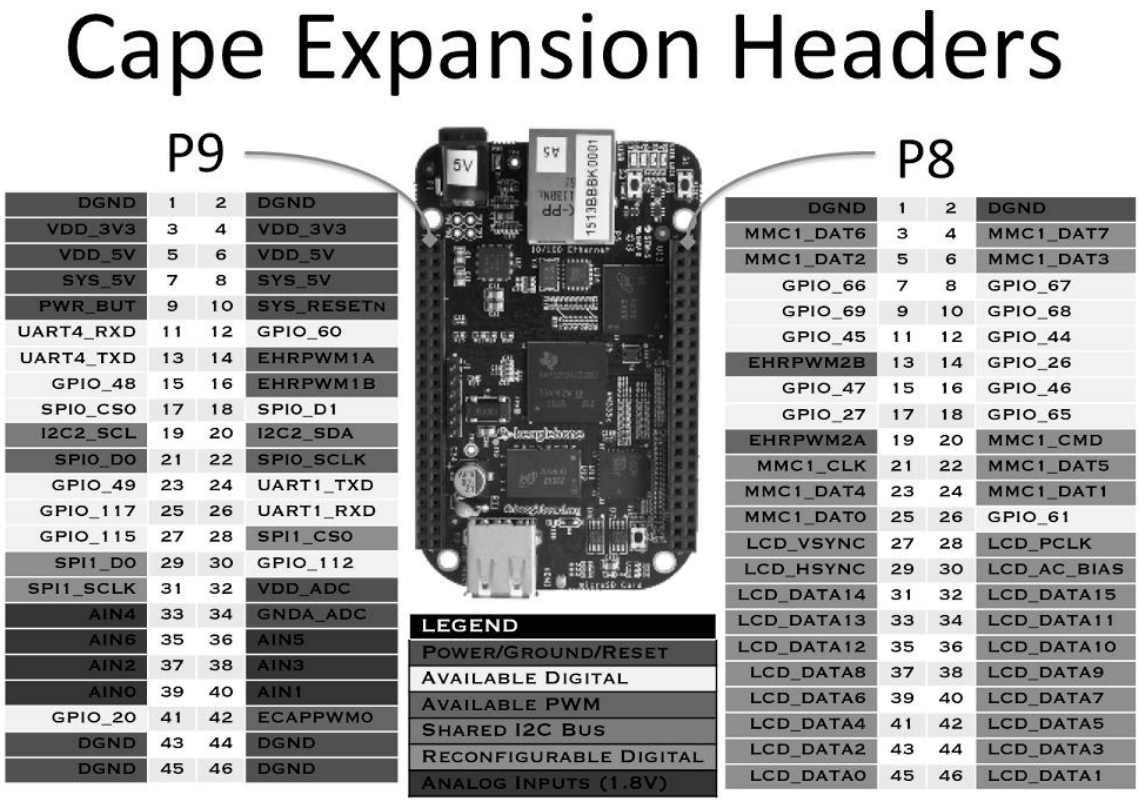
The people who are into the hardware and like to do everything from scratch can put in use the number of devices (timers, PWM) and GPIO that BBB offers. Users can read directly the electrical signals from a sensor, a thermocouple for example, and write its own code to interpret the values or can use the variety of more sophisticated communication protocols like serial (UART), CAN, I2C, LAN etc. to communicate with devices and computers and even other BBBs.

Beagle Bone Black is a computer and as such it comes with an OS. BBB Rev C comes with a Linux version called Debian. However, there are many other OS that can be used – other Linux distros, Android and even a version of Windows.

Normally the OS is loaded in the eMMC memory of the BBB and this is the first option in the booting process. The second choice is booting from the SD card. The order can be reversed by using the boot button of the BeagleBone.

A user can experiment with another OS either installing it as a fresh copy on the eMMC card or loading it from an SD card keeping the original OS safe. And if something goes wrong or one does not like the new OS one can goes back the familiar OS by simply rebooting the BBB.

In the Table 1 I will summarized the most important features of the three boards. Keep in mind that all three of them are highly customizable and some variations might not comply with the data in the table.



DGND	1	2	DGND
VDD_3V3	3	4	VDD_3V3
VDD_5V	5	6	VDD_5V
SYS_5V	7	8	SYS_5V
PWR_BUT	9	10	SYS_RESETN
UART4_RXD	11	12	GPIO_60
UART4_TXD	13	14	EHRPWM1A
GPIO_48	15	16	EHRPWM1B
SPI0_CS0	17	18	SPI0_D1
I2C2_SCL	19	20	I2C2_SDA
SPI0_D0	21	22	SPI0_SCLK
GPIO_49	23	24	UART1_TXD
GPIO_117	25	26	UART1_RXD
GPIO_115	27	28	SPI1_CS0
SPI1_D0	29	30	GPIO_112
SPI1_SCLK	31	32	VDD_ADC
AIN4	33	34	GNDA_ADC
AIN6	35	36	AIN5
AIN2	37	38	AIN3
AIN0	39	40	AIN1
GPIO_20	41	42	ECAPPWM0
DGND	43	44	DGND
DGND	45	46	DGND

DGND	1	2	DGND
MMC1_DAT6	3	4	MMC1_DAT7
MMC1_DAT2	5	6	MMC1_DAT3
GPIO_66	7	8	GPIO_67
GPIO_69	9	10	GPIO_68
GPIO_45	11	12	GPIO_44
EHRPWM2B	13	14	GPIO_26
GPIO_47	15	16	GPIO_46
GPIO_27	17	18	GPIO_65
EHRPWM2A	19	20	MMC1_CMD
MMC1_CLK	21	22	MMC1_DAT5
MMC1_DAT4	23	24	MMC1_DAT1
MMC1_DAT0	25	26	GPIO_61
LCD_VSYNC	27	28	LCD_PCLK
LCD_HSYNC	29	30	LCD_AC_BIAS
LCD_DATA14	31	32	LCD_DATA15
LCD_DATA13	33	34	LCD_DATA11
LCD_DATA12	35	36	LCD_DATA10
LCD_DATA8	37	38	LCD_DATA9
LCD_DATA6	39	40	LCD_DATA7
LCD_DATA4	41	42	LCD_DATA5
LCD_DATA2	43	44	LCD_DATA3
LCD_DATA0	45	46	LCD_DATA1

Fig. 6. BeagleBone Black with GPIO

Table 1. Summary

	Arduino Uno rev3	Raspberry Pi 4B	BeagleBone Black
based on	microcontroller	processor	processor
SoC	no	BCM2711	AM3358/9
procesor	ATmega328P	ARM Cortex-A72	ARM Cortex-A8 + Dual PRU (200 MHz)
bits	16	64	64
Friquency	16 MHz	1.5 GHz	1 GHz
Operating Voltage	5 V	3,3 V	3,3 V
Digital I/O Pins	14 - pin header	40-pin header	2x 46 pin headers
RAM	32 KB	8 bit, eMMC, up to 8GB, microSD card	8 bit, eMMC, 4GB, microSD card
Memory	no	8 GB	512 MB DDR3
OS	no	yes	yes
own IDE	yes	yes	yes
Analog Input Pins	6	0	6
Video & sound	no	2 × micro HDMI ports (up to 4Kp60 supported) 2-lane MIPI DSI display port2-lane MIPI CSI camera port4-pole stereo audio and composite video port	1 x Micro-HDMI
USB	1xUSB2.0	2X USB 3.0, 2X USB 2.0	1 x Standard A host port
ETHERNET	no	Gigabit (full throughput)	LAN (Fast Internet)
Wireless	no	2.4 GHz and 5.0 GHz IEEE 802.11ac wireless, Bluetooth 5.0, BLE	no
Low-level peripherals:			
UART	1	6	4
PWM	6	1	8
SPI	2	2	2
I²C	1	6	2
CAN bus	0	0	2
Timers	3	4	4
Length	68.6 mm	85.0 mm	86.40 mm (3.402 in)
Width	53.4 mm	56.0 mm	53.3 mm (2.098 in)
Weight	25 g	49.90 g	39.68 g (1.400 oz)

CONCLUSION

Based on the table above I decided to use the BeagleBone Black in my automation project.

Of course BBB has its own limitation which include: only 512 MB RAM, only 4GB eMMC storage card and the USB host has only one port. But all this is easy to overcome, using SD card to increase the memory or to use a USB hub to increase the number of USB ports, and the abundance of GPIOs, OSs and programming languages and the embedded IDE (Cloud9) makes BeagleBone Black logical choice.

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