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COMPARISON STUDY OF TOP DEVELOPMENT BOARDS IN THE CONTEXT OF IOT

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Key words: Arduino; Raspberry Pi; Wi-Fi microchip ESP8266; Internet of things (IoT); Multicriterial analysis.

The Internet of Things (IoT) is an uprising technology. However, this was possible due to an open-source hardware project - Arduino Uno, which made IoT accessible to the people. Combined, the IoT provided the means and methodologies, while the Arduino offered an easy-to-use, easy-to-program system which led to an ascending trend for both. After more than ten years of successful collaboration between IoT and Arduino systems, several new competitors launched development boards created especially for IoT. The most popular are Raspberry Pi Pico, ESP8266, STM32, etc. This paper applied a multicriterial analysis (MCA) to rank the performances of the development mentioned above boards in the IoT context. The main goal is to establish if Arduino Uno, which dominated the market, will continue to lead, or will be replaced by one of its competitors.

1. INTRODUCTION

In the year 2005, following the path of Piaggio, a group of young Italian entrepreneurs launched what would be the "Vespa" of Electronics – the Arduino Uno development board. Built around an AVR microcontroller, this easy-to-program, easy-to-use system will become the preferred tool for students and electronic hobbyists worldwide.

The key improvements that made the Arduino Uno a success was not linked to the hardware setup but primarily to its communication interface. The communications device class protocol, part of the operating system, makes a driverless USB serial port possible. It is incorporated in Arduino as a piece of firmware that emulates an FTDI chip and enables it to function without a driver. This feature also enabled MIDI and HID firmware to emulate computer peripherals [1].

Like all great projects, some features were discovered by mistake, as the right connector moved slightly from the center, which restricts attaching shields only in one way.

On a different level, years before the Arduino project was launched, a different technology was making its impression over the world. The Internet of Things (IoT), first coined in 1999 as *"Sensors and actuators embedded in physical objects are linked through wired and wireless networks"* [2], needed eleven years to become mainstream, just as Arduino Uno celebrated its ten million units sold. From that point forward, both technologies were linked.

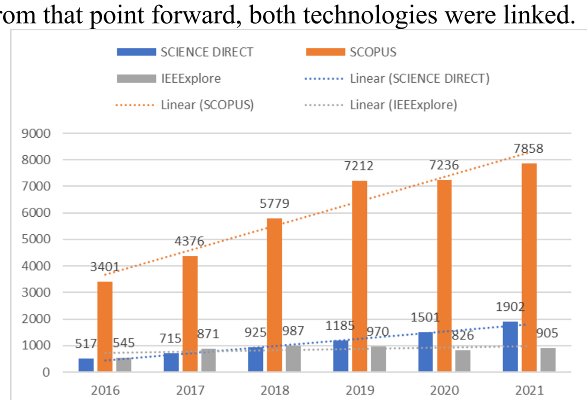

Fig. 1 – Number of Arduino Uno articles published by major editors

Arduino Uno made possible a wide range of IoT applications from simple household monitoring [3–8] to complex injured people rescue [9] and advanced agriculture [10,11] and learning systems [12]. While most of these projects are designed and implemented by amateurs, the IoT made possible the transition to academia for the Arduino board. Since 2016, many research projects and scientific articles have been based on the Arduino system. The survey results from 2016 and 2021 revealed an ascending trend of papers published by significant editors – Fig. 1.

While there is an evident influence of the Covid-19 pandemic in the number of articles written during 2019-2021, the average increase rate is still. 20.64 %.

The articles written during this period covered a wide range of topics, from the e-health [13] to the robotics [14] and from the environment measurements [15] to the home automation [3]. Still, IoT has a special place in the scope of the paper. For this, the number of papers covering Arduino and IoT was extracted from the primary survey – Fig. 2.

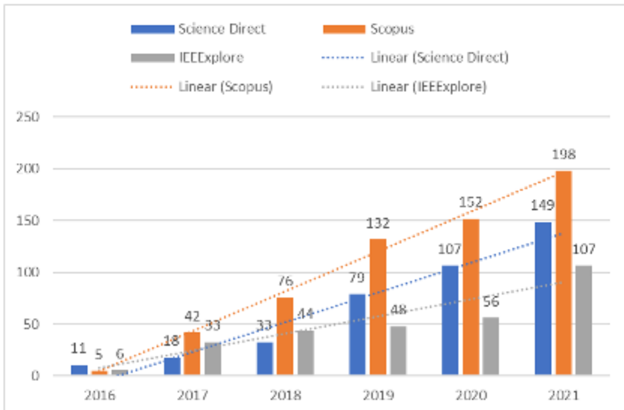

Fig. 2 – Number of Arduino Uno and IoT articles published by major editors

These specific articles follow the general trend with a steep increase in the last few years.

After more than ten years of dominating the scientific and amateur IoT communities, Arduino Uno reached a turning point. Several competitors have been developed especially to meet the IoT requirements, *i.e.*, high, speed communications, high flexibility, extended sensor arrays,

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low power consumption, and low price [14]. In this context, the paper's main objective is to establish if Arduino Uno will continue to dominate the IoT future or if a new development board will replace it. A multicriteria analysis (MCA) covering hardware setup, economic perspective, and technical documentation was applied to test this.

The main contributions of the paper are:

- Applying a multicriteria analysis used for quantifying the performance of each board (section 2);
- Summarizing the performance for each analyzed board in a shared context (section 3);
- Ranking the top development boards based on the proposed criteria (section 4).

2. MATERIALS AND METHOD

In most cases, several parameters must be considered to establish if a technology has reached its maturity phase or is still in the growth part of the S-curve. These cover various technical specifications, economic perspectives, competitors, population opinions, etc. Multicriteria analysis is usually the best approach to accommodate these different areas [16].

MCA is a hierarchy technique that quantifies each object's performance considering a set of criteria.

For our study, the objects that will be compared are the Arduino Uno and its main competitors: Particle Photon, ESP8266, Beagle Bone, MSP 430, STM 32, and Raspberry Pi Pico. These boards were considered based on the following criteria: they are development platforms and not single-board computers, their price is under 25€, and they have strong communities around them.

The criteria that were used to rank them were divided into three domains:

- Hardware setup: CPU clock, memory, communication interfaces, wireless communication, measurement accuracy, number of analog and digital pins;
- Economics: price and power consumption;
- Documentation: number of IoT projects based on each board hosted on GitHub (https://github.com/).

The performance matrix for the chosen objects and criteria is calculated to perform the MCA. Each domain has a specific weight in the matrix, and each object receives a score for each criterion. The element with the highest score receives the entire criterion weight, while the others get proportional scores.

The weighting adopted is based on the Mean weight method [17], a straightforward weighting approach that considers all attributes equally important. So, since there are ten criteria in total, seven in the Hardware category, two in the Economic part, and only one for documentation, an equal weight of 10% is attributed to each component.

The point allocation method proposed by [18], which states that "The total of all criterion weights must sum up to 100", was applied for scoring.

Each board must run the same source code to have a fair evaluation of the hardware setup. This presents a problem because some boards use their modified version of the C/C++ programming language and different libraries. After carefully evaluating different techniques to port the source code from one type of board to another due to many unknowns, this was considered unfeasible, so several boards were removed from the study. The Particle Photon, Beagle Bone, and MSP 430 are incompatible with the Arduino programming application - Arduino IDE and were removed from the study. The STM 32 is compatible with Arduino IDE but requires an external FTDI chip, which was also removed from the study. Because only two other boards meet all our criteria, another board produced by Arduino – Arduino Nano 33 IoT was introduced. This board was not considered in the first place because the same manufacturer produced it, but in the spirit of the study represents the answer offered by the Arduino CC to the new generation of competitors.

3. BOARDS SPECIFICATIONS

3.1. Hardware specifications

The hardware specifications for all the boards were obtained based on the manufacturer data [19]–[23] and are summarized in Table 1.

Table 1

Hardware specifications

Specification		Arduino Uno	Arduino Nano 33	Raspberry Pi Pico	ESP 8266
CPU [MHz]		16	48	133	80
Memory	SRAM [kB]	2	32	264	64
	Flash [kB]	32	256	2000	4000
Comm. Interface		2	4	6	3
Wireless		0	1	1	1
Analogue pins		6	8	3	1
Digital pins		14	14	23	11

The measurement accuracy was determined based on an experimental study using a voltage calibrator and the same source code. Metrawatt developed the calibrator used as a voltage standard. It had been set for two domains, *i.e.*, D1 = 0 – 3 V, which had a resolution of 0.1 mV and an intrinsic uncertainty of 0.05% FS + 0.02 mV, and D2 = 0 – 10 V, where the resolution was 1 mV and the uncertainty 0.05 % FS + 0.2 mV.

To make a fair evolution, the calibrator voltages were limited to 3.3 V due to most of the board's input voltage limit. Because the Arduino Uno has a higher limit of 5V, an external reference of 3.3 V was developed and used, so all the ADC references must be as close as possible voltage.

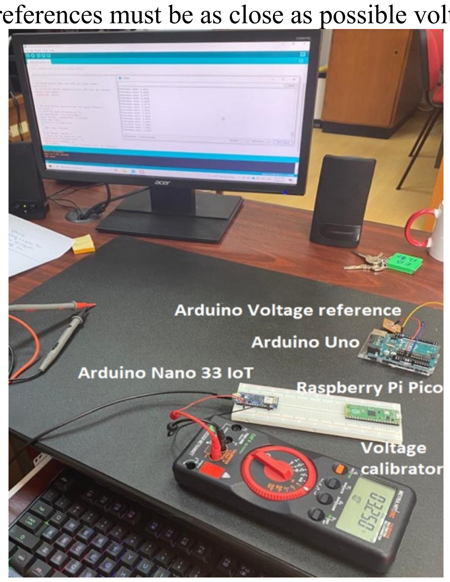

Fig. 3 – The hardware setup

The hardware setup used for measurement accuracy is presented in Fig. 3. The function for measuring the voltage makes ten different measurements. It outputs the average value in a period of 110 ms. The source code is:

```
// take a number of analogue samples and add them up
while (sample_count < NUM_SAMPLES) {
   sum += analogRead(VoltagePin);
   sample_count++;
   delay(10);
}
// calculate the voltage
voltage = ((float)sum / (float)NUM_SAMPLES * 3.3) / (2^res10);
// send voltage for display on Serial Monitor
//res10 is for Arduino Uno and ESP8266 for the others is res12
Serial.print(voltage);
Serial.println (" V");
sample_count = 0;
sum = 0;
}
```

The only difference between the source code used for the four boards is the analog-to-digital converter resolution, which is 10 for the Arduino Uno and ESP 8266 boards and 12 for Arduino Nano and Raspberry Pi Pico.

The obtained results are summarized in Table 2.

Table 2

Measurement accuracy

Calibrator [V]	Arduino Uno [V]	Arduino Nano33 [V]	Raspberry PiPico [V]	ESP 8266 [V]
0.532	0.5262	0.5355	0.5374	0.5289
1.247	1.2444	1.2484	1.2439	1.2476
2.536	2.5385	2.5387	2.5437	2.5502
3.250	3.2534	3.2548	3.2603	3.2568
Average relative error [%]	0.379	0.255	0.468	0.350

The values from Table 2 are the average values recorded for each board for ten measurements taken. In contrast, the average relative error is the average value of the relative errors, considering the calibrator value as the actual value.

3.2. ECONOMIC ASPECTS

The economic aspects considered the initial investment cost, *i.e.*, the price for each board and the power consumption during the voltage measurements.

Power consumption is relevant for IoT applications because they require constant measurements for extended periods, leading to increased operating costs.

The price for each board was obtained from a large chip supplier, i.e., Farnell, which had all the analyzed boards in stock. The prices were considered in Euros on 30.12.2021.

The power consumption was measured using a USB power meter – KWS-V20. The obtained results are presented in Table 3.

Table 3

Economic aspects

Specification	Arduino Uno	Arduino Nano 33	Raspberry Pi Pico	ESP 8266
Price [€]	19.55	18.73	3.27	6.69
Power [mW]	251	200.8	502	150.6

3.3. DOCUMENTATION

The documentation, in this study, is considered, in a broader sense, a project that is available free of charge over the internet, contains hardware schematics or source code, and is validated by the community.

To have a common denominator, we analyzed the IoT projects in the GitHub database related to the boards included in the study. The gathered data are presented in Table 4.

Table 4

Documentation

Specification	Arduino Uno	Arduino Nano 33	Raspberry Pi Pico	ESP 8266
GitHub projects	9369	281	1804	35510

4. **RESULTS AND DISCUSSIONS**

The MCA performance matrix – Table 4, was constructed, scoring a 10 point for each criterion where the best result is found. All the other boards received a proportional score considering their performance reported the best result.

Table 4

MCA performance matrix

Specification	Arduino Uno	Arduino Nano 33	Raspberry Pi Pico	ESP 8266
CPU [Mhz]	1.20	3.61	10.00	6.02
Memory [kB]	0.04	0.61	5.00	1.21
	0.04	0.32	2.50	5.00
Comm. Interface	3.33	6.66	10.00	5.00
Wireless	0.00	10.00	10.00	10.00
Analogue pins	7.50	10.00	3.75	1.25
Digital pins	6.09	6.09	10	4.78
Average relative error [%]	6.73	10.00	5.44	7.28
Price [€]	1.67	1.75	10.00	4.89
Power [mW]	6.00	7.50	3.00	10.00
GitHub projects	2.64	0.08	0.51	10.00
Total	35.25	56.61	70.20	65.43

After summing all the scores obtained by each board, the total value represents the ranking criterion for the developed MCA.

As can be seen, the Arduino Uno scored the lowest value with 32.25 points from 100. This, corroborated with the fact that now several boards with superior performances are available on the market, it is a clear indicator that Arduino Uno reached its maturity on the product developing S-curve and is now entering the decline phase. Even worse, Uno did not obtain the highest mark for any criteria, which clearly indicates that it will start to detach from the IoT future and remain a perfect starting board for electronics enthusiasts.

The Raspberry Pi Pico scored almost twice as much as Arduino Uno and is placed at the other end of the scale, being the best board according to the proposed MCA. Also, the Pico board obtained top marks for four criteria CPU frequency, number of communication interfaces and price. The only criterion where the Pico board scored worse than all the others was the measurement accuracy, but this is in concordance with other studies [23,24] and is something the manufacturer will resolve in the future. The Raspberry Pi understood the lesson that made Arduino Uno a formidable board, *i.e.*, the communication interfaces, and adapted these specifications to the IoT environment by doubling the number of means for communication.

The ESP8266 scored second, close to the Raspberry Pi Pico, with 65.43 points. Its strong points are related to its low power consumption and many projects developed by the community. However, having only one analog pin and a few digitals pins help the board easily integrate into other larger designs, but not in this case.

The Arduino Nano 33 IoT completes the hierarchy, representing that the company is still interested in the IoT market and has a good product. Even though the Nano is third on the list, one of the balanced boards produces high marks at communication and analog pins and has a lot of growth potential if the community switches from the Uno to the Nano.

5. **CONCLUSIONS**

The paper analyzes the Arduino Uno board's evolution in the IoT context. While the system's evolution was spectacular once electronic enthusiasts adopted it, several new competitors and demands from the IoT challenged its supremacy in the last years. Hardware setup, economic feasibility, and documentation were considered MCA criteria to evaluate its role in the future of IoT. After gathering all the data and constructing the performance matrix, one can conclude that the Arduino Uno will no longer be part of the IoT future but will remain a viable solution for an IoT starter kit. The best-suited board for IoT applications is the Raspberry Pi Pico, which has excellent communication capabilities and balanced economics and hardware proprieties.

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