ANALYSIS OF THE INSTANTANEOUS ENERGY CONSUMPTION OF AN ELECTRICAL DEVICE

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Technology is evolving at a rapid pace, and recent advances in this field provide the opportunity for the mass deployment of energy-efficient devices whose architecture is composed of low-cost and low-power sensors to monitor and control in real time the ambient of the spaces in which they operate. In this article, a device built for environmental monitoring and control is presented, a set of measurements is made regarding its instantaneous energy consumption in several scenarios, and the results obtained are analyzed.

Keywords: energy measurement, sensors, ambient monitoring, electrical device, instantaneous power

1. Introduction

Air pollution is a danger to the health and comfort of the inhabitants, whether it is personal or professional space, in the urban environment the low quality of the air has multiple harmful effects on human health and the environment [1]. Air pollution is mainly caused by vehicles and industries which cause various serious respiratory diseases. The World Health Organization (WHO) confirms that approximately 92% of the planet's population lives in places where the air quality exceeds the permitted safety limits [2]. Considering that people spend approximately 90% of their time indoors, repeated exposure to air pollutants affects their well-being, work performance and productivity level [3]. The impact of indoor air pollution can be up to 100 times greater than the level of outdoor air pollution. This is mainly due to the fact that closed spaces accumulate potential pollutants with a significantly higher efficiency than open spaces [4]. Electrical devices used in homes and office buildings cover a large amount of energy consumption. Building lighting and appliances account for 30% of electricity consumption [5]. In order to become as efficient as possible from the point of view of consumption and to be able to realize an economy from this point of view, it is very important to carefully monitor this process. It is advisable to be aware of the hours in which we choose to use the electric equipment, in this way we can create a energy consumption optimization plan. A well-organized and implemented plan can provide both residential and office customers with

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substantial savings by using devices at the time of day when electricity is cheaper [6].

2. Description and technical specifications of the constructed device

It is about an electrical device made for environmental monitoring and control, whose instantaneous energy consumption was measured, Table 1 shows the technical specifications of the components that make up the device.

The device consists of two microcontrollers and six sensors for the acquisition of ambiental data, a current sensor to monitor its own consumption, and to save energy, a PIR sensor was integrated, which when it does not detect movement, it activates the optional standby function.

Table 1

Technical specifications of the components

Name	Purpose	Supply voltage	Operating temperature
NANO V3 [7]	Development board	3.3V~5V	-40°~85°C
WeMos D1 [8]	Microcontroller	3V~5.5V	-55°~125°C
DHT22 AM2302 [9]	Temperature and humidity sensor	5V	-40°~80°C
GP2Y1010AU0F [10]	Dust particle sensor	4.5V~5.5V	-10°~65°C
BMP280 [11]	Atmospheric pressure sensor	3V-5V	-40°~85°C
MQ-135 [12]	Air quality sensor	5V	-10°~45°C
MQ-7 [13]	Carbon monoxide sensor	5V	-10°~50°C
CCS811 [14]	TVOC and CO^2 sensor	3.3V ~5V	-40°~80°C
HC-SR501 [15]	PIR motion sensor	4.5V~20V	-15°~70°C
RTC DS3231 [16]	Real Time Clock	3.3V ~5V	0°~70°C
DFR0034 [17]	Sound sensor	3.3V~5V	-40°~60°C
LM386 [18]	Audio amplifier	5V~12V	-40°~85°C
Display [19]	OLED	3.3V ~5V	-40°~80°C
Relay [20]	Command	5V	-40°~85°C
SG90 [21]	Servomotor	4.8V	0°~55°C
Fan [22]	Cooling	5V	-10°~75°C
Fan [22]	Air ventilation	5V	-10°~75°C
INA219 [23]	Current sensor	3V~5V	-40°~85°C
Matrix [24]	Led	4V~5.5V	0°~70°C
Speaker [25]	Audio	5V	-25°~60°C
Board [26]	Buttons	3V ~6V	-40°~75°C

Fig. 1 shows the circuit diagram of the electrical device whose instantaneous consumption is measured.

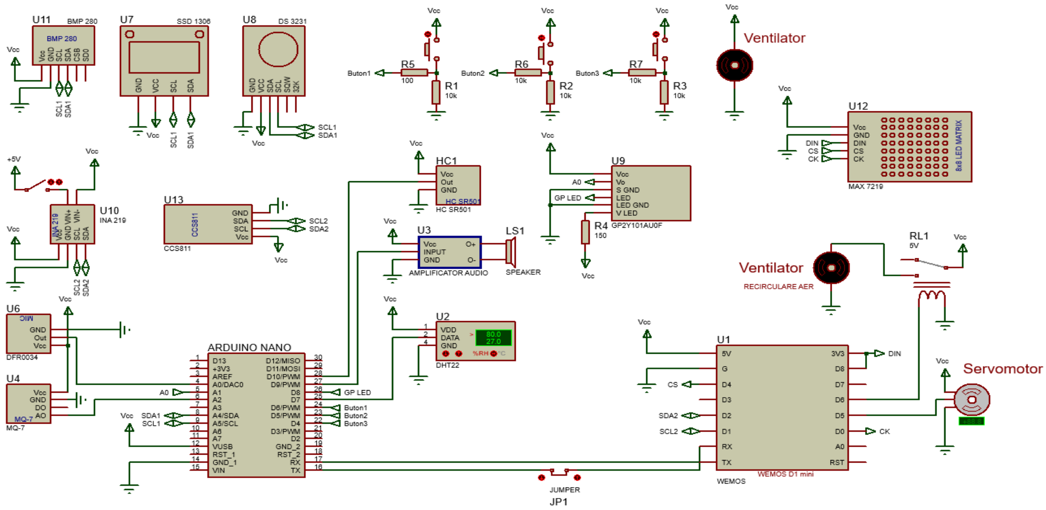

Fig. 1. Electrical diagram of the device

3. Making measurements regarding the instant consumption of the device

To monitor the instantaneous energy consumption of the electrical device was used Adafruit INA219 current sensor. The CJMCU-219 module has an I2C interface with bidirectional integrated circuits (ICs) for low-power current and power monitoring. The INA219 with the highest accuracy and smallest size is used to monitor voltage sag. The device is available in a SOT23 package, used for digital current reading in laptops, power supplies, battery management, and automotive and telecommunications equipment [27].

The monitoring of the instantaneous energy consumption of the electrical device was performed on a number of 16 different scenarios, and to obtain the measurements we created an application that with the help of a web page displays the results, their screenshots are presented below [28], [29], [30].

ID	Temperatura	Umiditate	CO	CO2	Particule	Prezență	Alarmă	Zgomot	Tensiune [V]	Intensitate [mA]	Putere [mW]	Dată server
9380	28.39	37.2	95	410	0	1	0	21.8	5.4	356.8	1894	2023-06-30 15:10:16
9379	28.39	37.2	90	415	0.03	1	0	22.2	5.4	352.5	1946	2023-06-30 15:10:10
9378	28.38	37.3	90	415	0.02	1	0	8.8	5.41	359.7	1894	2023-06-30 15:10:06
9377	28.37	37.3	91	427	0	1	0	26.8	5.42	357.2	1910	2023-06-30 15:10:01
9376	28.37	37.3	93	424	0	1	0	29.4	5.41	356.4	1916	2023-06-30 15:09:56
9375	28.37	37.2	92	415	0.02	1	0	6.6	5.41	358.5	1904	2023-06-30 15:09:50
9374	28.37	37.2	96	415	0	1	0	15	5.41	359.8	1934	2023-06-30 15:09:46

Fig. 2. Web interface that presents the results of the measurements

In Fig. 2 is a screenshot of the way the server presents the results obtained regarding the measurements.

Table 2 shows the results of the measurements regarding the consumption of the device, which were made with the help of the sensor mentioned above.

Table 2

Measurement results obtained

Scenario	Voltage [V]	Current [mA]	Power [mW]
1. Normal mode of operation	5.37	497.80	2670.00
2. Acoustic signals on	5.31	683.20	3670.00
3. Led matrix on	5.38	512.40	2724.00
4. Acoustic signals and led matrix on	5.37	776.60	4174.00
5. Fan on	5.31	689.20	3588.00
6. Fan and acoustic signals on	5.32	963.80	5046.00
7. Fan and led matrix on	5.31	717.80	3684.00
8. Fan, acoustic signals and led matrix on	5.31	977.00	5112.00
9. Servomotor on	5.36	507.80	2670.00
10. Servomotor and acoustic signals on	5.37	695.70	3588.00
11. Servomotor and led matrix on	5.36	509.10	2762.00
12. Servomotor and fan on	5.31	706.00	3634.00
13. Servomotor, acoustic signals and led matrix on	5.34	723.60	3936.00
14. Servomotor, acoustic signals and fan on	5.32	966.40	4902.00
15. Servomotor, led matrix and fan on	5.30	700.30	3674.00
16. Servomotor, acoustic signals, led matrix and fan on	5.32	943.30	5102.00

4. Analysis of the results obtained

The power consumption values for each scenario were sorted in ascending order. Linear regression was used to model the resulting power consumption. The scenario index (Si) serves as input for the regression function used for power consumption modelling:

$$P_{predicted} = b_1 \cdot Si + b_0$$

where b_1 is intercept and b_0 is slope. The values of b_0 and b_1 are computed such that the sum of squared differences between the measured and predicted power is minimized:

$$\underset{b_0, b_1}{\arg\min} \sum_{i=1}^{N} \left(P_{measured}[i] - P_{predicted}[i]\right)^2$$

where N represents the number of scenarios. The values of b_0, b_1 were computed using the scikit-learn library. The power prediction equation was determined by the python script as:

$$P_{predicted} = 175.0647 \cdot Si + 2495.5147$$

Next, the Pearson correlation coefficient is used to evaluate the quality of the proposed linear prediction model. The R^2 is a statistical measure of the goodness of fit for the linear regression model (R is Pearson correlation coefficient). The R^2 calculus formula is the following:

$$R^2 = 1 - \frac{\sum_{i=1}^{N}\left(P_{measured}[i] - P_{predicted}[i]\right)^2}{\sum_{i=1}^{N}(P_{measured}[i] - \overline{P_{measured}})^2}$$

where $\overline{P_{measured}}$ represents the arithmetic mean of the measured power values. From the above formula we observe that the maximum value for R^2 is 1. A value close to 1 indicates that the prediction algorithm provides a good estimate of the measured value. The computed value of R^2 of the proposed linear regression model is 0.92, which confirms the linear increase of power consumption. The chart below illustrates this aspect [32].

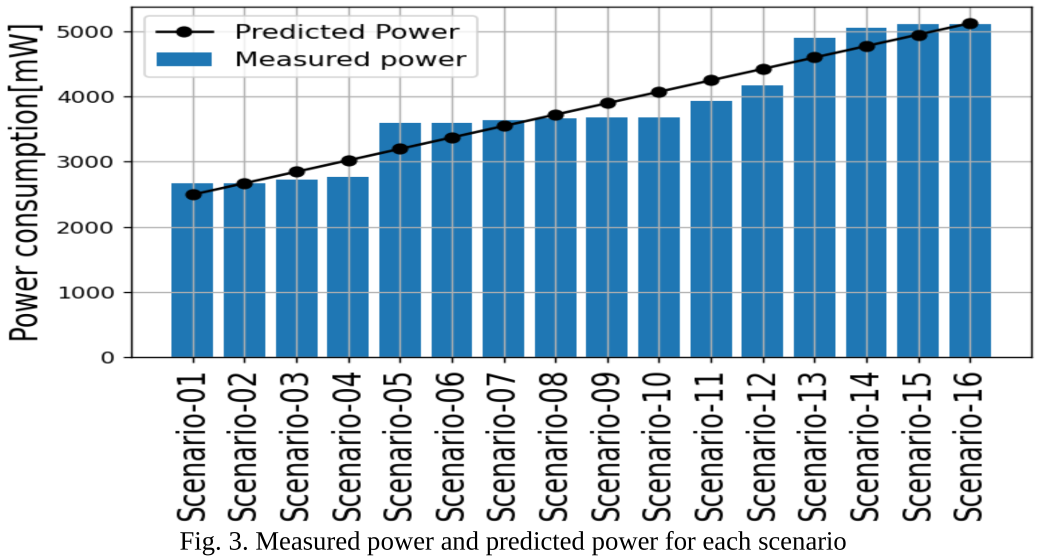

Fig. 3. Measured power and predicted power for each scenario

To be able to make a conclusive analysis, the results of measurements accomplished were ordered according to the power consumed.

X scenario index | Y approximate power consumption | R^2=0.923

Table 3

Analysis of the obtained results

Scenario	Power (mW)	Power (mW) Interpolated	Difference
1. Normal mode of operation	2670.0	2495.514706	174.485294
9. Servomotor on	2670.0	2670.579412	-0.579412
3. Led matrix on	2724.0	2845.644118	-121.644118
11. Servomotor and led matrix on	2762.0	3020.708824	-258.708824
5. Fan on	3588.0	3195.773529	392.226471
10. Servomotor and acoustic signals on	3588.0	3370.838235	217.161765
12. Servomotor and fan on	3634.0	3545.902941	88.097059
2. Acoustic signals on	3670.0	3720.967647	-50.967647
15. Servomotor, led matrix and fan on	3674.0	3896.032353	-222.032353
7. Fan and led matrix on	3684.0	4071.097059	-387.097059
13. Servomotor, acoustic signals and led matrix on	3936.0	4246.161765	-310.161765
4. Acoustic signals and led matrix on	4174.0	4421.226471	-247.226471
14. Servomotor, acoustic signals and fan on	4902.0	4596.291176	305.708824
6. Fan and acoustic signals on	5046.0	4771.355882	274.644118
16. Servomotor, acoustic signals, led matrix and fan on	5102.0	4946.420588	155.579412
8. Fan, acoustic signals and led matrix on	5112.0	5121.485294	-9.485294

6. Conclusions

The large increase in consumption has significantly increased costs, in order to achieve a habit of electrical equipment users regarding energy saving, it is necessary to develop and permanently promote smart consumption monitoring solutions.

The purpose of the study was to present the architecture of an electrical device made for monitoring and controlling the environment, to perform instant measurements of its energy consumption based on a set of different scenarios, and to analyze the results obtained.

The presented results provide a starting point for future research, as the instant consumption of a device is monitored with the help of an integrated sensor that has the ability to measure the own consumption of the equipment. In order for users to be more aware of the amount of energy they consume, it would be interesting for most manufacturers of electrical devices to include a function that provides real-time monitoring of their own consumption.

Considering that the results of the measurements accomplished were ordered according to the power consumed, the growth trend is linear from one scenario to another, as demonstrated in the mathematical model.

Appendix A

Script runed to obtain the values from Table 3

```
“import numpy as np
import pandas as pd
from sklearn.linear_model import LinearRegression

# load measurements file
data = pd.read_csv('data.txt', delimiter=';')

data = data.sort_values(by=['Power[mW]'])

# convert power consumption values to 1D array
power = data['Power[mW]'].values.reshape(-1, 1)

noScenarios = len(data)
# build scenarios index 1D array
scenarios = np.arange(1, noScenarios + 1).reshape(-1, 1)

# build a LinearRegression object
linear_regressor = LinearRegression()
# perform linear regression
reg = linear_regressor.fit(scenarios, power)
# extract regression coefficients
b0, b1 = reg.coef_[0, 0], reg.intercept_[0]

data['Power[mW] Interpolated'] = b1 * np.arange(1, noScenarios + 1) + b0
data['Difference'] = data['Power[mW]'] - data['Power[mW] Interpolated']

# print Table 3 values
print(data[['Scenario', 'Power[mW]', 'Power[mW] Interpolated', 'Difference']])”
```

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