**Statistical Analysis of Processor Frequency Scaling Algorithms**

Recently can be observed a growth in mobile device sales, including smartphones and tablets, with its high quantity and diversity of hardware and software models, it put on focus the fragmentation problem. Batteries with low capacity are constraints in design of embedded systems. The increase of features highlighted the need for greater capacity in mobile batteries to provide an extended time of use. This work proposes an environment for simultaneously execute tests on mobile devices with support for energy analysis. Two major technology smartphones were used to evaluate the proposed environment. Experiments to provide energy efficiency optimizations in mobile processor frequency scaling were conducted. From the analysis made in the environment, techniques using DVFS that allowed energy savings of up to 25\% were created.

**Introduction**

Devices such as smartphones and tablets that use the Android operating system grew surprisingly, increasing from 200.000 activated per day in 2010 to 1.5 million devices activated per day in 2013 and actually is the platform with more active devices \cite{statista2014}. This growth can be explained by the amount of features that are aggregated to smartphones and tablets each year, reducing costs of equipment and the variety of options that encompass the various user profiles, from simple and inexpensive to more complex solutions.

In the world the most used operating system by these devices is the Android. It is built based on the contributions of the open-source Linux community, owning more than 300 versions of hardware and software. The open source Android code and the easy way to publish applications in the virtual store favored to make it the favorite for consumers and developers. Currently are more than 1.5 billion apps on Google Play \cite{adeveloper2015}.

The need to prolong the use of devices, the strong growth of mobile devices and Android operating system, the breakthrough in the development of multicore processors, it becomes necessary to develop techniques that reduce the energy consumption of these devices to increase its time of use. This is a concern of most mobile devices design, among these are smartphones and tablets.

Devices with more features require more processing power and consequently more energy dissipation. This processing power is measured by the amount of processors and cores and the clock frequency of each core of the processor. For developing techniques that allow energy efficiency it is necessary to understand the problem addressed and the characterization of their energy spent on mobile. To perform the characterization is necessary to have an energy measurement infrastructure.

The motivation of this work is the lack of a measurement environment (hardware and software integration) that assists in characterizing the energy consumption of mobile devices and allows automate tests. The characterization is a necessary step in the development and testing of new techniques to reduce power consumption in mobile devices.

The remainder of this paper is organized as follows:

**Resultados**

Question

Data source

Processing

Analysis

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| Tabla XXX. Sumarize | | | | | | | | | |
|  | Min. | 1st Qu. | Mediam | Meia | Sd. | Var | 3er Qu. | Max. | N |
| PS | 238.00 | 242.13 | 244.45 | 244.70 | 3.64 | 13.26 | 246.47 | 252.20 | 30 |
| O | 223.33 | 237.70 | 240.57 | 240.69 | 6.22 | 38.72 | 244.14 | 257.51 | 30 |
| P | 186.36 | 198.72 | 199.32 | 201.25 | 5.18 | 26.83 | 202.40 | 208.22 | 30 |
| PQ | 188.94 | 200.75 | 202.45 | 201.32 | 4.60 | 21.18 | 203.46 | 208.20 | 30 |
| **700MHz** | **172.37** | **179.30** | **180.96** | **180.45** | **3.27** | **10.69** | **182.25** | **185.60** | **30** |
| **1100MHz** | **191.85** | **194.08** | **195.92** | **195.58** | **1.69** | **2.85** | **196.96** | **198.20** | **30** |
| 1400MHz | 226.20 | 227.51 | 229.04 | 229.74 | 2.68 | 7.18 | 231.85 | 234.50 | 30 |

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| allboxplotgraph |
| Figura XXX. Box plot. |

Os gráfico Box-plot evidencia as diferenças existentes entre os algoritmos.

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| alldensitygraph |
| Figura XXXX. Gráfico de densidade aproximada. |

Analisis de kurtosis/skewness

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| --- | --- | --- | --- | --- | --- | --- | --- |
| Tabela XXX. Análises de kurtosis/skewness. | | | | | | | |
|  | PS | **O** | P | **PQ** | 700MHz | 1100MHz | **1400MHz** |
| kurtosis | 2.58 | **4.76** | 3.27 | **4.60** | 3.34 | 2.23 | **1.82** |
| skewness | 0.25 | **-0.10** | -1.04 | **-1.29** | -0.67 | -0.43 | **0.34** |

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|  | | | | | |
| pshistnorm | ohistnorm | | C:\Users\Pedro\AppData\Local\Microsoft\Windows\INetCache\Content.Word\phistnorm.png | | C:\Users\Pedro\AppData\Local\Microsoft\Windows\INetCache\Content.Word\pqhistnorm.png |
| PS | PQ | | P | | PQ |
| x700histnorm | | X1100MHzhistnorm | | C:\Users\Pedro\AppData\Local\Microsoft\Windows\INetCache\Content.Word\X1400MHzhistnorm.png | |
| 700MHz | | X1100MHz | | X1400Mz | |
|  | | | | | |

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| --- | --- | --- | --- | --- | --- |
|  | | | | | |
| spqqnorm | oqqnorm | | pqqnorm | | pqqqnorm |
| PS | PQ | | P | | PQ |
| X1100MHzqqnorm | | C:\Users\Pedro\AppData\Local\Microsoft\Windows\INetCache\Content.Word\X1400MHzqqnorm.png | |  | |
| 700MHz | | X1100MHz | | X1400Mz | |
|  | | | | | |

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| Test Aderência | Shapiro-Wilk | Lilliefors | Anderson-Darling |
| PS | 0.6321 | 0.6164 | 0.658 |
| O | 0.2109 | 0.2101 | 0.19 |
| P | 0.0009075 | 0.0007678 | 3.791e-05 |
| PQ | 0.0008656 | 0.0009473 | 0.0002399 |
| 700MHz | 0.09014 | 0.195 | 0.09208 |
| 1100MHz | 0.1943 | 0.2782 | 0.1491 |
| 1400MHz | 0.02742 | 0.2689 | 0.05013 |

**Test no parametrico de friedman con post test de nemenyi**

H\_0: mu\_1 = mu\_2 = ... m\_n

H\_1: existe mu\_i != mu\_j; i!=j

> test\_friedman$tfriedman Friedman rank sum test

data: X

Friedman chi-squared = 168.51, df = 6, p-value < 2.2e-16

> test\_friedman$ptnemenyi

Pairwise comparisons using Nemenyi multiple comparison test

with q approximation for unreplicated blocked data

data: X

PS O P PQ X700MHz X1100MHz

O 0.99161 - - - - -

P 2.3e-08 1.6e-06 - - - -

PQ 2.0e-07 1.1e-05 0.99983 - - -

X700MHz 6.6e-14 6.2e-14 0.00095 0.00020 - -

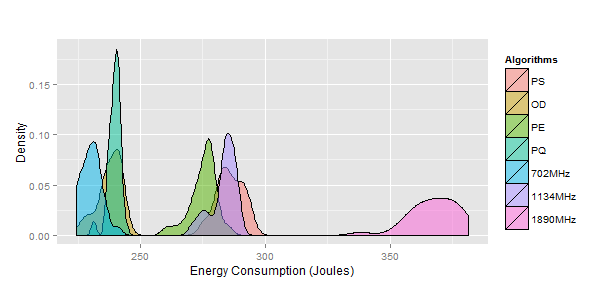
X1100MHz 1.7e-13 1.6e-11 0.55289 0.32245 0.25817 -

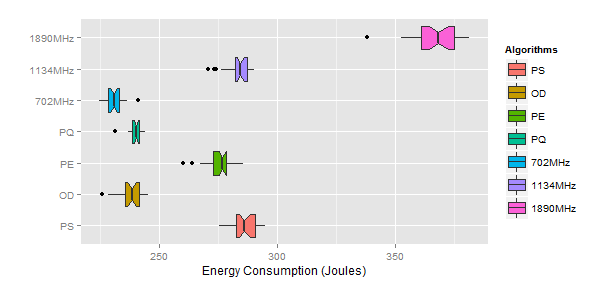
X1400MHz 0.06265 0.32245 0.02133 0.06265 6.5e-12 1.1e-05

P value adjustment method: none

S4

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| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Tabla XXX. Sumarize | | | | | | | | | |
|  | Min. | 1st Qu. | Mediam | Meia | Sd. | Var | 3er Qu. | Max. | N |
| PS | 275.3 | 282.3 | 285.9 | 285.8 | 5.185784 | 26.89236 | 290.4 | 294.6 | 30 |
| O | 225.5 | 235.3 | 238.2 | 237.7 | 4.829817 | 23.32713 | 241.3 | 245.0 | 30 |
| P | 260.1 | 272.7 | 276.7 | 275.1 | 5.295362 | 28.04086 | 278.3 | 285.5 | 30 |
| I | 231.3 | 238.3 | 240.0 | 239.6 | 2.389887 | 5.711561 | 241.2 | 244.0 | 30 |
| 702MHz | 224.5 | 228.0 | 230.6 | 230.5 | 3.97174 | 15.77472 | 232.8 | 241.0 | 30 |
| 1134MHz | 270.5 | 282.1 | 284.3 | 283.3 | 4.997017 | 24.97018 | 287.2 | 289.9 | 30 |
| 1890MHz | 338.2 | 361.0 | 368.2 | 367.4 | 9.678511 | 93.67358 | 375.1 | 381.5 | 30 |





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| Tabela XXX. Análises de kurtosis/skewness. | | | | | | | |
|  | PS | O | P | I | 702MHzMHz | 1134MHz | 1890MHz |
| kurtosis | 2.265748 | 3.050844 | 4.084406 | 6.021741 | 3.010252 | 3.266138 | 3.919491 |
| skewness | -0.1651545 | -0.8431631 | -0.8960374 | -1.272297 | 0.4522422 | -1.06603 | -0.8309137 |