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CONCEPT OF INTELLIGENT MEASURING SYSTEM FOR ANALYZING THE ENERGY CONSUMPTION OF IOT MODULES

The conducted analysis showed the shortcomings of known techniques for measuring MCU (microprocessor systems and IoT modules - hereinafter MCU) current consumption.

In order to improve self-powered systems, designed to perform complex algorithms (learning ANNs, searching for signatures of suspicious software code, etc.), it is necessary to minimize the energy consumption of software, since hardware of modern MCU has low consumption. Optimizing MCU software in terms of energy consumption requires experimental studies of the energy consumption of the execution of instructions, commands and programs. Due to the lack of specialized measuring equipment that has sufficient accuracy (the error must be less than the difference in power consumption of instructions and commands) and immunity to interference, known models do not allow optimizing the software in terms of power consumption and thereby increasing the operating time of autonomously powered systems without recovery battery charge. And this is important for MCU and IoT modules operating in remote locations, dangerous for people, and critical infrastructure systems. However, a direct study of the energy consumption of MCU instructions, commands and programs as part of IoT modules is very time-consuming. RISC microcontrollers have few commands, but many modes of their execution, so it would be necessary to investigate 10-20 thousand options. It is proposed to use the methods of artificial intelligence for the classification of teams and the forecast of energy consumption of those teams that were not studied.

The basis of the concept of a measuring system for the analysis of current consumption of smart devices and IoT modules can be the architecture developed in this paper. At the same time, a more detailed study of them and provision of noise protection, in particular, due to non-contact measuring devices, is required.

Keywords: self-powered system, complex algorithm, software power consumption.

АНАТОЛІЙ САЧЕНКО, ОЛЕКСАНДР ОСОЛІНСЬКИЙ, ВОЛОДИМИР КОЧАН, ОЛЕГ САЧЕНКО, ПАВЛО БИКОВИЙ, ДІАНА ЗАГОРОДНЯ
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КОНЦЕПЦІЯ ВИМІРЮВАЛЬНОЇ СИСТЕМИ ДЛЯ АНАЛІЗУ СПОЖИВАННЯ СТРУМУ РОЗУМНИМИ ПРИСТРОЯМИ ТА МОДУЛЯМИ IOT

Проведений аналіз показав недоліки відомих методик вимірювання струму споживання мікроконтролера.

З метою вдосконалення систем з автономним живленням (мікропроцесорних систем та IoT модулів – надалі МК), призначених для виконання складних алгоритмів (навчання ШНМ, пошук сигнатур підозрілого програмного коду та ін.), необхідно мінімізувати енергоспоживання програмного забезпечення (ПЗ), оскільки апаратне забезпечення (АЗ) сучасних МК має мале споживання. Оптимізація ПЗ МК за енергоспоживанням вимагає експериментальних досліджень енергоспоживання виконання інструкцій, команд і програм. У зв'язку із відсутністю спеціалізованого вимірювального устаткування, яке має достатню точність (похибка має бути меншою за різницю енергоспоживання інструкцій та команд) і завадостійкість, відомі моделі не дають змоги оптимізувати ПЗ за енергоспоживанням і збільшити тим самим час роботи систем з автономним живленням без відновлення заряду акумуляторів. А це важливо для МК та IoT модулів, що працюють у віддалених місцях, небезпечних для людей, та систем критичних інфраструктур. Однак пряме дослідження енергоспоживання інструкцій, команд і програм МК в складі IoT модулів дуже трудомістке. RISC мікроконтролери мають мало команд, але багато режимів їх виконання, тому треба було би дослідити 10 – 20 тисяч варіантів. Пропонується використати методи штучного інтелекту для класифікації команд і прогнозу енергоспоживання тих команд, які не досліджувалися.

Основою концепції вимірювальної системи для аналізу споживання струму смарт-пристроями та IoT-модулями є розроблена у статті архітектура. При цьому потрібне більш детальне забезпечення шумозахисту, зокрема, за рахунок безконтактних вимірювальних приладів.

Ключові слова: система з автономним живленням, складний алгоритм, енергоспоживання програмного забезпечення.

Introduction

The main reason for difficulties in measuring the power consumption of MCU is their current consumption as peaks synchronous with clock pulses. The reason for this is the CMOS technology of their production. The average current consumption of the MCU was measured using a shunt and a digital voltmeter [1-9]. At the same time, uncontrolled energy exchange led to significant errors. If the capacity of the capacitor in the power supply circuit is 1000 μF, a change in voltage on it by 10 μV corresponds to the energy of executing 25 instructions of MCU ARM7TDMI [1-6]. Turning on the shunt between the capacitor and MCU introduces parasitic inductance [7, 8]. Even 0.1 μH at a clock frequency of 25 megahertz creates a resistance of 15 ohms. At a peak current of 50 milliamps, this creates a voltage drop of 0.75 V. But at least the fifth harmonic, that is, a frequency of 125 megahertz, must be taken into account. Therefore, such switching on of the shunt leads to MCU failures. The scheme of current measurement using an operational amplifier with current consumption in the form of peaks causes MCU failures due to the limited response speed of the amplifier [9]. The scheme for measuring the instantaneous current consumption of MCU using a current mirror [10] has a drawback - the effect of voltage changes on the base-emitter junction of transistors with large current changes. MCU does not go astray. But these changes lead to changes in the voltage on the MCU up to 0.5 - 0.6 V. This creates a methodical error in the consumption current measurement, which is difficult to correct. Therefore, the error of the models built according to the methods [10] reaches 7-10%.

The scientific idea of the authors is to combine the method of measuring the instantaneous power consumption of the microcontroller and the method of measuring the average power consumption of the MCU, as well as deep neural networks for predicting the energy of instructions that will not be studied, which will ensure high accuracy of the measurement results, their mutual comparison and addition. Very often there is a situation when new IoT modules controlled by a microcontroller are being researched and self-adaptation of the system to new types of processor systems made by CMOS technology is necessary. An organic combination of such methods allows you to use the advantages of each of them.

Currently, the main technology of microelectronics is CMOS. The IoT industry is rapidly developing and the basis of all IoT devices are embedded microprocessor systems (microcontroller-based systems) with autonomous power. Their components, manufactured using CMOS technology, have a high speed of execution of instructions with low energy consumption. However, to date, the problem of extending the time of their autonomous operation without recharging the batteries is a constant one. An obvious method of increasing the autonomous operation time of MCU is to increase the energy capacity of power sources. This requires fundamental research on the creation of new materials and their testing. The second way is to improve CMOS technologies, which is also time-consuming. The third way is the optimization of the hardware structure, which is actively used. But it applies only to new developments. Optimizing software by energy consumption is a promising and universal way. However, optimization of software by energy consumption requires the development of a mathematical model of the energy consumption of the processor core. Such a model should be based on the results of experimental studies. At the same time, existing models have low accuracy (7-10%). To increase the accuracy, it is necessary to use equipment that ensures high accuracy of measuring the power consumption of CMOS microcircuits, in which the current is consumed at the moments of change in the logical state of the elements. It should be noted that today various devices are manufactured using CMOS technology - microprocessors, microcontrollers, specialized microcircuits, memory, logic elements, programmable logic matrices. The nature of their energy consumption is determined only by CMOS technology, and the methods and tools proposed in this project are suitable for all these devices. However, the currently existing methods and means of measuring the current, power, and energy of software execution have a large error, because they do not take into account the pulse nature of the energy consumption of devices made according to CMOS technology. The devices made as part of the preparation for the defense of dissertations by A. Borovyi and O. Osolinskyi were separate models. They made it possible to check the possibility of achieving high accuracy of measuring the impulse energy consumption of MCU. To ensure the possibility of developing optimal software, it is necessary to create a specialized intelligent system that combines the above-mentioned systems in a way that makes it possible to automate the process of researching the energy consumption of various types of MCU.

Conceptual model of the measuring system

Based on the analysis of the methods that were described in the previous section, several characteristics and requirements were identified that must be met by the method of measuring the current strength in the MCU power supply circuit:

1. Non-contact method of measuring the current and voltage in the MCU power supply circuit, the contact method is permissible only with theoretical and experimental confirmation that the noise level is permissible;
2. Sufficiently small measurement error of current and voltage in the MCU power supply circuit, as well as a bit rate sufficient to analyze the results of changes in the executable code;
3. The ability to filter out external interference that can affect the result of measuring current and voltage;
4. Possibility (if necessary) to amplify the received signal;
5. Control of the output current and voltage of the power source of the tested module/MCU;
6. The ability to control the MCU clock generator in a wide frequency range;
7. Necessity of mutual censorship of measurement results and rejection of false results.
8. The possibility of accumulating and classifying large volumes of data that will come from measuring channels;
9. Possibility of using neural networks for Matched filter functions.

Based on this, the system architecture can be synthesized (Fig. 1).

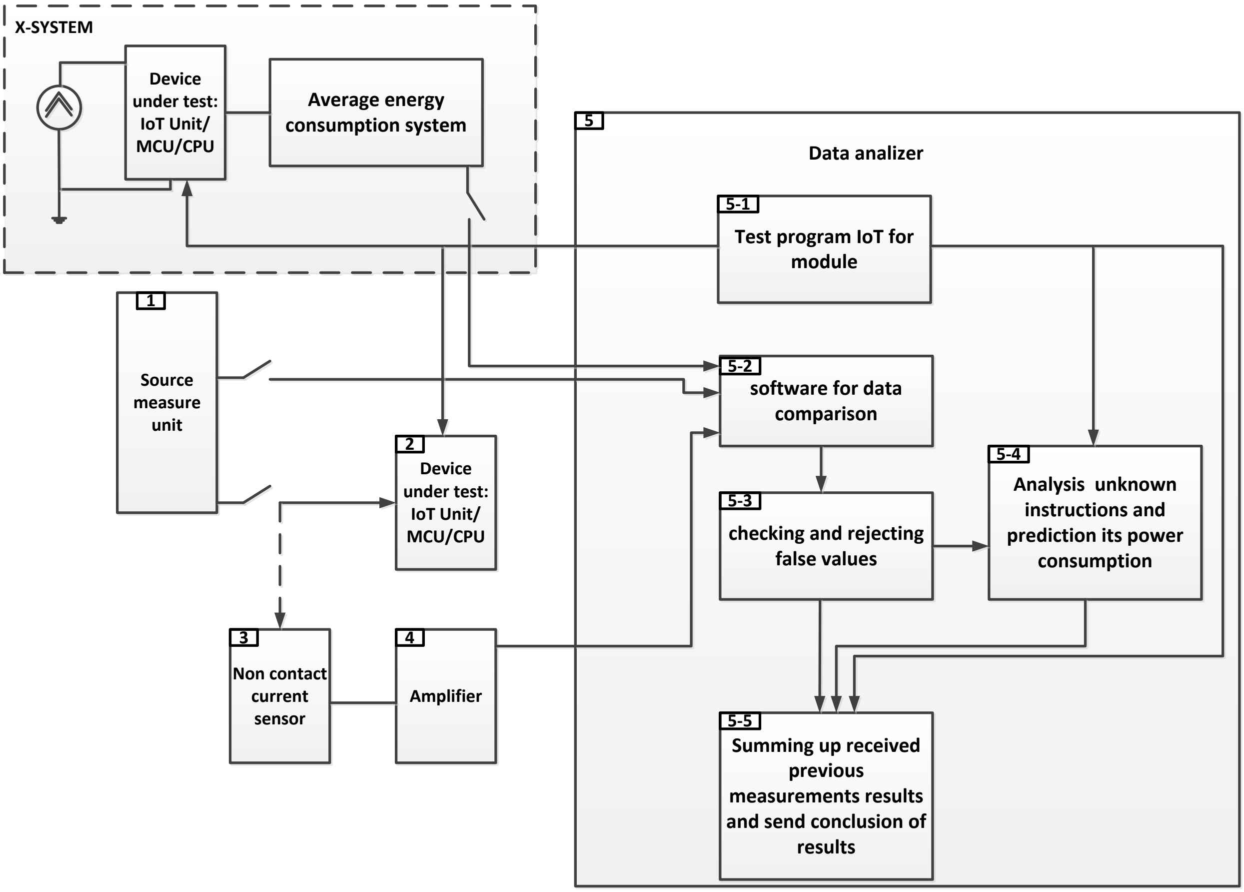

Fig. 1 Architecture of the intelligent system for measuring the energy consumption of IoT module

The system includes:

1. Source measure unit (SMU) – a specialized current source with the ability to measure its output voltage and current with sufficient accuracy and resolution;
2. Device under test (DUT) – a researched smart device or IoT module;
3. Current Sensor - Non contact current sensor - in this case, it is a non-contact device for current-current conversion
4. Amplifier - signal amplifier (current or current-voltage converter);
5. Data Analyzer – A set of software tools (software) for processing measurement results from unit 1 and 4

The Data Analyzer itself includes:

a) The system for downloading the executable code for the IoT module, that is, special software for MK where you can create code, compile it and download it for execution.
b) Software for obtaining, accumulating and comparing measurement results
c) A specialized program for censoring the received data from block 5.2 and rejecting false values in the measurement database
d) A software module based on deep learning ANNs for parallel analysis of the boot code for the IoT module and the energy consumption evaluation results of this code, if the data on the energy consumption of unknown instructions is included in the array of measurement results, then this software predicts the probable energy of executing the instructions or code fragment.
e) The software module summarizes the results about the total energy consumption of the executed code and displays detailed information about code improvements or critical blocks of code where there is the largest share of energy consumption.

The system can also include additional energy consumption analysis systems to improve the measurement results, for example, the MK average energy consumption measurement system (X-SYSTEM) [26] This is due to the fact that the system is divided into hardware and software parts, and blocks 5b) and 5d) above can take several vectors of the array for measuring data.

Thus, the essence of the idea is a universal inexpensive measuring tool (system), and additional elements can be added to increase the accuracy due to the tasks that are set before the developers of software and hardware of IoT modules.

Conclusions

When analyzing the methods and techniques for measuring the current consumption of MCU and IoT modules, or other MCU-based devices, it was found that this issue requires a more in-depth comprehensive approach to measurements. The conducted analysis showed the shortcomings of known techniques for measuring MCU current consumption. The task is relevant because there are many MCU-based devices on the market, especially smart devices or IoT devices, and a set of methods and tools is needed to evaluate their performance and the possible effectiveness of optimizing the executable code.

Thus, the basis of the concept of a measuring system for the analysis of current consumption of smart devices and IoT modules can be the methods proposed in [24-26] and the architecture developed above. At the same time, a more detailed study of them and provision of noise protection, in particular, due to non-contact measuring devices, is required.

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