Analysis of Single-Board Computers for IoT and IIoT Solutions in Embedded Control Systems

Pavlo Galkin, Lydmila Golovkina, Igor Klyuchnyk
Department of Engineering of Embedded Control System
Kharkiv National University of Radio Electronics
Kharkiv, Ukraine
pavlo.halkin@nure.ua, liudmyla.holovkina@nure.ua, ihor.kliuchnyk@nure.ua

Abstract — The article presents analysis of single-board computers for Internet of Things solutions. Analysis of single-board computers for Industrial Internet of Things solutions. Overview of the use of single-board computers in embedded control systems. Analyzed the possibility of application distribution by using ESP8266 and CC2530. As a result of the analysis, criteria were established by which it is possible to choose a single-board computer for Internet of Things or Industrial Internet of Things solutions. Single board computer model selection propose based on vector synthesis. The paper also discusses the design and use of these criteria when choosing single-board computers.

Keywords — Internet of Things; Industrial Internet of Things; single-board computer; ESP8266; CC2530

I. Introduction

Technically speaking, the Internet of Things (IoT) is the interconnection of uniquely identifiable devices to provide the remote monitoring or control services [1]. To solve such tasks it is possible to use single-board computers (SBCs). Modern home needs intelligent systems with minimum human effort. With the advent of digital and wireless technologies, automated security systems becomes more intelligent [2]. Such systems are implemented with using low cost, single board computers with embedded Linux like Raspberry Pi (RPI) [3]. Raspberry Pi has the ability to perform parallel tasks and data processing in soft and hard real-time mode [4]. For industrial applications it is important to the program runtime. Thus, the tasks of industrial management are divided into a soft and hard real-time. For example, in paper [5] model of industrial embedded computer is proposed based on the OMAP5 processor from Texas Instruments. SBCs can also be used for creation Smartlab [6] or design of intelligent automation equipment [7]. For advanced management and monitoring is possible to use the wireless sensor networks (WSN) [8-9], which have a good autonomous lifetime [10]. Lifetime IoT system approximately from 5 year to 10-20 years [11]. By popular SBCs models also include BeagleBone Black (BBB) [12]. In BBB available 65 GPIO pins, it's a little more than in RPI 3 [13]. For connection Industrial IoT (IIoT) application possible used ZigBee-gateway between wireless sensor network and industrial network [14]. A cheap expansion of the use of SBCs can be the construction of wireless networks based on CC2530 [21] or ESP8266.

II. Analysis of Single-Board Computers

A. *Analysis of single-board computers for IoT solutions*

IoT solution is simple instrument for developing applications capable to run on inexpensive embedded computers, available for everyone everywhere. The main thing that allows single-board computers to communicate with the outside world is the GPIO ports. These are ports that can be both inputs and outputs, allowing the device to interact at the "on-off" level like 0 or 3.3 volts.

One of the first single-board computers on the mobile ARM architecture, developed by the Raspberry Pi Foundation [2]. Produced in several trim levels, from the cheapest (Raspberry PI Zero) with a single-core processor and 256 Mb of RAM and up to the Raspberry Pi 3 (Fig. 1) with a 4-core Broadcom BCM2837 processor and 1Gb of RAM. The current version is the Raspberry Pi Model 3 B+, released for “International Pi Day” on 14 March 2018. Topline specs are 1.4GHz 64-bit quad-core processor, dual-band wireless LAN, Bluetooth 4.2/BLE, faster Ethernet, and Power-over-Ethernet support (with separate PoE HAT).

Fig. 1. Appearance of a single board computer of Raspberry Pi 3

The BeagleBone Black (BBB) [12] is a low-cost credit-card-sized development platform. The BeagleBone Black (Fig. 2) with AM3358 processor and possible connect by JTAG.

Banana Pi (Fig. 3) and Banana Pro it is a clones of Raspberry Pi with improved characteristics, developed by the company "Lemaker". Banana Pi (Banana Pi M1) is built on the hardware platform Allwinner A20 SoC.

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Fig. 2. Appearance of a single board computer of BeagleBone Black model

Fig. 3. Appearance of a single board computer of Banana Pi model

In December 2014, South Korean company HardKernel introduced its new platform ODROID-C1 (Fig. 4), which is close to Raspberry PI at a price, form factor and functional.

Fig. 4. Appearance of a single board computer of ODROID-C1 model

Characteristics of single-board computers we will reduce to the table 1.

As can be seen from Table 1, the greatest opportunity for periphery has BeagleBone Black. Single board computers Banana Pi, Raspberry Pi and ODROID-C1 have similar functionality. Thus, we can conclude that if the device will be used with a large number of inputs, outputs, then need to choose BeagleBone Black. In other cases, can select any of the analyzed platforms.

TABLE I. COMPARISON OF BOARDS BY H/W COMPONENTS

Characteristic	**Single-board**			
	BeagleBone Black	***RPI***	***ODROID - C1***	***Banana Pi***
UART	4	1	1	2
SPI	2	2	1	1
ADC	7	0	2	4
All available GPIO pins	65	26	25	23
PWM	8	2	2	1
eMMC	+	-	socket	-
Minimum available GPIO pins	19	9	13	10

B. Analysis of single-board computers for IIoT solutions

The Industrial Internet of Things (IIoT) is part of a larger concept Internet of Things (IoT). The application of the IoT for the industrial automation is called the IIoT and close to concept Industry 4.0. The IIoT is new step for industrial revolution.

The most common use of Raspberry Pi is to use it as a programmable logic controller. Starting with simple solutions, as shown in the figure 5.

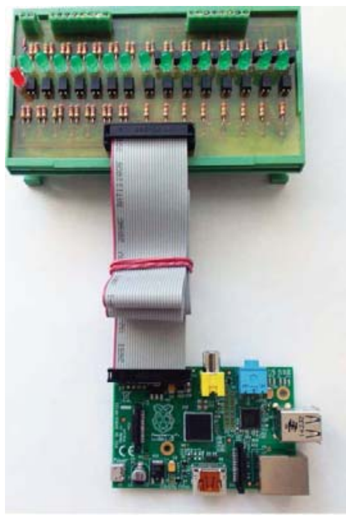

Fig. 5. Simple solution creation PLC using Raspberry PI

Or industrial design as the PiXtend V1.3. PiXtend V1.3 is a Raspbery Pi based universal programmable logical controller (PLC) platform. PiXtend multiplies the capabilities of the Raspberry Pi with numerous digital and analog inputs & outputs (Fig. 6). PiXtend V1.3 computer is already used in smart house systems too.

Fig. 6. PiXtend V1.3 industrial design for using Raspberry PI

Analyzing existing platforms for the creation of PLCs it was found that the Raspberry PI has the greatest popularity. At the same time, by the number of inputs, the output of the BBB is more promising.

III. SINGLE-BOARD COMPUTERS IN EMBEDDED CONTROL SYSTEMS

Embedded single board computers ready for deployment into industrial applications requiring long lasting and real time operation cycles [16].

Before the advent of the model the Raspberry PI, single-board computers were expensive as industrial solutions, such cards were much closed, and technical information about them is usually small. To systems of industrial automation high demands are made for accident-free operation, rapid recovery from failures, high performance with desirable low power consumption.

Industrial computer ModBerry 500 (Fig. 7) based on Raspberry Pi Compute Module is capable of performing the functions of a built-in computer, a multichannel telemetry module, a PLC, an industrial modem and a LTE / 3G / GPRS router, a protocol converter and interfaces, and a GPS satellite navigation module.

Fig. 7. ModBerry 500 based on Raspberry Pi Compute Module

Thus, we can conclude that single-board computers find application in embedded control systems.

IV. ANALYZED THE POSSIBILITY OF APPLICATION DISTRIBUTION BY USING ESP8266 AND CC2530

The practical application of the IoT also implies the use of a big number of devices. Such expansion is possible due to the use of wireless sensor networks base on CC2530 transivers (Fig. 8) or wi-fi network base on ESP8266 (Fig 9).

Fig. 8. CC2530 transiver

CC2530 transiver is Second Generation System-on-Chip for 2.4 GHz IEEE 802.15.4 [21]. The CC2530 combines RF transceiver with an industry-standard 8051 MCU. The CC2530 is designed to organize networks of the standard ZigBee Pro, as well as remote controls based on ZigBee RF4CE and equipment of the standard Smart Energy. All of the above allows to use this transceiver to organize Internet of Things solutions using a wireless sensor network.

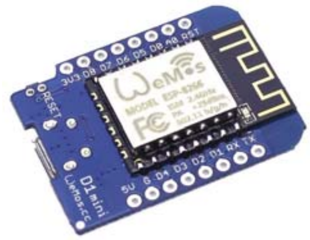

Fig. 9. ESP8266-12E

There are several ESP8266 boards available, usually numbered ESP-01 through ESP-12. The ESP-12 is popular because of its size and the number of pins brought to the side of the board. For connect ESP8266 to a single-board computer, it is possible to use of UART, SPI, I2C or network transmission.

V. IOT AND IIOT DEVICES DISTRIBUTED SYSTEM

Ensuring the interaction of devices from the same manufacturer is a challenge for designers and designers, since, despite the variety of physical interfaces, the user must feel the unity of the system. To design devices that will exchange data, should also consider which systems they will be used for. According to the response time, such systems should be divided into:

- hard real-time systems;
- soft real-time systems;
- non real time systems.

Response time depends on system reaction to event (Fig. 10). For IoT systems possible response in non real time and some delays in providing data, up to tens of seconds, are also acceptable. In IIoT-devices such delays are inadmissible: information is provided in real time with a maximum delay not exceeding tens of milliseconds.

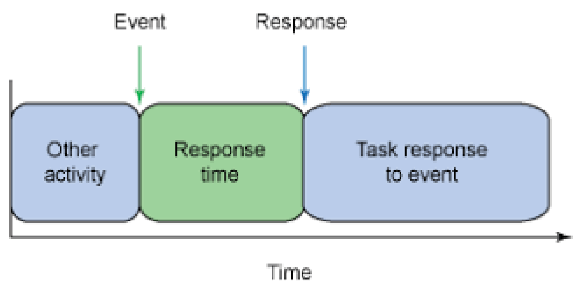

Fig. 10. System response to an event

The similarity of the terms IoT and IIoT does not mean a similarity in the concept of design and implementation. All considered single-board computers can run on the Linux operating system base. For IoT solutions is proposed uses tasks priority selector (Fig. 11). .

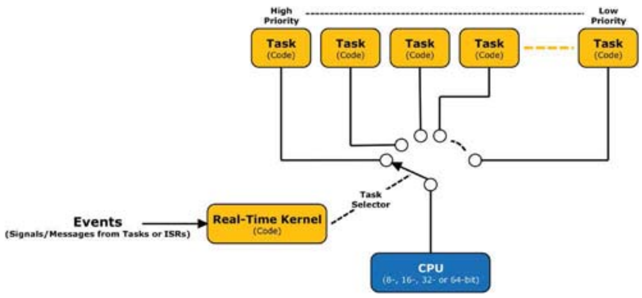

Fig. 11. Tasks priority selector

For IIoT solutions is proposed uses RTLinux [29] - microkernel that runs the entire Linux operating system as a fully preemptive process (Fig. 12).

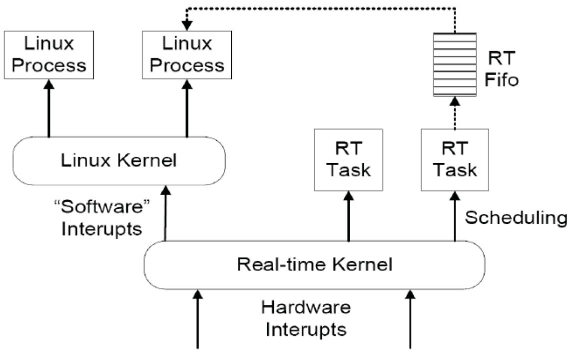

Fig. 12. IIoT solution base on RTLinux

Single board computer platforms for the IoT provide the exchange of data between end devices and cloud storage. IoT platforms support various types of communications, can be successfully used in manufacturing, industry, surveillance systems, automation applications.

VI. Designing Devices Based on Single Board Computer for IIoT

When designing devices with a high degree of fault tolerance, first of all, questions of the construction of a fitting system in general arise. In the design of devices as a rule, typical calculations are carried out:

- thermal calculation;
- electromagnetic calculation;
- vibratory calculation.

The thermal image of a single-board computer Raspberry Pi 3 is shown in (Fig. 13).

For usage ready-made Single-board computers electromagnetic and vibration components changing, it is quite difficult to influence, since such computers are already delivered in a bundled circuit board with installed components. Thermal problems can be solved by installing radiators. The most effective are the needle radiators (Fig.. 14).

Plate radiator, which comes with a single-board computer is less efficient (Fig. 15).

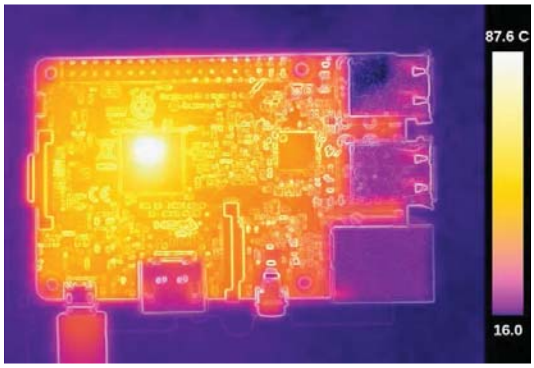

Fig. 13. Thermal image Raspberry Pi 3 Model B

Fig. 14. Needle radiator

Fig. 15. Plate radiators installed to Raspberry by default

Thus, the thermal indicators of the board can be one of the criteria for choosing a single-board computer to IoT or IIoT solutions.

VII. Single-Board Computer Selection Model

As a result of the analysis, criteria were established by which it is possible to choose a single-board computer for IoT or IIoT solutions. Single board computer model selection propose based on vector synthesis.

The task of vector synthesis with the best vector of quality indices is reduced to the search for a system S that satisfies the set of output data (conditions, constraints) and the quality indices of this vector with selected criteria of advantage. Quality indices have different dimensions, therefore the components of the vector are not the same values, but their normalized values. Comparison of systems on a quality vector is impossible without additional criteria of advantage. In this context, consider unconditional benchmarking criteria (Pareto criteria), conditional benchmarks and combinations of these approaches:

$$K_p = c_1 k_1 + \ldots + c_i k_i + \ldots + c_m k_m, \quad (1)$$

The expression shows c-weight indicator, k-normalized indicator value.

The weight of the indicator can be calculated based on the best indicator of this factor (Cmax):

$$C_m = \frac{1}{C_{\max}}, \quad (2)$$

The expression an average indicator of a number of relative indicators (k).

Normalize the values given in table 1 we obtain the normalized table 2.

TABLE II. NORMALIZED COMPARISON OF BOARDS BY H/W COMPONENTS

Characteristic	Single-board			
	BeagleBone Black	***RPI***	***ODROID - C1***	***Banana Pi***
UART	1	0.25	0.25	0.5
SPI	1	1	0.5	0.5
ADC	1	0.0	0.28	0.56
All available GPIO pins	1	0.39	0.37	0.34
PWM	1	0.25	0.25	0.12
eMMC	1	0	0	0
Minimum available GPIO pins	1	0.45	0.65	0.5

Using the data in Table 2, it is possible to plot a graph for beaglebone black (Fig. 16).

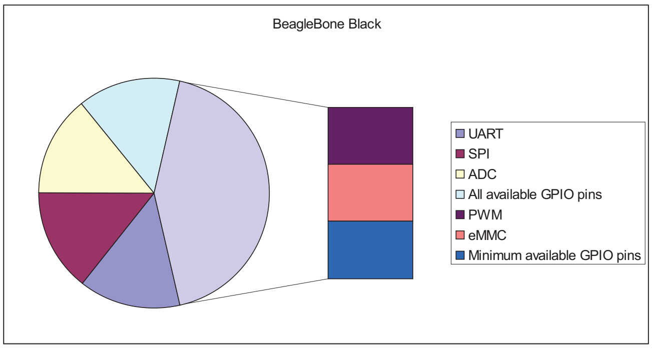

Fig. 16. The influence of hardware components on the choice of single-board computer

Using a similar approach, it is possible to construct the necessary objective function. Instead of numbers it is suggested to use a specific functionality or parameter:

$$K_{board} = c_{spi} k_{spi} + c_{gpio} k_{gpio} + c_{temp} k_{temp}, \quad (3)$$

In the expression of the parameter which is not important for the decision can be equal to zero.

VIII. FUTURE WORK

For further research, it is proposed to make thermograms of all reviewed single-board computers. The problem of the most optimal solution is proposed to be solved by increasing the number of coefficients. For prototyping industrial solutions it is proposed to make solutions based on industrially compatible logic.

IX. CONCLUSION

The work was carried out analysis of single-board computers for IoT and IIoT solutions. Analyzing existing platforms for the creation of PLCs it was found that the Raspberry PI has the greatest popularity. By the number of gpio the beaglebone black board is more promising. Single board computer model selection propose based on vector synthesis.

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