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Raspberry Pi as a Wireless Sensor Node: Performances and Constraints

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Abstract - The main building block of Wireless Sensor Network (WSN) is sensor node consisted of four basic elements: the sensor unit, processing unit, communication and power units. In this paper we propose the Raspberry Pi, cheap, flexible, fully customizable and programmable small computer board and abilities of its usage as WSN node and SensorWeb node. The Raspberry Pi brings the advantages of a PC to the domain of sensor network, what makes it the perfect platform for interfacing with wide variety of external peripherals. Comparative analysis of its key elements and performances with some of current existing wireless sensor nodes have shown that despite few disadvantages, the Raspberry Pi remains an inexpensive computer with its very successfully usage in sensor network domain and diverse range of research applications.

I. INTRODUCTION

A wireless sensor network (WSN) is composed of spatially distributed nodes equipped with sensing devices to monitor and to measure characteristics of the physical environment at different locations. WSNs are designed and deployed for different purposes by various organizations. WSN based monitoring applications range from simple data gathering, to complex Internet-based information systems. In other words, the observations obtained from sensor networks may be helpful in many software applications like environmental, industrial and meteorological monitoring, building and home automation, medicine, urban sensor networks, intelligent transportation, security, military defense, etc [1].

Sensor nodes, as building blocks of WSN, are consisted of four basic elements shown in Fig. 1: the sensor unit, processing unit, communication and power units.

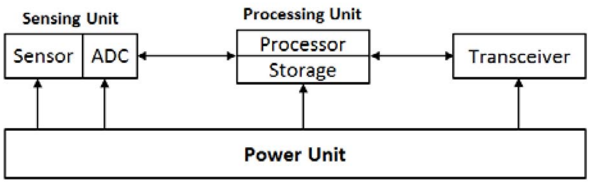

Figure 1. Typical sensor node architecture

Sensor nodes are the small, low power single board computers with a radio for wireless communication. Number and types of sensors depends on the applications. Sensor nodes collect and transfer data using four stages: collecting the data, processing the data, packaging the data and communicating the data [2].

Currently in the market there are many commercially available sensor node platforms. In this work emphasis will be on Raspberry Pi computer making a comparative study of its performances and constraints with current popular wireless sensor nodes presented in [2, 3]. The main goal of this research is to define and present advantages and disadvantages of Raspberry Pi and abilities of its usage as a sensor node.

The rest of this paper is organized as follows. The basic information about Raspberry Pi and literature review of its usage in sensor networks are presented in Section 2. Raspberry Pi's performances, constraints and abilities of its usage as a wireless sensor node and SensorWeb node are shown in Section 3. Finally, Section 4 provides conclusion remarks and outlines directions for future work.

II. WHAT IS RASPBERRY PI ?

Raspberry Pi is a small, powerful, cheap, hackable and education-oriented computer board introduced in 2012 (Fig. 2). This credit card-sized computer with many performances and affordable for 25-35$ is perfect platform for interfacing with many devices.

Figure 2. Raspberry Pi

The Raspberry Pi board contains a processor and graphics chip, program memory (RAM) and various interfaces and connectors for external devices (Fig. 2). Some of these devices are essential, others are optional but all Raspberry Pi models have the same CPU named BCM2835 which is cheap, powerful, and it does not consume a lot of power [4]. Raspberry Pi operates in the same way as a standard PC, requiring a keyboard for command entry, a display unit and a power supply. SD

Flash memory card normally used in digital cameras is configured in such a way to 'look like' a hard drive to Raspberry Pi's processor. The unit is powered via the micro USB connector. Internet connectivity may be via an Ethernet/LAN cable or via an USB dongle (WiFi connectivity) [5, 6].

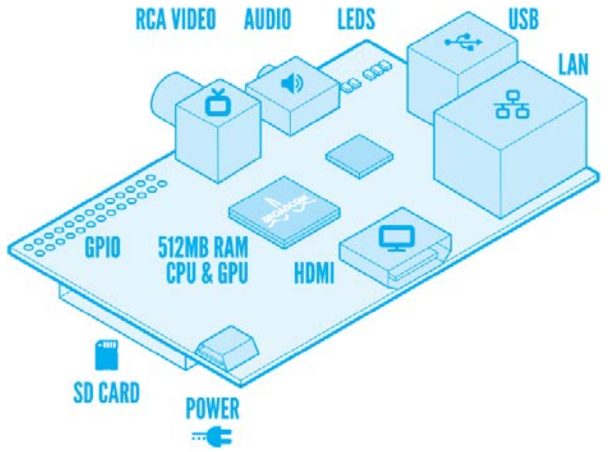

Figure 3. Raspberry Pi components [13]

Like any other computer, the Raspberry Pi also uses an operating system and the "stock" OS is a flavor of Linux called Raspbian. Linux, as a free and open source program, is a great match for Raspberry Pi. On one hand, it keeps the price of the platform low, and on the other, it makes it more hackable. There are also a few non-Linux OS options available [5]. The additional hardware and software requirements can be achieved by already existing hardware modules and open source software.

One of the great things about the Raspberry Pi is that it has a wide range of usage. Numerous recipes of Raspberry Pi usage with sensors, displays and motors is given in [7]. In the workshop [8] a Raspberry Pi is used to read sensors (inputs), store their vales in a database for historical trending and turn relays (outputs) on and off when a sensor value goes outside of a certain range. In other words, a system that turn on a light if the door is open or motion is detected in an area is built. In [9] is stated that wireless sensors and a Raspberry Pi open up a world of possibilities. Author of [10] also state that sensor networks are just one example of how these small, powerful, and inexpensive components can be used. On the example of XBee–ZigBee Mesh network author shows how to with a moderate skill build own sensor network. The possibility to use Raspberry Pi board as a ZigBee home automation server, which can be set up to support a range of tasks, including remote controlled air conditioning and lighting, and checking whether doors are open or closed is presented in [11]. Works [7, 12-16] propose combining the Raspberry Pi with the power of the open source Arduino platform, and present numerous home automation and sensor networks projects.

The performances and constraints of Raspberry Pi will be described in rest of the paper.

III. The Raspberry Pi's Performances and Constraints

The Raspberry Pi performances will be compared with following wireless sensor nodes [2, 3]:

- MicaZ – is based on the Atmel ATmega128L which is a low-power microcontroller and runs MoteWorks from its internal flash memory. The MICAz (MPR2400) IEEE 802.15.4 radio offers both high speed (250 kbps) and hardware security (AES-128).
- TelosB - bundles all the essentials for lab studies into a single platform including: USB programming capability, an IEEE 802.15.4 radio with integrated antenna, a low-power MCU with extended memory and an optional sensor suite. This platform delivers low power consumption allowing for long battery life as well as fast wakeup from sleep state.
- Iris – is used for enabling low power WSN. Iris provides users a wide variety of custom sensing applications providing up to three times improved radio range and twice the program memory over previous generations of MICA Motes.
- Cricket - is a location aware version of the popular MICA2 low-power Processor/Radio module. The Cricket Mote includes all of the standard MICA2 hardware and an ultrasound transmitter and receiver.
- Lotus - is based on the NXP LPC1758, 32-bit ARM Cortex-M3 based microcontroller. A single processor board can be configured to run sensor application/processing and the network/radio communications stack simultaneously. Lotus, as all previously mentioned sensor node platforms, has the data rate of 250 kb/s.

A. Size & Cost

The physical size and cost of each individual sensor node has a significant and direct impact on the ease and cost of deployment. Physical size impacts the ease of network deployment because smaller nodes can be placed in more locations and used in more scenarios. One of the main goals of every network is to collect data from as many locations as possible without exceeding fixed budget. A reduction in per-node cost will result in the ability to purchase more nodes, to deploy a collection network with higher density, and to collect more data [17]. The comparison of size, weight and cost of basic models of Raspberry Pi and above mentioned wireless sensor nodes is given in Table I (the smaller values are better).

TABLE I. The Comparison of Size, Weight and Cost

Name	**Size (mm)**	**Weight (g)**	**Cost per node US$**
Raspberry Pi	85.6*53.98*17	45	**25-35**
MicaZ	**58*32*7**	**18**	99
TelosB	65*31*6	23	99
Iris	**58*32*7**	**18**	115
Cricket	**58*32*7**	**18**	225
Lotus	76*34*7	**18**	300

The values presented in Table I show that Raspberry Pi's advantage against other systems lies in its smallest per unit price.

B. *Power and Memory*

To meet the multiyear application requirements individual sensor nodes must be incredibly low-power. The average power consumption of WSN nodes should be measured in micro amps. Ultra-low-power operation can only be achieved by combining both low-power hardware components and low duty-cycle operation techniques. Also, algorithms and protocols must be developed to reduce radio activity whenever possible. This can be achieved by using localized computation to reduce the streams of data being generated by sensors and through application specific protocols. One of the solutions is to combine together events from multiple sensor nodes by a local group of nodes and then transmit a single result across the sensor network [17].

The CPU is the main component of the Raspberry Pi, responsible for carrying out the instructions of a computer program via mathematical and logical operations. The processor of Raspberry Pi is a 32 bit, 700 MHz System on a Chip (SoC), which is built on the ARM11 architecture and can be overclocked for more power. ARM chips come in a variety of architectures with different cores configured to provide different capabilities at different price points. This means that the vast majority of the system's components – its central and graphics processing units, audio and communications hardware along with 256 – 512 MB memory chip, are built onto single component. The ARM-based BCM2835 is the reason why the Raspberry Pi is able to operate on just the 5V 1A power supply provided by the onboard micro USB port. The Raspberry Pi for operating requires up to 700mA [18]. The unit of Raspberry Pi can be powered using a range of power sources (assuming they are able to provide enough current ~700mA) like [6]:

- Computer USB Port or powered USB hub (will depend on power output),
- Special wall warts with USB ports,
- Mobile Phone Backup Battery (will depend on power output),
- Alkaline batteries (six rechargeable AA batteries and a voltage regulator [7] or high capacity rechargeable batteries depending of Raspberry Pi power needs),
- Solar cells system (for outdoor usage).

The Raspberry Pi has four distinct power modes [19]:

- The run mode - the CPU and all functionality of the ARM11 core are available and powered up.
- The standby mode - the main core clocks are shut down (the parts of the CPU that process instructions are no longer running) although the power circuits on the core are still active. In this mode the core can be quickly woken up by a process generating a special call to the CPU called an interrupt. This interrupt will stop any current processing and do what the calling process has asked for. This mode is known as Wait for Interrupt, or WFI.
- The shutdown mode - there is no power.
- The dormant mode - the core is powered down and all caches are left powered on.

The two approaches of powering Raspberry Pi with batteries are discussed in [7]. The both approaches use the small capacity batteries which power Raspberry Pi model B and ensure Raspberry Pi working time of approximately 2 hours (depends of attached peripherals). Depending on power modes and active modules, power consumption can vary from 700 mA to 1 A. The Raspberry Pi's biggest limitation regarding the power supply is that no external device should draw more than 100 mA from any of its USB ports [4].

It is important to note there's no hard drive on the Raspberry Pi; everything is stored on a Secure Digital (SD) Card. Although large SD cards holding 32 GB, 64 GB or more are available, they are often prohibitively expensive, but the minimum required size of SD card is 2 GB depending on the distribution demands of the operating system. If possible, it is necessary to use the SD card class 10. This storage can be expanded by using devices that provide an additional hard drive upon using the USB ports. Known as USB Mass Storage (UMS) devices, these can be physical hard drives, solid-state drives (SSDs) or even portable pocket-sized flash drives [18] (Table II).

TABLE II. THE COMPARISON OF CPU AND MEMORY *

Name	Processor	RAM	External memory
Raspberry Pi	ARM BCM2835	**256-512 M**	**2-64 G**
MicaZ	ATMEGA128	4 K	128 K
TelosB	TI MSP430	10 K	48 K
Iris	ATMEGA1281	8 K	128 K
Cricket	ATMEL128L	4 K	512 K
Lotus	ARM NXP LPC1758	64 K	512 K

*(The higher value is better)

It is also important to note that the Raspberry Pi Model A has 256MB of RAM while the Model B has 512MB. Compared to other considered systems Raspberry Pi has the largest amount of memory (Table II) what generally leads to improved overall systems' performances.

C. *Flexibility*

For a wide range of usage scenarios WSN architecture must be flexible and adaptive. Each application scenario demands a slightly different mix of lifetime, sample rate, response time and in-network processing. Additionally, for cost reasons each device will have only the hardware and software it actually needs for considered application. The architecture must make it easy to assemble just the right set of software and hardware components. Thus, these devices require an unusual degree of hardware and software modularity while simultaneously maintaining efficiency [17].

One of the great things about the Raspberry Pi is that it is very flexible and there's no single way to use it. For example, it can be used for: general purpose computing, learning to program or integrate it with electronics projects [5]. The following core components enable the wide range of its usage [20]:

- Two USB 2.0 ports allows connecting peripherals and storage devices while one micro USB serve for powering device.
- The 3.5mm analog audio jack allows connecting headphones and speakers to the Raspberry Pi what is especially useful for audio and media player based projects.
- Composite RCA port for attaching the yellow video cable from TV allows using TV as a monitor.
- The High Definition Multi-media Interface (HDMI) port allows the Raspberry Pi to be hooked up to high-definition televisions and monitors that support the technology. It is also used for streaming video and audio from the web to TV.
- Support for DSI (Display Serial Interface) - Raspberry Pi can be expanded with display.
- Support for CSI (Camera Serial Interface) - Raspberry Pi can be expanded using camera.
- The GPIO (general purpose input and output) pins on the Raspberry Pi are the main way of connecting with other electronic boards. It consists of 26 pins arranged in two rows containing 13 pins each. The left row contains the even-numbered pins, and the right row contains the odd-numbered pins (Fig. 4). The GPIO pins on the Raspberry Pi are the main way of connecting with other electronic boards. In other words, the GPIO pins can accept input and output commands and thus can be programmed on the Raspberry Pi. It is important to note that there is a certain difference between GPIO pins schedule among model A and model B of the Raspberry Pi. GPIO pins can be accessed for controlling hardware such as LEDs, motors, and relays, which are all examples of outputs. As for inputs, Raspberry Pi can read the status of buttons, switches, and dials, or it can read sensors like temperature, light, motion, or proximity sensors (among many others) [4]. Some of GPIO pins can be used as digital inputs/outputs and as interfaces for embedded protocols. Two most important protocols based on their widespread are:
    - I^2C – low-speed interface – Inter-Integrated Circuit (I^2C) is a serial bus interface which supports multiple devices and only requires two wires for communication. It's work on relatively low speeds [21].
    - SPI – Serial Peripheral Interface Bus (SPI) is a synchronous full-duplex (two way) serial connection [22].
- Extended GPIO – in addition to standard GPIO port, Raspberry Pi Model B Rev 2 has an expanded set of connectors. It is important to mention P5 header which is made up of 8 pins (+3.3 V, +5 V, two ground pins and four GPIO pins that can provide the second I^2C protocol) and P6 header with two pins – their short circuiting provides soft reset of BCM2835.

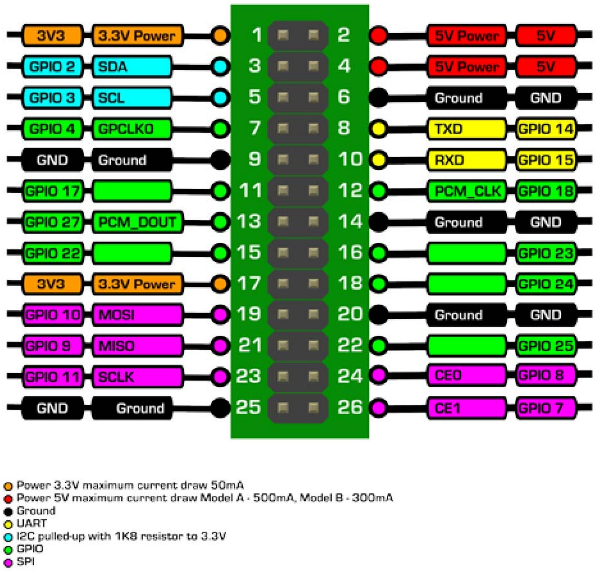

Figure 4. Raspberry Pi Model B Rev2 – GPIO connectors [20]

Analysis of the Raspberry Pi has shown that it, as above mentioned wireless sensor nodes, has expansion connector which supports Analog Inputs, Digital I/O, I^2C, SPI and UART what make easy their connection to a wide variety of external peripherals.

D. Communication

A key evaluation metric for any WSN is its communication rate, power consumption, and range. In order to create an interconnected network, nodes can not be placed too far apart. Most application scenarios according to desired sensing have natural node densities. If the radio communications range demands a higher node density, additional nodes must be added to the system in to increase node density to a tolerable level. The communication rate also has a significant impact on node performance. Higher communication rates mean less transmissions time and lower network power consumption. However, an increase in radio bit rate is often accompanied by an increase in radio power consumption. All things being equal, a higher transmission bit rate will result in higher system performance. But an increase in the communication bit rate has a significant impact on the power consumption and computational requirement of the node [17].

The Ethernet port is the Raspberry Pi's main gateway for communication with other devices and the Internet. The model B has a standard RJ45 Ethernet port while model A doesn't, but can be connected to a wired network by an USB Ethernet adapter. The Raspberry Pi's Ethernet port is auto-sensing which means that it may be connected to a router or directly to another computer (without the need for a crossover cable) [5, 6]. USB Ethernet adapter has two-speed mode, 10 Mb/s and 100 Mb/s. With a cable connected, the Raspberry Pi will automatically receive the details it needs to access the Internet when it loads its operating system through the

Dynamic Host Configuration Protocol (DHCP). This assigns the Raspberry Pi an Internet Protocol (IP) address on network, and tells it the gateway it needs to use to access the Internet (typically the IP address of router or modem). Internet connectivity of Raspberry Pi besides an Ethernet/LAN cable (standard RJ45 connector) may be via an USB WiFi adapter. Using such a device, the Raspberry Pi can be used for creating ad-hoc networks or to connect to a wide range of wireless networks, including those running on the latest 802.11n high speed standard [18].

Raspberry Pi can serve as static websites, but it can also generate dynamic content using databases and web applications. In addition, it can even provide access to its GPIO ports via web technologies. Also, Raspberry Pi can be used as SensorWeb node by connecting it to a network so it can be accessed from other computers. On the other side, the administration of Raspberry Pi can be done over Secure Shell (SSH), a network protocol for secure data communication [4].

E. Operating systems

Sensor nodes run embedded software that samples the physical environment, load data, aggregates and communicate with higher level (peers or gateways). Regardless of the hierarchical approach each sensor node still needs a program, and the most common approaches to programming each sensor node, is to either program it using some form of operating system or to choose a higher level of abstraction. The operating systems vary from traditional operating systems in terms of goals and technique and each system differs substantially in the approach to memory protection, dynamic reprogramming, thread model, real-time features, etc. [17].

Like every computer, the Raspberry Pi needs an operating system, and the preferred one for the Raspberry Pi is Linux distribution. That's partly because it's free, but mainly it's because it runs on the Raspberry Pi's ARM processor [4]. There are several distribution of Linux ported to the Raspberry Pi's BCM2835 chip, including Debian, Fedora Remix and Arch Linux [19]. The Raspberry Pi uses an operating system called Raspbian (Table III) based on Linux but there are also a few non-Linux OS options available.

TABLE III. THE COMPARASION OF USED OPERATING SYSTEMS

Name	Operating system
Raspberry Pi	RASPBIAN
MicaZ	TINY OS,MOTE RUNNER
TelosB	TINY OS,SOS,MANTISOS
Iris	TINY OS,MOTE RUNNER
Cricket	TINY OS
Lotus	RTOS,TINY OS

There are several reasons for deciding to go with the Raspbian operating system [19]:

- Raspbian has a desktop environment similar to Windows and Mac called Lightweight X11 Desktop Environment (LXDE), so it provides an easy transition for those not familiar with Linux command line.
- It comes pre-installed with software useful for writing codes.
- The operating system has been tailored to run on the Raspberry Pi. The code compilation is optimized for on-chip floating-point calculations (hard-float) rather than a slower software-based method.
- There is wide spread community support for the operating system.

F. Advantages

After analysis above performed, general conclusions about the Raspberry Pi advantages can be stated.

- First of all, it is important to mention that Raspberry Pi is a small independent computer that runs on the Linux operating system and can be programmed as needed.
- It has a very large working memory (many other sensor nodes do not have).
- It has expandable memory to store the data.
- It works on processor which supports a large set of instructions.
- It operates at speeds from 700 MHz to 1000 MHz.
- It has support for USB 2.0 which allows its expansion with a large number of peripherals.
- Depending of the needs it is possible to expand the Raspberry Pi with WiFi and Bluetooth adapters (power and range can be changed by changing the adapter).
- Expansion and communication with network devices over a LAN adapter are possible.
- It is possible to form an expandable system with various electronic components (sensors and electronic circuits) using digital inputs and outputs, I^2C or SPI protocols (most of today's devices use one of these methods of communication).

G. Disadvantages

Based on the above mentioned it can be noted that for small amount of money the Raspberry Pi comes with a lot of nice things, but it also lacks some useful features. The main disadvantages of Raspberry Pi are [4]:

- It does not have a real-time clock (RTC) with a backup battery. The fact of missing clock can be workarounded using a network time server, and most operating systems do this automatically.
- The Raspberry Pi always boots from an SD card. It means that even a perfectly valid installation of an operating system is available on a USB stick or an external hard drive, it can't be booted. In other words, external storage devices can be used but can't be used to boot the Raspberry Pi.
- It does not support Bluetooth or WiFi out of the box but these supports can be added by USB dongles.

- Unfortunately, most Linux distributions are still a bit picky about their hardware, so it should be first checked whether flavor of Linux supports particular device.
- It doesn't have built-in an Analog to Digital converter. External component must be used for AD conversion.
- Its power consumption varies depending on how busy Raspberry Pi is and what peripherals are connected. Typically, the model B uses between 700-1000 mA depending on what peripherals are connected, and the model A can use as little as 500 mA with no peripherals attached. Thus, it is necessary to provide a power supply that can provide enough current to power the device plus any connected peripherals.

IV. Conclusion

Based on the comparison of Raspberry Pi's key elements and performances with presented current existing wireless sensor nodes it is possible to summarize Raspberry Pi's pros and cons against to other systems:

- pros: processing power, memory, connectivity, multipurpose usage (USB), Linux,
- cons: power consumption.

The analysis above performed has shown that beside the power consumption issue, Raspberry Pi is ultra-cheap-yet-serviceable computer board. With support for a large number of input and output peripherals, and network communication it makes the perfect platform for interfacing with many different devices and using in wide range of applications. By coupling it with WiFi it can communicate remotely what the Raspberry Pi makes very suitable for the construction of wireless sensor nodes and SensorWeb nodes. Moreover, Raspberry Pi can be used as processing node in WSN networks, not just as sensor node but also as controller. In addition, data processing and decision making can be based on artificial intelligence.

Further, The Linux operating system usage provides additional advantages of using Raspberry Pi as a SensorWeb node. Programming in high-level languages such as C, C++, Python, or Java, solution implementation is quite simple and it is enabled to a large number of users, opposed to micro controller programming which usually depends of development kit.

By installing the Web Server on the unit and providing access to the Internet, Raspberry Pi becomes complete and ideal system (hardware and software) for building SensorWeb nodes. One of the possible Raspberry Pi usage scenarios, which is already implemented, is creation of hardware device that has implemented sensor units and communicate with Raspberry Pi via peripheral devices or via GPIO (I^2C) interface. The developed Raspberry Pi prototype SensorWeb node is based on RESTful services and created in order to build the infrastructure that supports fast critical event signaling and remote access to sensor data via the Internet (the detection of critical events is performed using fuzzy logic). The final evaluation of this prototype and Raspberry Pi usage as wireless sensor node and SensorWeb is planned to be performed by its implementing in home automation and Internet of things projects what are directions of our future work.

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