An Integrated Low Cost IoT Node based on Discrete Components for Customized Smart Applications; Use case on Precision Agriculture

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***Abstract*— This work depicts the concept and methodology as well as the architecture and physical implementation of a low-cost Internet of Things (IoT) node for customized smart-applications. The presented node efficiently integrates state-of-the-art discrete electronic components able to support a variety of smart applications. The node comprises an ARM CortexM based microcontroller designed for low power wireless applications, a power management unit and several sensors for which special adapters have been implemented. The proposed IoT node is being validated in vineyard fields, in the framework of precision agriculture practice, with the aim of collecting critical environmental parameters, to be used as input to algorithmic models for the detection and subsequently prevention of related agricultural diseases.**

Keywords*— *internet of things, disrete electronic components, Customized Smart Applications

I. Introduction

The Internet started as a global network with services but through its revolution over time has become an unprecedented ecosystem with interconnected objects / devices characterized by advanced sensing and actuating capabilities, distributed processing power and storage capacity whilst their size is getting smaller and smaller. All these technology advances are expanding the Internet's boundaries as well as changing the nature and the opportunities offered by the devices. This network of interconnected devices not only collects information from the environment and interacts with the physical world, but it also uses existing Internet standards to provide diverse services regarding information and communication. The use of intelligently connected devices and systems to leverage data gathered by embedded sensors and actuators define the "Internet of Things" (IoT). For the consumers, IoT has the potential to deliver solutions that dramatically improve energy consumption, security, health, ageing and many other aspects of daily life while for the enterprises IoT can support solutions that improve decision-making and productivity in manufacturing, in retail, in agriculture and other sectors.

In this work, we introduce a low-cost Internet of Things (IoT) node ideal for smart-application domains, i.e, smart cities, smart hospitals, smart agriculture, etc. The presented node is built around a state-of-the-art microcontroller which is based on a low power Cortex™ M3 processor from ARM®, a high-performance RF and mixed-signal system, a high speed 12-bit ADC, nonvolatile Flash/EE memory and SRAM. A power supply system based on an integrated boost regulator that converts dc power from a PV cell charges a Lithium-ion storage element for unceasing operation. Moreover, the proposed node provides I2C, SPI and UART connectors for connecting various sensors and Serial Wire Debug (SWD) for system debugging or firmware download. Furthermore, the operation of the proposed IoT node is demonstrated in the precision agriculture by aggregating customized environmental data aiming to feed algorithmic models for the detection as well as the prevention of vineyard fields diseases.

The rest of the paper is organized as follows. Section II briefly describes the background regarding open IoT platforms / protocols and related work about their utilization. Section III depicts our approach and decomposes our proposed system in its components while Section IV reveals a demonstration of the proposed system. Section V summarizes the progress made so far along with the future steps to follow.

II. Related Work and Similar Products

A. Open Hardware Platforms

The open source initiative is capable of supporting the free use of open source-licenses. It is through this open source movement that the popularity of open-hardware has been triggered and consequently made available with different options for open-hardware microcontrollers-based platforms. The question of which platform would be ideal to use, depends on the requirements of the system. These requirements comprise power consumption, cost and type of connectivity among others. A description of some of the most notable open-hardware platforms and their features follows:

- Arduino Genuino 101: The module contains two tiny cores, an x86 (Quark) and a 32-bit ARC architecture core, both clocked at 32MHz. The Intel toolchain compiles Arduino sketches optimally across both cores to accomplish the most demanding tasks. The Real-Time Operating Systems (RTOS) and framework developed by Intel is open sourced. The 101 comes with 14 digital I/O pins (of which 4 can be used as PWM outputs), 6 analog inputs, a USB connector for serial communication and sketch upload, a power jack,

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an ICSP header with SPI signals and I2C dedicated pins. The board operating voltage and I/O is 3.3V but all pins are protected against 5V overvoltage. Finally, the 101 can be programmed with the Arduino Software (IDE) and the board is preprogrammed with the RTOS, which handles USB connection and allows to upload new code without using an external hardware programmer [1].

- LinkIt ONE: The hardware core for LinkIt ONE development platform is MediaTek MT2502A and its processor core is 32-bit ARM7EJ-S, clocked at 260 MHz. The MediaTek MT2502 is a feature-rich and extremely powerful single-chip solution for high-end GSM/GPRS (2G) capabilities. Furthermore, it comes with pin-out similar to Arduino UNO, including digital and analog I/O, PWM, I2C, SPI and UART. It also features a highly integrated Bluetooth transceiver which is fully compliant with Bluetooth specification v4.0. This chipset also works with Wi-Fi (MT5931) and GNSS (MT3332) chips, offering high performance and low power consumption for Wearable and IoT devices [2].
- ESP8266EX: The ESP8266EX microcontroller integrates a Tensilica L106 32-bit RISC processor, which achieves extra-low power consumption and reaches a maximum clock speed of 160 MHz. The Real-Time Operating System (RTOS) and Wi-Fi stack allow about 80% of the processing power to be available for user application programming and development. ESP8266EX achieves low power consumption with a combination of several proprietary technologies. The power-saving architecture features three modes of operation: active mode, sleep mode and deep sleep mode. This allows battery-powered designs to run longer [3].
- Seeed Studio BeagleBone Green: BeagleBone Green is a low-power single-board computer with an AM3358 ARM Cortex-A8 processor running at 1 GHz and 512 MB of DDR3 RAM. It features also a 3D graphics accelerator, a NEON floating-point accelerator and 2 PRU 32-bit microcontrollers and GPIO comes with 65 digital and 7 analog I/O. As it concerns connectivity, it includes an USB client for power and communications, an USB host, Ethernet, 2-46 pin headers and I3C and UART as Grove connectors. BeagleBone has also a power-saving mode, in a sense that it provides the ability to let processor put board into a sleep mode to save power. Unlike RTOS, BeagleBone Green run on Linux and Android, that is necessary for applications of higher end IoT nodes [4].

B. IoT Protocols

The IoT system can function and transfer information only when the devices are safely connected wired or wireless to a communication network. This connection is established by choosing the appropriate type IoT protocol based on our system's specific requirements, like the bandwidth and power consumption [5]. The two major M2M (Machine to Machine)/IoT protocols are defined below:

- Constraint Application Protocol (CoAP) is a specialized web transfer protocol created for use within constrained nodes, like low power sensors and actuators, and constrained networks in IoT. It enables those nodes to communicate with other constrained nodes over the Internet. More specifically, the CoAP runs on devices that support UDP protocol, in which client and server communicate through connectionless datagrams. Due to its compatibility with the HTTP, its strongest potential use would be among other protocols. Finally, in a similar way of the HTTP, the CoAP has the ability to carry different types of payloads and to integrate any data format of the user's choice [6].
- Message Queuing Telemetry Transport (MQTT) is one of the most commonly used protocols in the IoT projects and like other internet protocols, it is based on the clients and a server. Contrary to others, the MQTT makes it easier to implement a software, transmit data at quicker pace, but it also minimizes the data packets and consumes less energy. This protocol functions on top of the TCP/IP and it includes a subscriber, a publisher and a broker. The publisher collects the data and sends it to subscribers. Consequently, the broker tests publishers and subscribers, check their authorization. It's through the real time interaction between the devices on a wide area network that makes the MQTT an ideal protocol for IoT applications [7].

Both the MQTT and the CoAP are designed as a long-term vision that will enable them to get used in a lightweight environment. Both work well with low power and network constrained devices. Thus, the choice depends on the application use case. If an M2M network needs to be created and the messages would need to be sent from one node to other multiple interested nodes, then the best choice would be to use an MQTT protocol. If on the other hand, an M2M network has to be created, in which commands need to be circulated among nodes, then the CoAP will be most appropriate choice.

Our proposed IoT node is a microcontroller-based device (MCU) following a modular lean design, both at the hardware components level and at the behavioral level. In this way it is intended to achieve, within a limited budget, a transversal robust structure able to satisfy as many as possible aggregation and transfer requirements thus practically accommodating many smart application use cases. Based on our system's specific requirements, such as bandwidth and power consumption, MQTT protocol is adopted.

III. IoT Node Architecture

Our proposed IoT node architecture proposal follows a modular design both at hardware level (physical constituent modules) as well as the behavioral level (operational conceptual modules). This section is divided into three subsections. The first subsection presents how the IoT node is implemented at the hardware level, the second subsection reveals the firmware configuration and how the IoT node operates at the software level, while the third subsection details the system performance and the energy consumption aspects.

A. Physical Constituent Modules

At the hardware level, the physical constituents are grouped in three different function blocks as described below:

- Microcontroller and Radio Function Block

The proposed node is utilizing Analog Devices ADuCRF101 microcontroller. The ADuCRF101 is a fully integrated single chip data acquisition solution designed for low power wireless

applications. It features a 12-bit ADC, a low power Cortex™ M3 processor from ARM®, a 431 MHz to 464 MHz and 862 MHz to 928 MHz RF transceiver (ADF702x radio on chip), and 128KBFlash/EE memory packaged in a 9 mm × 9 mm LFCSP.

- Power Supply Function Block

The power supply system is built around Analog Devices ADP5090 chip. The ADP5090 is an integrated boost regulator that converts DC power from PV cells or TEGs. The device charges storage elements such as rechargeable Li-Ion batteries, thin-film batteries, super capacitors, and conventional capacitors, and powers up small electronic devices and battery-free systems. The ADP5090 provides efficient conversion of the harvested limited power from 16 µW to 200 mW. A 4x4cm 2V solar panel has been used with 60mA peak output. The photovoltaic panel charges a 3,7V - 650mAh Li-ion battery. The output from the solar panel and the battery drives a ADP190 (linear voltage regulator) which finally provides a 3.3V stable output.

- Input / Output Function Block

The node provides connectors for various sensors, such as I2C interface, SPI, UART, Interrupt pins, A / D interface and SWD for system debugging or firmware download.

- Sensors and corresponding adapters

Through the use of the appropriate interface a wide range of sensors can be connected to the IoT node. Currently, there is an extensive list of sensors for which the corresponding adapters have already been implemented as shown in Table 1. More adapters for additional sensors are envisaged to be developed eventually.

Table 1List of Integrated Sensors

Sensor	Scope	Interface	Product
12-Bit Digital Temp. (±2°C accuracy)	Node's Battery Temp.	I2C	ADT75
Humidity & Temp.	Ambient H&T	I2C	SHT21
Humidity & Temp. & Pressure	Ambient H&T&P	I2C	BME280
Rain Collector	Rain amount	Interrupt	Davis6463
Wetness	Leaf Dew & Precipitation	A/D	Davis6420
Moisture	Soil Moisture	A/D	Davis6440

B. Operational Conceptual Modules

Analog Devices offers the RapidNet IP and the AD6LoWPAN stack. The RapidNet IP is a star or ex-star topology self-healing wireless communication protocol stack focused on providing a high level of scalability, extreme ease of use, and small code footprint. The AD6LoWPAN is an alternative mesh topology Analog Device's 6LoWPAN solution. Even though both stacks easily could be placed on our node, a more simplistic and very stable stack was built with the aim of minimizing energy consumption. In a typical configuration there are many broadcast node stations (end nodes) and a single center node station. The topology of the network is star or extended star since a node could be used as a repeater. No mesh logic is used. The end node is in a hibernate state. Every 10 minutes wakes up, collects the measurements from the sensors and emits them at a pre-agreed speed and frequency channel without storing them locally. Each end node has a unique 16bit ID. The end node does not expect any acknowledgement from the receiving node (center node) assuming that the measurements have reached the destination. The end node, with no hardware changes, is also used as a center node but with the appropriate firmware installed. The center node is continuously in reception mode at the pre-agreed speed and frequency channel. When the center node receives a packet of measurements with the correct CRC it forwards it directly to its serial port which is connected either with a PC or any other device with a full TCP / IP stack. i.e., Raspberry Pi. Eventually, the measurements are pushed to a back end through the Internet.

A center node can serve concurrently multiple end nodes. The probability of simultaneous packet transmission from the end nodes is negligible. In the unfortunate situation of a collision, the packets of measurements are lost but a small shift on the end nodes' clocks ensures that such a collision will not occur during the next broadcasting session.

Figure 1 depicts the final view of our IoT node pcb and its components.

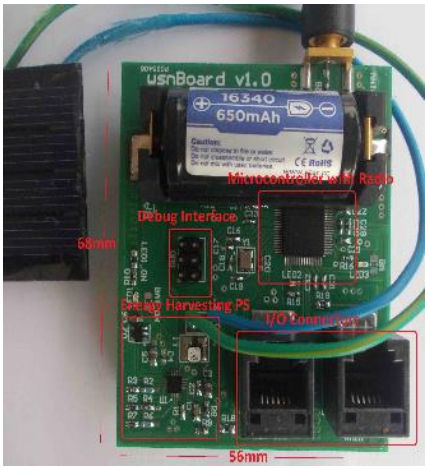

Figure 1 IoT node pcb and components

C. System Performance

- Firmware

No embedded operating system is used. The bare metal firmware code is in C language and its total size, along with radio and sensors control libraries, is approximately 10Kbytes.

- Coverage Distance

The maximum, transmission distance is a function of antenna power, frequency and transmission speed. For 868MHz radio frequency, 1Kbps transmission speed and 10dbm antenna power, a 12.5Km line of sight has been achieved. For a 433MHz frequency the distance is doubled. The transmitter and receiver use antennas of half wave 1.2dBi peak gain. In case the field topology requires longer distances, then one or more IoT nodes will be used as repeaters (with minor modifications to the firmware).

- Energy Consumption

Hibernate mode is the dominant mode for the IoT node since the total consumption in this state is 6µA. During broadcast, for output power of 10dbm in the antenna, the consumption is 32mA. Fifteen (15) levels of output power are available, while

the transmission speed can be selected from a range of 1Kbps to 300Kbps. Therefore, for a 20bytes transmission packet every ten (10) minutes with maximum antenna power and 1Kbps transmission rate, the average power consumption of the IoT node is approximately 22μA and its 650 mAh battery could endure for approximately 3.5 years. Node's battery will be recharged through the photovoltaic panel which has the ability to fully charge the battery within 20 hours of solar radiation.

- Cost Aspects

The below mentioned material costs are valid for prototype development. For larger scale reproduction, prices are significantly lower. More specifically, the cost of passive (L, R, C) is 6€, the cost for the ICs is around 11€, for the connectors 8€, for the battery 5€, for the photovoltaic panel 1€, for the antenna 6€ and 3€ for the IP65 casing. All the above sum up to a cost of 40€ per IoT node. Figure 2 depicts the final prototype.

Figure 2 The Prototype IoT Node

IV. Verification and Small-Scale Demonstration

To demonstrate the operation ability of the proposed system the application domain of precision agriculture is chosen due to numerous sensors being used enabling the farmers to closely monitor the field and take precaution actions- thus substantially increasing the yield and quality and lower production costs. In this case, the system is used to gather the needed data from a vineyard pilot. The IoT prototype node, as described in section III has been reproduced in five (5) copies which are deployed at the pilot site. A representative example is shown in Figure 3.

Figure 3 The IoT Node Integrated with Sensors

The physical installation of the IoT nodes and the sensors followed a sensing cell approach as Figure 4 depicts. Each sensing cell covers 25m radius and the minimum distance between two nodes is 50m. In the particular use-case, in each sensing cell we gather various set of data. For example, in sensing cell 1 the following parameters are collected: soil moisture, air temperature & humidity and atmospheric pressure. In sensing cell 2 the following parameters are collected: leaf wetness, air temperature & humidity, atmospheric pressure. In sensing cell 3 the following parameters are collected: rain amount, air temperature & humidity, atmospheric pressure. All the above parameter data have been gathered uninterruptedly in a backend system for approximately five (5) months.

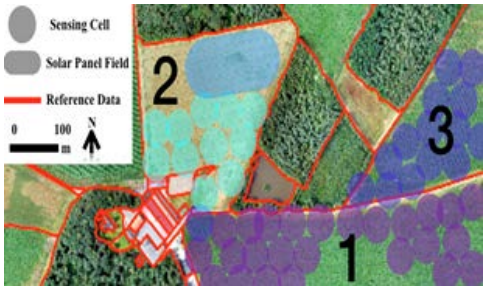

Figure 4 Topology of the Application Use Case

V. Conclusion

In this paper, an integrated low cost IoT Node based on discrete components is presented that efficiently collects, and processes field data. It is designed to be robust, modular and easily adopted to any application domain. Its uniqueness lies in the way it integrates features as well as the integrity it exposes, and the new business model it supports. All its architectural as well as operational aspects are depicted, and the use-case example demonstrates the overall functionality of the proposed IoT node. Future actions include the conduction of exhaustive system audits in the field to assess the unobstructed connectivity of the nodes. The presented IoT node has been designed and implemented in the framework of the national project "AgrIoT", promoting a customized precision agriculture framework for environmental data collection.

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