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Design and Implementation of a Low-Cost Core Board for Mobile IoT Rapid System Prototyping and Service Roll-Out

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Abstract

To enable fast development of specific and general mobile Internet of Things (IoT) systems and services, apart from writing cloud-side applications, the requisite hardware production, e.g., procurement of chips and materials, design and manufacturing of printed circuit boards (PCBs), completion of surface mounted technology (SMT) operations, etc., can be a source of delay. Here a low-cost generic core board, which is IoT-service and IoT-system prototyping ready, is proposed. Flexible and adaptable to many mobile IoT applications, it is based on a robust low-power consumption microcontroller unit (MCU), with boot-loading and remote software upgrading attributes, and running an open-source real time (RT) operating system (OS), which is well supported with IoT sensor and peripheral sensor drivers. The key hardware, supporting IoT communication protocols embedded, comprises GPS/GPRS, NB-IoT, and LTE modules. The paper sets out the basics of the board design.

1 Introduction

Our goal is the creation of a generic Internet of Things (IoT) platform, called EMULSION [1], to enable fast development of specific and general IoT systems, especially for the rapid roll out of IoT services and applications. As is well-known, IoT system solutions, e.g., for smart homes, smart metering, smart agriculture, smart environmental protection, ubiquitous health, etc., for the most part utilize an embedded hardware. Commercially available single- and multi-chip MCUs solutions being used for developing low-cost IoT systems are many, e.g., ARM, MIPS, RISC, etc. The STMicroelectronics STM32 is among the most popular single-chip MCUs. Designed with the popular and robust Cortex kernel, it can be boot loaded, has remote software upgrading capability, has suitable peripherals, reasonable power consumption and comes at a low price. For these and other attributes, it became our selection for the designed core board.

In [2], a low-cost electrical smart power meter prototype was proposed, based on STM32F2, but its price and hardware design were not clearly stated. In [3], a low-cost Wi-Fi based IoT prototype was proposed, costing around US $60 for a single unit. In [4], a low-cost IoT system for irrigation monitoring and control, utilizing ESP-12F 8266 as MCU, was proposed, with a cost of US $54.90. In [5], low-cost agriculture devices were built with Raspberry Pi 3. However, with a typical cost of US $40, Raspberry Pi 3 seems still expensive, if compared, for instance, to open-source hardware boards running Linux and Android. Our aim was to design a core board, which costs less than US $5.

The low-cost Winbond W25Q32JVTCIQ serial flash memory was selected for providing data storage on the core board. A lightweight flash-based key value database was used in this board to save hardware parameters, real-time datasets, and history.

The communication module is an important part of the designed core board. The short-distance communication techniques, i.e., ZigBee, Bluetooth, etc., are not quite suited for industrial IoT (IIoT) applications. Also, Wi-Fi was not considered in this design, as it needs an extra configuration with username and password. As the cellular wireless communication meets the requirements of most ground IoT applications, it was selected for use in the designed core board in the form of a 2G/3G/4G module with an inserted SIM card.

2 Hardware Design

The main hardware modules of the core board, depicted on Figure 1, are briefly described in the subsections below.

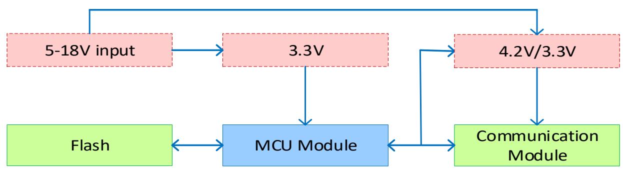

Figure 1. The functional scheme of the core board.

2.1 Power supply module

The input voltage range of the designed power supply module is from 5V to 18V. The output is 4.2V/3.3V for the wireless communication module and 3.3V for the MCU and the peripheral circuit. The monolithic buck voltage converter Joulwatt JW5033T was utilized as a cheap and efficient (up to 95%) light load, supporting wireless communication. To enable the core board to work in an ultra-low-power consumption mode, the low dropout linear regulator TPS70933 was selected for the MCU power supply, as it needs only 1μA quiescent current for functioning, thus enabling the use of the core board in battery-powered IoT devices. Figure 2 shows the scheme of the designed power supply module, whereby PWR421 acts as a controller of the buck converter.

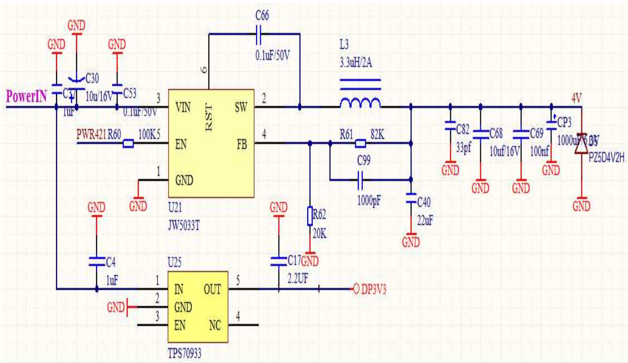

Figure 2. The power supply module's scheme.

2.2 MCU module

For the MCU design, the ARM Cortex-M3 STM32F103RE with a 512-kB flash memory and a 72-MHz CPU, was selected as it can operate in a temperature range of –40°C to +105°C. For communication with sensors, it utilizes three 12-bit ADCs, two I2Cs, 11 timers, three SPIs, and five USARTs. The layout of the developed PCB is shown in Figure 3.

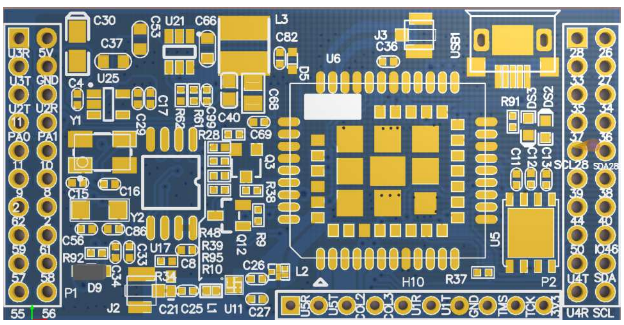

Figure 3. The 4-layer PCB layout of the MCU module.

2.3 Communication module

Three types of communication modules were developed for the core board: (1) GPS/GPRS, based on MTK 2503 chipsets; (2) NB-IoT, based on MTK 2625 chipsets; and (3) LTE Cat.1 and Cat.4, based on UIS8910DM and MTK 6737 chipsets, respectively. From these, the most utilized type to date is the GPS/GPRS communication module as the cheapest implementation option available with a Bill of Materials (BOM), including the PCB cost, coming to only 11 RMB (€1.40). Figure 4 shows the PCB design of the GPS/GPRS communication module.

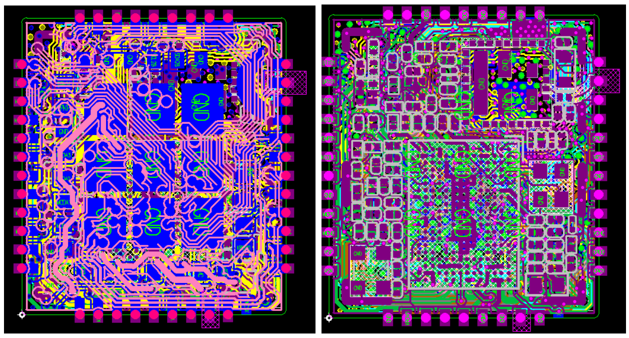

Figure 4. The PCB of the GPS/GPRS communication module.

Besides providing GPRS communication, the utilized MTK 2503 also supports GPS navigation, which is quite useful in many IoT applications. The main chipset also includes a radio-frequency power amplifier RF7178, a GNSS low-noise amplifier MAX2569ELT, and a Murata surface acoustic wave (SAW) filter SAFEA1G84FA0F00R15. Figure 5 depicts the scheme design of the antennas.

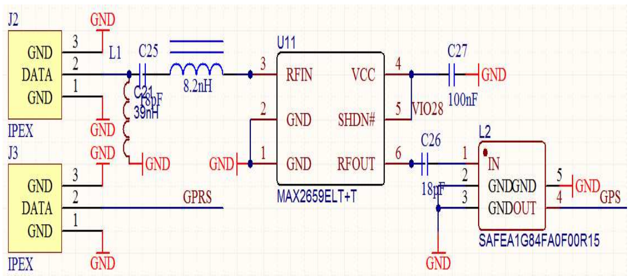

Figure 5. The scheme design of the antennas.

3 Software Design

There is quite a range of real time (RT) operation systems for embedded systems to choose from, e.g., μC/OS-II, FreeRTOS, RTX, Huawei LiteOS, RT-Thread, etc. Thinking both of cost and future development, our preference was for open source. RT-Thread was chosen not just for this reason but also because of the great number of drivers already available for IoT peripherals and sensors.

A number of software components were developed for inclusion in the architecture shown in Figure 6, e.g., a bootloader (with an ability for upgrading via a serial port), a database, a sensors interface, timers, a threads manager, a logger, a power manager, etc.

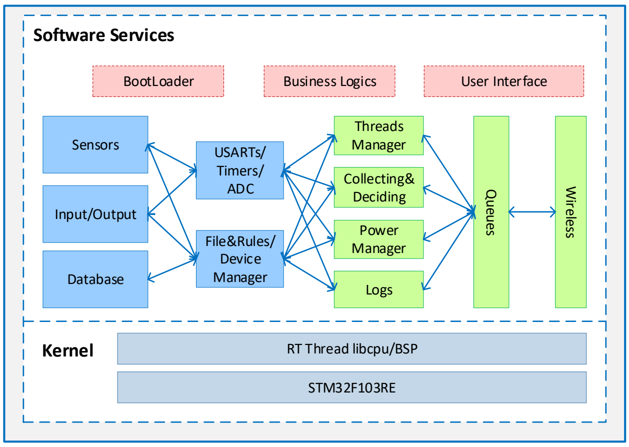

Figure 6. The developed software architecture for the core board.

4 Conclusion

A low-cost core board's hardware and software design has been briefly presented in this paper. More than 200,000 core boards of this kind were produced and successfully used in a variety of IoT systems, deployed in China. The production cost of a typical GPS/GPRS-based core board is around 30 RMB (€3.83).

5 Acknowledgements

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6 References

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