A LOW-COST HIGH-PERFORMANCE EMBEDDED PLATFORM FOR ACCELERATOR CONTROLS

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Abstract

Over the last years the mobile and hand-held device market has seen a dramatic performance improvement of the microprocessors employed for these systems. As an interesting side effect, this brings the opportunity of adopting these microprocessors to build small low-cost embedded boards, featuring lots of processing power and input/output capabilities. Moreover, being capable of running a full featured operating system such as GNU/Linux, and even a control system toolkit such as Tango, these boards can also be used in control systems as front-end or embedded computers. In order to evaluate the feasibility of this idea, an activity has started at Elettra to select, evaluate and validate a commercial embedded device able to guarantee production grade reliability, competitive costs and an open source platform. The preliminary results of this work are presented.

INTRODUCTION

During the last years the requirements of particle accelerator control systems moved from the traditional distributed architecture, based on modular but complex platforms, such as VME, to even more distributed systems based on simple embedded devices [1,2,3]. The ever-growing performances of the modern hand-held oriented system-on-chip devices allow nowadays to fulfil these requirements. Desirable characteristics are:

- a large set of Input Output (I/O) subsystems (GPIO, SPI, UART, PWM, …);
- remote control/communication interfaces;
- multiple communication protocols (UDP, TCP/IP, field-bus based);
- full Operating System (OS) support, with multitasking, multi-user, real-time capabilities;
- hardware, software and documentation support by either the manufacturer or a dedicated third part player;
- long term commercial availability and support;
- flexibility and modularity to cover a wide range of different fields of application;
- competitive cost-performance ratio;
- competitive development and maintenance costs;
- deterministic (real-time) capabilities.

Commercial-off-the-shelf (COTS) products that can match most, even if not all, of the described features are now available. Adopting the "system integrator" point of view, the available devices can be classified into the following levels:

- SOC (system on chip) level;
- SOM (system on module) level;
- SOB (system on board) level.

Design complexity, available resources and manpower are practical reasons that lead to choose the easiest, fastest and most effective solution: find the most suitable commercial SOB and customise it in order to fit the specific requirements.

MARKET SURVEY

A market survey has been carried out to find COTS products to compare, taking into account performance, reliability, lifetime and, last but not least, cost. This preliminary step has led to three product platforms: the iMX by Freescale [4], the OMAP and the Sitara by Texas Instruments (TI) [5].

The Freescale iMX53 "QSB" board has turned out to be a clean design, quite powerful for an embedded board, allowing the native porting of the Tango control system framework [6] in use for the FERMI@Elettra project [7]. On the downside, lacking a simple way to reach the I/O connector, the flexibility of the platform hasn't been satisfactory.

On the TI side, the "Beagle" family boards have been evaluated with good and encouraging results .

THE "BEAGLE" PLATFORM

Formally announced by Digi-Key [8] on July 28th, 2008, the "Beagle" project has been immediately able to collect the attention of a large community of developers whose main interest is focused on real and complete open source projects [9]. The Beagle family includes, at present, three different SOB's:

- the BeagleBoard, the first member of the family, a fully featured, low-power, high-performance Single Board Computer (SBC) based on TI OMAP3530 SOC, designed for user-oriented applications;
- the BeagleBoard-xM, the evolution of the BeagleBoard, based on OMAP compatible TI DM3730 SOC;
- the BeagleBone (Fig. 1), the most recent board of the family, based on TI Sitara AM335x SOC, designed for machine and/or industrial-oriented applications.

The BeagleBoard and the BeagleBoard-xM are, in principle, very similar to the iMX53 QSB board. This means that they are powerful devices from the computational point of view but, due to design decisions, they feature a small expansion connector, too limited to be used in an industrial oriented platform.

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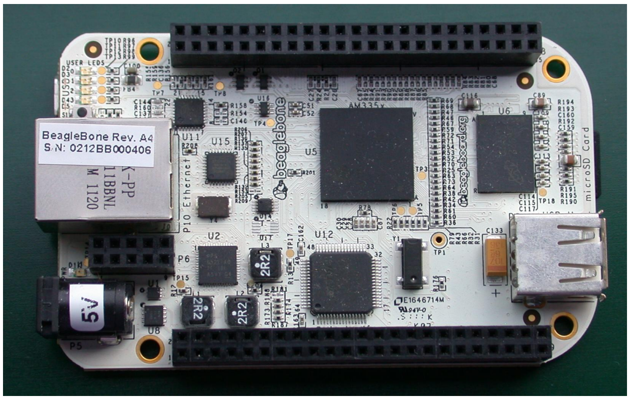

Figure 1: BeagleBone board.

On the other hand, the BeagleBone has some key features as:

- compact form factor;
- robust, accessible expansion connectors;
- large number of exported I/O pins;
- enough computational power;
- deterministic execution hardware support by means of a dedicated processing unit;
- 256 MB RAM and microSD card slot:
- native Ethernet interface;
- open source approach, on both hardware and software;
- manufacturer board support packages (BSP) for Linux and Android;
- large community of developers and users.

Furthermore, a number of interesting projects have already been based on the BeagleBone platform.

THE AM335X PROCESSORS FAMILY

The core of the BeagleBone is presently the AM3359 SOC, a member of the AM335x family. The general architecture of this family is shown in Fig. 2.

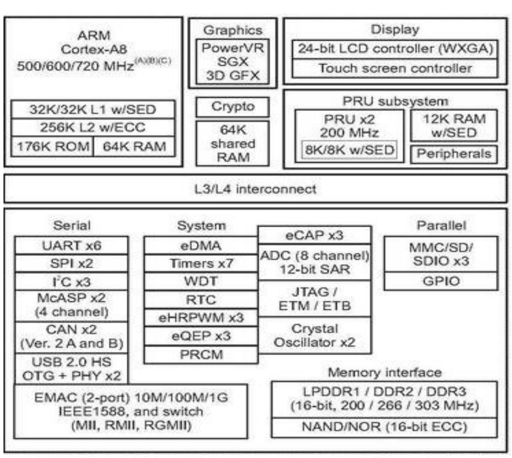

Figure 2: AM335x SOC architecture.

The main features of the AM3359 device are:

- ARM Cortex-A8 core running at up to 720 MHz clock frequency;
- programmable real-time subsystem unit (PRUSS) [10], made of a couple of deterministic RISC cores able to access the whole SOC memory space;
- rich set of peripherals accessible from both ARM and PRUSS cores;
- native Ethernet interfaces supporting PTP (IEEE 1588) and Ethercat.

Currently the AM3359 is the top level device of the AM335x family and supports the whole set of functionalities depicted in Fig. 1. The AM3358, AM3357, AM3356, belonging to the same family but less feature-rich, could be, nonetheless, suited for specific applications where Ethercat and PTP capabilities are not required. Due to the lack of the PRUSS engine, the entry level devices AM3354 and AM3352 have been discarded.

PLATFORM EVALUATION

The board evaluation process has been split in three phases. The first phase has been dedicated to testing of both the native and cross development tools (GCC tool chain) and building and running a number of sample applications. A Ubuntu [11] distribution flashed on a bootable microsSD card has been used. These tests have shown that it is possible to compile and run natively OmniORB, Tango and Tango based device servers, both locally on microSD and remotely on an NFS mounted root file system. A number of minor issues have still to be fixed to successfully cross compile Tango based applications.

The second phase has been focused on testing the Linux kernel and platform BSP. The device drivers for specific peripherals such as SPI, PRUSS and the support for kernel subsystems have been studied and modified to fulfil the required performance figures. Starting from the official TI Linux BSP, an extended kernel has been obtained by patching and cross compiling the original one. The original Ubuntu distribution root file system has been kept on the microSD card whereas the new kernel has been booted by TFTP and some remote storage has been mounted via NFS. This set up has been extremely helpful because it has allowed to share the same remotely stored kernel and applications under test between multiple boards, leading to a simple, quick and effective bug fix activity, especially for the PRUSS.

Finally the original BSP kernel on the microSD card has been replaced by the renewed one, tested and validated. In this way, the device has become a complete stand-alone system that boots from the local removable storage and then loads the specific drivers and applications.

THE FIRST APPLICATION

Within the context of particle accelerators control systems the set of possible applications of the BeagleBone ranges from low to middle level complexity. It could be used as an intelligent hub for networks of sensors directly connected to the machine, as a gateway

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between different interface field-buses or as a controller embedded into a device or equipment.

A concrete example is the “TipTilt Controller” (TTC), a real-time mirror mover designed in house. In order to perform “pump and probe” experiments at the experimental stations, a laser transport system (LTS) is currently under development at the FERMI@Elettra Free Electron Laser. The LTS is made by a multiple-mirror 170-meter long optical path wherein the laser beam trajectory must be kept stable within few microradians. Each mirror is controlled by a dedicated TTC that, after receiving an UDP packets containing the X/Y offset information, issues the required voltages by a piezoelectric drive. The control system generates and distributes the UDP packets at up to 1 KHz repetition rate, and every TTC must be able to apply the driving signal at the same rate.

The final release of the TTC, i.e. the assembly of BeagelBone plus the expansion piezoelectric driver board, depicted in Fig. 3, is in the final stage of development, and all the main functionalities have already been tested and validated in laboratory.

The laboratory set up consists in a crate hosting an adapter board that carries a couple of SPI DACs driven by the PRUSS, and a variable rate UDP packet generator that simulates the control system.

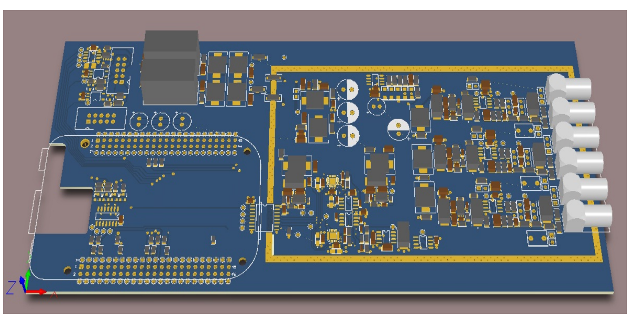

Figure 3: TipTilt board (Courtesy P. Sigalotti).

The UDP packets collected by the TTC are managed in user space by a routine that extracts the set points and sends them to the SPI control loop running in the PRUSS subsystem. Inside the PRUSS a smooth ramp is calculated and the mirror is moved to the new X/Y position before a new UDP packet arrives.

It is worthwhile to observe that, in principle, the SPI channel could be driven by Linux itself, without using the PRUSS. However, dedicated tests have shown that the performance that the PRUSS can guarantee is at least one order of magnitude higher and, even more important, the PRUSS has a deterministic behaviour.

Moreover, the use of a real-time capable kernel [12] or of some real-time extensions [13] is foreseen to guarantee the determinism of the whole system.

CONCLUSIONS

The tests for the final validation of the BeagleBone platform is not yet complete, but the already obtained results are very encouraging and no important difficulties have been encountered so far. The AM335X family has the potentiality to cover both low-end embedded system and high-end demanding applications, where the determinism of the PRUSS can help. The design of the TipTilt controller has been the first BeagleBone based project at Elettra, and is the starting point for future applications, such as the ones in the field of power supply and motion control.

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