Table of Contents

1. The apaBoard

My intention was to make a generally usable device which enables the acquirement of knowledge in a relatively inconspicuous way and, by the acquired knowledge, provides experience in creating new devices. I would like to present that the actuation of the embedded systems, which are responsible for the working of our modern devices, is easily comprehensible and applicable in practice. We are able to obtain the data in our environment simply and effectively, and transmit them to the intelligent devices created by us.

My educational and experimental device for ARM Cortex M4 and MSP430 microcontrollers, named apaBoard, version number 0.5, had been done by the beginning of April 2014 and it is the subject of my documentation. As the simplicity of usage of the device is also a purpose of my application, in April 2014 I have been working on a method that would enable the presentation and better understanding of the apaBoard. It is a 2x45 minutes presentation supported by experiments and explanations that guides the young, interested people from generating electrical current to the embedded systems.

I became acquainted with the microcontrollers as a teenager and I would like to awaken young people's interest in the engineer profession that I am preparing for, as well. So that our narrower or wider environment might be part of that moral and financial opportunity which lies in the structuring and constructing of the forecasted 20-50 billion IoT[1].

My starting point was based on the experience that one of the essential possibilities of failure occurs when the components are assembled inappropriately[2] while electronic devices being learnt. In addition, the purchasing and the correct use of components also provide high probability to fail during the connection of more experiments. The apaBoard is a device various experiments with appropriate components and it also provides the connectivity of those experiments. As an illustrative example I compared the device to a robot spread out which has every component so the task was just to connect all of them to the central processing unit and to each other.

Everyone is able to find the aspect that they are mainly interested in, and may begin to discover how useful and enjoyable device the microcontroller is as well as the opportunity to obtain knowledge about it. The discovery might be started at the generation of sound, at the driving of light, powering of the motor and at the data input or storage of data.

Although, the device is useful for learning it does not necessarily teach directly and it has no intention to be an educational device. But the device is able to provide the experience of an electronic device working in practice therefore it can establish the interest which later helps to learn easily and to become motivated.

Despite having the example above, the device is not necessarily intents to build a robot: if someone would like to assemble only a blinking thermometer that also can be achieved easily. As a matter of fact, students or curious individuals are able to learn the usage and the widespread applicability of microcontrollers even in the lack of previous erudition/pre-education in IT, programming, physics or mathematics. Later it is possible to deepen the earned knowledge and employ that in a chosen specialty.

Once completed the device seems to act independently: maybe as a result of its complexity it possesses features that are fortunately positive but were not foresighted. Therefore beyond the basic use it is suitable for the professional education of the ARM at a higher degree. Here is an example for the case above: the visualizing of PORT_B (8 BIT correspond to 8 LED) which is principally responsible for the understanding of parallel GPIO data transmission.

While working it seems to enable the learning and understanding of hexadecimal numbers and operations or binary mathematics[3], which is indispensable to comprehend the working and programming of the registers of microcontroller, and the latter is necessary to a high degree of knowledge. Here must be mentioned also the capacitive

[1] Internet of Things: network of devices

[2] E.g. the generally used ADXL3xx accelerometers can be tested only with special converter and surface-mount seals because of the 16-Lead LFCSP_LQ frame

[3] BITWISE AND, OR, NOT, XOR, SHIFT, MASKING

touchpad, which was made with a MSP430G2553 processor for data input but it is appropriate for the learning of SBW[4], the I2C data transmission between the Tiva and the MSP430, and the learning and application of releases. Meanwhile there left 6 available MSP430 GPIO which were led out by a socket to spare it for a later use.

I have no information about former or similar attempts in Hungary, even the device is considered as new. The TI[5] has developed a recommendation named BoosterPack[6] which helps developers. Then different BoosterPacks were appeared such as LCD, CapSense, etc. Their disadvantage is that they are able to be built on the top of each other so that they can cover only a few areas. If the GPIOs are shared, as a result they can cause errors. The Educational BoosterPack can be considered as the most similar to the development in question. As the apaBoard is beyond the sizes of a standard BoosterPack, it contains much more important modules; practically it has 4-5 times the modules of a BoosterPack and an extra microcontroller the MSP430G2553.

When I started to work on the subject of my application I had an image of how much work I was supposed to do. Now, four months later it is finished and I may submit my documentation, the work I had invested in it appears to be ten times more.

a) The standard actuation of the apaBoard

It is recommended from the age 13-18 and consists of 4 steps:

1) Apply a TivaC123 Launchpad microcontroller programmer and debugger emulation[7] on the apaBoard

2) Video presentations and experiments are available on the website of apaBoard[8]

3) Upload the codes of videos and experiments to apaBoard by a simple tool similar to a text editor[9]

4) The codes can be varied at will: newer in- and output modules can be integrated.

b) The possible usage of apaBoard in higher education

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[4] Uploading a SPY BI WIRE type programming code

[5] Texas Instruments, hereafter called TI

[6] http://www.ti.com/ww/en/launchpad/boosterpacks.html

[7] Produced by Texas Instruments, 3000 HUF
http://www.ti.com/ww/en/launchpad/launchpads-connected-ek-tm4c123gxl.html

[8] http://apa.eskolar.com

[9] Energia IDE programozoi kezelőfelulet http://energia.nu

Meanwhile having the development in progress, I had been the *UT.6.01x Embedded Systems – Shape the World* online course[10] at the University of Texas at Austin. It was a great pleasure to learn that all the tasks being taught in higher education can be done by the apaBoard, including the representation of logical operations, digital logic, resistance, voltage, current, logical operations with transistors, GPIO in- and outputs, LED control, switches, sequences, FSM machine, IO with UART series, ADC, DAC, I2C, SPI, etc. All the gained experience supported the idea of using the apaBoard in high education.

According to the requirements of the application, on 26 March 2014 I presented the ongoing development to **Dr. László Vajta**, the Dean of the Budapest University of Technology and Economics Faculty of Electrical Engineering and Informatics, who supported the trial of the device. For the students attending to higher education the arrangement of the presentation and testing is in progress.

*c) Register (*online work schedule)

During the preparation for the submission I had been having a register (online work schedule) [11] from 8 January 2014 to the beginning of April, taking picture and video documentations of every step from the circuit designing through the handmade prototype to the structuring of components on the custom-built printed circuit.

At the beginning of April 2014 I have started to work on the presentation materials and I believe that they are astonishing and spectacular enough to awaken the audience's curiosity and interest to intend to make a device on their own. This kind of interest was the starting point of the experiments named "*Mona Lisa's eyes follow you"* and "*The upgrading of Johnny Cash's tremolo"*. These materials are YouTube videos made especially for people at my age, and appeared to be appropriate for educational use as well. The Facebook profile of the device is a good proof for the efficiency of online communication as the faculty members of the 6.001x course at UT Austin did like the YouTube video of Mona Lisa[12] posted in English language on Facebook.

The presentations in schools and workshops, and the summary of the finished work have been scheduled at the end of April. All the materials were made with open source software such us LibreOffice, Kicad, Inkscape, Gimp, MediaWiki and Energia IDE. The Eskolar Multimedia, appearing on the hand-outs, is a nominal name with a hat as a brand logo, and originates in my website's name the eskolar.com. The preparation for the submission, a video

[10] https://www.edx.org/course/utaustinx/utaustinx-ut-6-01x-embedded-systems-1172

[11] http://apa.eskolar.com/index.php/Munkanaplo

[12] Appendix, page 18

presentation, summarizing the story of the development and the presentation of apaBoard in English are in progress simultaneously.

d) Technical definition of the apaBoard

The apaBoard is a modular structured device and is suitable for standardized production, can be produced and developed individually or manufactured; furthermore it is available in public without restrictions.

It is built on a 10x10 cm printed circuit board which can be connected to the TivaC123 ARM Launchpad with the TI standard 40-pin BoosterPack. Hundreds of experiments can be performed with it. Some of the most general experiments are the following: analog and digital data input, analog and digital data displaying, ADC, HD44780 LCD, ADXL335 3-Axis accelerometer, 3.3V, 5V level shifter, matrix display, sound input and output, sound amplifier, SD card data management, EEPROM data management, keyboard, capacitive touch sensor, servo, stepper motor and DC motor control I2C, SPI, UART data transmission, etc. The built-in Solderless Prototype Breadboard with 170 tie-points enables to do any experiments that are not default. The appendix explains the 34 modules' setting on the printed circuit board and the pin assignment of the modules, in other words it describes that which module uses which GPIO for what function and which jumper detaches and attaches it.

The technical details (see appendix) of the 80 MHz TivaC123 ARM reveals that it is worth to rely on the world's most cost-efficient ARM development board (12.99$) developed by TI in 2013. It guarantees an up-to-date knowledge as I have experienced – the educational material of the 6.001x course in UT Austin in 2014 was based on it. In these days the mobiles and tablets are typically built on ARM type processors.

e) The reasonableness of the development and application of the apaBoard

A new sector of technology named IoT, which is connected to the IT industry, begins to evolve recently. Technological forecasts place the number of IoT between 20 and 50 billion by 2020.

The younger someone is and gains enjoyable experiences of these devices that appear to be very complex, but actually consist of simple subparts and components, the more chances are provided for them to have the ability to create the future IoT devices.

2. Results, solutions, appraisals

a) Modular structure

The device's modular structure is simple which means that each module can be detached by jumpers. I.e. the certain modules are operable also independently but more modules can be connected after having the cause learnt and understand. The connection of the modules is able to be formed at will.

b) Possibilities of standardized production, supplies

The 0.5 circuit is already available as standardized product; the first series of 10-piece printed circuits were made this way. I worked out more methods of making printed circuits:

- I uploaded it to Open Hardware website so that anyone is able to order it at manufacturing costs and at any quantity.
- It is downloadable from my website and can be ordered at any producer.
- Practically, it can be home made (DIY) as it is proved by my own material but it is recommended for experienced users only, and many tools and equipments are necessary.

c) Online appearance on MediaWiki

At the same time with the submission, the information of the apaBoard became accessible on the http://eskolar.com domain under the http://apa.eskolar.com subdomain powered by MediaWiki[13] which is a Wikipedia platform that I chose for the reason that it provides a free access to edit, improve and complete the materials for anyone. During the time of the application I uploaded 55 videos to the YouTube video-sharing website that are embedded into the Wiki website as well.

The Upverter embedding is an online service what TI has drawn the users' attention to, and it provides the online sharing of designing printed circuit boards. Though the platform has been developed to be better and faster, besides using the general PDF format, it is safer to make the original Kicad version of the designs available for downloading from the website. During the term of application, the structure forming of source codes happened and the uploading of the codes is in progress.

[13] http://www.mediawiki.org/wiki/MediaWiki

d) Report of the latest expriences

I believe that everything I have experienced during the preparation of this submission can be useful for others as well, therefore I am planning to make more videos about it. For instance:

- How to learn and use Kicad – serial
- Where and how PCB can be produced, what the producers' , what must be considered in case of order, or how to make double-sided PCB at home
- homemade CNC, usage of Linux CNC, Kicad, gode, Inkscape, etc.

e) Documentations of the circuit and production

In most of the cases I used the reference circuits given by producers for designing and when I varied then problems came up that had to be solved. Following the OSH[14] method I marked the precedents such as website, producer or name on the circuit diagrams.

This way I have experienced that the Open Source range requires a significant amount of source criticism, and it is safer to rely on the references by producers and their developed and documented variants.

As a part of the documentation I made a poster[15] for users which presents the modules of apaBoard and besides the basic functions, it shows as well the specific functions enabled by the pin assignment (40-pin TI standard BoosterPack)[16].

f) Flyer (hand-out) for students

The purpose of apaBoard is not to educate but provide the pleasure of understanding which later results in knowledge and ability. Those who pass the first success experiments they will want to individually find the rules and principles. Therefore I wanted to design a hand-out[17] that addresses students on their own language and invites them to the presentation. The is 2x3 pages, double-sided, colorful print folded into one third of an A4 paper. It contains lot of pictures (own photographs and non-infringement pictures bought from fotolia.com) and the inside is similar to a questionnaire. As an example for the questions: “Which is more difficult? The cat or the MCU?” On the outsides information can be found about the simplicity and easy learning of the IoT and embedded systems.

[14] Open Source Hardware

[15] Appendix, page 15

[16] Appendix, page 19

[17] Appendix, page 16

g) The apaBoard as a possible product

The apaBoard is ready for distribution. It can be packed into a 14,8x21 cm box[18] which contains the following:

- a short, 4 page about the steps of the first start-up
- in the device's SD card slot there is an SD card on which there is a video presentation about the start-up
- the apaBoard
- LCD, TivaC123 Launchpad with USB connection cable, 9-12 V 1000-1500mA power supply

The gross retail price of the device is 11.000-13.000 HUF. Prime cost is likely preferential. The TivaC123 Launchpad costs 12.99$ (3000 HUF).

h) Ideal applicability of public interest

I believe that the ideal applicability of the device would be the following: a nonprofit organization or foundation orders - or supports financially the companies concerned in production – an optional series of the device which can be presented with technical documentation and hand-outs in schools and workshops to interested students. People who are interested in it may apply for free devices. The condition of applying might be the publishing of their results achieved.

i) Press appearance

On 15 April 2014 the Veszprem Journal (Veszprémi Napló)[19] published an interview report with me in which I wished to present the device in progress of developing. This report has been republished on the website of the Research Centre for Natural Sciences of Hungarian Academy of Sciences (MTA TTK)[20] on 30 April 2014.

3.The structure of entertaining presentations

In order to awaken interest in microcontrollers and embedded systems the best solution seemed to be presenting simple and spectacular experiments that can be implemented at home as well. The order of the experiments was based on the idea to eventually prove even to the less interested students how many-sided these devices are.

[18] Appendix, page 23. On 5 May 2014 I have sent it with priority mail postal service to the address of the Innovation Center

[19] http://veol.hu/tudomany/apaboard-egy-diak-innovacioja-1616385

[20] http://www.ttk.mta.hu/2014/04/apaboardegy-diak-innovacioja/

The scheme of the presentation was the following: the current → cables → circuits → printed circuits → resistance → resistance models (voltage, current dividing) → signals → digital signals → PWM → embedded system, components, sensors, motors → the possible experiments with apaBoard.

The scheme of the presentation basically follows the structure of the online course of Embedded Systems - Shape The World of UT Austin. My mentor, Dr Krisztián Kertész supported me during two presentations in the Fransiscan Grammar School, Szentendre where Dr Venczel Borbély, phisics teacher welcomed us. The second presentation was more flowing because the experiments were not implemented during the presentation but they were projected onto a screen as a video record so that I could focus on the explanations. After the presentation the opportunity to talk and implement experiments was given. During the experiments and discussion several questions emerged such as where the device is available, whether the device would be developed in the future and how long I have worked on it.

In addition, the appendix contains the structure of the presentation, and the video records are available on the website.

4. The problems emerged and solved from version 0.1 – 0.5

– I had to reconsider the development for manufacturing, instead of wire jumpers I had to construct a double-sided PCB, however, in order to maintain the low prime cost I had to apply the one-side component placement instead of the double-sided

– Regarding the widest range of usability, the experimental possibilities had to be based on general purpose therefore more modules were added, such as , capacitive touch sensor and optical isolator. By the new modules new setting problems emerged (AFSEL functions).

– The Eagle PCB design software could not be used because of license restrictions therefore I had to learn to use the Kicad open source software during work.

– The Hungarian producers made an offer that would have cost over 40.000 HUF, the Chinese production would have caused a delay, therefore the only certain solution was a handmade, testable prototype of PCB; in my own workshop at home I exposed and etched the double-sided PCB (12mil wire width), using a DIY CNC I drilled the 353 holes; for the conduction holes I used an 0.3mm drill bit, and an 0.8mm drill bit was used for the holes where the other components can fit into. This solution proved to be appropriate as having no financial sponsor, and though the deadline I had set was a bit delayed, the prototype has been completed, eventually.

– Had several theoretically correct solutions which proved to be unsuccessful: had to change the TXB0108 level shifter that enables only low power supply so I applied a bi-directional transistor level shifter. The ADXL377 worked correctly but having the device subjected to high endurance it had to be replaced with ADXL335 which worked well after redesigning the PCB.

– According to my opportunities, the PCB of the 0.5 version was produced in China[21] within five days and two days later it was delivered by parcel service.

5. A personal afterword

I was born in Inota, a little village near to Várpalota, and I also live here. If someone would like to start to do something here, they have to face with highly limited opportunities even in the case of ordinary situations like buying a resistor, not to mention any special, rare or unique matters.

Fortunate coincidences were necessary to find answers to my questions but now after few years later I consider myself as part of a real community. My first question about the resistors and transistors was welcomed and answered as seriously and thoughtfully as later I have been working on the documentation and tutorials of the MSP430F2012 processor programming from MSP430 Launchpad debug.

I believe that I have the right to say that I belong to this community of TI engineers, countless professionals, other interested people and specific forums. I believe that I could express my gratitude to this community if I shared the experiences I had gained and provided help to avoid failure and achieve success.

[21] http://sitopway.com/en/index.php