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IMPROVING THE QUALITY OF RAPID PROTOTYPING PROCESSES OF ELECTRONIC CONTROL UNITS BY USING A DEDICATED SOFTWARE PLATFORM

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Abstract: *The scientific paper presents the possibilities of improving the quality of the rapid prototyping processes of the electronic control units using a dedicated software platform. Embedded systems (ECU – Electronic Control Unit) products are analyzed, based on an original communication protocol through which the state of the system can be diagnosed in real time in different phases of development.*
This software platform called BIOComProP (Basic Input Output Communication Protocol Platform) is used especially in the ECU prototype phase for the individual testing of each hardware component connected to the inputs and outputs of the microcontroller which is the command-and-control element of the ECU. The BIOComProP platform is intended to be portable and extensible on any microcontroller family from different suppliers of electronic components and brings added value to reduce the development and implementation time of new projects based on this platform. The platform consists of two parts: BIOComProP_ECU - the software that runs in the ECU and BIOComProP_TS - the software that runs on the computer where ECU diagnostics and testing are performed. The authors also present a dedicated research methodology as well as the research results and not least the conclusions obtained.
Key words: *process quality improvement, software platform, ECU, microcontroller, prototype.*

1. INTRODUCTION

Considering the increasingly strong advance of technology, today the production process is faced with new challenges. New methods are being sought to shorten the production process and to reduce the product development time because the classic production methods no longer satisfy the requirements. In order to meet this issue, Rapid Prototyping (RP) is a more flexible solution for faster production [1].

To face the challenges of the consumer electronics market, there is a fierce battle between the organizations that have to offer consumers new, last-generation, high-performance products with low energy consumption and as small as possible. The market is increasingly dynamic, especially among mobile phones, where mobile device manufacturers must provide consumers with new models at maximum 2-year intervals. In this context, manufacturers are forced to develop new and advanced technologies to produce phones to meet demand [2].

In the 80s, the first invention in the field of rapid prototyping takes place. In the natural process of innovation, after applying the invention, prototypes and models are made. Having the right technology available, after several iterations, complex parts can be manufactured through rapid prototyping, in a faster and more efficient time [3].

Of course, before starting the journey towards a functional prototype, the requirements imposed by the project or invention must be analyzed. In many inventions or projects, embedded systems are involved as main or auxiliary tools. In the field of embedded systems, or in any other field that uses some as embedded systems, the electronic unit for data acquisition, data processing, decision-making and electronic action in this regard, is called Electronic Control Unit (ECU). The first step for the rapid design of ECUs is to establish the requirements. The ECU must be approached as a process and begins with the identification of the inputs and outputs of the ECU. A very good tool in this sense is SIPOC (Supplier Input Process Output Customer).

2. SIPOC FROM ECU PROCESS PERSPECTIVE

SIPOC refers to S - Suppliers, I - Inputs, P - Process, O - Outputs, C - Customers. If SIPOC is applied to optimize processes, then it provides an overview of the process. At each exit from the process, there is an entry for clients [4].
SIPOC is a Six Sigma tool and is used to map processes to get a high-level overview. SIPOC diagrams are most often found in project presentations as a description without too many details. At first glance the descriptions for SIPOC are: S (supplier), I (Inputs), P (Process), O (Output), and C (Customer) [5].

This Six Sigma method can be applied in all fields, not only in engineering.

In the field of embedded systems, the system formed by the ECU with inputs and outputs connected to sensors and actuators through which it senses and acts in the real world, can also be viewed from the perspective of SIPOC from the point of view of the operating process. Thus, the ECU processes the input information provided through the sensors, makes decisions, and then acts on the execution elements through the outputs that control the actuators.

Figure 1 shows the mapping of the SIPOC concept in the functioning process of an ECU according to the authors' vision.

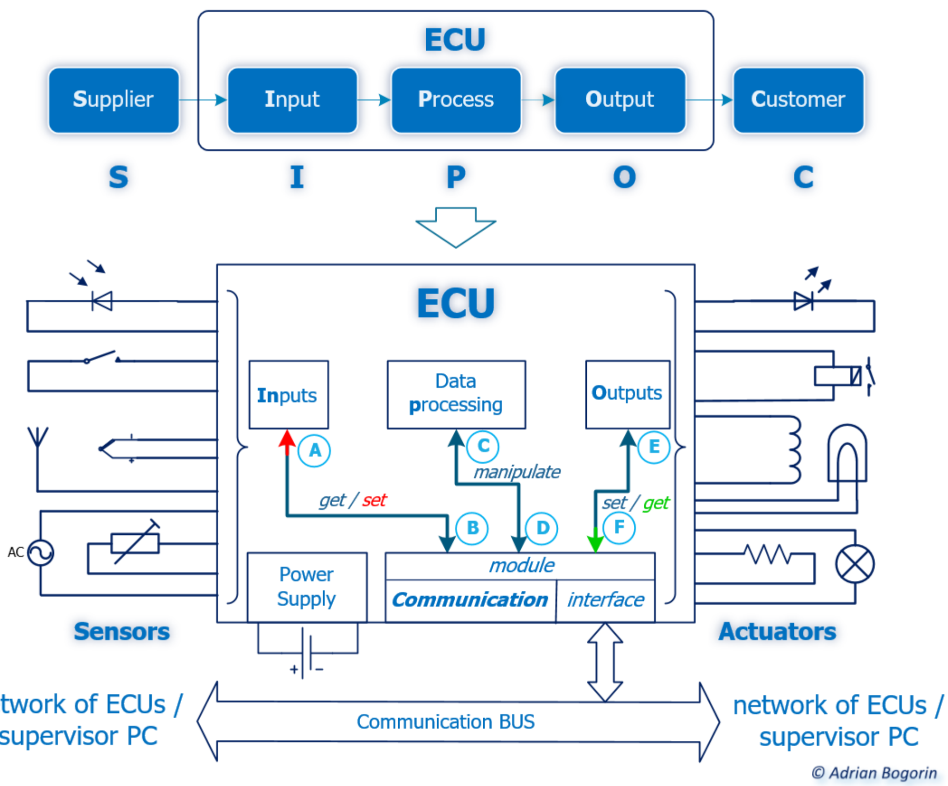


Fig. 1. ECU from the SIPOC perspective

Thus, from this new perspective, SIPOC becomes:

- "Supplier" consists of sensors (switches, optical, thermal, tensometric, acoustic, acceleration and gravity sensors, etc.) connected to the ECU that provide data collected about the surrounding world;
- "Input" are the inputs and blocks formed by the electronic components in the ECU for adapting the signal levels from sensors and

converters from analog signals (with which the surrounding nature works) to digital signals (with which the microcontrollers/microprocessors, digital computing systems work) for ECU;

- "Process", the microcontroller processes the data from the input, decisions are made, and actions are taken on the outputs;
- "Output", constitutes the outputs of the ECU through drivers which are hardware blocks actually made up of electronic power components for driving actuators, motors, signaling elements, etc.;
- "Customer" represents the end customer who benefits from the system in which the ECU is present, more precisely the effect that is consumed by the actuation elements from the actuators.

There would be another extremely important element shown in figure 1, which is not included in the SIPOC mapping, but which can "virtually" read and modify the data from I (Input), monitor and influence processing (P), and can read and modify the O (Output) data.

This new actor is the communication module in the ECU which is networked with other ECUs or even with a computer system used for diagnosis and/or control. Thus, it is possible to intervene in the system consisting of ECU, sensors, and actuators.

In this way, the input data provided by the sensors, from the "Inputs" block, can be read ("get") at point "B" through the communication interface and provided on the communication bus. In this way, each individual input can be individually tested.

Also, through the communication bus, the data present at point "A" can be altered by the "set" function. This action is useful for testing data processing algorithms from the "Data processing" block.

Even if the input data is valid, the system must be tested under boundary conditions, and this can only be achieved by injecting erroneous input data.

The "Data processing" block can also be interrogated, read internal data at point "D", or modify (rewrite) the value of internal data used by the operating algorithms at point "C" through the communication bus by a supervisory computer.

The process status of this block can also be read or modified. In this way the behavior of the ECU can be influenced. It is possible to act ("set") on the output block by changing the state of the actuators at point E for individual testing of each actuating element.

Thus, each execution element that is connected to the ECU can be tested individually. Also, through the communication bus, the states of the outputs (actuators) at point "F" can be read with the "get" function.

Data or errors can be injected into points A, C and E to test the ECU's behaviors under various conditions.

3. THE HOLISTIC APPROACH OF EMBEDDED SYSTEMS

The authors are of the opinion that a holistic approach to embedded systems should be given. The Hardware part, i.e., the physical part (electronics together with the electronic components and the microcontroller) must be in direct harmony with the firmware part (the software that runs in the microcontroller), to be mapped to the hardware. As shown in figure 2, the Hardware and the Firmware intertwine, like "body and soul". In the field of embedded systems, one cannot do without the other. Hardware without Firmware is nothing more than a lot of electronic components, wires and printed circuits that have no value, do not react to external stimuli and commands. Likewise, firmware without Hardware cannot exist.

The supervisory computer in figure 2 has the main role of supervising the activity of the embedded system in the prototyping phase, until the system is set up. It is also through it that each hardware component of the embedded system is tested.

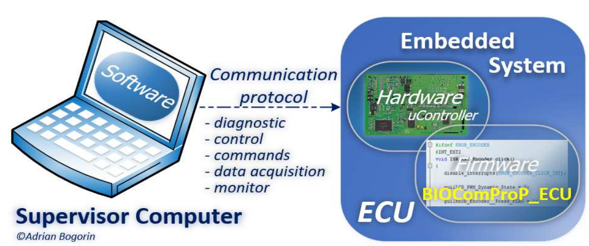


Fig. 2. Holistic approach to embedded systems

The supervisor computer's software is known as BIOComProP_TS (Test Software). The whole spectrum of microcontrollers on which the BIOComProP_ECU platform is installed can be tested, controlled, and monitored through the use of this program. The software is simply flexible and customizable to the demands of the user. The BIOComProP platform is made up of the BIOComProp_ECU firmware and the BIOComProP_TS software.
The "language" used to comprehend the computer with the embedded system is the communication protocol. This language is used for all computer commands, diagnosis, and monitoring of the embedded system.

4. BASIC INPUT OUTPUT COMMUNICATION PROTOCOL PLATFORM

In order to implement rapid prototyping, from the point of view of the software side. that runs in the microcontroller in the ECU, the authors propose the software platform BIOComProP_ECU from the figure 3.

Actually BIOComProP_ECU is part of the holistic approach of the BIOComProP software platform from the **B**asic **I**nput **O**utput **Com**munication **Pro**tocol **P**latform, more or less dependent on Hardware (microcontroller), compiler and the project that implements the prototype.

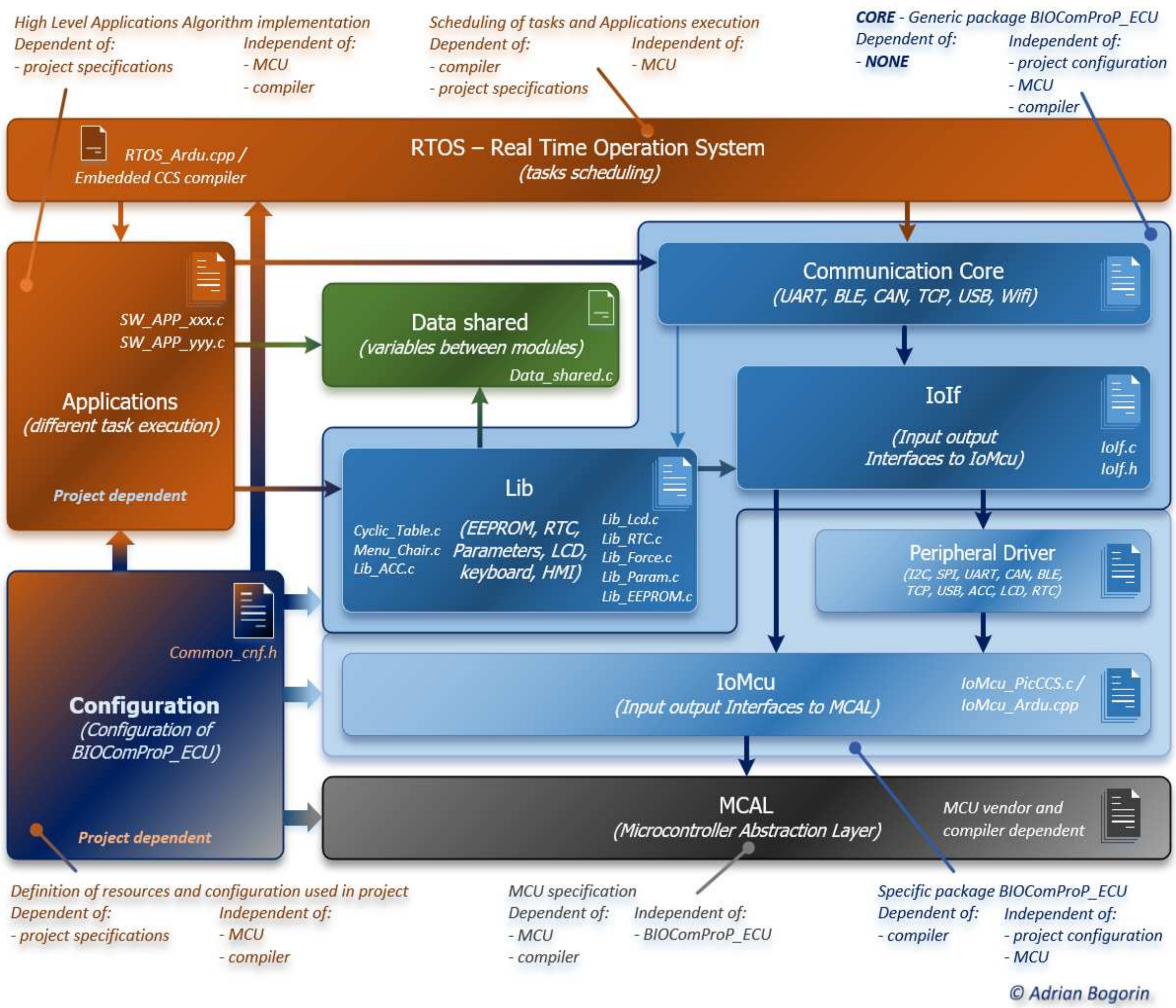


Fig. 3. "BIOComProP_ECU" Platform Architecture

The "*Configuration*" configuration module is a header file (*.h) under the name "Common_cnf.h" and the parameters in this file dictate the behavior of other software modules in the ECU. In relation to the MCAL module, the type of microcontroller used in the project is chosen, and each input and output that is used is assigned. In relation to the core "Generic package BIOComProP_ECU" defines which communication channels are used, select the libraries used in the project which can be the EEPROM permanent memory, the cyclic table "Cyclic_Table" for data acquisition, the libraries for processing signals from peripherals such as accelerometer, force sensors, LCD, and others. It also dictates what kind of peripherals are used, depending on their implementation at Hardware (electronics) level in the ECU. This module also controls the dedicated Applications module and the real-time operating system.

The "*Applications*" application module can consist of one or more apparently independent applications, but which use the same libraries to access hardware resources. It is recommended that each application be isolated in separate files suggestively named "SW_APP_xxx.c" and/or "SW_APP_yyy.c", where xxx and yyy denote the application names. The "Application" module is independent of the microcontroller and compiler used, but is strongly dependent on the requirements of the project in which it is implemented.

The module that implements the real-time operating system, "*RTOS*" (Real Time Operating System), has the main task of planning and executing tasks. Task, in the context of the operating system, can be equated to a running process. In microcontrollers with a single core (single core) there is no parallelism of task execution. Only one task can be executed (run) at a time, and all tasks are run sequentially, one after the other according to their priority and how often they need to be executed (repetition interval).

"*Communication Core*" ensures the ECU's communication. It is independent of the project configuration, microcontroller, and compiler.

The "*Lib*" module consists of "libraries" that implement various algorithms with different functionalities depending on the library used.

The "*IoIf*" (Input output Interfaces) module facilitates the access of modules from the core and modules that implement libraries to the microcontroller interfaces. This module makes the transition from "BIOComProP_ECU core generic package" to "BIOComProP_ECU specific package" but is included in the core.

The "*Peripheral Driver*" module, from the specific package of BIOComProP_ECU, consists of "drivers" for sensors and actuators that are added to the inputs or outputs of the microcontroller using the dedicated I2C and SPI buses.

The lowest module of the BIOComProP_ECU platform is "*IoMcu*" (Input output Microcontroller). This module makes the connection between MCAL (Microcontroller Abstraction Layer) which is dependent on the microcontroller on one side and "IoIf" and "Peripheral Driver" (if applicable) on the other side.

5. USE CASE

Several projects in the fields of innovation and IoT (Internet of Things) applicability have successfully used the BIOComProP_ECU platform. These initiatives include:

- Weather Station;
- Hydro-electric turbine linear unfolded on the streams;
- Portable Hydro-electrical Turbine with deformable paddles;
- Computer Chair with an Active Principle of Spine Relaxation.

The projects mentioned above make use of microcontrollers from several distinct chip families.

5.1 Weather Station

The project "Weather Station" falls within the Internet of Things (IoT) umbrella. However, a Wifi connection was required to the router, which is connected to the internet, in order to have access to the internet. The ESP32 is a 32-bit two core microcontroller that is available commercially and has Wifi capabilities.

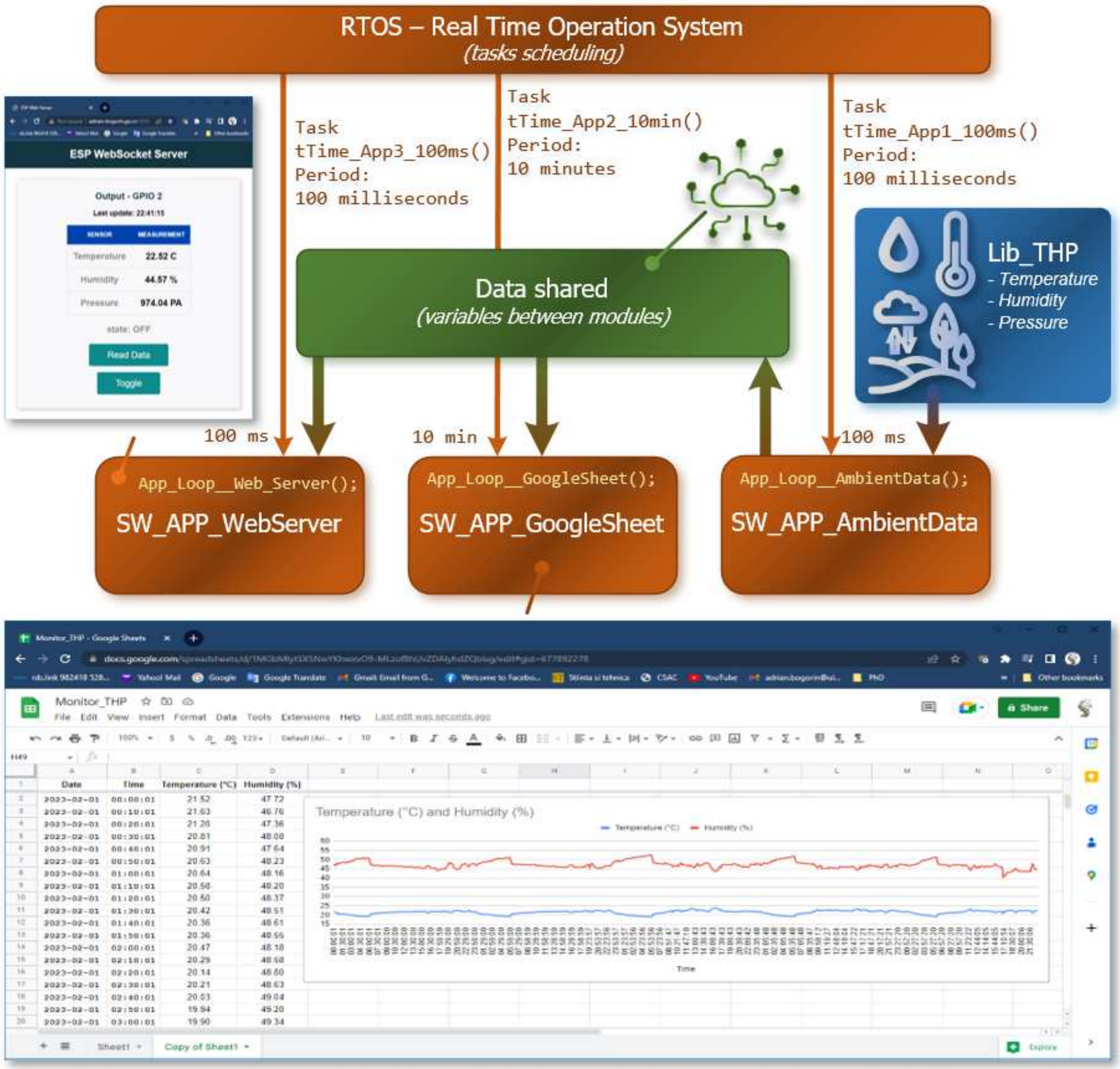


Fig. 4 Weather Station

The weather station is made up of a temperature, humidity, and air pressure sensor that is linked to the ESP32 microcontroller. The firmware architecture for the ESP32 microcontroller's BIOComProP_ECU platform is shown in Figure 4. The RTOS operating system manages the three software programs that make up the firmware. The BIOComProP_ECU platform's "Lib_THP" library allows the "SW_APP_AmbientData" application to read data from the ambient sensor. Every 100 milliseconds, the RTOS triggers the "tTime_Appl1_100ms" task, which calls the "SW_APP_AmbientData" application to read data from the ambient sensor and store it in the "Data shared" module.

The "tTime_App2_10min" task calls the "SW_APP_GoogleSheet" app every 10 minutes. This application's function is to store the temperature and humidity in the cloud (Google Sheet) so that it is able to be utilized later to graphically analyze the evolution of the environment. The third application "SW_APP_WebServer" provides the web server for monitoring temperature, humidity, and atmospheric pressure via a mobile terminal, such as a smartphone, and is called by the task "tTask_App3_100ms" every 100 milliseconds.

The project has demonstrated exceptional stability in the six months after Weather Station went live.

5.2 Hydro-electric turbine linear unfolded on the streams

The "Hydro-electric turbine linear unfolded on the streams" project is an application for Romanian innovation patent number 127219 (2017), and it comprises of a working prototype. This invention's goal is to convert some of the water's kinetic energy into electrical energy without harming the environment [8].

a) Prototype b) Remote Software

Fig. 5. Hydro-electric turbine linear unfolded on the streams

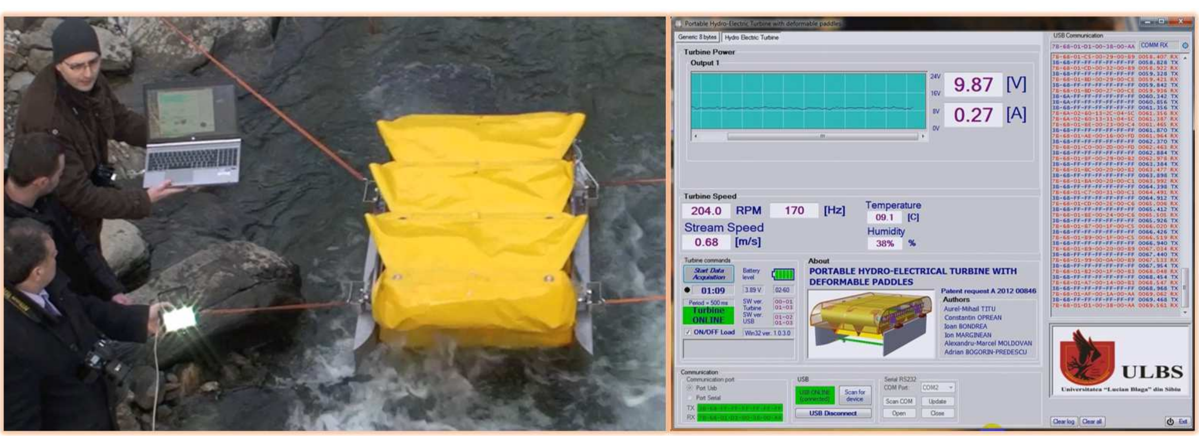
Figure 5 (a) depicts the prototype being tested on the Cibin River in Sibiu, Romania, while Figure 5 (b) displays the graphical user interface set up on a computer situated in the vicinity.

Here again, the BIOComProP_ECU platform was used to acquire data on the electrical parameters from the turbine. An electronic system with the PIC18F255 microcontroller and batteries was installed at the turbine in the mobile part of the system, which is positioned on the river. This system's job is to send the electrical characteristics of the turbine to the shore by half-duplex (double way) radio transmission.

5.3 Portable Hydro-electrical Turbine with deformable paddles

A functional prototype for the "Portable Hydro-electrical Turbine with Deformable Paddles" project has been submitted as an application for Romanian invention patent number 128224 (2018) [9].

On the Sadu river, near Sibiu, Figure 6 a) depicts the functional prototype being tested, and Figure 6 b) displays the visual user interface set up on a distant computer on the shore.



a) Prototype b) Remote Software

Fig. 6. Portable Hydro-electrical Turbine with deformable paddles [6][9]

The difference between this invention and the previous one is that it reduces the turbine's mass without compromising performance. The initial turbine's metal blades were changed to pliable textile blades, and the size of the floats was also decreased. This makes it easier and quicker to install the new turbine on the river [6].

The microcontroller that was used is a PIC18F2550, and the firmware design is the same as the previous turbine's BIOComProP_ECU. The protocol for communication between the computer on shore and the microcontroller at the turbine has been improved.

5.4 Computer Chair with an Active Principle of Spine Relaxation

The "Computer Chair with an Active Principle of Spine Relaxation" project is yet another application of the BIOComProP_ECU platform, but this time in the fields of medicine and offices. This puts into practice the Romanian innovation patent with the same name and number 129280 (2021).

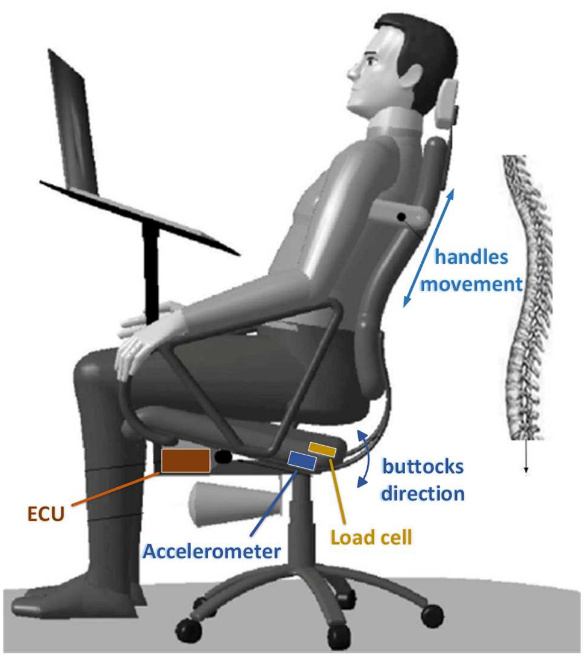


Fig. 7. Computer Chair with an Active Principle of Spine Relaxation [7][10]

The invention refers to a chair, shown in figure 7, intended for people who work for a long time at the computer. The invention's chair is made up of an ergonomic assembly that includes a computer and its accessories, a sub-assembly for independent, limited raising and lowering of a seat, an assembly of two folding levers for support of the human trunk in a partially suspended position, a control panel for operating and changing work sequences, and an electronic module built around a microcontroller PIC18F46K80 for implementing automatic and programmable work sequence.

Fig. 8. Chair exhibited at EUROINVENT 2018

The prototype depicted in figure 8 was embraced enthusiastically by the jury and visitors at the international inventory salons, and in 2018, while it was presented at the "EUROINVENT" Salon, the "Lucian Blaga" University in Sibiu won the top prize for its achievement.

Figure 9 illustrates the chair performing tests in a laboratory environment.

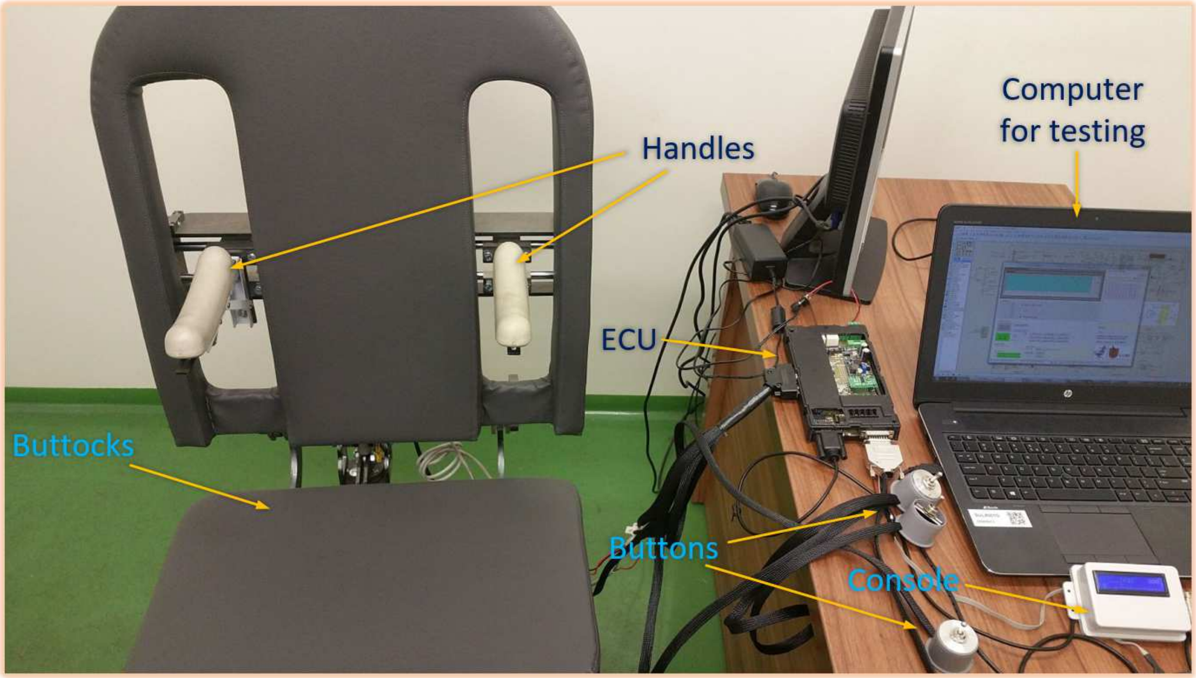


Fig. 9. Computer Chair with an Active Principle of Spine Relaxation, prototype in tests [7]

The invention's goal is to lessen the detrimental and stressful health effects of prolonged, continuous spinal compression when using a computer, as well as to lessen and remove the spine's already-accumulated damage from earlier, prolonged office work [10].

The chair was invented with the intention of decreasing the harmful health effects of the current compression of the spine during prolonged immobility of the human body, as well as to decrease and eradicate the current injuries of the spine. It is meant for those who spend a lot of time working at computers.

6. CONCLUSION

The main advantage of the BIOComProP_ECU platform is the reuse of source code that is available from projects where it has already been implemented and used. Each new project in which this platform is used is an opportunity for its improvement and development.

The BIOComProP platform is implemented in several applications in the energy and medical field [6] [7].

Also, this software platform is intensively used in the field of innovation by "Lucian Blaga" University in Sibiu for validating functional prototypes through data acquisition [8] [9] [10]. Another advantage is that it is independent of the microcontroller used. This reinforces the idea of portability without much intervention in the source code of the platform.

Probably the most powerful and important feature consists in reducing the development time of the software (Firmware) that runs in the microcontroller, saving financial resources and time for future projects in which this platform is used.

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ÎMBUNĂTĂȚIREA CALITĂȚII PROCESELOR DE PROTOTIPARE RAPIDĂ A UNITĂȚILOR ELECTRONICE DE CONTROL PRIN UTILIZAREA UNEI PLATFORME DE SOFTWARE DEDICATE

Lucrarea științifică prezintă posibilitățile de îmbunătățire a calității proceselor de prototipare rapidă a unităților electronice de control folosind o platformă software dedicată. Sunt analizate produsele din categoria sistemelor embedded (ECU – Electronic Control Unit), pe baza unui protocol de comunicare original prin care starea sistemului poate fi diagnosticată în timp real în diferite faze de dezvoltare. Această platformă software numită BIOComProP (Basic Input Output Communication Protocol Platform) este utilizată în special în faza de prototip al ECU pentru testarea individuală a fiecărei componente hardware conectate la intrările și ieșirile microcontrolerului care este elementul de comandă și control al ECU. Platforma BIOComProP se dorește a fi portabilă și extensibilă pe orice familie de microcontrolere de la diferiți furnizori de componente electronice și aduce valoare adăugată pentru a reduce timpul de dezvoltare și implementare a noilor proiecte bazate pe această platformă. Platforma este formată din două părți: BIOComProP_ECU - software-ul care rulează în ECU și BIOComProP_TS - software-ul care rulează pe computerul unde se efectuează diagnosticarea și testarea ECU. Autorii prezintă, de asemenea, o metodologie de cercetare dedicată, precum și rezultatele cercetării și nu în ultimul rând concluziile obținute.

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