MECHATRONICS LEARNING WITH A "PLUG AND PLAY" TRAINING PLATFORM

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Abstract. *The challenges of Mechatronics teaching were never small, yet they grow fast in order to follow the pace of the evolving technologies and requirements of the 21st Century. This article presents a flexible and modular training platform for affordably allowing students and educators to enjoy a more effective Mechatronics teaching. By easing the task of implementing, setting up and developing multidisciplinary laboratory experiments, this platform helps to narrow down the gap between conceptual/theoretical teaching and the tangible aspects of the real world. This system is currently being considered for use in the Mechatronics specialization course at COPPE/UFRJ.*

Keywords*: Educational technologies, training platforms, learning by doing, hands-on projects, project-based learning (PBL)*

1. INTRODUCTION

While the challenges of Mechatronics teaching have never been small, they have been growing rapidly to keep up with changing technologies and new demands of our times. The very conceptual nature of control theory alone often becomes a factor of discouragement for the students, already overwhelmed by the multidisciplinary characteristics of Mechatronic´s learning (Bernstein, 1999a). On the other hand, the diversity inherent to the curriculum of Mechatronics ends up facilitating the sharing of theoretical and practical tasks when the teaching method is through "learning by doing" (Li et al., 2005). Therefore, there is room or even the need to develop educational tools that make easier the implementation of laboratory experiments capable of narrowing the gap between conceptual/theoretical teaching and the tangible aspects of the real world (Bernstein, 1999b). This paper presents an educational training platform designed to affordably improving the experience of students and educators involved with the learning of Mechatronics and Control Systems, where there is much to be gained with a hands-on approach (Lee et al, 2008). Multidisciplinary experiences that include data acquisition, automatic control, microcontrollers, sensors and actuators are possible just with the help of a desktop computer or a regular notebook. The general design of the equipment allows exercises to be programmed in LabView, C, C + +, Visual C + +, Visual Basic, Delphi and also in environments such as Matlab / Simulink. The training platform itself is standalone, compact, portable, easy to configure and operate and can be powered by a standard AC outlet or by batteries when needed. Recent studies do not measure efforts to encourage intimacy between students and laboratory practices, with the introduction of educational platforms intended to be used at home by students (Jouaneh et al., 2009). To cross the barrier that separates the virtual world from the physical reality, it is necessary to have more equipments than just the common personal computer found everywhere. A working mechatronic plant, actuators and sensors that detect the behavior of the system; data acquisition modules to convert physical data into digital information that can be processed by suitable computers, indicators, displays and recorders to track process, and of course, power supplies to feed all components. The international market offers a variety of educational kits to support and complement the teaching of engineering in general and of Mechatronics in particular. Offered by various suppliers, for use in class or lab, capable of local or remote operation, one factor stands out when it comes to learning platforms, however, is its high price. The essential software for the use of such learning platforms itself already represents a substantial cost to the often limited budget of universities, schools and training centers. The growing recognition of the importance of team-working and hands-on practical work (Lengerke et al, 2010), clearly shows the convenience if not the need of having learning platforms that are affordable, versatile and easy to set up. Thus, the initial goal that led to the development of the educational platform proposed, herein called MTP-11, is to design a complete and independent training set that dismisses the use of sophisticated data acquisition modules. Even more, a platform that requires just a minimum of external resources for its operation, yet maintaining a low enough cost to assure its widespread use.

The first step to take is to produce an easily configurable and simple unit for data acquisition using serial communications through the USB ports commonly available in PC computers nowadays.

2. SOFTWARE

At the start of the second decade of this century, a substantial number of software packages for engineering is available: simulators, emulators, compilers and integrated development environments. Classics such as Matlab, Simulink, Mathematica, LabView, PSCAD, OrcCad, SolidWorks and several implementations of Spice are extensively used by educators, engineers and students in universities, research centers and industries. The primary software environment chosen to be used by the MTP-11 is the LabView from National Instruments, which offers unique features and extensions that would permit the expansion of the initial proposals of the learning kit, not being something new the recognition of the flexibility and convenience of this software environment (Matey, 1993). However, the development of exercises and laboratory practice using programming languages like C, C + +, Visual C, Delphi or Visual Basic is also possible through the use of a dynamic link library (DLL),-developed and distributed by Microchip Technology Inc. Overall, simulation and analysis programs allowing input/output operations via USB or serial ports, such as Matlab/Simulink, for example, can also be used successfully. LabView is a graphical object-oriented programming language designed to allow the development of virtual instrumentation, data acquisition and control. Its use as a tool for rapid prototyping (McKerrow, 2001) is especially attractive in the development of PID controllers, which allows students of automatic control to develop systems without having to write lengthy individualized programs and make use of various electronic instruments laboratory at the same time. With the help of its library functions, it is also possible to implement signal processing, motion control, navigation and object perception. Programs written in this environment are called virtual instruments (VIs) and contain two parts: a front panel and a block diagram, as shown in Fig. 1a and Fig. 1b below:

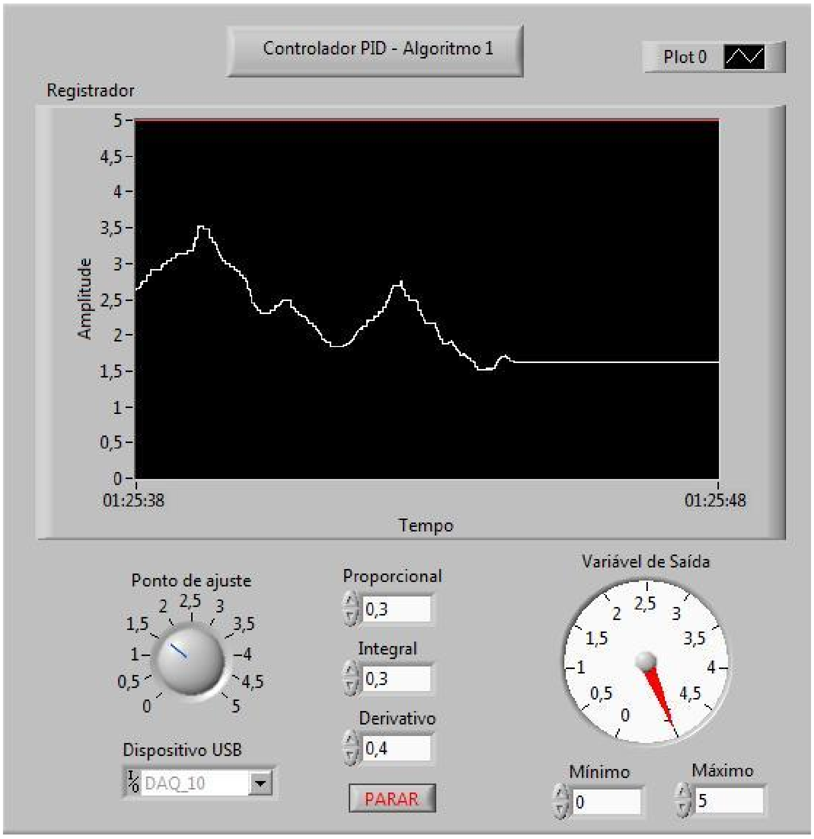

Figure 1a. Typical control panel

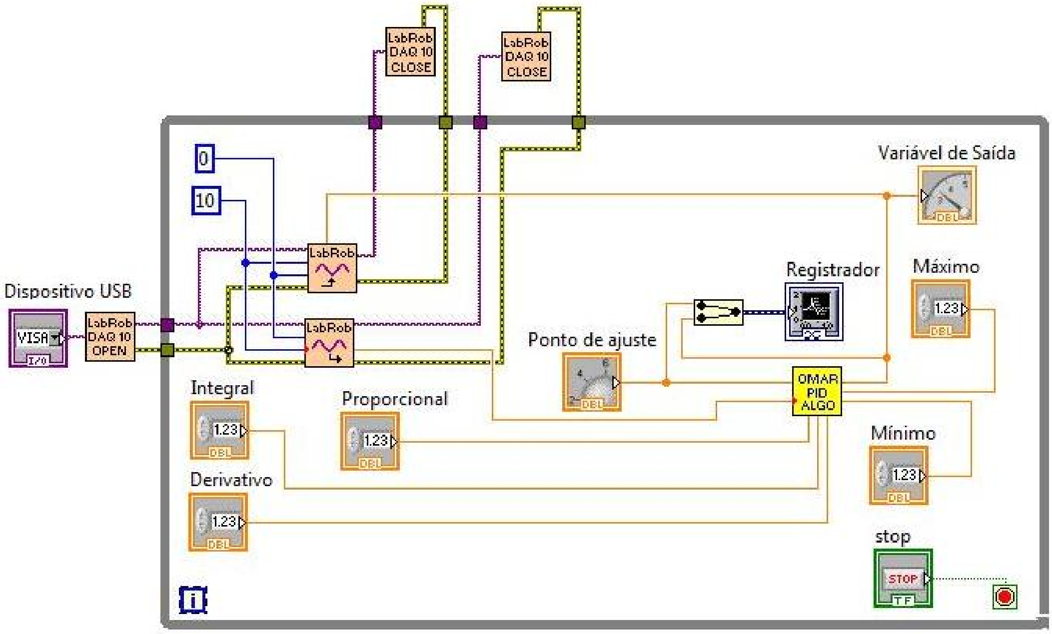

Figure 1b. Typical block diagram

The control panel represents a metaphor of a set of conventional measurement instruments and can be designed to show as many individual instruments as desired. The block diagram contains functions, logical structures, indicators, switches and interconnections that give functionality to the system as a whole.

3. SYSTEM DESCRIPTION

The educational platform MTP-11 can basically be understood as a mechatronics interface between a personal computer and the real world. The mechanical assembly was designed to allow the installation and use of custom modules that can easily be changed to modify the nature and type of training that one wishes to perform, not differently from the concepts applied to the electronics on board. For the companion PC computer, desktops, laptops or notebooks running Windows, Linux, or even variants of the Mac family can be used, provided they are able to comfortably meet the demands of the analysis and simulation programs intended to be used. However, the preferred option is for a notebook computer of modest cost, which enables the system to be used without the need for external power and at the same time making easier the transport and storage of all components. The educational platform MTP-11 was sized to be stored and transported in a shoulder bag or a common notebook hard case, getting its power through the USB port of your computer when running practices that do not involve power components. In this mode of use, the variety and type of possible laboratory practices are limited by the capacity of the USB port to supply electrical current, which is nominally less than 0.5 A. In practice, as even lower power levels should be used, this mode of operation does not support the use of motors, heaters and other power devices. However, the basic module of Mechatronics, for example, can normally be used without an external source, since their sensors, switches and indicators are low power devices by nature. For use in conventional classrooms, laboratories, or even at home, the educational platform MTP-11 makes use of an external universal type AC-DC power supply, which enables the use of the equipment in several regions of Brazil and other countries as well. Internally, another multiple outputs power supply is intended to feed the circuits of pluggable modules for training and also the additional user circuitry. The internal source is sized to provide energy to power actuators, electric motors, heaters, solenoids and incandescent lamps, provided the total power drain is less than 40W, and symmetrical supply voltages for low power other circuits such as amplifiers operating converters, interfaces and solid state indicators. The equipment is designed to use an external battery power supply too, making its use feasible in situations where the availability of electricity is limited.

4. DATA ACQUISITION MODULE (DAQ)

To meet the needs of connection to the real world, we chose to develop a simple and easily configurable module for data acquisition. The connection to the companion computer is done using the USB port, which at present is the de facto standard for serial connection between personal computers and external peripherals. The interface chosen is the full speed type, which provides an actual speed communications of up to 1MB / s under the standard USB 2.0. It was also decided to use single end analog inputs and outputs with a voltage range between 0 and 5 volts. In this manner, it was possible to avoid using in the DAQ itself circuitry like dual polarity conditioning circuits, programmable attenuators and amplifiers, simplifying the design and easing the requirements for reconfiguration of the module prior to each experiment. This decision, however, does not prevent performing experiments that require dual polarity inputs or outputs, variable gain or attenuation, where appropriate. This can be accomplished with operational amplifiers, discrete components and integrated circuits assembled in the space reserved for the user or even in the section intended for rapid prototyping. All analog and digital inputs are equipped with full protection against overvoltage and reverse polarity, in view of the typical conditions they are submitted while an educational kit, not always entirely predictable. The main features of the data acquisition module - DAQ, are presented in Table 1:

USB Data Acquisition Module	
Analog inputs	8 fully protected inputs
Analog inputs type	Single-ended, 12 bits resolution, 0 / + 5V
Sampling rate	10k samples per second
Analog outputs	2 outputs, 10 bits resolution, PWM, 0-100%, 0 / + 5 V
Digital inputs	8 fully protected inputs
Digital outputs	8 buffered outputs, 20mA source/sink max. each
Digital I/O logic levels	TTL/CMOS, 5 volts
PC connection	USB 2.0 or USB 1.1
Power source	5V @ 100 mA max., supplied by USB port
Operational Systems	Windows 7 / XP, Linux e MAC OS

Table 1. DAQ module features

During the early stages of development and testing, independent prototypes were built of the data acquisition module, an experimental plant and power supplies. The first version of the data acquisition module, termed as DAQ-10, can be seen in Figure 2:

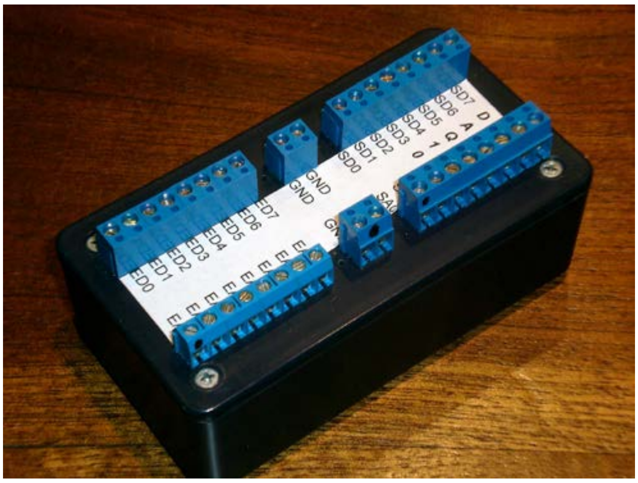

Figure 2. Prototype of the DAQ module

4.1 HARDWARE

The micro-controller (MPU) selected for data acquisition and control of the platform is the 18F4523 from Microchip Technology Inc. This device has the necessary analogue to digital converters and the ability to generate analog output via pulse-width modulation (PWM), and also has a high speed built-in USB interface. It is a low cost and high performance device which can reach 12 million instructions per second (MIPS) when using an external crystal of 20MHz. This crystal is used as a reference in an internal phase locked loop -PLL circuit, that generates a 48MHz frequency for clocking the MPU. The available input/output ports of the device were distributed among the system and user sections of the platform as shown in Table. 2:

System Interface Module	
One 10-bit PWM analog output	Power amplifier
Two 12-bit analog inputs	Current meters, 0-2.5A range
Three 12-bit analog inputs	Voltmeters, 0-5V range
One 12-bit analog input	Voltmeter, 0-15V range
Four digital inputs	General purpose TTL/CMOS inputs
Four digital outputs	General purpose TTL/CMOS outputs
User Interface Module	
One 10-bit PWM analog output	General purpose PWM analog output.
Two 12-bit analog inputs	General purpose 0-5V analog inputs
Four digital inputs	General purpose TTL/CMOS inputs
Four digital outputs	General purpose TTL/CMOS outputs

Table 2. MPU ports assignment

The assignments shown in Table 2 above can be changed and configured differently, both in the section of the user as the default section. However, the user interface module is designed specifically for this purpose and may be modified or even replaced by a custom module that complements the hands-on experiments available.

4.2 FIRMWARE

The resident software (firmware) in the microcontroller platform is based on the Microchip USB Firmware Framework, by the company of the same name, which is a set of modules that constitute a standard structure intended to be used in applications that use USB ports. Such applications, running under Windows, can have indirect access to USB ports through the driver mchpusb.sys and the library mpusbapi.dll, which includes the basic functions needed for this kind of communications. A custom user module, consisting of initialization routines, AD and DA conversion, read and write ports and a protocol type of command / response structure was added to the USB stack.

4. 3 SUB-VIs

In the LabView environment, sub-Vis are the equivalent of subroutines, functions and methods found in other programming languages. There should be VIs prepared to read and write to digital and analog ports, as well as to neatly open and close each one of these operations, Fig. 3:

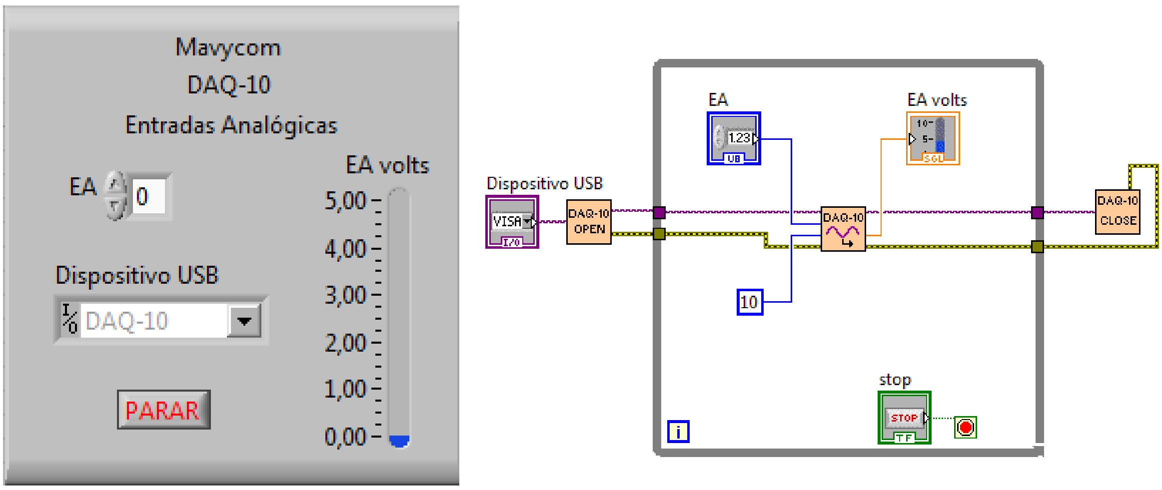

Figure 3. Analog inputs panel and block diagram

The panel of Figure 3 shows that it is only needed to select the USB device in use and the analog channel to be read, among the eight available. In the block diagram, one can identify three different DAQ VIs and a constant value that determines how long the program waits for a response after a command is issued.

5. MAINFRAME

The mainframe consists of a rigid base to be placed on top of a regular table or countertop. It is powered by an external AC-DC universal switching power supply, which can be connected to the power mains supplying from 90 to 250VAC, without the need of any kind of switching. The trainer´s circuits, plug-in modules and additional user circuits are powered by an internal power supply, fed from the main external power supply. To supply power for actuators, motors, heaters, solenoids and incandescent lamps, limited to less than 40W, there is a separate voltage source, thus avoiding the transients associated with power actuators that may interfere with the low level circuits such as operational amplifiers, converters, interfaces and solid state indicators. For these circuits, two complementary low power outputs are available, together with a third output for feeding digital circuits in general. Contemplating the use of the platform in educational environments where the availability of electricity is limited, such as in rural areas or when travelling, an auxiliary pack was developed consisting of an external power supply, battery and smart charger, which keeps the battery always ready without requiring any operator intervention. For occasional use, external batteries with higher capacity are also provided for the use of, which may be connected where this need exists. The structural design of the mainframe, with its various sections, is shown in Fig. 5:

Figure 5. Mainframe with a plant about to be installed

The Mainframe has its top panel divided into five separate sections. In the first section on the left side are the power switch activity indicators of USB communication and power supplies status. The main section, which occupies most of the center part of the platform, intended to receive the pluggable modules of different plants developed, which fit easily and are fixed by two clamps. The data acquisition module - DAQ is located under the section where the mechatronics plant is fastened, and may have its top cover removed for inspection or components upgrading. Conditioning and interface circuits for the various plants provided are situated in the Standard Interface Module, located in the section just behind where the plant sits. On the right side of the training set there are sections for the user, comprising the User Interface Module and the User Prototyping Module, the latter contemplating the possibility of adding circuits for quick tests or even auxiliary circuitry that does not require many components or solid connections.

The arrangement of the different sections on the main module is shown in Fig. 4:

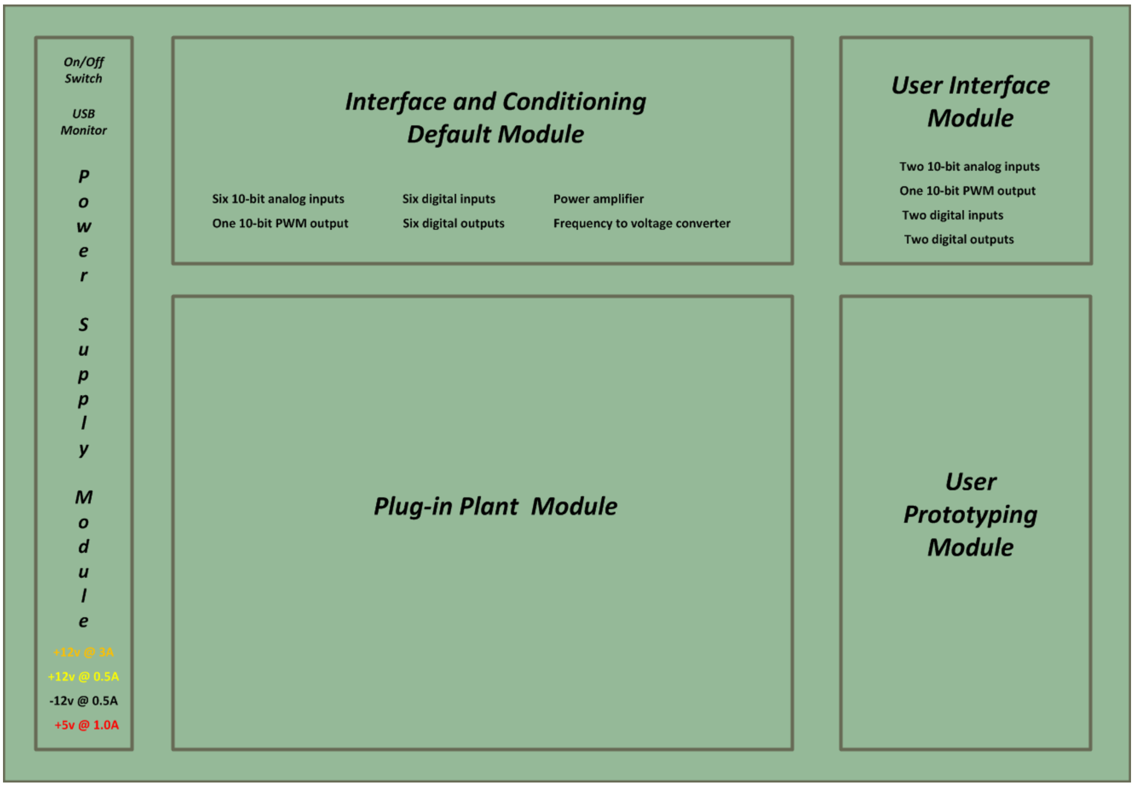

Figure 4. Mainframe top panel layout

The electronic modules of the system and user interface sections can be easily removed for maintenance, repair or upgrade, without having to disassemble the mainframe. For the module user, this feature includes customizing existing experiments or the introduction of new hands-on exercises.

6. PLUG-IN MODULES

The use of plug-in modules for the mechatronic plants entails that most of the time available for practical exercises is actually employed in its execution rather than in preparing or setting up the equipment. This feature allows a quick installation of the modules, without having to individually make the various electrical connections necessary to operate the plant. Several types of exercises of similar nature can be performed with the same plug-in plant. Initially four basic plants were designed, and the DC Motors plant will be presented as an example.

6.1 DC MOTOR PLANT

This plant has a symmetric configuration, where two permanent magnet electric motors are aligned to enable the coupling of their shafts when desired, thus forming a reversible motor-generator set. Each motor has its own optical tachometer, comprising a switch disc and a transmitter-receiver set with infrared LEDs. Despite its simplicity, this versatile configuration allows any of the two motors to be used as the active element, such as a controlled linear mechanical load or as a tachometric generator. Practices referred to this plan involve the estimation of parameters, speed and position control, PID control, open and closed loop response of electric motors. Each motor has a removable metal disc attached to one end of its shaft, the other end being used to hold the optical coded disc that comprises the tachometer. The DC motors shafts can spin in both directions; although most control exercises do not require this behavior, position control and servo control labs do need to change the direction of rotation on the fly.

The DC motor Plant prototype is shown in Fig. 6:

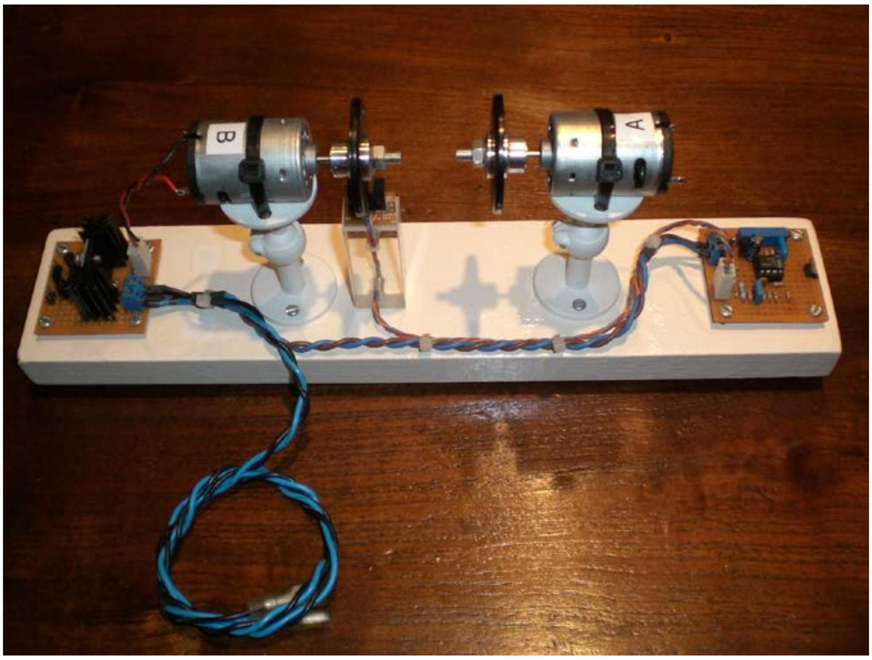

Figure 6. Prototype of the DC motor plant

6.2 OTHER PLANTS

The Mechatronics Plant is equipped with sensors (temperature, pressure, visible light and infrared (IR), position, magnetic field), magnetic and piezoelectric actuators and controls, switches and various indicators. The Heating and Cooling Plant employs a thermal chamber for the evaluation of sensors, heaters, fans and basic or proportional temperature control. The Environment and Weather Plant is equipped with a set of sensors for acquiring experimental data on temperature, pressure, rainfall, wind speed and direction. This plant is designed to be operated in local mode, for evaluation and initial calibration, or in remote mode, so as to permit controlled exposure to the elements. Additionally, the educational platform MTP-11 can also be used in teaching, training and validation of prototypes at a distance by means of conventional wired networks, through wireless networks or even via a conventional radio link. Moreover, while using LabView it is possible to have video acquisition and image processing, clearing the way for visual inspection of systems, for locating and identifying objects or routes and also for implementing machine vision.

7. CONCLUSIONS AND FUTURE WORK

By developing and using the prototype of the MTP-11, it was confirmed the advantages of having a simple modular learning kit for replacing data acquisition laboratory instruments that are usually employed to supplement the learning of Mechatronics. The basic premise of presenting a simple and effective alternative to the expensive imported kits was maintained, while keeping in sight the restrictions that are defined in the specifications of the platform. If it is necessary or desirable to extend the range of practical exercises already prepared, the MTP-11 educational platform provides space and resources for adding custom interfaces or circuits designed to expand their basic abilities. We conclude that the initial goal of developing a viable and simple to use training platform has been achieved by the trainer described in this article, considering its main features: versatility, the use of plug-in mechatronic plants requiring minimal effort to set up, affordability and simplicity of operation. An attractive alternative for the already defined and ready to use experiments is to use the platform as a basis for other customized variants of "hands-on learning" and mainly for project-based learning (PBL), which allows the teaching of Science and Technology students with varied backgrounds and enables them to research, plan and design (Doppelt, 2005, 2000). In these cases, new plants can be designed, developed and built as practical projects, increasing the amount of ready plug and play exercises and also serving the purpose of allowing students indeed to learn by doing throughout the course (Piguet et al., 2001). Educators and engineers can also benefit from an environment where ideas and concepts can be quick validated in practice without having to order different equipment and precision instruments that will be used often with only a fraction of their capacity. The rapid development of modular mechatronic prototypes is favored to the extent that the simplicity and low cost of the sets described enables the availability of several units that can work collaboratively, controlled by a single computer or several of them together.

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