An alternative approach in mechatronics curricular development at AFEKA – Tel-Aviv Academic College of Engineering and at Tel-Aviv University

Eli Flaxer (corresponding author), Israela Becker and Boris Fisherman
AFEKA – Tel-Aviv Academic College of Engineering, 218 Bney Efrayim Rd, 69107 Tel-Aviv, Israel
E-mail: flaxer@afeka.ac.il

Abstract The AFEKA – Tel Aviv Academic College of Engineering has developed a program in mechatronics studies designed not just for students of mechanical engineering but for every student in any field of engineering, as well as for experimentalists in natural sciences. This program supplies the students with tools that allow them to gain interdisciplinary insights and to carry out interdisciplinary final projects. In this paper we outline this program and give a detailed description of some unique features of the mechatronics laboratory.

Keywords mechatronics; laboratory; interdisciplinary

Introduction

In an interdisciplinary world, the term 'mechatronics' is no longer a futuristic term but rather a contemporary one (as with bioengineering, robotics or nanotechnology). As such, many engineering departments have developed impressive curricula in mechatronics as part of their programs in mechanical engineering [1–3]. Some departments even offer a BSc degree in mechatronics [1]. At AFEKA – Tel-Aviv Academic College of Engineering, we feel that if mechatronics is to be a truly interdisciplinary field of study, then it should not be restricted to students of mechanical engineering, but be offered to every student in each of the three departments of our school: mechanical engineering (ME), electrical engineering (EE) and software engineering (SE). Since the academic year 2000–01, we have been offering two courses in mechatronics *designed for all three departments*. Both courses are obligatory for each ME student. For students in either of the other departments, both are elective. Students who attend these courses acquire experience in carrying out interdisciplinary projects, which they value. Consequently, there is a growing number of final projects for the BSc degree which are interdisciplinary.

In this paper, we describe the key features of our mechatronics courses that make them relevant to many disciplines in engineering, as well as for students in chemistry and physics; these courses have been taught in parallel at the School of Chemistry in Tel-Aviv University (TAU).

Structure of mechatronics studies and course organization

The general purpose of the mechatronics courses is to expose students to an interdisciplinary field, one which is a principal industrial field. The more specific goal is to provide the students with tools to perform a mechatronics-oriented final project that counts towards the BSc degree and that will equip them with skills that will appeal to a potential employer.

In the light of this, we offer two courses of mechatronics. One is a weekly, one-semester, four-hour laboratory course. It provides students with both a theoretical background and applied tools with which they can solve problems in the field of mechatronics. This course is divided into four parts:

(1) The students first study the C programming language, along with data representation in binary systems, bit manipulation, basic computer architecture, and absolute memory and I/O port accessing.
(2) Then, the students learn the programming graphical user interface (GUI). We used the National Instrument [4] Lab Windows/CVI environment to write the program and the GUI. This environment was chosen because it has several distinct advantages: complete transparency to the programmer who programs in C, as there is no need to write any source code line to produce this GUI; full compatibility with ANSI C, and compatibility with C++ using an external compiler like visual C; a wide range of support in addressing many hardware devices and instruments; low-level support drivers for I/O port addressing; and a wide range of libraries (advance analysis, PID, TCP, Internet, GPIB, VISA, RS-232, VXI, etc.).
(3) Next, advanced toolbox libraries are introduced. We emphasize the use of advanced numerical analyses, data acquisition, signal processing, control, and communications. During the semester, the students numerically work out basic issues which are engaged with mechatronics – heat transfer, vibration, fluid flow, statics and dynamics.
(4) Lastly, as a final assignment of this course, the students read and write analog and digital signals from an oscilloscope and a function generator, through standard ports such as RS-232 and GPIB.

The other mechatronics course is a weekly, one-semester, five-hour laboratory course. It provides the students with practical mechatronics. We begin with basic hardware elements, such as counter timers, power-switching devices, power-amplifying devices (used in electromechanical control systems) and PWM controllers. All these devices are combined into a tailor-made I/O board, designed for this course (see below). The students experience multi-threading programming, real-time applications, and the use of the Transmission Control Protocol (TCP) for control and data acquisition. Then, the students are fully prepared to control DC motors, stepper motors, heating elements, thermoelectric coolers, and sensing elements, such as photo-resistor thermistors, opto-couplers and photodiodes. The final assignment of this course is chosen by the students themselves. They carry out an experiment in which they use the program they developed to PID control a system of their choice. In this experiment the students characterize the typical parameters of the system and present its real-time response.

Detailed description of the hardware

In this section we provide a detailed description of the IO drive 2000 interface board, the embedded evaluation board, and the systems that are controlled by the students. Students routinely use the IO drive 2000 interface board coupled to the PC to perform all the tasks on these courses. Students who wish to acquire further experience for their final project are given the embedded evaluation board to use for practice in their free time.

IO drive 2000 interface board

This board, presented in Fig. 1, was tailor-made for the mechatronics courses; however, it can also be used for other laboratory courses. It is unique because it contains the required power devices on board and is externally connected to the computer (to laptop computers as well as desktop computers). This allows for portability of the entire experimental set-up and enables trouble-free computer upgrading.

The board connects to the parallel port, communicates with the computer using the Extensible Provisioning Protocol (EPP), and enables a data transfer rate of one megabyte per second (depending on the operation mode and the specifications of the computer). The board requires an external power supply with a flexible voltage range (12–36 V) and current that meets the requirements of the system.

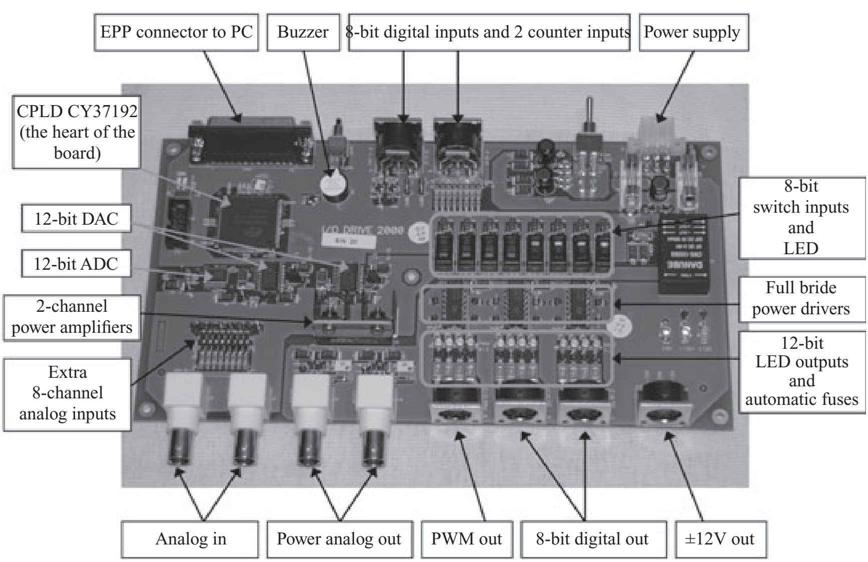

Fig. 1 *The IO drive 2000 interface board.*

This board has an 8-bit digital input that reads active and passive digital signals within the range of [0 V, 5–50 V]. This allows TTL levels to be read, as well as other standard levels of industrial and scientific equipment. The data reading rate can reach up to 1 MHz.

This board has an 8-bit digital output that enables it to simultaneously drive devices that consume up to 1 A each. In addition to the 8-bit digital output, there is a four-channel programmable PWM output that also enables the simultaneous operation of devices that consume up to 1 A each. The PWM switching frequency is 100 kHz, while the duty cycle can reach 256 levels, which represent 0.4–100%. All output channels permit inward and outward current flow, while the data change rate in the outputs can reach up to 1 MHz.

The board contains two independent analog outputs. Each supplies a variable voltage within the range of ±10 V, with a resolution of 12 bits, and a current of up to 1 A. The data change rate in the output can reach 100 kHz.

There are also eight independent analog inputs. Each enables a variable voltage to be read, within the range of ±10 V, with resolution of 12 bits. The data reading rate can reach 100 kHz.

The board also includes two programmable counter timers of a specific architecture, which can be modified by altering the programmable logic. The outputs of the counter timers are connected outwards and enable a current flow of up to 20 mA. The board can send an interrupt request to the computer through the parallel port. The interrupt can be triggered by the counter timer or by the user.

Embedded evaluation board

In addition to the IO drive 2000 interface board, we designed an alternative standalone embedded board that allows the user to control the systems without using a PC, as shown in Fig. 2. This prepares the student to work in any environment that requires portability or compactness of design.

This board is based on a Microchip [5] PIC16F877 8-bit microcontroller. This controller includes 8 kbyte of flash memory for programs, 256 byte of RAM for data storage and 128 byte of EEPROM. It contains five bi-directional ports and peripheral devices (among which are three timers), five analog input channels, a synchronous UART, an asynchronous UART, an I^2C communication bus and an interrupt controller.

The board itself contains additional peripheral devices, such as a matrix keyboard, eight digital switches, a 16-bit bi-directional bus, an 8-bit digital output with an eight-LED indicator, an LCD alphanumeric display, two analog output channels and a buzzer.

The development procedure, namely, programming, compiling, linking and debugging, is performed in an MPLAB environment, which is freely distributed by Microchip [5].

Laboratory equipment for processes control

The IO drive 2000 interface board is equipped to control various systems, for example to govern light intensity, temperature, speed of a DC motor, or the angle

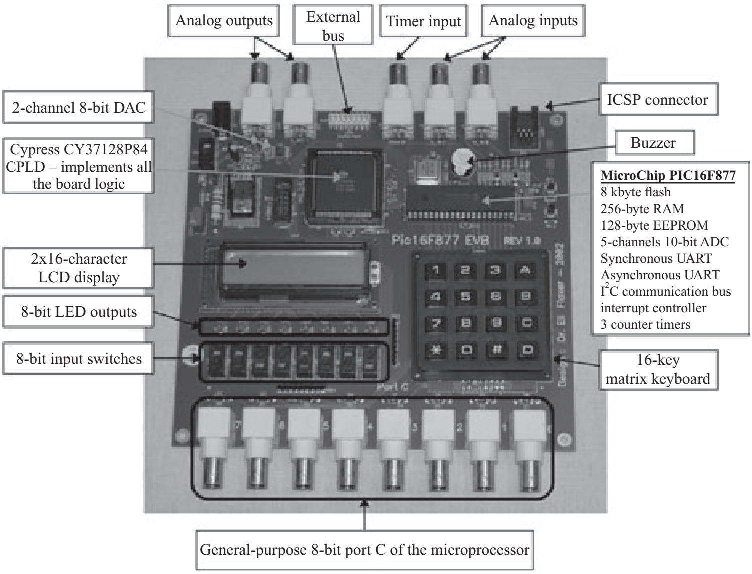

Fig. 2 *The PIC EVB evaluation board for the Microchip PIC 16/18 microcontroller.*

controlled by a stepper motor. Fig. 3 shows a typical workstation at the laboratory, with the IO drive 2000 interface board and a compact box containing the experimental set-up for the control of light intensity. This unit can be replaced by others for different control purposes.

Prior to describing the various systems to be controlled, we must indicate that the chosen control units are not necessarily linear over all the measurement range, as in real life. This is undesirable but can be easily compensated for, as we control the systems by computer and so the software can produce a corrected transfer function (by interpolation, hash function or table of values).

Light intensity control

The radiant element is a 12 V/1 A light bulb with a time constant of 30 ms. The sensing element is a photo-resistor that changes its resistance in a range from 100 Ω (for full daylight) to 1 MΩ (darkness). This photo-resistor is serially connected to a 10 kΩ resistor, and the two form a voltage divider that depends on the light bulb's intensity. The output of this voltage divider runs between 0 V and 10 V. Since the radiant element is a light bulb with a finite heat capacity, it has a typical time constant (30 ms, in our system), which can be measured using the sensing element. The time constant of the photo-resistor is in the range of a few microseconds, and therefore negligible with respect to the time constant of the light bulb. The set-up of this experiment is presented in Fig. 4(a).

Fig. 3 *A typical laboratory station, designed for the use by one or two students simultaneously. The computer is an all-in-one IBM PC, which saves laboratory space and allows the latter to contain additional stations. Note at the middle left side of the picture the compact external IO 2000 drive, which contains the required power devices and below it, the compact box that contains the experiment set-up for light intensity control.*

Temperature control

A 5 × 5 × 1 mm piece of copper with a heat capacity of ~0.1 J/Cº is attached to the hot side of a thermo-electric cooler (TEC), while its cold side is attached to a heat-sink. The temperature of this copper piece is sampled by a negative temperature coefficient (NTC) thermistor. The room temperature resistance of the sampling thermistor is 10 kΩ, while its B-constant is 3380 K, which leads to a resistance of 70 kΩ at –40ºC and 3 kΩ at 60ºC. The thermistor is serially connected to a 10 kΩ resistor and both form a voltage divider whose configuration depends on the temperature of the copper. The output of this divider runs between 1 V and 8 V. The heat transduction element is a TEC. This TEC has a power of 18 W, maximum current of 2.1 A, maximum voltage of 16 V, resistance of 6.3 Ω, and a maximal temperature difference (ΔT) of 70ºC. These parameters are compatible with the specifications of the IO drive 2000 interface.

The use of a TEC as the heat transducing element has a significant advantage over other methods of temperature control. Conventional heating elements can only introduce heat into the controlled element and therefore the cooling of the controlled element is dictated by the surroundings. The usage of a TEC allows the user either