The Control Subsystem of a Mechatronic System

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Abstract

The paper describes the main features of a control subsystem integrated in the structure of a mechatronic system. Examples of control systems developed by the authors in the frame of the Laboratory of Robotics, Actuators and Accurate Automated Systems are also presented.

Keywords
Control subsystem, mechatronic system, data acquisition board, microcontroller, PLC.

Introduction

Informatization of mechanical systems has leaded to a significant qualitative progress of the field. The mechatronic concept emerged naturally as a synergistic combination of three domains: mechanics - electronics – informatics and respectively pneumatics-electronics-informatics. Specialty literature does not offer a unitary definition of the term of mechatronics. IEEE (Institute of Electrical and Electronics Engineers) and ASME (American Society Mechanical Engineers) promote the following definition: “Mechatronics is the synergistic integration of mechanical engineering with the electronic control and the intelligent, PC-based control, in the design and manufacturing of goods and processes.”

In fact, everything that we denote as high technology product is a mechatronic product. The well-known mechanical systems represent the support for configuring mechatronic structures. For this reason, several subdomains of mechatronics were outlined in time: robotics, hydronics, pneutronics, optomechatronics, automotive mechatronics, mechatronics in civil engineering, mechatronics in home appliances, agro mechatronics etc.

Terms like micromechatronics, nanomechatronics and biomechatronics are also present in specialty literature. The “increase of intellect of machines and systems” represents nowadays the general tendency.

The structure of a mechatronic system

Today we meet mechatronic equipments (equipments that feature integrated control electronics and function by observing a pre-established program implemented at the level of a PLC or PC), but mostly mechatronic systems of high complexity. However, it is possible to find a common structure (fig.1), in which one can identify the main components of such a system, namely:

- hardware components:
  - the mechanical structure of the system, where the kinematic subsystem and the driving system can be located;
  - the control subsystem – the electronic control unit; the construction of some equipments can integrate the electronic unit; system electronics are considerably simplified in this case;
  - the informational subsystem;

- software components – programming/control languages and environments; based on these components, specific work programs are written for each application.

1. The mechanical structure consists of three subsystems:

   - kinematic subsystem – subsystem that enables the displacement of the mobile subassemblies of the system according to the work program; in the case of a robot, it fulfills the following tasks: generates the space trajectory of the mass centre of the manipulated object, orientates the
manipulated object, allows its gripping and detachment;

- motion subsystem – subsystem that allows the driving of mobile subassemblies;
- internal sensor subsystem – subsystem that sends to the control unit information on the configuration of the mechanical structure joints at a certain moment in relation to a reference configuration called initial configuration; a series of sensors (position sensor, speed sensor, acceleration sensor, force sensor etc.) can be identified at this level.

2. The environment – is the universe where the articulated mechanical system can be found. The function of the system is defined not only by the nature of performed operations, but also by the nature of the environment in which the movements take place. The specific features of the environment where the system works lead to some restrictions regarding its evolution.

The system receives information from the external environment through a specially designed sensor system that can contain video cameras, proximity sensors, force detectors, tactile sensors etc.

Figure 1: Structure of a mechatronic system

3. The control subsystem – contains the electronic subsystem and the control unit – “system’s brain”; its role is the analysis of the information input by the operator or received from the internal and external sensor systems; this module is in fact a PLC, a computer of a group of microprocessors. Based on the received information, the “brain” estimates in each moment the system state, the environment state and the task to be accomplished and outputs real-time control signals for the motors integrated in the system. These signals will establish the further evolution of the system, in relation to the pre-established program. Therewith, useful information is stored at this level:

- a model of the mechanical structure, that contains the relations that connect excitation signals to system displacements;
- an environment model – a description of the working space that outlines the obstacles and describes the objects to be manipulated;
- a series of control algorithms.

4. The objective to accomplish – represents the task (the function) that has to be fulfilled by the system. In order to reach the objective, it has to be described, defined using various means of communication with the system: gestures (when the needed movements are shown to the system), orally (when the system is told what to do), writing (the objective is described using an adequate language).

The control subsystem

The central element of a mechatronic system is the control subsystem that commands, controls and optimizes the process. Two components can be identified at the level of the control subsystem: the electronic unit and the control unit.
The electronic unit has to adjust the control signals output by the control unit and by the sensor subsystem to the level required by the motion system, in order to be useful to the control unit. Sometimes, this unit can fulfill additional tasks: system protection, display and setting of some functional parameters etc.

This unit can contain:
- basic electronic components: resistors, potentiometers, condensers, rectifier diodes, stabilizers, transistors etc.
- linear integrated circuits based on operational amplifiers: ramp generators, step generators, adders, PID regulators, Dither generators, current generators, oscillators, demodulators etc.
- supply units;
- A/D and D/A convertors.

The complexity of such a unit depends of the type of equipment used in the construction of the motion system; equipments that integrate in their construction the corresponding control electronics can be found nowadays, simplifying the structure of the electronic unit.

The control unit of a mechatronic system can be based on: a PC, a microcontroller or a PLC.

- **Control subsystem based on PC**

This version of control system is chosen in the case of very complex applications, mainly in research activities, in laboratory conditions, when an experimental model has to be tested. Large scale use is limited by the high costs involved.

The personal computer has to fulfill a series of other tasks: process control, signal analysis and treatment, control of series and parallel connections, display of results, diagram plotting etc. Accordingly, the manufacturers offer, beside systems, a series of software programs intended to users.

In the case of industrial systems, data has to be collected from the harsh industrial environment. In these cases it is recommended that the measurement be performed close to the phenomenon to be studied and data to be processing centrally, in a safe place. The control system has to be placed far from the served system.

The structure of the technical system often includes a high number of sensors from which the information has to be acquired. Concurrently, a number of digital or analogue outputs have to be sent to the system. The connection of sensors and actuators (magnets, proportional magnets, stepping motors, d.c. motors) to the computer would involve a high number of wires.

If the control system is configured around a PC, one of the following versions can be chosen:
- PC + data acquisition board + software;
- PC + I/O modules + software.

Generally speaking, the term of computer-aided data acquisition refers to a system consisting of a PC, a software product and a PC-controlled data acquisition board. The board is usually mounted inside the computer, but can be also found as an external module, for instance connected to the computer through the USB port.

The ideal solution is to mount the board inside the computer, because this way the acquired data can be treated in real time.

Data acquisition boards can include circuits for signal conditioning according to the physical magnitude to be acquired, one or more multiplexers, A/D converters whose resolution is defined by the requirements of the measurement process.

An elegant solution of solving such a problem [1] involves connecting the system to the computer through an I/O modular system (fig.2).

National Instruments offers for this purpose I/O modular systems. Such an example is the FieldPoint I/O system, whose main feature is a modular architecture, configurable according to users’ needs. The system allows connecting a number of analogue and digital I/O modules mounted on a rail through connection bases to a PC using a serial connection (RS232) or an Ethernet connection.

The I/O modules are placed as close as possible to the sensors integrated in the monitored processes or to the tested equipment. Configuration simplification (by suppressing the connections to the sensors and replacing them with a single connection, for instance RS232) leads to the following advantages: simplified structure of the system, reduced costs, less installation time, increased insensitivity to perturbations, very good performances.

Because the Fieldpoint I/O modular system was designed to function in industrial environments, characterized sometimes by harsh conditions, its components can work in a range of temperatures between 40\(^\circ\) and 70\(^\circ\)C, in presence of strong vibrations and impacts. Producers guarantee as well good electric isolation among the various inputs and outputs.
Control subsystem based on microcontroller

The microcontroller represents an efficient low cost solution for the control of a mechatronic system. Because the microcontrollers are designed using ‘all in one’ technology – all the components on the same board – their power requirements are reduced and they can fulfill complex tasks involving real-time data acquisition, monitoring and control. The same board integrates: the microprocessor, memory circuits, A/D and D/A converters, digital and analogue inputs and outputs, counters, real-time clocks, serial ports (RS-232/485/422), lithium battery, expansion port PLCBus etc.

Keyboards and LCD/VFD or touchscreen displays can be attached to microcontrollers if needed. If the keyboard and the display are not present, they can be connected through a PLCBus port. A wide range of expansion modules facilitates adding analogue or digital lines or increasing the number of serial ports. These modules can be easily connected to microcontrollers through the PLCBus port as well.

The applications are developed on a personal computer, using various development environments. The program is then transferred in microcontroller’s memory through the serial port.

Today the manufacturers offer a wide range of microcontrollers. Figure 3 presents an example of mechatronic system controlled by a PIC18F2420 microcontroller [2].

Control subsystem based on PLC

Electronic control subsystems based on PLC (Programmable Logic Controller) are the most used in industrial applications. According to user-defined software programs, these subsystems control applications, display process state, signal failures and communicate among them or with other control structures through standardized networks.

An example of mechatronic system (a pneumatic driven robot) [3] controlled by a PLC is presented in figure 4.

The robot is controlled by a PLC of type ECC–PNAL–24M–D, belonging to the αPneuAlpha2 series and manufactured by SMC.

Signals output by the two controllers, by the proximity sensors from the system and by the START and RESET buttons are connected to its digital inputs.

The magnets of the system’s spool valves and the START and EMERGENCY inputs of the two controllers are connected to the digital outputs of the PLC.

The work program was developed using Pneu Alpha Visual Logic, a software package specially designed to be used with the controllers of the series αPneuAlpha and αPneuAlpha2.
The system presented in figure 4 features the following modules and constructive elements:

- Ox axis translation unit - UTOx;
- Oy axis translation unit - UTOy;
- Oz axis translation unit - UTOz;
- orienting device and mechanical hand - DO+MM;
- PLC;
- pressure regulators – RP;
- work programs selection system – SP.

Conclusions

The central element of a mechatronic system is the control subsystem, which controls, sets parameters and optimizes the process. The control subsystem can be structured around a personal computer, a microcontroller or a PLC. The option for a certain version depends on the complexity and destination of the mechatronic system.

High complexity systems, mostly found in research activity, in laboratory conditions, when the testing of an experimental model is intended, are controlled by a PC. The most part of industrial mechatronic systems
are controlled by PLCs.

For complex processes, the interaction between the two families cannot be anymore avoided. The need of networks that would integrate PCs as well as PLCs emerged.

For modern applications that use PLCs, the type of processor integrated in the PLC is not important, meaning that the main difference between PCs and PLCs consists in the operating system or the application’s software.

An increasing number of applications feature a control subsystem structured around a microcontroller. The microcontroller represents today an efficient low cost solution for the control of a mechatronic system.

Bibliography