A low-cost control system for hydraulic applications

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Abstract— **This paper discuss the main technical issues related with the development of a low-cost control system for hydraulic applications. A prototype of the device equipped with sensors was first tested and calibrated in the laboratory before operating it under actual field conditions. The control system was developed using exclusively free programs which can easily be downloaded on Internet and easy-to-find components, which can be purchased in any electronics store.**

Keywords- low cost, design, contro,l system, hydraulic

I. INTRODUCTION

A growing number of organizations are implementing a new approach to research and development, granting awards and contracts to researchers who invent or adapt low-cost technologies to meet the needs of people in the world's poorest places [1].

The engineering profession must revisit its mindset and contribute to the building of sustainable, stable, and equitable countries. As Maurice Strong, Secretary General of the 1992 United Nations Conference on Environment and Development, said, "*Sustainable development will be impossible without the full input by the engineering profession*". For that to occur, engineers must adopt a different attitude toward natural and cultural systems and reconsider interactions between engineering disciplines and nontechnical fields.

Engineers in developing countries have to cope with difficulties and challenges that their colleagues in developed countries do not even think about. As an example, many electronic components and mechanical parts may be difficult or impossible to purchase. Moreover, importation may be slow, complicated and expensive because of corrupt officers, taxes, intermediary firms, etc.

Another source of problems is that often technicians and operators are not used to complex state-of-the-art technologies, simply because they have never been exposed to it.

This paper discuss the main technical issues related with the development of a low-cost control system for hydraulic applications. A prototype of the device equipped with sensors was first tested and calibrated in the laboratory before operating it under actual field conditions. Control hardware and software have been developed using exclusively free programs which can easily be downloaded on Internet.

The proposed control system is able to handle different hydraulic applications: constant pressure pumping, hydro-pneumatic applications, waste water pumping, etc.

The system is also low cost, easy-to-fabricate, using components that can be found in local stores. The particular conditions due to economical restrictions in our country were considered for the final design. But these conditions also apply to many other developing countries.

Another goal of this work is trying to jump the well-known gap which exists between the academic world and the industrial/residential needs.

The exposition is organized as follows. In section II, a brief analysis about previous related works is presented. In section III the development process is described. In section IV the control system is introduced, in both hardware and software aspects. Finally, conclusions are drawn in section V.

II. PREVIOUS WORK

Many authors have proposed low cost systems to solve different technical problems. Next, several publications are reviewed.

In [2] a methodology for the low-cost design of fail safe circuits and networks is presented. The proposed methodology is independent of the functional dependence between inputs and outputs, and provides a systematic framework for exploring different implementations of fail safe circuits for graceful degradation.

In [3] a low-cost flyback ac/dc converter with harmonic current correction and fast output voltage regulation is proposed. An extra winding wound in the transformer provides two key advantages. First, the size of the bulk inductor used in the conventional boost-based power factor correction cell is significantly reduced. Second, the voltage across bulk capacitor is held under 450V by tuning the transformer winding ratio, even though the converter operates in a wide range of input voltages.

In [4] a low cost digital solution, based on DSP, is proposed to control a UPS system. In addition, the digital controller provides advantages such as programmability, less susceptibility to environmental variations, fewer parts count, complex current control and system integration.

In [5] the authors propose a low cost antialiasing method that operates in the image domain. It is based on fitting curves to the discontinuity edges extracted from the aliased images to shade those edge pixels. To improve the performance and the simplicity of the method, the authors propose to preprocess all possible edge patterns and fit curves in advance. During runtime, they construct an index to obtain the filtering information from a lookup table. The authors claim the proposed method is extremely simple and efficient. It provides a good compromise between hardware cost and output image quality. In addition, because the new method has a very low computational cost, and hence low power consumption for hardware implementation, it is particularly suitable for low-cost mobile applications such as computer game consoles and palm computers, where low implementation cost and low power consumption are important design factors.

III. HYDRAULIC APPLICATIONS

A. Constant pressure system

In this application the pumps are alternated, always holding a constant pressure in the pipeline. Alternating pumps is a good strategy from both maintenance and operation point of view: it allows easy pumps replacement in case of failure.

B. Hidro-pneumatic system

Another way to guarantee the constant water pressure is to install a hydro-pneumatic system, where a cumulative tank of air assumes the energy reserve. Depending of the pressure level and pipeline operation, the system has a compressor in order to elevate the pressure range inside the accumulator tank. The water to use in this process has to be clear or at least filtered.

C. Calibration of instruments

Calibration of instruments like flowmeters (see figure 1) may be improved by a multi-purpose configurable control system.

Figure 1. Venturi meter in a 10 inch pipeline

Figures 1 and 2 show pictures of a Venturi meter and a calibration tank in the Laboratory of Fluid Mechanics, at Simón Bolívar University, Venezuela.

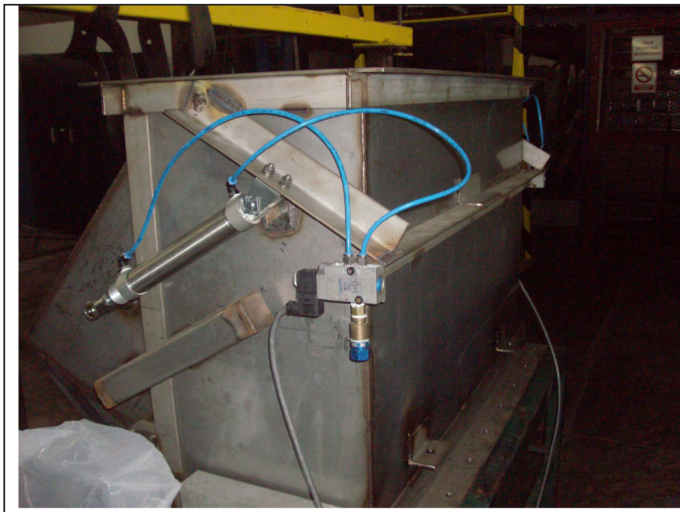

Figure 2. Calibration tank

IV. DEVELOPMENT PROCCESS

The development process was divided in the following stages:

A. Information Gathering

At this is stage the goal is to have the best knowledge related to the needs of those who will install, use and maintain the system. There are many different ways to collect information, including:

- conversations and meetings.
- workplace documents (emails, minutes, reports).
- customer and supplier feedback (surveys, suggestions, complaints).
- journals, newsletters, books and Internet.

B. Program edition and simulation

The **MPLAB** Integrated Development Environment (IDE) has been used to edit and simulate the control program. It is a free, integrated toolset for the development of embedded applications employing Microchip's PIC® and dsPIC® microcontrollers. It includes a host of free software components for fast application development and super-charged debugging. MPLAB IDE also serves as a single, unified graphical user interface.

C. Protoboard testing

A protoboard is a construction base for a one-of-a-kind electronic circuit, a prototype. It is reusable, and thus can be used for experimenting with circuit design more easily. This is also in contrast to stripboard and similar prototyping printed circuit boards, which are used to build more permanent soldered prototypes or one-offs, and cannot easily be reused. A variety of electronic systems may be prototyped by using breadboards, from small analog and digital circuits to complete central processing units (CPUs).

Once a prototype is wired on a protoboard, the designer can check whether the system is working as it should and fix the *bugs* he could encounter. At this stage, we have selected only easy-to-find components, which can be purchased in any electronics store. Of course, this makes the design more difficult but simplifies the purchasing process.

D. Prototype PCB design

Electronic design automation (also known as EDA or ECAD) is a category of software tools for designing electronic systems such as printed circuit boards and integrated circuits.

For this project the software **Free PCB** was used. It is a free, open-source PCB editor for Microsoft Windows®, released under the GNU General Public License. It was designed to be easy to learn and easy to use, yet capable of professional-quality work. Some of its features are:

- 1 to 16 copper layers, board size up to 60 inches by 60 inches
- uses English or metric units (i.e. mils or mm) for most functions.
- footprint libraries, wizard and editor for creating or modifying footprints.
- copper fill areas
- footprint Imports and exports PADS-PCB netlists
- Exports extended Gerber files (RS274X) and Excellon drill files
- design rule checker
- auto save function

E. PCB fabrication

A printed circuit board, or PCB, is used to mechanically support and electrically connect electronic components using conductive pathways, tracks or traces etched from copper sheets laminated onto a non-conductive substrate. It is also referred to as printed wiring board (PWB) or etched wiring board.

PCBs are inexpensive, and can be highly reliable. They require much more layout effort and higher initial cost than either wire-wrapped or point-to-point constructed circuits, but are much cheaper and faster for high-volume production. Much of the electronics industry's PCB design, assembly, and quality control needs are set by standards that are published by the IPC organization.

To generate Gerber files the software GC-Prevue has been used. Provided free of charge, GC-Prevue allows viewing and printing electronic manufacturing data. GC-Prevue reads all of the common CAD generated electronic manufacturing outputs, including Gerber-X (RS-274X), Gerber-D (RS-274D), DPF (Barco), Excellon, Sieb & Meyer, HPGL, and HPGL2.

F. PCB assembly

A PCB populated with electronic components is a printed circuit assembly (PCA), also known as a printed circuit board assembly (PCBA). In through-hole construction, component leads are inserted in holes. In surface-mount construction, the components are placed on pads or lands on the outer surfaces of the PCB. In both kinds of construction, component leads are electrically and mechanically fixed to the board with a molten metal solder.

There are a variety of soldering techniques used to attach components to a PCB. High volume production is usually done with machine placement and bulk wave soldering or reflow ovens, but skilled technicians are able to solder very tiny parts (for instance 0201 packages which are 0.02 in. by 0.01 in.) by hand under a microscope, using tweezers and a fine tip soldering iron for small volume prototypes. Some parts are impossible to solder by hand.

Often, through-hole and surface-mount construction must be combined in a single assembly because some required components are available only in surface-mount packages, while others are available only in through-hole packages. Another reason to use both methods is that through-hole mounting can provide needed strength for components likely to endure physical stress, while components that are expected to go untouched will take up less space using surface-mount techniques.

V. CONTROL SYSTEM DESCRIPTION

A. Hardware

The system hardware can be explained from Figure 3. It is composed of the following elements:

a) Input signal conditioners: These devices convert the electrical signals coming from pressure and flow sensors (that can not be read directly by the microcontroller) into a more easily read format. In performing this conversion three functions take place: amplification, electrical isolation and excitation. Two easy-to-find chips were used at this stage:

- a 4001 which contains 2-Input NOR gates based on CMOS technology, constructed with N- and P-channel enhancement mode transistors. This device has also buffered outputs which improve transfer characteristics by providing very high .gain.
- a 74109 wich contains two independent positive-edge triggered J-K flip-flops, with preset and reset inputs.

b) Micro-controller: A microcontroller can be considered a self-contained system with a processor, memory and peripherals and can be used as an embedded system [6]. For this project the microcontroller PIC16F877 (Microchip®) has been selected. It is an easy-to-program (only 35 single word instructions) CMOS FLASH-based 8-bit microcontroller. It features 256 bytes of EEPROM data memory, self programming, an ICD, 8 channels of 10-bit Analog-to-Digital (A/D) converter, 2 additional timers, 2 capture/compare/PWM functions, and a synchronous serial port. All of these features make it ideal for advanced level A/D applications in automotive, industrial, appliances and consumer applications.

c) Output signal conditioners: These devices convert the low-voltage signals generated by the microcontroller into high-voltage signals that can energize control relays or contactors. In this project, we have used the chip 7407 which contains 6 TTL buffers/drivers featuring high-voltage open-collector outputs for interfacing with high-level circuits (such as MOS), or for driving high-current loads (such as lamps or relays), and also are characterized for use as buffers for driving TTL inputs.

d) Control Relays: These are electromechanical devices which activate one or more switches according to the current through a coil not connected to the switches. A thyristor is a semiconductor device which can be used to carry out similar functions. A relay allows high power circuits to be switched by a low power control system. For many years relays were the standard method of controlling industrial systems. Several relays can be used together to carry out complex functions. Relay logic is the predecessor of ladder logic, which is commonly used in Programmable Logic Controllers (PLC).

Note that both PLCs and PCB technologies have different advantages. If the controlled is a typical production equipment with an electrical cabinet, PLC could be preferable. Not only are they easier to troubleshoot, they have the ability to be modified easily in the field and there is no minimum quantities to order. In terms of cost, a simple PLC might cost $100 and a large unit might cost over $5000.

Moreover, the ladder logic used by PLCs is a very simple way to program simple control functions like turning motors on and off based on a set of inputs. In PLC the logic is obvious and easily modifiable. Industrial control systems are almost always done with PLC's.

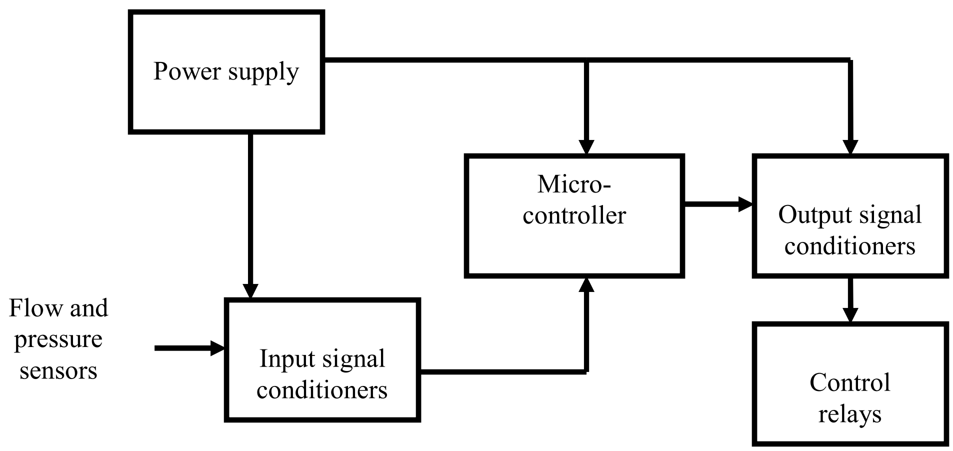

Figure 3. Block diagram of the control system

Designing a PCB system has lower component costs and a much smaller footprint, but there is much more time involved. As it has been shown before, not only it is necessary to write a control program and specify all the components, the designer must also design the PCB and get it manufactured (which can be expensive), and finally assembly the board.

Thinking about the current project, there is an economical reason which justifies the development of a PCB-based control system: there are not local PLC manufacturers and the importing process is slow and expensive. Furthermore, the number of potential customers is high this is another reason to justify the proposed approach in the present work.

B. Software

Figure 4 shows a flowchart representing the program which is executed by the micro-controller. First, the inputs coming from field sensors are read. According to their values, a security test is performed, to prevent potentially dangerous situations (e.g to pump water from an empty storage tank).

If the security test is passed, a control mode is selected. Each control mode is defined by a different algorithm. Then, control outputs are computed and the program loop is repeated. The sampling period can be easily adjusted changing the program code. In fact, several timing procedures have been set up (not shown in the flowchart for simplicity) to improve the system robustness against noise and meaningless electrical perturbations.

VI. CONCLUSIONS

The main technical aspects related with the development of a low-cost control system for hydraulic applications were discussed.

Control hardware and software have been developed using exclusively free programs which can easily be downloaded on Internet: MPLAB IDE, Free PCB and GC-Prevue

Because the technology is low cost relative to its income-generating potential, users and vendors can recoup their investment in short time. Maybe the most important lesson we have learned from this work is that for low-cost systems, basic is better.

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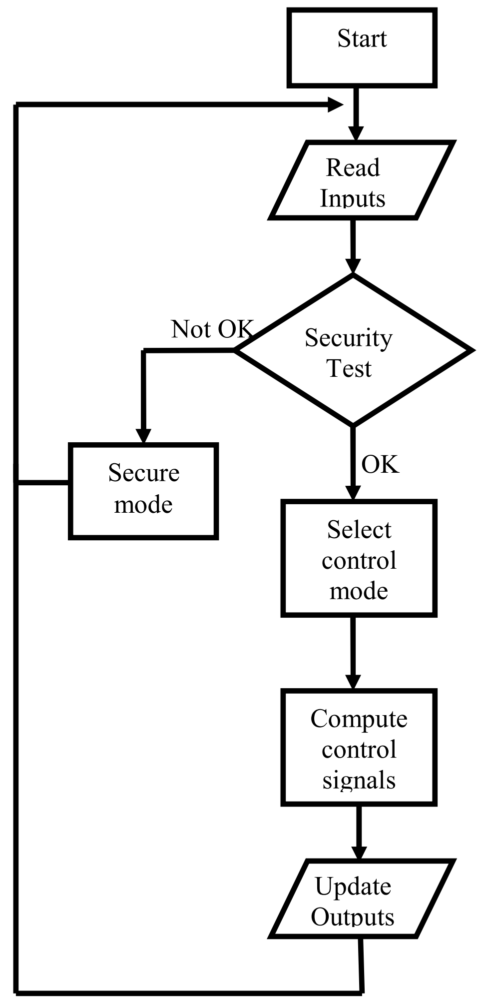

Figure 4. Flowchart of the control system