HARDWARE/SOFTWARE ARCHITECTURE FOR ADAPTIVE CONTROL SYSTEMS

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ABSTRACT: An architecture that combines hardware and software components in order to setup an adaptive control system is here presented. To act as an adaptive control for cutting processes, a system has to perform some specific tasks, as measuring the instantaneous values of a certain parameter of the process, and delivering correction inputs to the process. Furthermore, it must have a specific component that allows dimensioning the correcting inputs for the process, related to the perturbations occurred, to ensure the process stabilization. The main hardware component of the solution proposed consists of a Kistler platform, and the software that gathers data from the platforms' sensors, computes the value of the correction and delivers it to the process is LabVIEW.

KEY WORDS: Adaptive control, Kistler dynamometer, LabVIEW.

1 INTRODUCTION

During the past decades the number of computerized numerical controlled (CNC) systems has grown tremendously in almost every field of manufacturing. A common drawback of these systems is that their machining control variables, such as speeds or feed-rates, are prescribed by a part programmer and consequently depend on his or her experience and knowledge. In order to reduce the risk of a tool failure, the part programmer must consider the most adverse conditions (which in practice will seldom occur), and select conservative values for the machining variables. This practice consequently slows down the system's production.

The availability of a dedicated computer in the control system and the need for higher productivity has greatly accelerated the development of adaptive control (AC) systems for metal cutting.

These systems are based on real-time control of the cutting variables with reference to measurements of the machining process state-variables. The adaptive control is basically a feedback system that treats the CNC as an internal unit (see figure 1), and in which the machining variables automatically adapt themselves to the actual conditions of the machining process.

AC systems for machine tools can be classified into three categories (P. Stavropoulos, 2013):

1. adaptive control with optimization (ACO)
2. adaptive control with constraints (ACC)
3. geometric adaptive control (GAC).

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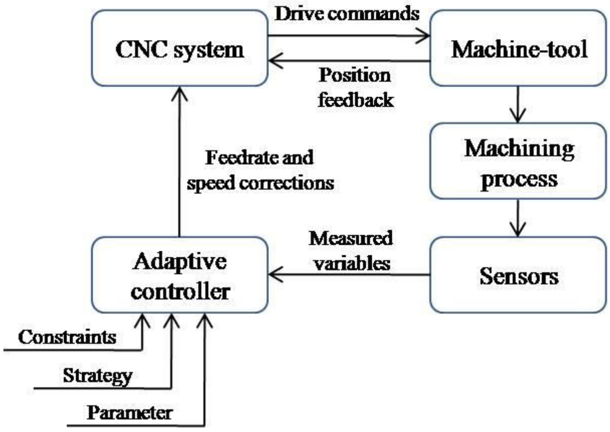

Figure 1. Adaptive control system for CNC machine-tool

ACO refers to systems in which a given performance parameter (usually an economic function) is the optimization subject to process and system constraints. With ACC, the machining variables are maximized within a prescribed region bounded by process and system constraints, such as maximum force or power. ACC systems, however, do not use a performance index and their operating point is always on the constraints. In GACs the part quality is maintained in real time by compensating for the deflection and wear of cutting tools. By their definitions ACC systems usually applied in rough cutting and GAC systems in finish operations. In all systems an adaptation strategy is used to vary the machining variables in real time as cutting progresses.

Although there has been considerable research on the development of ACO systems, few, if any, of these systems are used in practice. The major problem with such systems has been the lack of suitable sensors which can reliably measure on-line the necessary process variables (e.g., tool wear) in a production environment. Most commercial AC metal-cutting systems which are used in industry today are of the ACC and GAC types, and seldom involve the control of more than one machining variable.

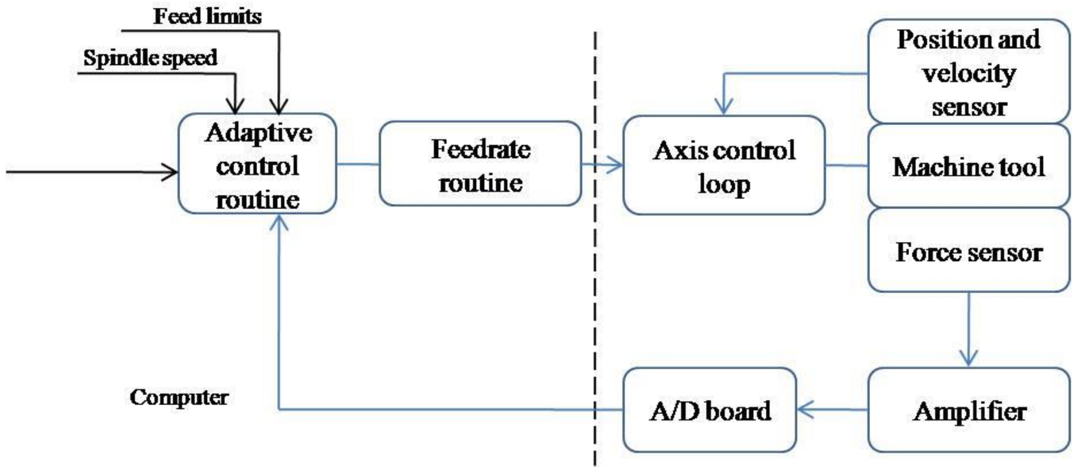

Figure 2. Basic structure of ACC system

The objective of most ACC systems is improvement in productivity, which is achieved by increasing the metal removal rate (MRR) during rough cutting operations. Several studies have been published (Zuperl, 2011) which present the productivity increase achieved with ACC system as compared to conventional machining. The increases in productivity range from approximately 20 to 80 percent and clearly depend on the material being machined and the complexity of the part to be produced. The AC systems show the most marked advantages in situations where there are wide variations in the depth of cut during machining or for machining materials with heterogeneous characteristics such composite materials.

2 SYSTEM ARCHITECTURE

An adaptive control system for cutting processes consists of three main components:

- a measuring system that allows capturing data about a certain parameter of the process, in order to detect the occurrence of perturbations in that process:
- a mean to deliver correction inputs to the process;
- a way to compute the appropriate value(s) of the input(s), related to the perturbation detected, to be delivered to the process in order to stabilize it.

An established system for gathering data in the cutting processes is the Kistler platform (www, 2014).

It works with its' own software that allows selecting the way of work and makes the necessary computations in order to aggregate the data delivered by the various sensors the platform is equipped with. Kistler is designed to work rather as a monitoring system, than an integrated one in an adaptive control system.

Since LabVIEW can be used both as a data acquisition and distribution system, and it provides users with programming facilities, it is very suitable to assume tasks of each of the three components mentioned above. Integrating Kistler hardware platform and LabVIEW software is presented in the next paragraphs.

2.1 Hardware system

The hardware system consists of a educational purpose CNC milling machine (EMCO 55 MILL), on which is mounted a dynamometric table (Kistler type 9257B). The cutting forces are measured with piezoelectric sensors. Piezoelectric sensors convert mechanical quantities such as pressure, force and acceleration directly into an electric charge. The charge produced is proportional to the force acting on the quartz crystal contained in the sensor. The sensitivity of the sensor is stated in pC/M.U.

The electrical signal is sent via RS-232 cable to a charge amplifier (Kistler type 5070A11100). The mains-operated multi-channel charge amplifier receives the charge from the piezoelectric sensor and converts it into a proportional voltage.

The interface hardware module consists of a connecting plan block, analogue signal conditioning modules and a 8 differential channel A/D interface board (PCIM-DAS1602/16).

In the A/D board, the analogue signal will be transformed into a digital signal, so that the LabVIEW software is able to read and receive the data. With this program, the three axis force

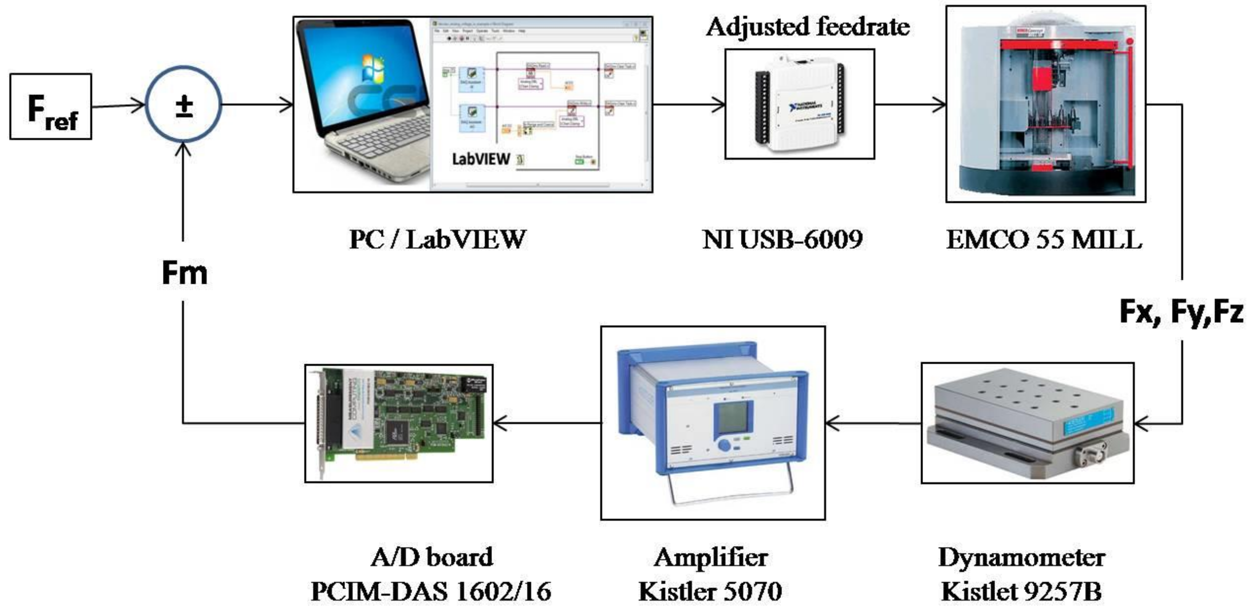

Figure 3. Hardware architecture

components can be obtained simultaneously, and can be displayed on the screen for further analysis. The Feed Rate Override percentage variable is available to the control system at a frequency of 1 kHz.

Communication between the control system and the CNC machine controller is accomplished with a NI USB-6009 over USB protocol. The output signal (electric voltage) will override the programmed values of the cutting parameters (ex. feed-rate and/or spindle speed) according to the real cutting condition in order to maintain the proposed characteristic (ex. cutting force or MRR) at a certain level

2.2 Software system

Software system consists of two stage software application: the calibration stage and the measuring stage.

2.2.1 Setup and calibration software

Prior to data acquisition from the machining process, calibration of the hardware components must be performed using appropriate software tools. A configuration and calibration of the A/D board has to be performed after installation, using delivered INSTACAL software as shown in figure 4.

The dynamometric table parameters are to be setup for a specific measurement type with the appropriate values of measuring range and sensor sensitivity in the hardware configuration inside the DynoWare software, delivered by Kistler (figure 5). These settings must fit with the amplifier settings. This can be achieved by pressing the "Send parameters" button.

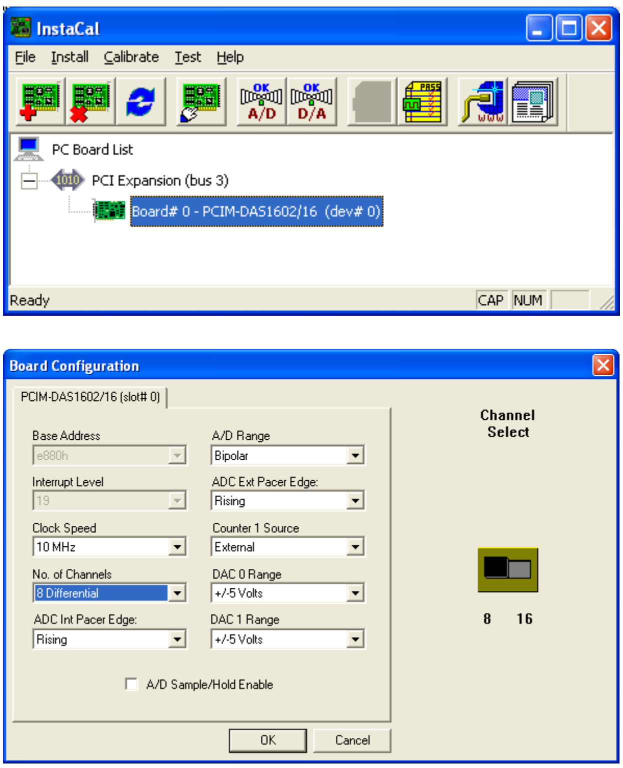

Figure 4. A/D board configuration

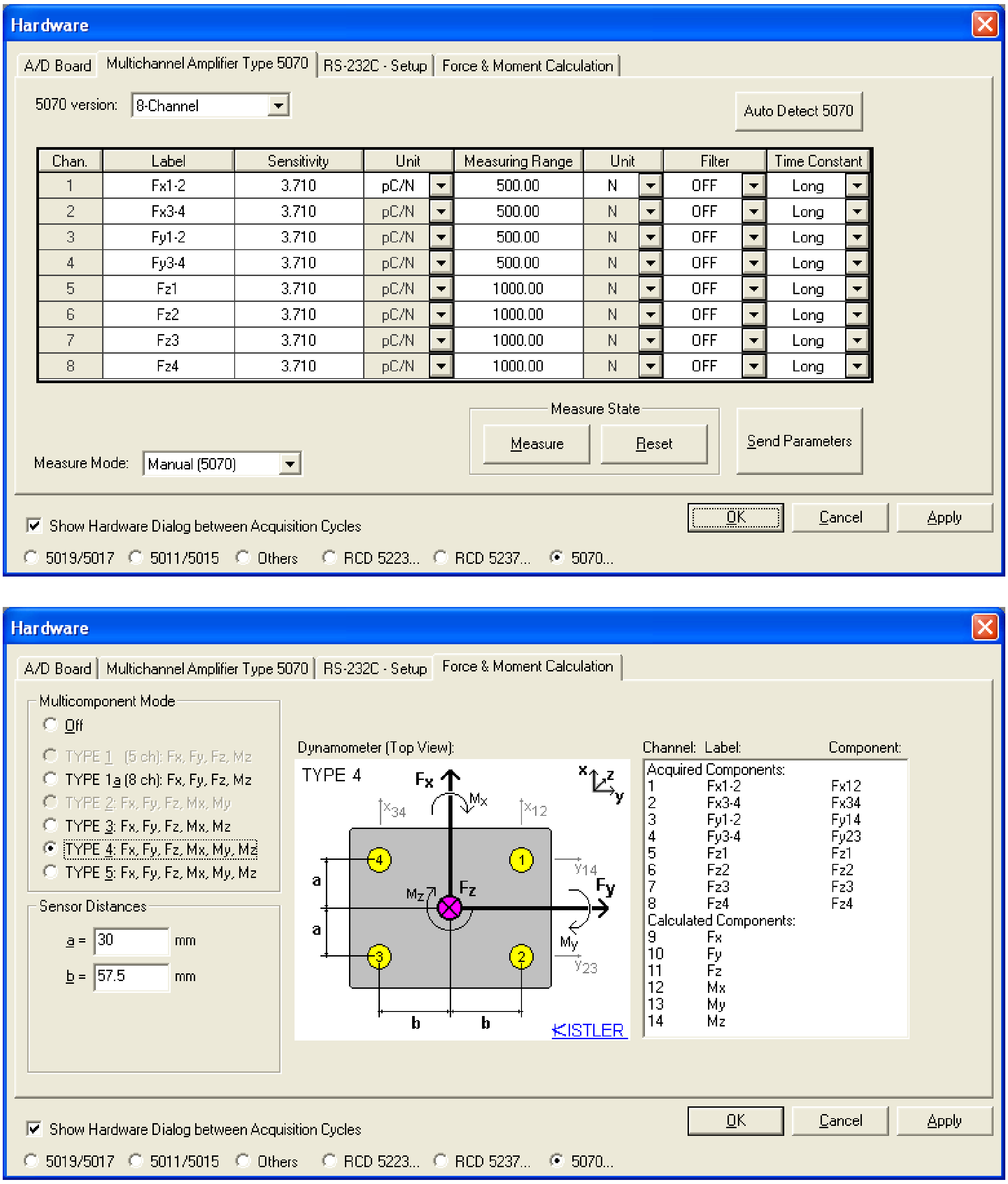

Figure 5. Dynamometer and Amplifier configuration

The measured cutting force is combined of 3 independent force components measured along the X, Y and Z axis. The resultant cutting force is obtained by using the mathematical models (1) according to the measurement type.

$$
\begin{aligned}
F_x &= F_{x1+2} + F_{x3+4} \\
F_y &= F_{y1+4} + F_{y2+3} \\
F_z &= F_{z1} + F_{z2} + F_{z3} + F_{z4} \\
M_x &= [b \times (F_{z1} + F_{z2} - F_{z3} - F_{z4})] \\
M_y &= [a \times (-F_{z1} + F_{z2} + F_{z3} - F_{z4})] \\
M_z &= [b \times (-F_{x1+2} + F_{x3+4}) + a \times (F_{y1+4} - F_{y2+3})]
\end{aligned} \tag{1}
$$

where:

a = distance of the sensor axis from the y-axis

b = distance of the sensor axis from the x-axis

(as shown in figure 5).

After installing and setting the parameters of the dynamometer, amplifier and A/D board, a calibration of the measurement is to be performed.

The calibration consists of two activities: calibration of the measured parameter (force [N] and torque [Nm]), and determination of the corresponding electric voltage. The calibrated electric voltage is used in the measuring stage for comparing the reference value of the monitored parameter with the on process measured one. The calibration is performed by using known loads on the dynamometer table and recording the values of the electric voltage indicated by the voltmeter tool from DynoWare Software.

2.2.2 *Measuring software*

The software used for monitoring the cutting process is LabVIEW fron National Instruments. In addition NI-DAQmx module is used to facilitate the intercommunication between LabVIEW and A/D board. The NI-DAQmx Driver software is the layer of software for easily communicating with the hardware. It forms the middle layer between the application software and the hardware. Driver software also prevents a programmer from having to do register-level programming or complicated commands in order to access the hardware functions. As a programming tool the DAQ Assistant is used. The DAQ Assistant, included in NI-DAQmx, is a graphical, interactive guide for configuring, testing, and acquiring measurement data.

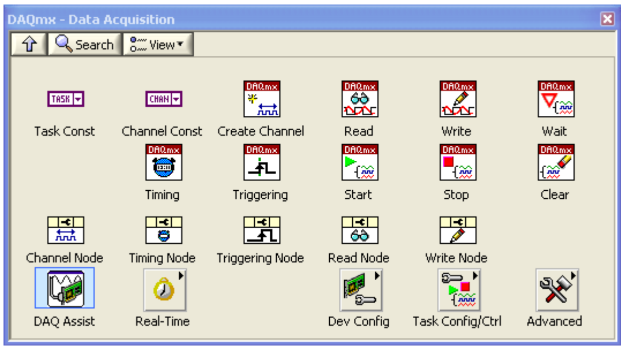

Figure 6. DAQmx pallete / DAQ Assistant tool

The data acquisition uses the DAQ Assistant integrated within a LabVIEW virtual instrument (VI). After the calculation of the necessary correction over the controlled parameter(s) using appropriate mathematical models, the correction signal (electrical voltage variation) will be sent to the machine-tool using a NI USB-6009 A/D device.

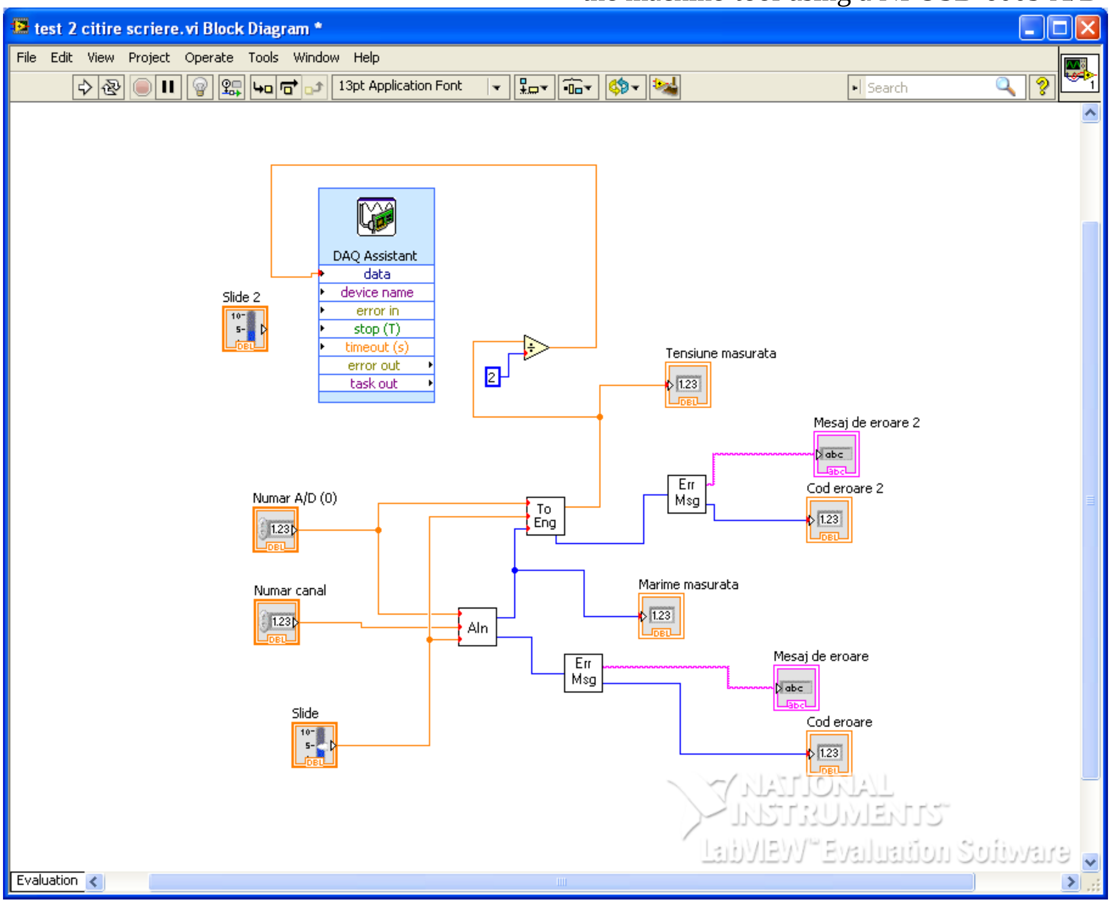

Figure 7 LabVIEW Virtual Instrument for gathering data from Kistler dynamometer and delivering corrections to machine-tool *Overwrite* knob

3 CONCLUDING REMARKS

An adaptive control system for cutting process is presented in the paper considering the hardware and software components. The setup, calibration and measuring stages are eloquently presented. This system architecture was created for ongoing researches meant to highlight the different behaviour of some heterogeneous material (eg composites materials).

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6 NOTATION

The following symbols are used in this paper:
CNC =computerized numerical controlled
AC =adaptive control
ACO =adaptive control with optimization
ACC =adaptive control with constraints
GAC =geometric adaptive control
MRR =metal removal rate
M.U.=measuring units
A/D=acquisition/distribution