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USING PROTOTYPE THE COMPUTER NUMERIC CONTROL MACHINE DESIGN

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Abstract: The use of digital fabrication in the production and making of architecture is becoming a prevalent vehicle for the design process. As a result, there is a growing demand for computer-aided design (CAD) skills, computer-aided manufacturing (CAM) logic, parametric modelling and digital fabrication in student education. This paper will highlight a case study project that sought to ingrate computational prototyping with digital fabrication techniques in the production of architecture. The goal is to use virtual and physical prototyping to educate students in CAD, CAM, parametric modelling and digital fabrication. Rather than repeating conventional approaches or recreating from precedent, iterative prototyping challenges students to understand the CAD technique or parameters for modelling and translate intentions for CAM production. Students engage real world constraints of materials, time and tectonics. In the end, these projects are critical of the digital and speculate on the architectural detail in an age of digital ubiquity.

I. INTRODUCTION

The Computer Numerical Control (CNC) is a technology that uses microcomputers to generate, parse and execute the sequential control that describes the end effector's behavior. The application of this technique is often used in turning, drilling, milling and, nowadays, expanding its application to others tasks than machining, like in electronic components insertion, tube welding and cutting robots [1]. Comparing to the older CNC controllers developed, a great improvement took place, in means of integration and standardization of the interfaces, but it still misses ways to watch variables that are of great importance to the productive process.

Using the LabVIEW's virtual instrumentation, it is proposed an interactive easy-to-learn user interface, capable of communicating with external equipments, through the serial connection. The choice of the IDE was based on its programming easiness and its capability of adding new properties to the system, in such a way that the electromechanical plant's application is suitable to both educational and research fields. On education, it is intended to create a didactic way to show the machine's operation. On research field, it is intended to investigate: i) power efficiency; ii) process efficiency; iii) process optimization; iv) simulation on Computer Integrated Manufacturing – CIM; v) development of supervisory systems, with real time three dimensional animation; vi) application of artificial and computational intelligence to estimate parameters, like a tool life cycle.

II. THE COMPUTER NUMERIC CONTROL MACHINE

CNC Machines are often used in metal machining, like drilling, milling and taping. This kind of machine consists, usually, of a servo mechanism controlled by computer, a high speed spindle and specific tools. This servo mechanism can be realized in closed loop fashion, using servo controllers driving DC or synchronous AC machines, or open-loop fashion, using stepper motors. The open-loop based machines are only suitable to small loads. Therefore, industrial sized machines do not, in general, use open-loop machine.

The machine is based on the removal of the material of a work piece, being the amount of time necessary to finish the piece proportional to both the difference between the initial and final volume of the work piece and to the final piece complexity. Nowadays, there are machines with six or more axes, which allow the machining of pieces with such a high level of complexity that it would not be feasible by other means.

MECHANIC PARTS OF A CNC MACHINE

A CNC prototype machine was designed, with three Cartesian axes, with 600 mm of length both X and Y axes and 100 mm of length Z axis.

In this project were used: i) as mechanical drive, three stepper motors with holding torque of 10 kgf.cm, 8 W of power per phase, 1.8º step angle and positioning precision higher than 95%; ii) as end effector, an universal DC machine, with nominal power of 150 W and nominal speed of 35000 RPM, non-specified precision; iii) a 1045 steel threaded rod as rotational to translational mechanic converter, with 3 mm step and precision higher than 95%; iv) bronze and polyacetal nuts. The machine's general characteristics are listed on Table 1.

TABLE 1 MACHINE'S CHARACTERISTICS

Travel on axis X and Y	480mm
Travel on axis Z	100mm
Maximum torque on axis	10 kgf.cm (unipolar)
Motor wiring	Bipolar
Bipolar motor parameters	L = 0.020H, R = 4Ω
Resolution	200 steps per revolution
Driving mode	Half step
Threaded Rod	Trapezoidal, 14 mm diameter, 3mm Step
Nut	Polyacetal e Bronze
End effector	Universal Machine, 150W, 35000 rpm. Variable speed, controlled by a phase controlled TRIAC
Mandrel	Manual, 3.2 mm diameter

It is assumed that in no occasion the machine will be used to machine a material that requests mechanic power higher than the available power in the plant. It eliminates the possibility of the stepper motors suffering loss of synchronism. Therefore, the minimum precision will be afunction of the precision of the rotating parts, the stepper motors and threaded rods.

III. THE SOFTWARE

The software developed should be user friendly, should be able to display electrical and mechanical variables and should be able to send commands and receive answers. The commands must be sent in a manual or automatic way. Therefore, the computer program would have to be able to communicate with peripherals connected to the computer.

Although interfacing with peripherals connected through a serial port is massively documented in various programming languages, i.e. [2] and [3], the LabVIEW IDE was chosen, because it presented more features aligned to those desired.

The program should implement a bidirectional interface, controlled by the computer. The communication should happen in a way that the computer always has the knowledge of the present task being executed by the machine. Therefore, a protocol would have to be developed, allowing the data exchange between the machine and the computer.

The program should feature two operation modes: the manual and the automatic. In the manual mode, the user should be able to send commands of discrete steps, which would send to the controller a number of discrete steps on each axis, and fast forward, which would send to the controller a command to move the spindle to the extreme positive or negative of the related axis. In the automatic mode, the user would have to load a file containing CNC code, such as G and M codes. The program then loads the selected files, decodes commands and sends them to the machine.

IV. THE ELECTRONIC CIRCUIT

The electronic circuit was developed in a modular fashion, where there was a master, which was responsible for the interface with the computer running the LabVIEW application, and the slaves, that were connected to the master and were responsible for the control of each axis.

The master device is based on a PIC18F2550 micro controller [4], which features the necessary hardware to communicate through Universal Serial Bus – USB – [6]. Therefore, a firmware based on [5] was developed, that acts as a serial port, in a way that when connected to the computer, the operational system would recognize the device as a virtual serial port. This approach would largely reduce the difficulties the computer program, since interfacing the computer with those ports are extensively documented.

The USB communication runs at Full-Speed – up to 12 Mbps. This data transmission rate allows enough of data do be transferred in order to the machine and the computer exchange data in real time. The firmware uses a polling technique that is responsible for the execution of all tasks related to the micro controller’s peripherals. This mechanism consists in calling periodically functions related to the USB communication, so that the dataflow can be controlled. Once the device is correctly setup by the operational system, the firmware periodically reads and writes the USB end-points, in order to send and receive data. The USB implementation utilizes the Communication Device Class, as define in [6].

The master device has a bidirectional data channel and three unidirectional control channels. Through the data channel, high level data are sent, for example the current set point of the stepper motors, the mean current on phase winding of the motors and present angular position of the motor. The control channels are used to send signals that are going to control the step triggering and direction.

The dataflow at the master device is based on three main elements: USB connection, Inter-Integrated Circuit Bus – I^2C – [7] and digital outputs. The computer communicates with the master through the USB, sending and receiving data related to machine operation, such as CNC Code, current measurements, actual position, write to the current set point and reset of the position. Through the digital outputs the master sends information related to the step direction and step pulse. Through the I^2C bus, the master sends and receives information like current position, mean current on the phase winding and current set point. Figure 1 shows the dataflow of the involved equipments.

The slave devices are based on a PIC16F677 micro controller [8]. Each one occupies a control channel of the master device and shares the data channel, being each slave linked to an I^2C address of 7 bits. The slave main function is to control the stepper motor. Therefore, it is necessary to: keep the actual position in the memory, be capable of receive input pulses of direction and step trigger; be capable of driving the motors windings sequentially; be capable of control the current flowing in the windings. The secondary functions of the slave device are to compute the root mean square of the current on each winding. To run all tasks, the necessary micro controller’s peripherals are: Analog to Digital Converter - ADC –, I^2C slave bus, 8 and 16 bits timers and border sensitive inputs.

The first task is the easier to accomplish: consists of a register which, once initialized with a reference value, it should be incremented or decremented whenever a step trigger pulse is received. To acknowledge commands pulses, the border sensitive input interrupt was utilized, in a way that whenever a rising edge is detected, the motor should be stepped, according to the desired direction. To drive motors winding, four command lines were used to control a double integrated H bridge, physically implemented by the integrated circuit L298 [9].

To manage the current control, a digital chopper was developed. The treated signal was achieved by means of a current sensing resistor in series with the load and an amplifier and conditioning circuit. The current signal conditioning was achieved with a circuit that applies a DC level voltage at the input signal, coming from the current sensing resistor, and amplifies this signal. The DC level is necessary to allow full swing at the ADC input. The signal amplification is necessary to drive at full voltage the ADC, which would reduce the quantization error created by the digitalization and discretization process. Besides the amplification and DC level, it is necessary to filter the signal to avoid the aliasing phenomenon, which is detailed at [10] and [11]. The circuit that achieves this is shown at Figure 2, as suggested by [12]. In the Figure 2, the input signal is represented by the "SENA" label and stands for Sensing Resistor at A Winding Phase. The conditioned signal is available at the "CONDA" label that stands for Conditioned Signal from A Winding Phase.

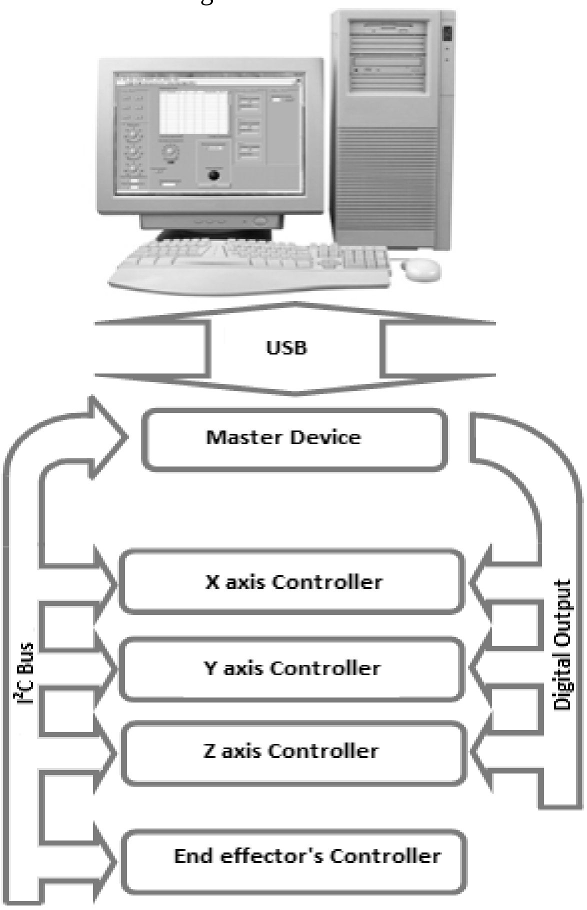

Figure 1 – Dataflow between the machine's modules.

The discrete signal is then compared to a reference value: if the actual current is less than the reference value, more current is applied, by turning on the switch related to that winding; or else, the switch is turned off. The data acquired this ways is then accumulated in a buffer and then the root mean square current is computed.

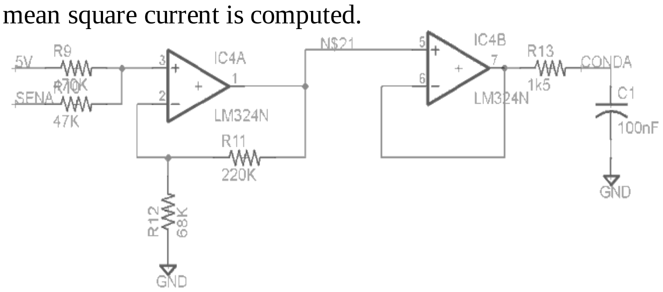

Figure 2 – Analog current signal conditioning circuit.

V. RESULTS

After the definition of all the mechanical parameters of the plant, an initial 3D model was developed using the software SolidWorks 2009, shown in Figure 3. The model is of great relevance for the physical implementation of the machine, allowing the individual design of each component, reducing the possibility of errors. The partial assembly of the machine is shown in Figure 4. Some details present in Figure 3 were further considered of less relevance and therefore were omitted or discarded. Some of the parts of the machine are not meant to be permanent, such as the nut holders, which are presently wood made parts.

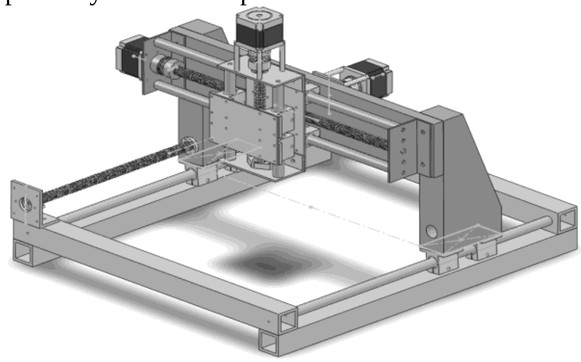

Figure 3 – Virtual 3D image of the projected machine.

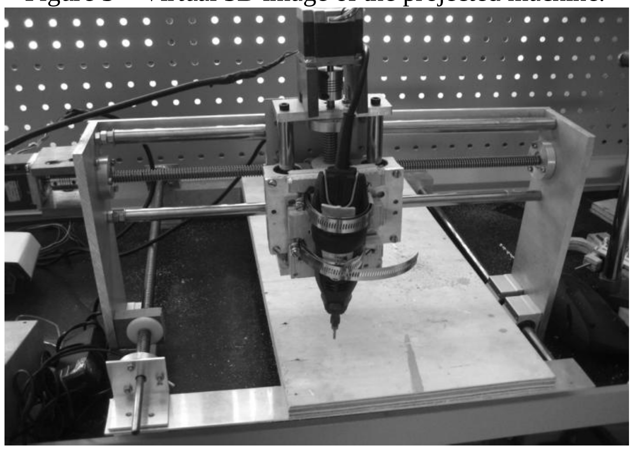

Figure 4 – Real machine assembly, built with some

The software was designed in such a way that it is both user-friendly and informative about the process. In order to achieve this, the software was programmed in LabVIEW, which provided powerful tools to easily design the program. Figure 5 exemplifies the main screen. The screen includes the necessary controls for the operation as well as all useful variables for the process in a simple and intuitive way.

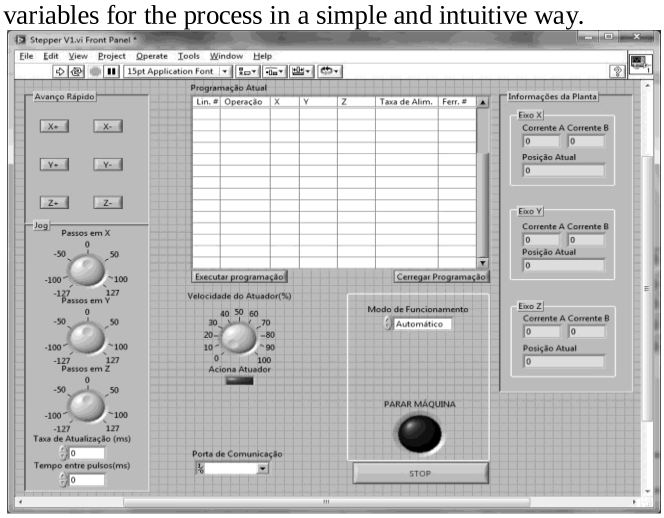

Figure 5 – User interface of the LabVIEW program.

The solution for the regulation issue was the implementation of a digital chopper, which is responsible for the load switching, allowing the control of its current by comparing it with a reference current value. Simulations using MATLAB revealed decent results even with adverse situations such as voltage fluctuation in the DC power source, a result of the rectifier capacitors charge and discharge cycles, as can be confirmed by Figure 6, in which the current is represented as a continuum line, and the voltage, as a dashed line.

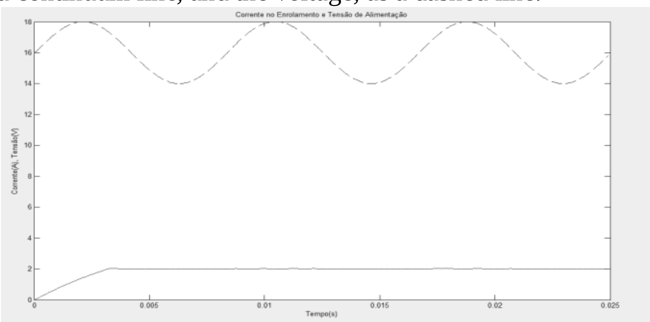

Figure 6 – MATLAB Simulation, where the current regulation by the digital chopper was observed, being the regulated current shown with continuum line and the input voltage as dashed line.

To ensure that this control alternative would lead to satisfactory results, expressed by low ripple currents and average current equal to the nominal current, there will be a relation between the input voltage, the inductance and resistance parameter of the motor and the minimum ADC acquisition rate. Figures 7 and 8 show the results of the implemented digital controller, with a 15 V input voltage and 1V ripple, running a bipolar motor with 20.4 mH, 4.3 Ω, 2 A of nominal current.

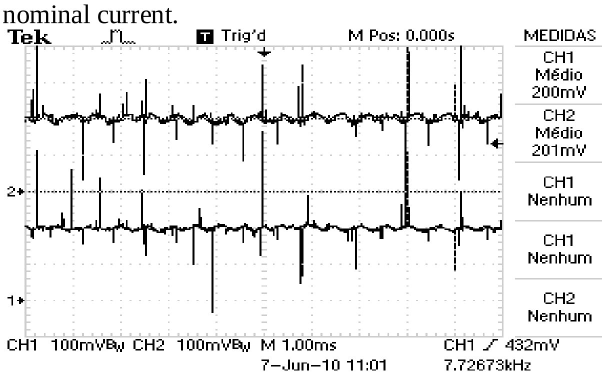

Figure 7 – Final controller's performance operating with 2 A set point.

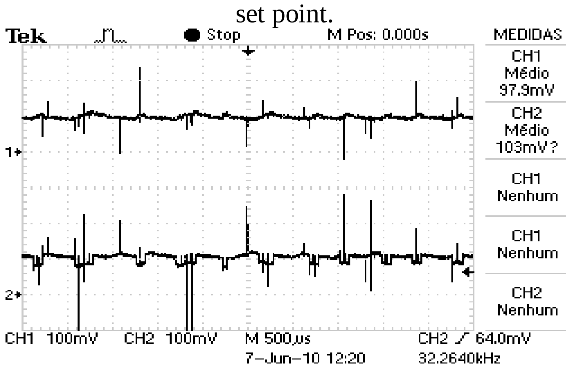

Figure 8 – Final controller's performance operating with 1 A set point.

VI. CONCLUSION

Although all the electronic parts are already built and fully functional, the proposed prototype CNC machine is still being build. Therefore, no practical results but those presented in the previous section are available at the present time. It is expected to use the CNC machine with the non-permanent parts to produce more rugged – and therefore, permanents - parts made of 2011 aluminium alloy, in order to extract all the mechanical precision available at the machine. In terms of current regulation, it was observed that the current regulator achieved the objective, which was to simply control the current flowing on phase winding, even when facing input voltage ripple. In its real implementation, however, it was observed current spikes that might lead to motor overall life cycle reduction. The analysis led to the conclusion that the current spikes were caused by: i) switching-off latency; ii) diode latency too high; iii) lack of coordination on switching the H bridge transistors; iv) measurement interference caused by the currents surge that in its turn are caused by the switching of the load. As solution to these problems, it was suggested: i) the replacement of the BJT based H bridge by a power mosfet based H bridge; ii) use of diodes even faster than those MBR350 used; iii) reduction of switching frequency by using a hysteresis curve to trigger the switching; iv) revision of the driver board, considering more carefully the design of the board in what it refers to the current carrying lines. For future works, it is intended to: develop educational modules to show the inner working of each piece of the machine; develop prediction tools based on artificial and computational intelligence to infer results from measurements, like vibration and end effector's drained power; development of modules for process efficiency analysis.

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[12] HOROWITZ, Paul, WINDFILD, Hill. Art of Electronics, 2 ed. New York: Cambridge University Press. 1989. in 1992 and her Doctor's degree in 2003, from the graduate program in Electrical Engineering from the same University. She is Professor of the Electrical Engineering Faculty and now she is principal of the Technology Institute of the Federal University of Pará. Her themes of interest are power quality, industrial processes and power distribution.

