

Design of a universal robot controller

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Abstract - The paper deals with a general purpose industrial robot controller. Due to the modules of the system is universal. It can be connected to several types of robots, even to CNC, turning-mill or other machines. It was connected to an Adept Scara robot successfully, experimental results will be presented. The basic element of the system is the EMC2 open source robot controller program, which runs in a real-time Linux kernel. A PCI card creates the high speed connection between the EMC2 and the machine. DC servo amplifier, digital input and output module, teach pendant, and power electronics designed for the system. The system is RT-middleware (Robotics Technology Middleware) compatible. The RT-middleware is a common robot control platform, which can easily connect different robots to the same network for a common work.

- Section 3 give a short overview of the theoretical background of motion control in robotics
- Section 4 presents a compact 3-axis motion controller for desktop CNC machines.
- Section 5 describes a flexible concept for robot control architecture, presenting a working 4-axis system.
- Section 6 gives an investigating on the CNC conversion of a HBM DM45 manual milling machine.
- Section 7 summarizes the results of the finished developments, and gives an introduction of the feature plans.
- Section 8 contains the list of references.

1. INTRODUCTION

Used robots is a fast growing sector of the automation market. The technology and build quality of robots made over ten years ago means that they are a viable alternative to new robots with little or no difference in capability in many applications. Nowadays the only main problem with used robots is their outworn control systems that makes hard to setup an automated production line from different robots. Small companies have no money for new manufacturing cell, they build it up step by step from used machines. For eliminating the difficulty of this setup process, we have to develop a new modern control system for industrial robots, which can easily connect to different types of machines, and has many configurable communication interfaces to connect it to other industrial units.

1.1. Report outline

The structure of the development report is the following:

- Section 2 explains the main goals of the project.

2. CONCEPTS FOR ROBOT CONTROL ARCHITECTURE

With a few years experience in robot control and with the deep investigation of existing control architectures we created the concept of easily configurable hardware architecture for de-centralized and centralized robot controls. For first, I would like to give an overview of the existing hardware elements on the market.

2.1. Existing hardware elements

For AC and DC servo amplifiers the market gives a very wide choice, hence we don not deal with this topic. The more interesting area is the control electronics that interprets the robot program and gives reference the signals for each joint. The most of the suppliers give only complete finished solutions for an exact problem.

2.1.1. Mesa electronics

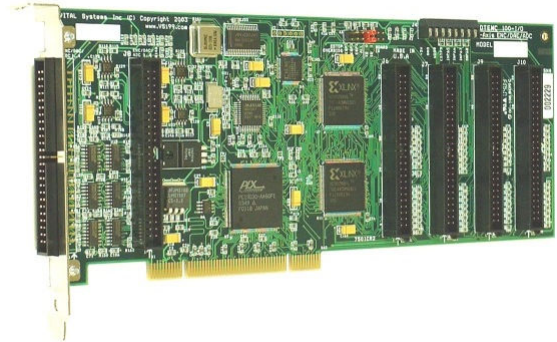
In the field of universal controls a very noticeable developer is Mesa electronics. They produce only PCI I/O cards, that's suitable for transferring the signals for motion controllers generated by the PC based EMC2 robotic platform. The most used card is the mesa 5i20 that can be seen on figure 5.1. For making a complete control system with these I/O cards, there are many additional workaround, like building up the interface between GPIO pins and servo amplifiers.



2.1. Figure: Mesa electronics 5i20 I/O PCI Card

2.1.2. Vital Systems

A better solution for configurable control is Vital Systems Inc. They have 8-Axis Motion Control & Data Acquisition PCI Board, see figure 5.2.



2.2. Figure: Vital System's 8-Axis Motion Control & Data Acquisition PCI Board

This card developed exactly for motion control applications hence it has all the I/O data functions that a control system needs and implemented for working with EMC2 open source robotic platform. The manufacturer provides wide variety of expender cards for I/O, DAC/ADC etc. The only problem with this card, that it cannot handle inverse dynamics, it is only good for Cartesian robots.

2.2. DSP-FPGA concept

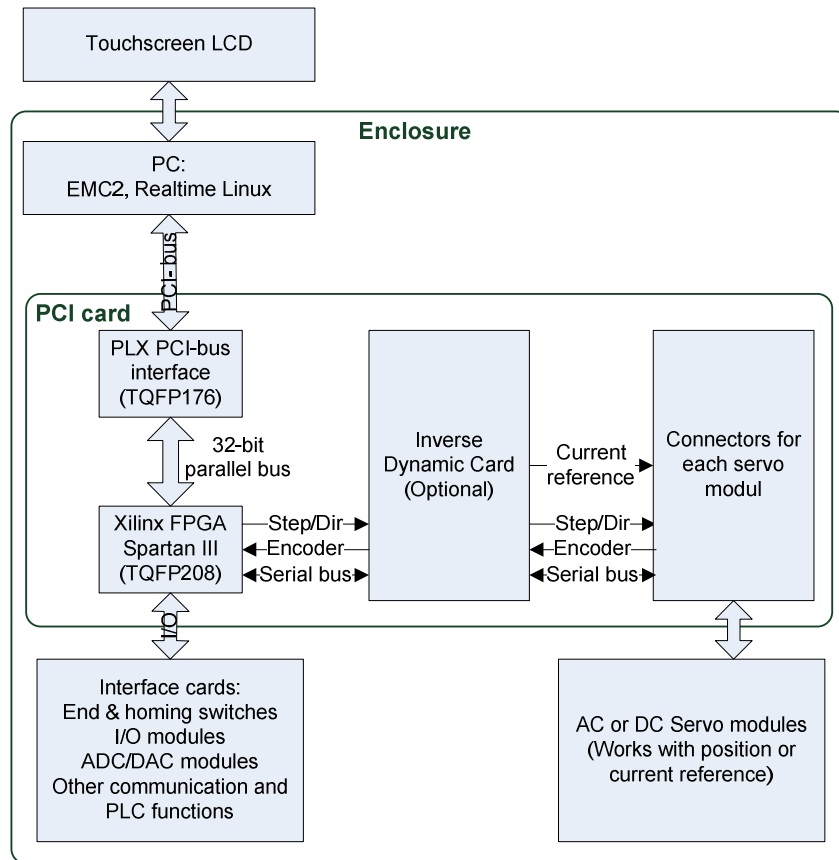
Our first PCI based concept can be seen on figure 5.3. After a PCI bridge interface ASIC there is a bigger (more gates and I/O lines) FPGA on the PCI card, therefore it is possible to handle more signals.

For a decentralized control the Step/Direction reference signals goes throw to the servo modules for position control. The encoder signals are coming back just for diagnostic, and DRO functions. And there is an additional serial line for configuring the servo modules for position control (PID terms etc.).

For centralized control, an additional inverse dynamic card can be connected to a board-to-board socket that contains a DSP-FPGA system. This card connecting parallel to the

signals mentioned before, and connecting with the servo modules with an additional serial line for giving them current reference. The servo modules are configured along the

serial bus for current control, and the inverse dynamic card has all the signals for solving the Lagrange equations of computed torque method.

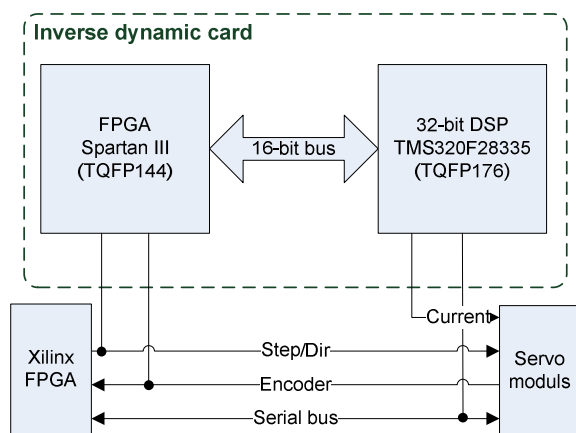


2.3. Figure: Concept of the configurable controller with optional DSP-FPGA card for inverse dynamics

On the inverse dynamic card, the FPGA works only as an encoder and step/dir counter interface, and a 32-bit floating point DSP can do the computing, giving the current reference signals for the servo modules.

In the whole system, the configuration firmware of the two FPGA is fixed and there is no need of modification. The servo modules can be configured easily. Only the DSP firmware has to be modified for each different mechanical structure.

The block diagram and the connection of the inverse dynamic card can be seen on figure 5.4.

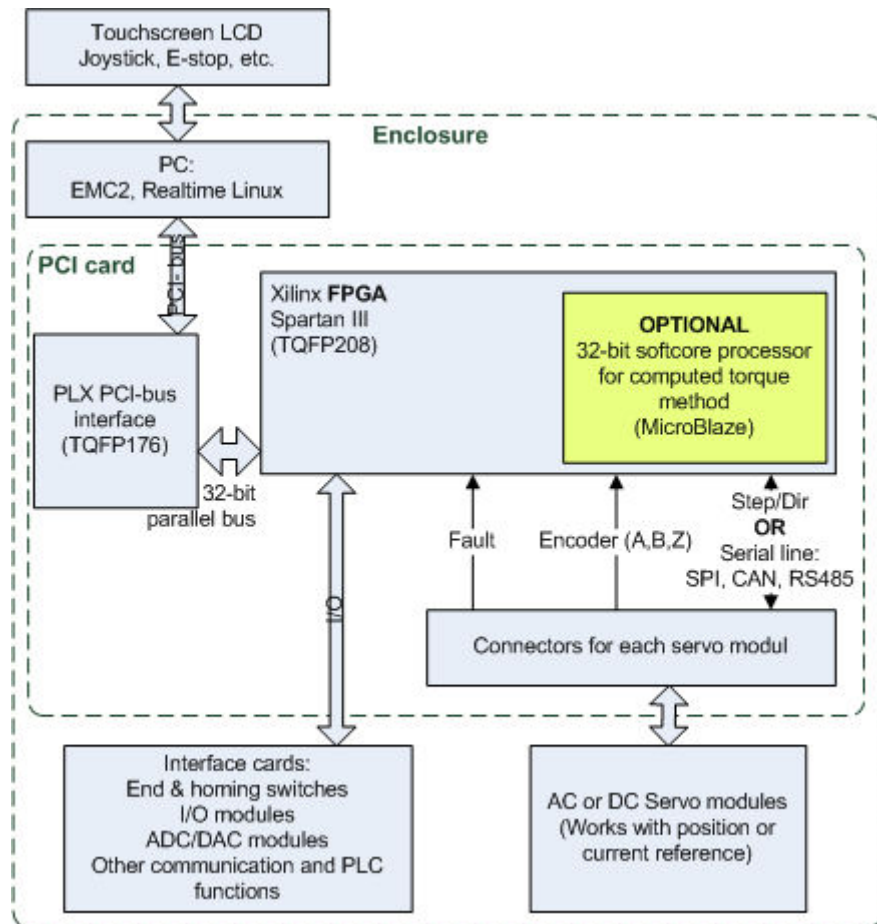


2.4. Figure: Block diagram of the optional inverse dynamic card

2.3. FPGA with soft core processor concept

With further investigation of the system requirements and the available hardware elements those suitable for this application,

a simplified solution can be achieved. If the FPGA has enough recourse for an additional 32-bit soft-core processor along with all other gate based signal processing, the additional hardcore DSP-FPGA board can be left. The block diagram of this version of the PCI card can be seen on figure 5.5.



2.5. Figure: Second concept of the configurable controller with optional soft core processor for inverse dynamics

The hardware should be eligible for adapting all the two concepts mentioned above. This can be solved by designing for the first concept, because the second concept is only a simplification that lives the additional inverse dynamic card.

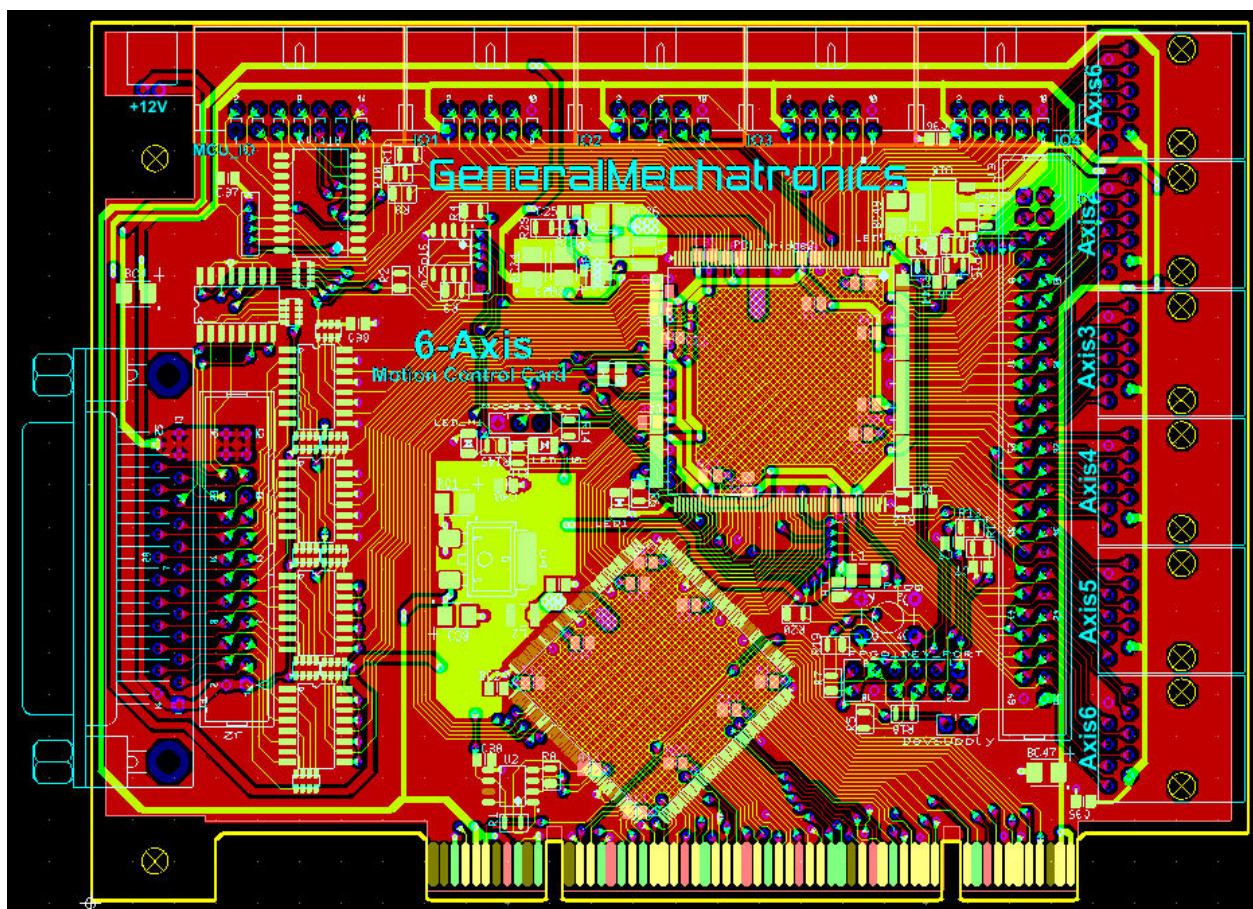
2.4. Hardware design

For realizing the concepts of the architectures mentioned above, we needed practical experiences in hardware design. To get a smart ready to work equipment, we had to well align the schematic design, the PCB layout and the mechanical design.

2.4.1. Routing the PCI card

The schematic of the PCI card was designed by Bence Kovács, more information can be found in his final work [6]. My task in

connection with this circuit was to design the PCB layout. The contour and thickness of the PCB was given by PCI standards. The layout had to be fitted on two copper layers for a cost effective solution. Routing a high speed small signal circuit with these given boundary condition is only possible with manual routing. During routing care must be taken because of high speed data and clock signal lines, and the six different supplies for cores, I/O-s and other peripheral circuit elements. The finished layout design was successful because, there were no EMI/EMC problems during operation. The layout can be seen on figure 5.6.



2.6. Figure: PCI card routed on a two layer PCB

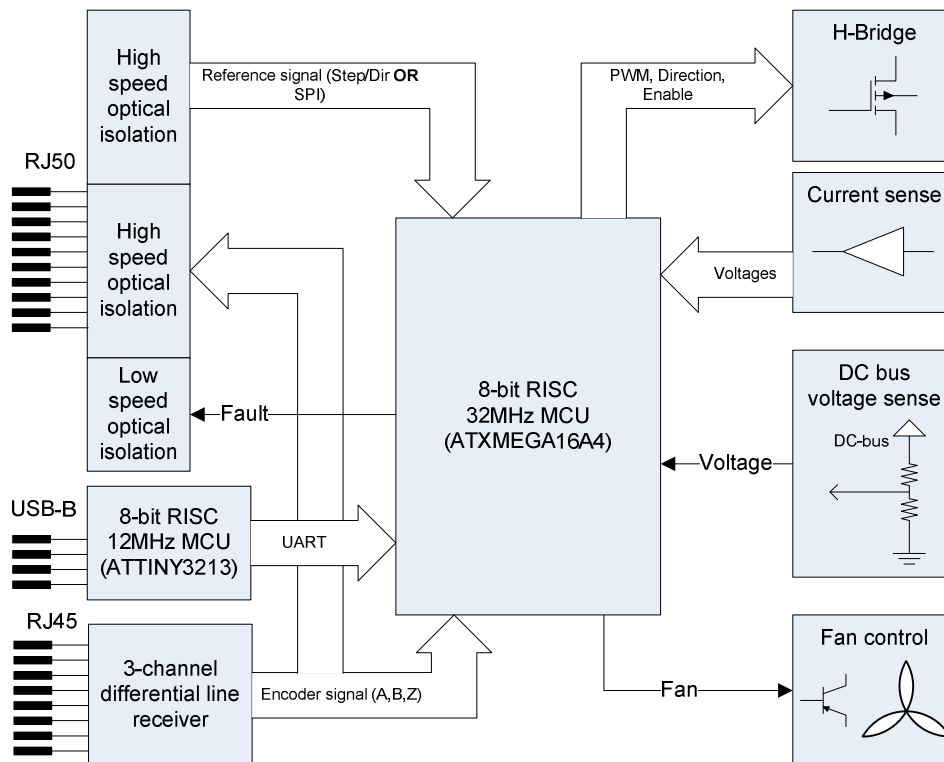
2.4.2. DC Servo amplifiers

In robotics and motion control, the position control of simple brushed DC servos is a very basic and common task. All other servos need more difficult hardware and control method. The old Adept 604-S robot

has brushed DC servos too; therefore I have started the servo controller design with a DC servo amplifier.

2.4.2.1. Overview of the hardware

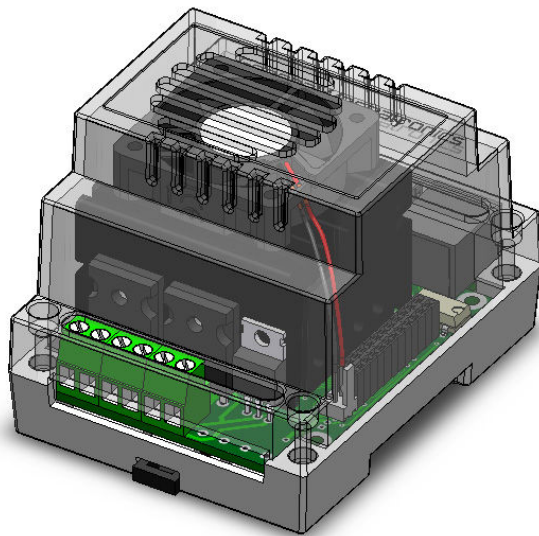
The block diagram of servo controller can be seen on figure 5.7.



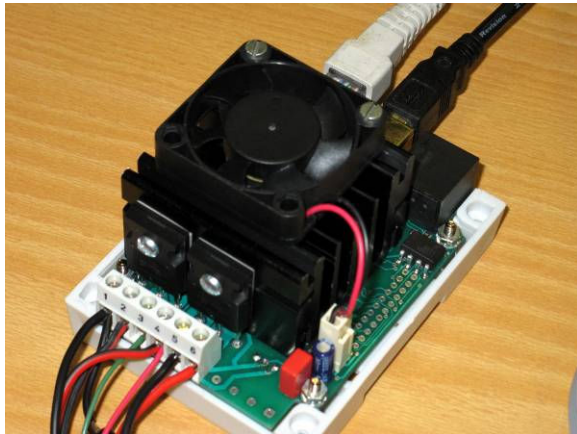
2.7. Figure: Block diagram of the brushed DC servo controller

All the signals from and to the PCI card are optically isolated. The reference signal can be SPI packets or the conventional Step/Dir signals. The encoder signals are handled by a differential receiver first, that can host absolute signal referenced to ground due to a resistor network before the differential inputs of the receiver. The encoder signals after the line receiver are connected to the microcontroller and fed back to the PCI card for diagnostic and for opportunity of centralized control. Finally one additional fault line is connected to the reference connector to indicate any fault conditions. The H-bridge is built up from discrete elements, except for the FET driver IC-s. For current sensing, I have used low side shunt resistors and an operation amplifier for each half-bridge. For sensing the DC bus voltage a simple resistor divider was used with an RC-filter. For active coolant, a small 12V fan was used, that can be turned on/off.

For configuring the parameters a low speed USB communication was used.



(a)



(b)



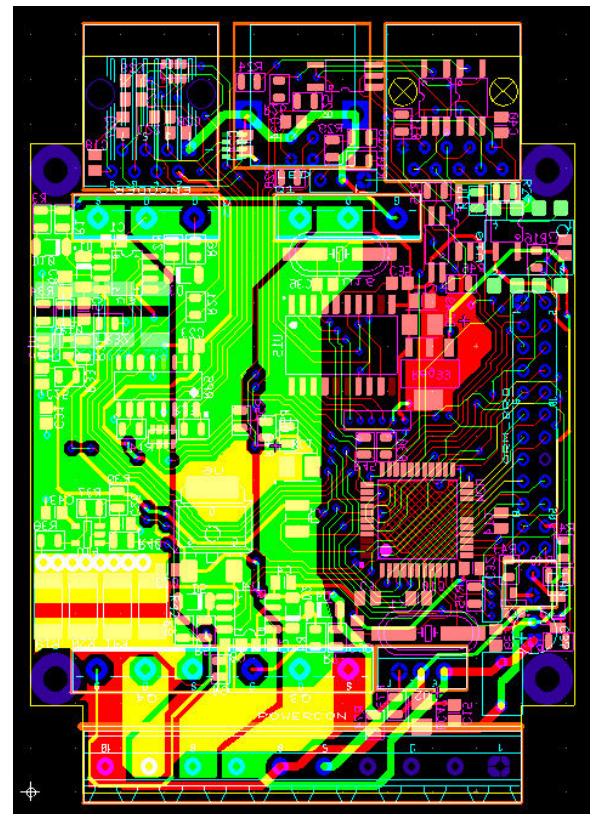
(c)

2.8. Figure: DC servo amplifier in DIN-rail mounted enclosure
3D model (a), electronics (b), enclosure (c)

The 3D model and photo of the assembled servo controller can be seen on figure 5.8.

2.4.2.2. EMI problems

During the first testing, several EMI/EMC problems occurred, because of the heavily packed design. Several additional bypass and filter capacitances were added to make the circuit work. In some cases the power and small signal traces are too close to each other, therefore this first version was very sensitive to electromagnetic disturbances. The next hardware will be updated by placing the MCU-s on a small vertical PCB next to the heat sink.

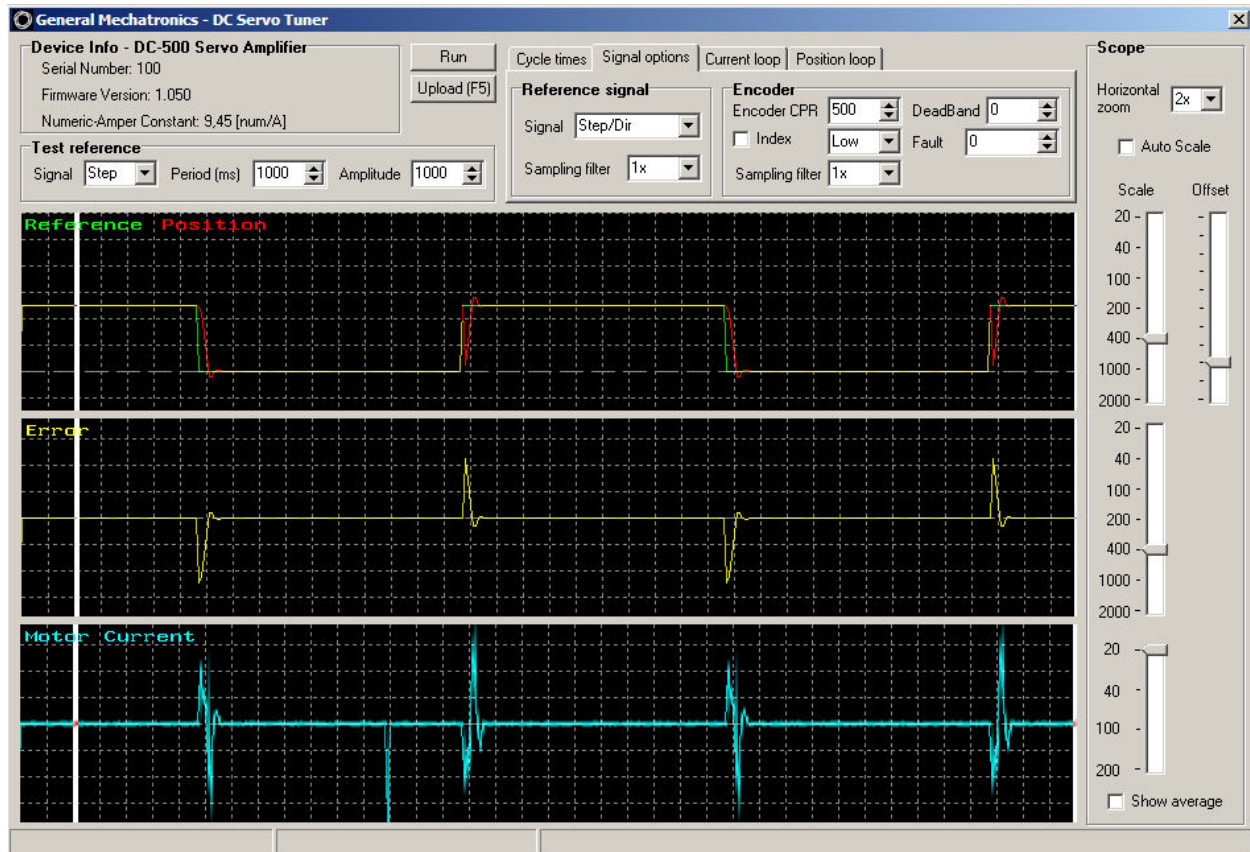


2.9. Figure: Routing power traces and small signal lines to one small two layer PCB:
The resonator is too close to the power trace on the right-lower side of the picture

2.4.2.3. Servo tuning interface

A PC application was implemented for configuring the parameters through USB port. The software was developed in Delphi 7. With this simple application the system integrator can easily adjust all the

parameters of the servo control. As test reference signal a step and a ramp function can be switched on with custom amplitude and period during the tuning of control parameters, while the response of the system can be seen on the scope. A screenshot of the software can be seen on figure 5.10.



2.10. Figure: Screenshot of the software during configuration and servo tuning

The program sends a configuration frame by clicking on the upload button. When an acknowledge frame arrives back, we can start the testing by clicking on the run button. The definition of the configuration frame can be found in appendix I.

The adjusted parameters of the joints of the Adept 604-S robot can be seen in appendix II.

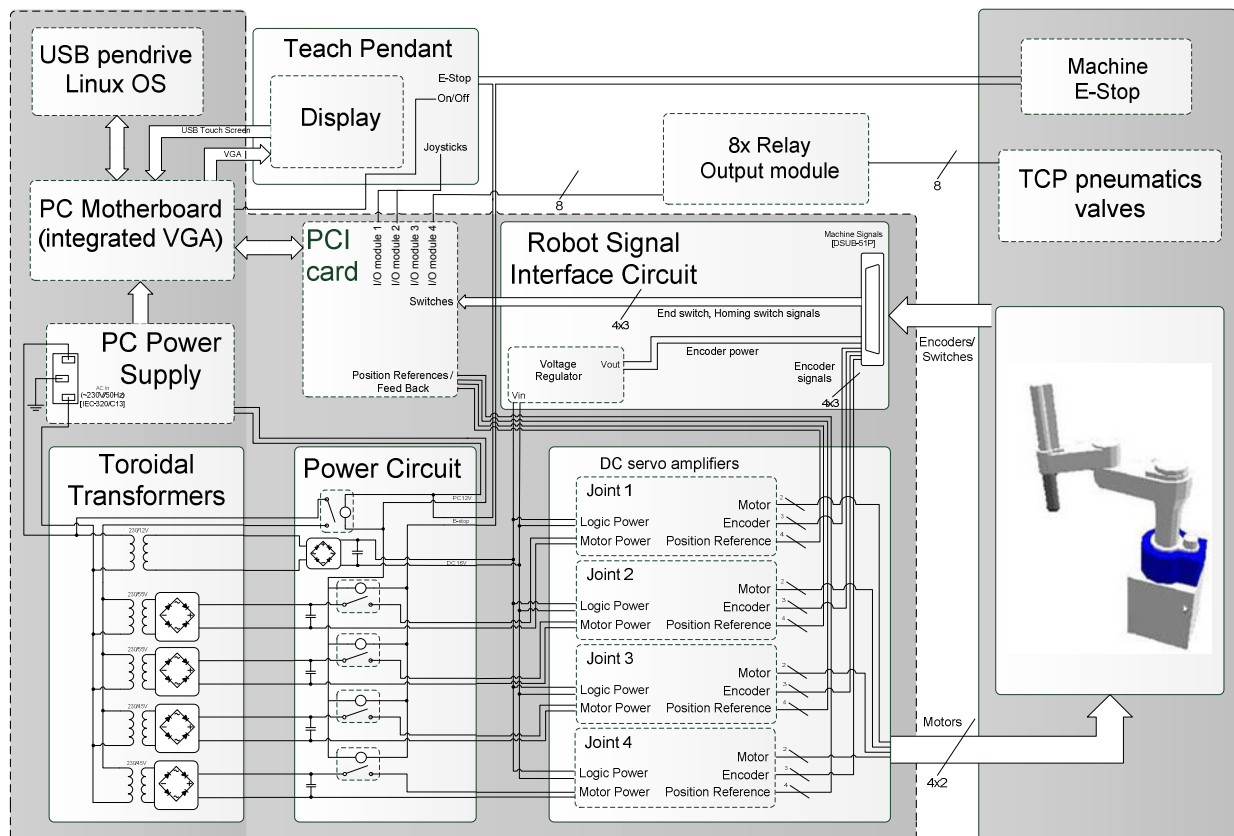
2.4.3. Description of the 4-axis system made for Adept 604-S

As a first EMC2 based control system, we assembled a 4-axis controller for the brushed DC motor driven Adept 604-S type SCARA.

2.4.3.1. Global hardware architecture

The block diagram of the 4-axis controller can be seen on figure 5.11. There are two

main hardware units in the system those have to be designed for each different robot: The first is the servo power supply that scaled for the power rating of the servos. The second is a signal interface board, which gives power for the sensors of the robot, and shares out the encoder, homing and end-switch signals.



2.11. Figure: Block diagram of the 4-axis controller of Adept 604-S

The servo amplifier blocks should be chosen for the types and power ratings of each servo. In this controller the servo amplifier of the first joint can drive a bit more current, the three other are made from the same parts.

The input and output modules can be chosen

for the application. The system integrator can choose from isolated digital I/O modules, DAC and ADC modules. All I/O lines of the modules can be virtually connected to any function in EMC2. For example we can connect one relay for an M-code.

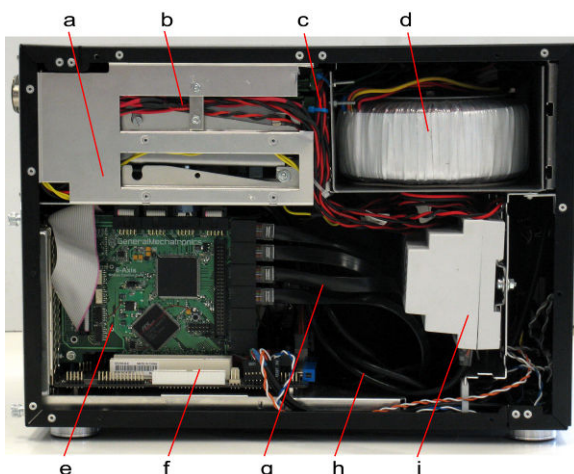
2.4.3.2. Mechanical construction

The whole controller could be fitted into a micro-ATX PC house [Figure 5.12], because the PC configuration we used was simplified: The hard-drive was replaced by small flash-drive and during startup the operation system loads a RAM-drive for faster data access.



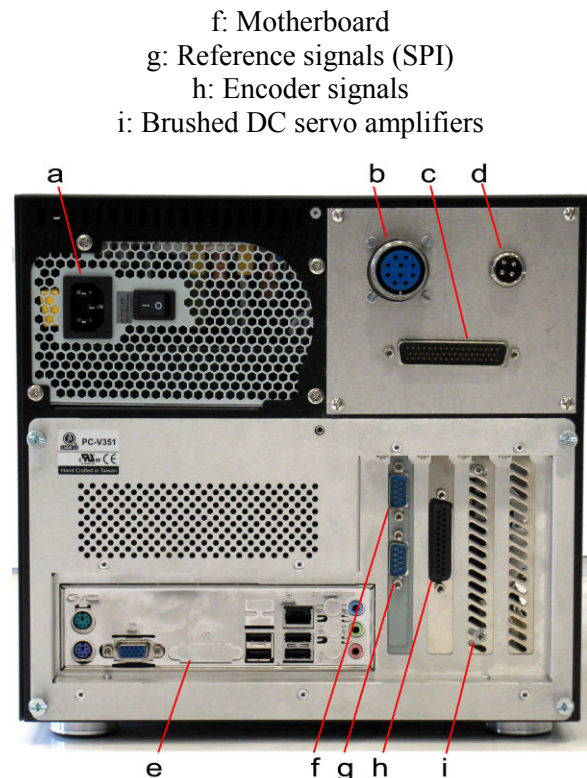
2.12. Figure: PCV-351 aluminium enclosure for micro-ATX PC

Therefore the whole upper part of the housing was free for other electronics, except for the PC supply. The global arrangement of the main parts can be seen on figure 5.13, and the connectors on the backplane can be seen on figure 5.14.



2.13. Figure: Global arrangement of the main parts:

- a: Signal breakout for Adept 604-S
- b: Rectifiers and supply circuits
- c: DC bus lines
- d: Transformers for DC buses
- e: PCI motion control card



2.14. Figure: Backplane connectors:

- a: Main supply (230V/50Hz)
- b: Arm power
- c: Sensor cable
- d: External E-stop
- e: Motherboard connectors
- f: 8 digital outputs
- g: 8 digital inputs
- h: teach pendant I/O
- i: PCI motion control card

3. CONCLUSIONS

In this chapter finally we summarize the achieved results, and give an overview of the feature plans.