# DEVELOPMENT OF CONTROL CABINET FOR INDUSTRIAL ROBOTS UP TO SIX DEGREES OF FREEDOM

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***Abstract.*** *Industrial robot retrofitting usually applies specific solutions for each type and size of robots. This work aims create universal control cabinet interfacing a computer (PC) and the manipulator (arm, motors and position sensors), following worldwide tendencies of standardization in automation and control systems. In this system, the PC runs the trajectory generation program and sends actuators set-points over a USB connection. The cabinet synchronizes the joints movements and returns to the PC the actual position of each axis.*

***Keywords***: *Retrofitting, Robot Motion Control, Industrial Robot*

## 1. INTRODUCTION

The Laboratory of Robotics, Welding and Simulation (Laboratório de Robótica, Soldagem e Simulação - LRSS) from Federal University of Minas Gerais (Universidade Federal de Minas Gerais - UFMG) works currently on a project for building some small didactic welding robots and industrial robots for especial applications. This robots have big differences in size, number of axes, geometry and power solicitation. These differences motivate the development of an universal control cabinet. The same controller can be connected to any of these robots with few or no modifications and to realize this we had to make a standard platform of motors, controller, connectors, cables and support trails.

Big companies are replacing the outdated robots and this creates a low cost robotization alternative for the small and medium companies (Lages and Bracarense, 2003, Lages *et al.*, 2003). The cost of the retrofitting of these robots is a critical parameter to make viable this alternative. The retrofitting of an industrial robot usually uses a specific solution for each type and size of robot and this spend costs and time because each company may have a different project to each robot. The mechanics parts of an old robot must be revised and repaired but in most cases a new project is not necessary. In another way the old control systems and electronics in most cases are obsolete and based in proprietary systems with no assistance by the manufacturer and no documentation, making unviable repairs or replaces of old parts. Following the worldwide tendencies of standardization in automation and control systems this work aim to create an universal control cabinet interfacing the trajectory generator in PC and the manipulator (arms, motors, position sensors).

Old control systems are based in analog components and analog sensors. These components cause precision errors, are vulnerable to field noises and have high power dissipation. The evolution of semiconductors and power electronics develop systems stronger for field noises, with improved precision and more energetic efficiently. The feedback sensoring of old robots many times is based in analog sensors (like resolvers and tachometers). The integration of these sensors with recently developed OEM (Original Equipment Manufacturer) systems is more difficultly. A good option for retrofitting the analog feedback sensors are the incremental optical encoders, which are cheaper and simpler and have best precision (Lima II *et al.*, 2004). The old motor drivers in most times are based in linear amplifiers with difficult maintenance, use expensive semiconductors and have high power dissipation. Today, we have OEM switched motor drivers for DC brushed motors with costs and specifications compatible with the proposed application. This variety brings the advantage of choice of the manufacturer. To use these drivers we have to put in robot motion control loop a new component: the pulse generator, which converts the trajectory generator commands to motor driver. That is, to simplify the control logic, to reduce costs e improve the power efficiency of the robot we use a discrete control system. Thus, using OEM components and knowing all the commands and signals changed between these components, we have a half-open architecture that allows to change the intermediate components. The costs of maintenance and project are reduced therefore are not necessary to project the whole system and the OEM components are produced on a large scale and not reduced or dedicated scales.

In the following sections, this work details all the retrofitting steps (Fig. 1) and all the components to be replaced considering some choices to be done. While detailing each step, we also show a case study of a retrofitting, which follows the control architecture shown in Fig. 2.

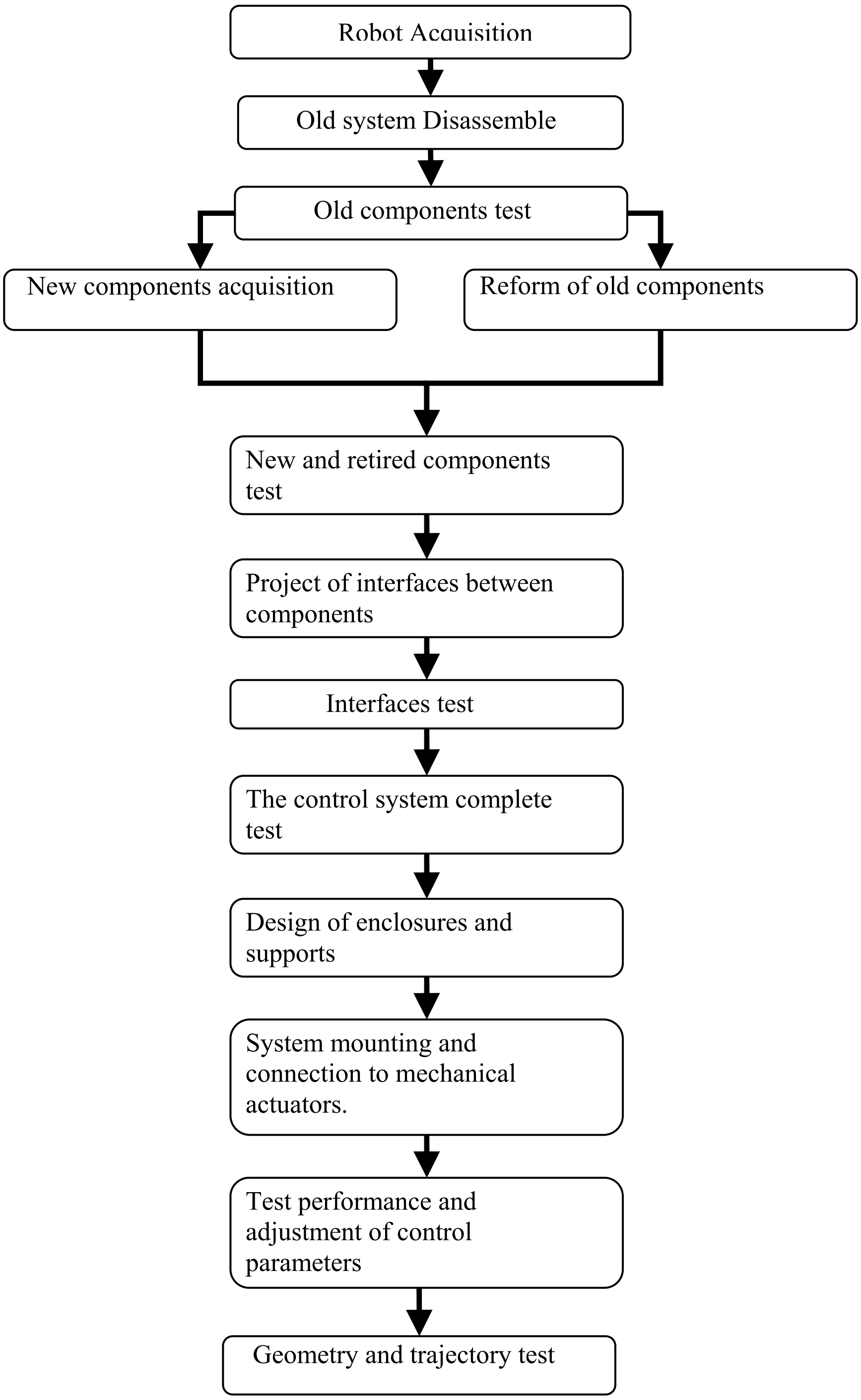


Figure 1. Diagram of possible methodology used for robot retrofitting.

## 2. DEVELOPMENT OF AN UNIVERSAL ROBOT CONTROLLER

The first step to develop the robots controller is the choice of the architecture to be used (Fig. 2), or which could be used, to list which component are essential to this architecture. Starting with a basic architecture of discrete movement control: a trajectory planner on a PC sending commands for a pulses generator that will control the motors driver, we have some choices. For example, to the pair trajectory planner/pulse generator we have two main options:

A MS Windows platform has the software drivers and APIs for connection with a external pulse generator. This option simplifies the development of user graphical applications due the many tools already developed for this, diminishes the training and software development cost, as the drivers and APIs are developed by the manufacturers. In disadvantage we have a less steady operational system and that does not support real time applications. For the usual robot control this disadvantage is solved using a command input buffer in the pulse generator. So, even if the time between commands varies, inside of a certain limit, the pulse generator isolates the motor drivers of this type of variation, but an advanced control system that requires working in real time is not needed.

Another possibility is to use a dedicated port of the PC (usually parallel port, LPT1) as the pulse generator and an operating system capable of running applications in real time (RTAI). Some Linux distributions have been specially developed for these purposes (Linux CNC), so the operating system serves as a trajectory planner and pulse generator. As advantages we have an open system which supports real time applications. However, the cost of developing and maintaining software and hardware grow and is necessary to train not familiar users with the operating system.

In this work we chose to use the first mentioned architecture (external pulse generator and MS Windows operating system).

Another feature that should be considered is whether or not the trajectory planner works with open or closed loop. Depending of the precision required by the application which the robot will be used, the closed loop is essential, but if the application does not require extreme precision, the open loop simplifies the interfaces and reduces costs. In our development we use a virtually closed loop, because the pulse generator does not receive the return signal from the position sensor: only the motor driver receives this information. The pulse generator records how many pulses were sent to each driver and creates a virtual robot position. However we let available in interfaces the feedback motion for further expansions.

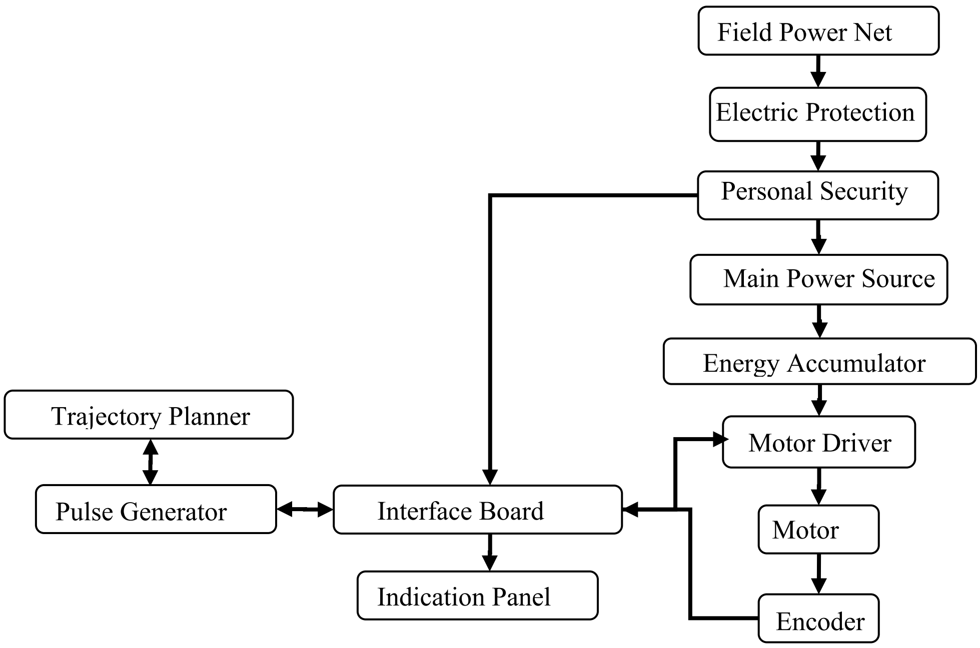


Figure 2. Control System architecture of projected cabinet.

**2.1. Test and retrofitting of old components**

Some of the electric and electronic components of old systems do not need to be replaced, especially the components of energy sources that tend to be simple and high cost. The main power sources, both old and new, are generally composed of a voltage transformer, a bridge rectifier and a capacitive filter. The use of switched drivers replaces the use of voltage regulators. Of those cited, the only component that must be replaced is the capacitive filter, because the capacitors are perishable and easily degrades over time, especially in temperatures above 25°C. The transformers and rectifiers, after properly tested can be reused.

Transformer manufacturers do not usually have the documentation about its features. Then one may have to use some techniques to check its integrity and to obtain their parameters. A good start is to find poles which are isolated windings. Using an ohmmeter to measuring the resistance between the poles, we observe that poles of the same winding have low resistance and poles of different windings have to provide infinite resistance. Inconsistencies in these measurements may represent the transformer is damaged. Another important test is fugue between windings, for this a dielectric strength measurement is need using a mega-ohmmeter. Low dielectric strength represents the transformer is proper to become defect. Knowing that the transformer has no short-circuit or broken windings we can continue to obtain the relations of transformation. To perform this test, we will set up an AC circuit limiting the input current of the transformer, typically a power resistor. We should also use high-current protection (circuit breaker) because we do not know the inductance of each winding of the transformer and high current peaks may occur when connecting the circuit.

With the circuit powered, make the input voltage measure (RMS) and on the poles of the other windings and thus raise the relationship based on equation: V1/N1 = V2/N2. Usually the transformers have more than one of transformation relationship, and then we have to assess what is the best answer.

Big differences between the obtained and the estimated relationship, based on the motor voltages and entry of the old system may indicate short-circuit between winding turns which condemns the transformer. If the transformer is an original part of the old robot system the power can be estimated by the sum of motors power, if the motors are exchanged one should perform the calculation not to exceed the power of the source.

To test the rectifiers, one must isolate them so that the measurement is more accurate. Semiconductors normally do not suffer large wear because usually the electrical networks that feed the robots are well protected. If possible, we must find the manufacturer datasheet of the rectifier diode and check the original parameters with the acquired on used components. If this is not possible, we must measure the resistance of the diode junction directly and reverse polarized. The lower resistance value found on diode with directly polarization should be considered the best case and the other values should not have a large standard deviation. Also the largest resistance value found for the junction when reverse polarized should be considered the best case. An interesting point is to compare these values with other diodes with same power and use. After verifying that the diodes are not short-circuited or broken we can connect it to an AC circuit and measure the voltages and wave forms on it. A large percentage of failures in the rectifiers can characterize the exposure to excessive wear and disqualify the entire bridge rectifier.

## 2.2. New components specifications

The choice of new components should be done with caution to avoid unnecessary costs and difficulties of integration between components. The selection of the pulse generator should be mainly based on the availability of drivers and APIs for the operating system being used, the parameters of maximum frequency of pulse generation and the number of axes to be controlled simultaneously. So it's more easily to integrate the trajectory planner software with the pulse generator and prevent an unexpected low motion speed.

In our application we chose as the pulse generator the GRex G100 (Fig. 4) of GeckoDrive, capable to control 6 axes with 8 step frequency ranges (maximum step pulse frequency is 4.194304 Mhz), 6 quadrature encoder inputs, 16 digital general purpose I/O, 4 analog inputs, 4 analog outputs and USB and Ethernet connections. The GRex also uses an integrated FPGA who makes possible future firmware actualizations or customization for especial applications.

The switched driver have to answer a wide range of voltage / power of input / output, so it can be used with different sources without the need of change. The switching frequency should be compatible with the pulse generator to avoid the loss of pulses. The possibility of an emergency stop input and an external current limit setting is needed as considerably increases the security of the system. The PID controller driver should have adjustable parameters to be optimized for various types of motors.

The choice for the developed cabinet was the G320's Gecko Drive (G320, 2008) (Fig. 5) with a large supply range (18 to 80 VDC) and current (20Amps max.). It uses TTL quadrature encoders to feedback, the maximum switching frequency is 25KHz, have an external emergency stop and maximum current limiter and adjustable PID parameters. Figure 3 shows how the computer and pulse generator interfaces with the G320 controllers.

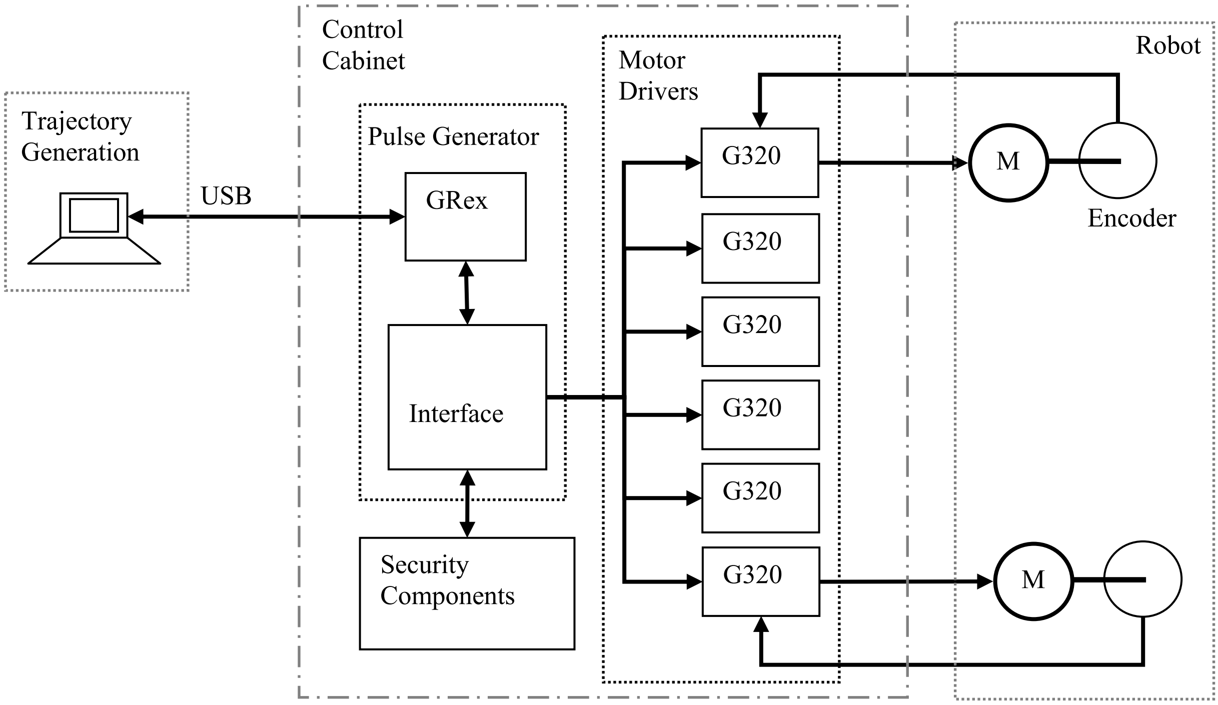

Figure 3. Components interaction diagram.


Figure 4. Grex G100 Pulse Generator.


Figure 5. G320 Geckodrive Motor Driver.

The standards for electrical systems suffered major changes in recent years. An electric protection system (Fig. 6) should be specified, containing the current limiters (circuit breakers), voltage surge and residual current device to ensure protection for the components and for the people who use the equipment (NR-10). The components specifications of collective and personal protection system should always take the premise of safe failure, the failure statistics of components (MTBF) should be considered in order to always ensure safety.

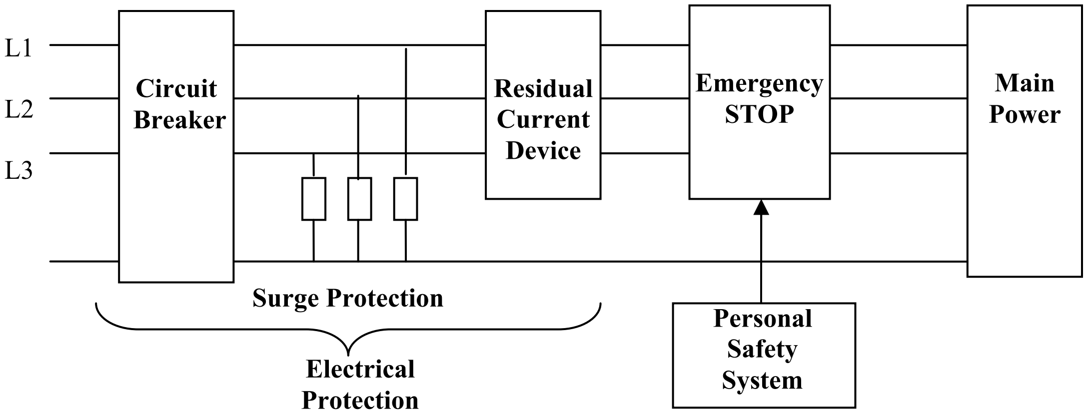


Figure 6. Main Power safety system.

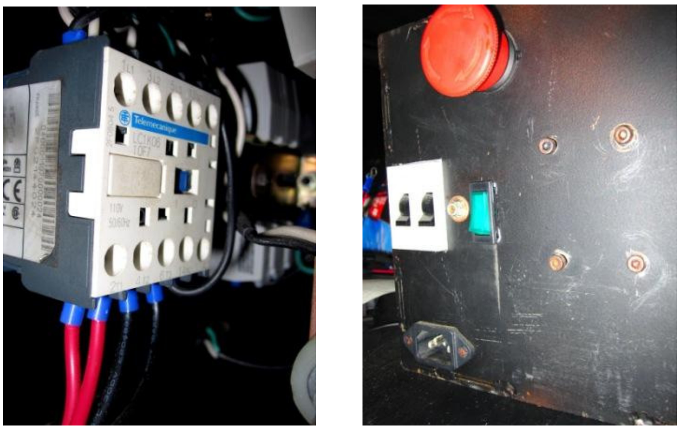

Figure 7. Emergency Stop Circuit and Circuit breaker and emergency stop switch.

The specification of the power source is a critical cost point and some characteristics of the system should be observed as differences between the original robot installations and where it will be installed, whether the motor changes, if there was an increase of the power system (installation of new components). The average cost per watt is U$0.15 for a new power source. Some characteristics of the components cost should be taken into account. For transformers, a greater transformation ratio and a higher output current means a higher cost, because it uses more material, hence for the same power a lower output voltage means a higher cost. Furthermore the cost of capacitive filter increases with elevation of voltage, while the cost of diode rectifiers increases with increasing current. A good practice is start from the components and specify the other components accordingly.

One method to increase the instantaneous power of a source is based on motor use demand; the critic case would be simultaneous start of motors as the start current of a motor is 6x higher than its rated current. Thus we can add a capacitive energy accumulator to support sporadic current peaks. Another interesting point is the amount of power phases used in the primary source. A greater number of phases and rectifier bridge quality makes lower the ripple noise of the source and a lower capacitive filter is needed.

### 2.3. Interfaces and wrappers project

The project of the interfaces between OEM components must meet the specifications of the chosen architecture and the modules being interconnected, and if possible consider further expansions or exchange of other compatible components. This is possible due to the standardization of the main signals as feedback signals from the encoders and step and direction. In the main interface of the developed system we can exchange driver for other compatible models, but the change of the pulse generator by another model is only possible by the introduction of an intermediate board for physical connection, and may represent loss of some resources as inputs and outputs for general use.

The interface between drivers and security systems should also follow the premise of safe failure, or any loss of signal or irregularity should take the system to the emergency stop state. The system should act in the power source, electrical emergency shutdown, as in the drivers and the pulse generator, electronics emergency stop, so that some accumulated energy does not allow any movement after an emergency. The stop system should be integrated with the physical isolation system of the robot (safety doors etc.) and the interface should be compatible with its standards.

Figure 8. Interface Circuit Board

The system box should be metallic in order to isolate the environment from possible electromagnetic noise generated by power switching of the drivers. Due to the proximity of the robot system and also the weather to which it is exposed, the casing should be specified according to the degree of protection required in the workplace. To support and storage of the casing, a good practice is to use the racks found in the market due to the versatility of mounting and expansion, good finishing, good heat dissipation, and low cost since it is not necessary to design and manufacture a support for the system, and are found on a great range of models, sizes and accessories.

Figure 9. Cabinet front panel.

Figure 10. Cabinet back panel.

**2.4. Control system test**

The initial test of the control system in the laboratory, already connected to the motor, indicates whether the functioning of the system is acceptable within the parameters of speed and accuracy. Some important points must be noted, such as:

- The maximum delay between a command generated by the trajectory planner and the execution by the motor: this time should not be large enough to hinder the progress of normal movements interpolated by the trajectory planner, or the movements will be slow and imprecise;
- Verification pulses loss: if there is a loss of pulses from the generator and the driver may be necessary to adjust the frequency of the pulse generation or check a problem with the signal of the feedback encoder. This failure may be characterized by the loss of repeatability of movement. We also noted the strength of the connection between the trajectory planner and the pulse generator so that no losses occur in between the two commands.

At this stage we can perform the adjustments of the driver/motor system by tuning the internal driver PID parameters to remove instabilities on the movement and positioning, overshooting in movement or vibration when the motor is in a fixed position

Figure 11. Vision system calibration table used in the tests.

Figure 12. Small Scale Mill with controller developed in same methodology.

Figure 13. Small Mill Control Cabinet front panel.

**2.5. Perfomance test**

In the first tests with the controller physically connected to the robot we should check some parameters. Even with a prior estimate of the motor acceleration and maximum speed values they should be adjusted based on movement tests. At this point we can test whether the set of trajectory generator and the pulse generator is running really consistently the planned trajectories. We should also look for mechanical or control breaks. In the event of the values of acceleration and maximum speed does not reach the expected values due to instabilities in the power source on critic demands (start of several motors simultaneously) we can add to the system a capacitive energy accumulator which will increase the instantaneous source power.


Figure 14. Five axes robot, ASEA, used in the experiments.

## 3. CONCLUSIONS

Using the techniques described in this paper, it can be developed a standard platform for robot retrofitting and prototypes of new robots with a final lower cost than the equivalent equipment already found in the market. However, some drawbacks have to be further studied, like reliability and repetibility of the retrofitted system. Several steps have to be reviewed in order to maintain low cost in any configuration of robot to be retrofitted, and generic components should be preferred in order to obtain the benefits of scale.

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## 5. RESPONSIBILITY NOTICE

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