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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 soldagem , robótica e simulação - LRSS) from Federal University of Minas Gerais (Universidade Federal de Minas Gerais - UFMG) works currently on a projects 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 a development of a 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 connectors, cables, support trails, motors and controller.

Big companies are replacing the outdated robots and this creates a low cost robotization alternative for the small and medium companies (Lages and Bracarense, 2003, Lages *et al.*, 2003), the cost of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 this robots is a critical parameter to make this alternative viable. 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 one 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 fabricant 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 causes 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 time is based in analog sensors (like resolvers and tachometers). The integration of this sensors with recently developed OEM systems is more difficultly. A good option for retrofitting the analog feedback sensors are the incremental optical encoders, which are cheap and simple and have best precision (Lima II ,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 us 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, who 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 it allows in to change them intermediate components since that keep the protocol. The costs of maintenance and project are reduced therefore are not necessary to project the whole system and the components OEM are produced on a large scale and not in 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.

ABCM Symposium Series in Mechatronics - Vol. 4 - pp.427-432

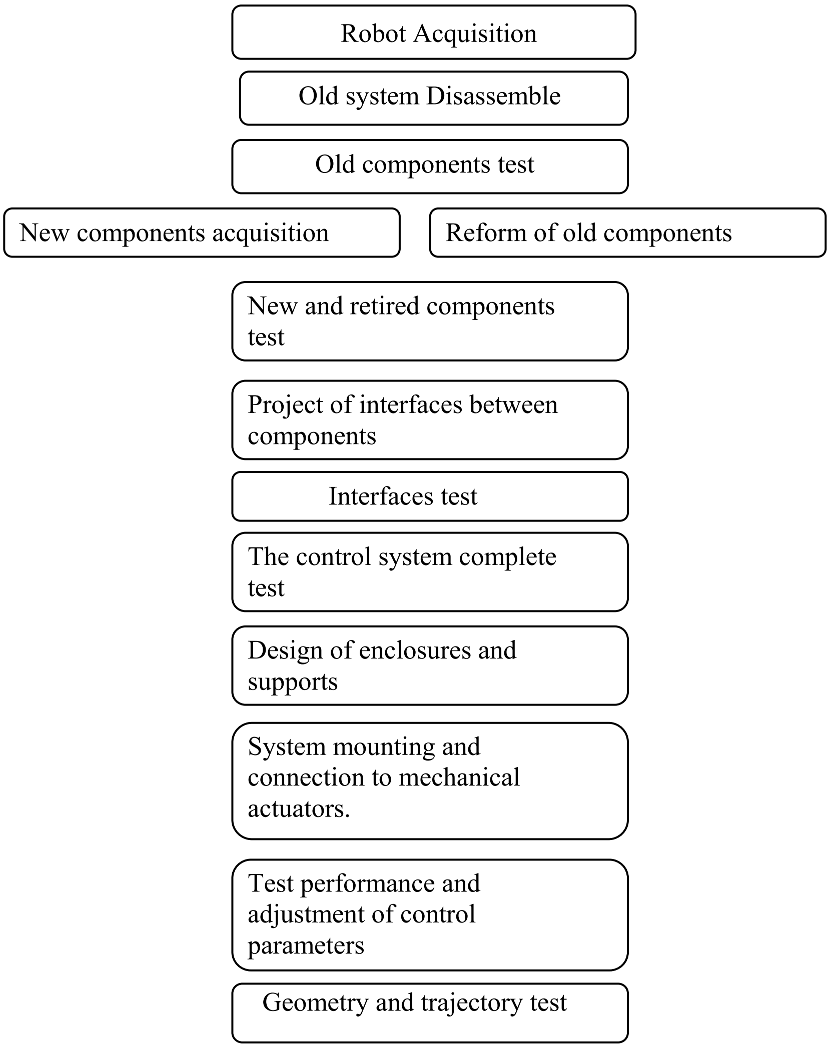

Figure 1. Diagram of possible methodology used for robot retrofitting.

2. DEVELOPMENT OF AN UNIVERSAL ROBOT CONTROLLER

The first step to develop the controller of robots 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 of a basic architecture of control of discrete movement if contend: a trajectory planner on a PC sending commands for a generator of pulses that will control driver of the motors, we have some choices for as to make these stages. For example, to the pair trajectory planner/pulse generator we have two main options:

A MS Windows platform if contend the 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 it does not support real time applications. For the usual robot control this disadvantage is contouring using a command input buffer in the pulse generator, even 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 prevented.

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 users not familiar with the operating system.

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

ABCM Symposium Series in Mechatronics - Vol. 4 - pp.427-432

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 of the motor driver. It holds as 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.

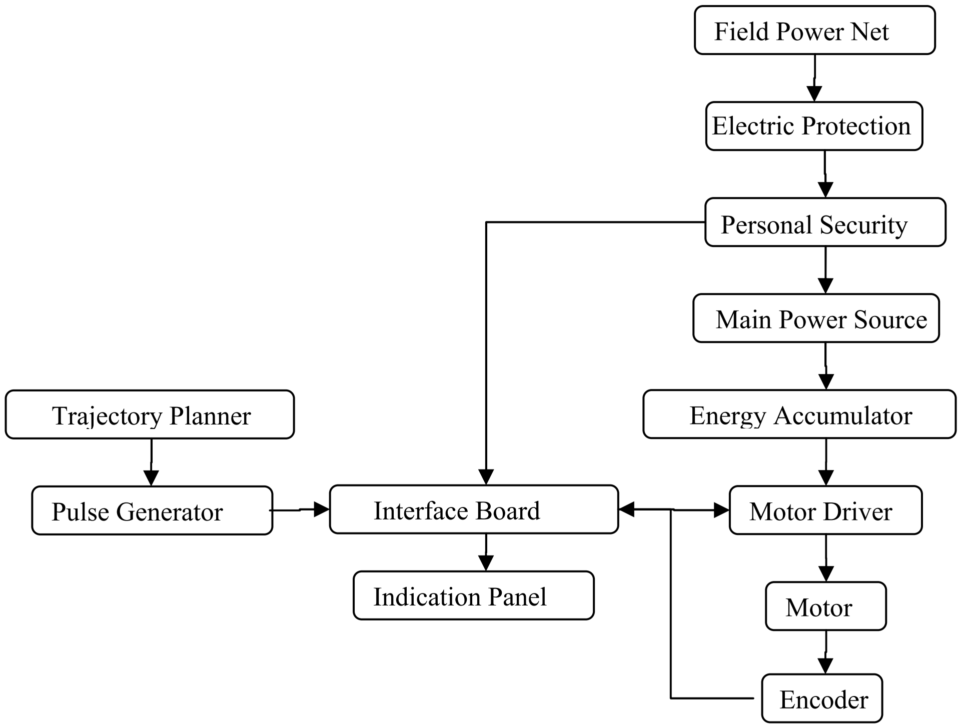

Figure 2. Control System architecture of projected cabinet.

2.1. TEST AND RETROFITTING OF OLD COMPONENTS

Some of electric and electronic components of old systems do not need discarded, 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 release the use of voltage regulators. Of these the only components that must be discarded is the capacitive filter, because the capacitors are perishable and are easily degrade over time and especially temperatures above 25 ° C. The transformers and rectifiers being properly tested can be reused.

Transformers manufacturers do not usually have the documentation about its features. Then we 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 providing 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 current input 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 the best answer.

Big differences between the obtained and the estimated relationship, based on the motor voltages and entry of the old system, may indicates 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 by chance the motors are exchanged should perform the calculation not to exceed the power of the source.

ABCM Symposium Series in Mechatronics - Vol. 4 - pp.427-432

To test the rectifiers, the first 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 confer 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 value of resistance 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 value of resistance found for the junction 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 choice of pulse generator should be based mainly 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 speed of motion.

In our application we chose as the pulse generator the GRex G100 of Gecko Drive capable to control 6 axes with 8 step frequency ranges (maximum step pulse frequency 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 very much 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) with a large supply range (18 to 80 VDC) and current (20Amps max.), use TTL quadrature encoders to feedback, the maximum switching frequency are 25KHz, have an external emergency stop and max. current limiter and adjustable PID parameters. Figure 3 shows how the computer and pulse generator interfaces with the G320 controllers.

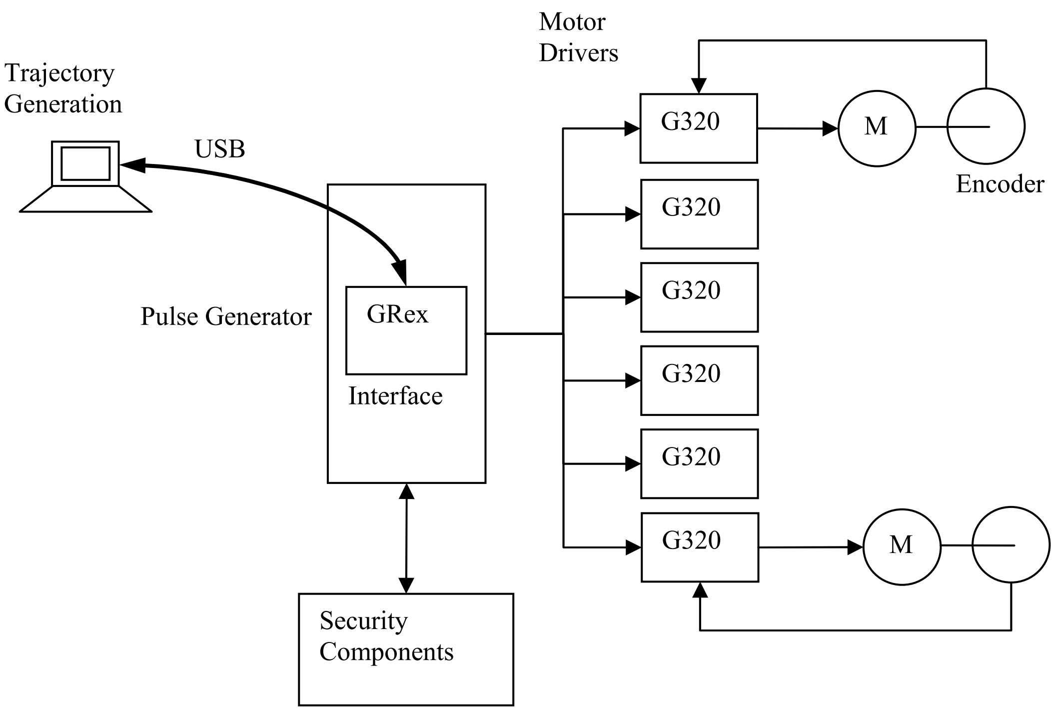

Figure 3. Components interaction diagram.

The standards for electrical systems suffered major changes in recent years. An electric protection system (Fig. 4) should be specified, containing the current limiters (circuit breakers), voltage surge and residual current device to ensure protection of components and the people who use the equipment (NR-10). The components specifications of

ABCM Symposium Series in Mechatronics - Vol. 4 - pp.427-432

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.

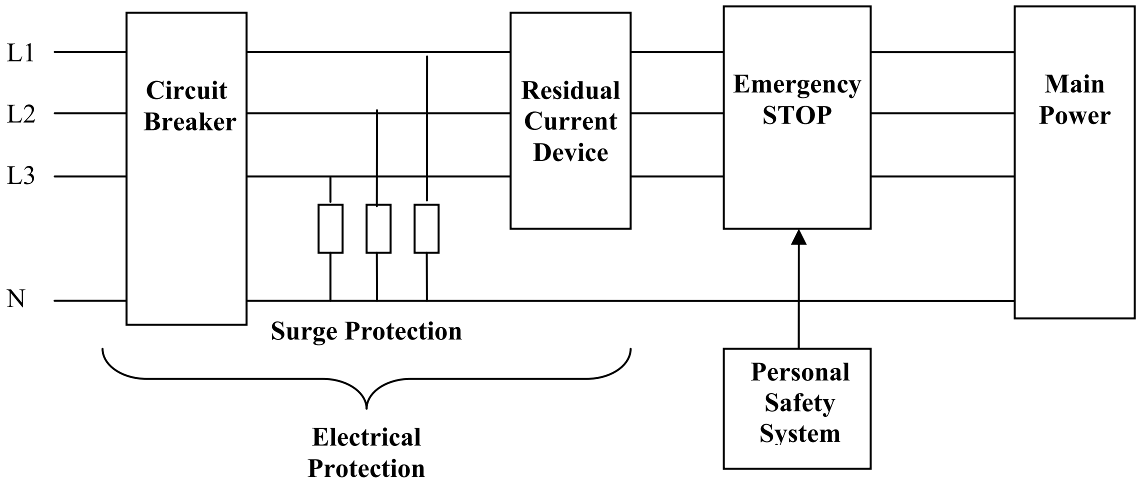

Figure 4. Main Power safety system

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 change, 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 spends more material, once for the same power the lower voltage is the higher cost; Furthermore the cost of capacitive filter increase with elevation of voltage, while the cost of diode rectifiers increases with increasing current. A good practice is start from the components and specifies 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 upper to 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 the number of phases and the 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 possible expansions or exchange of other compatible components. This it's 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 realize the exchange of driver compatible drivers for other models, but the change of the pulse generator by another model is only possible by the introduction of an intermediate plate for physical connection, and may represent loss of some resources as inputs and outputs for general use.

The interface between driver and security systems should also follow the premise of safe failure, or any loss of signal or irregularity should enter 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 (crates and doors or in case of worker robot interaction infrared or optical barrier) and the interface should be compatible with standards used by them.

The system containment should be metallic in order to isolate the environment from possible electromagnetic noise generated by power switching of the drivers. As well as the most sensitive to these noises, especially the generator of pulses should have barriers of electromagnetic isolation. 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 finish, good heat dissipation, and low cost since it is not necessary to design and manufacture a support for the system, and are find on a great range of models, sizes and accessories for them.

2.4. CONTROL SYSTEM TEST

The initial test of the control system in labs, already connected to the motor, indicates whether the functioning of the system is acceptable within the parameters of speed and accuracy. Must be raised some important points such as: The maximum delay between a command performed 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 of loss of pulses, if there is loss of pulses from the generator and the driver may be necessary to adjust the frequency of pulse generation or indicate 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 adjusts of the driver/motor system by the tuning the internal driver PID parameters to remove instabilities of the movement and positioning, as error of overshooting in movement or vibration when the motor is in a fixed position

2.5. PERFOMANCE TEST

In the first tests with the complete and physically connected to the robot we should see 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 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 power of source.

3. CONCLUSIONS

Using the techniques described in this paper, it can be concluded that the development of a standard platform for robot retrofitting and prototypes of new robots with a final cost much lower than the equivalent equipment already found in the market, but with some drawbacks that has to be further studies, 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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