AUTOREB - ROBOTIZATION OF THE DEBURRING OF CASTING PIECES

Ricardo Araújo[†], Nuno Queirós[†], Eduardo Pinto[†], Jaime Fonseca[‡] and Carlos Couto[‡]

[†] IDITE-Minho – Instituto de Desenvolvimento e Inovação Tecnológica do Minho, Av. Dr. Francisco Pires Gonçalves 4710-911 Braga - Portugal
email: raraujo@idite-minho.pt and epinto@idite-minho.pt

[‡] Department of Industrial Electronics, University of Minho, 4800-058 Guimarães, Portugal
email: jaime@dei.uminho.pt and ccouto@dei.uminho.pt

Abstract

In the industry of foundry, the deburring of casting pieces is an important stage. Since the piece presents edges in the junction zone of the casting moulds, those usually are not desirable and should be eliminated. For solving this problem it was idealized a robotic system capable of deburring casting pieces with minimum human intervention. Consists of an ABB robot, a table of coordinates for fixation and movement of the casting pieces, an artificial vision system for identification and quality control of the casting pieces, a Bosch high frequency straight grinder and an force sensor that closes the feedback loop of the deburring process control.

1 Introduction

The industry of foundry is characterized for the traditionalism of its methods and processes to which are always associated hard human tasks. This methods and processes are developed on a potentially dangerous environment for the people involved. The deburring of the casting pieces is an important stage in this industry. This operation demands, currently, a total control over its processes, a task that in most cases is performed by human operators.

Any casting piece presents edges in the junction zone of the casting moulds. Those edges are usually not desirable and must be eliminated. The traditional process of deburring is executed manually with angle grinders, straight grinders or millstones. This process involves hard work conditions, such as high noise levels and dirtiness, being also physically violent for the workers. Besides, workers are highly specialized, consequently raising the salaries. Another stage highly important for the productivity and the competitiveness of the company is the quality control of the finished parts that will have to be carried out manually. After melted and cooled down the pieces are removed from the mould and the feeding (channels used for the liquid metal and air) is taken away.

We are, thus, with the parts intended in raw. These, after being separated from the channels, also present edges that not only result from the channels of feed and breathe, but also from the junction between the upper/lower moulds. Some technologies have been tested and used to remove the edges, as, for example: Water Jet, Laser, plasma and milling cutter.

Currently, the greater part of deburring processes still follow the established traditional method in angle grinder and straight grinder**,** due to the difficulties created by the application of the new methods and to the associated costs.

The inclusion of multiple sensors in machines and systems is one of the most important, if not the main requirement to introduce some intelligence in these entities, allowing them to act in non-structured environments without the full control of the human operator. Sensors allow the system to apprehend the state of the environment, information that is afterwards represented by a model.

This model needs a continuous update, which implies a big storage capacity so that the environment representation is as trustworthy as possible and a big processing velocity to analyse the data originated from several sources, at the appropriate time. In this paper, it is introduced an intelligent robotized system that deburres metallic pieces and performs an automatic analysis of foundry's unconformities, making use of the synergy between multiple sensors, real time data processing and production technologies. The pieces submitted to the deburring process are iron leagues with weight varying between one and thirty kilos and with diverse geometry, most of the times a complex one.

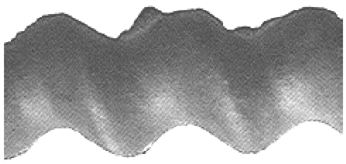


Figure 1 – Example of a piece with edge

This project is being developed in cooperation with MAQUISIS and Cruz, Martins & Wahl, Lda, being this last one the enterprise that produces the pieces to deburr. The production of this company is composed by a great number of small series with very short time of delivery, whose 90% of the production is destined to the German market.

2 The work cell

Before defining the constitution of the work cell, it was necessary to decide which method of deburring to use. After studying the previously mentioned methods, were chosen the traditional deburring techniques. A choice motivated by the high cost of the laser systems and water jet, an unnecessary investment in this situation.

In what concerns the plasma system, the results displayed by the producers were not satisfying for this type of application. The use of milling cutters was abandoned in consequence of the problems related with the vibrations created on the contact tool/piece.

Considering that the goal was to develop a traditional deburring totally automatized, it was necessary to select the following elements in order to settle the work cell: one manipulator robot to simulate the work of the operator's arm; a force sensor to place on the robot's wrist in order to enable the measurement of the forces registered, at each instant, during the entire deburring process; an automatic tool change that would allow the exchange of the tools, an alternative to the use of a single gripper; system for acquisition/processing of images, composed by cameras and an frame grabber that identifies and superintends the pieces and the areas to deburr; table to bear the pieces; tool to deburring. The selected elements were the following:

2.1 Robot

The set of characteristics that the robot should have included a load capacity of about 120 kg and the ability to communicate with a PC, using CAN or Ethernet. After a market research was selected the ABB robot, model IRB6400F (Figure 2 a).

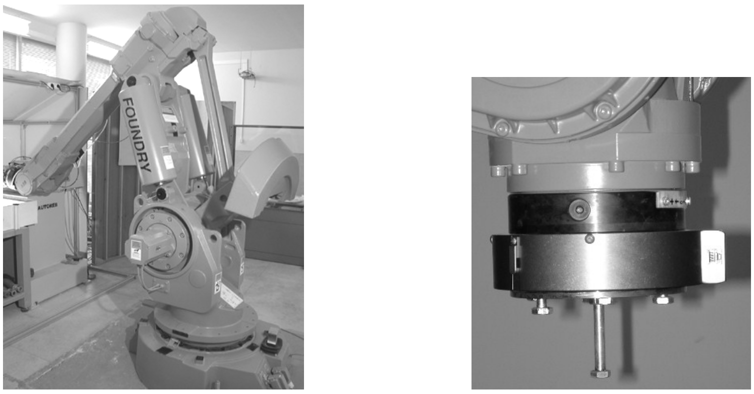


Figure 2 – a) ABB Robot model IRB 6400 b) JR3's force sensor placed on the robot's wrist

2.2 Force Sensor

The sensor intended should endure the possibility to measure complex loads with forces and moments in the three axis (x, y, z) and whose controller would make possible an easy interface with a PC, in order to permit the data acquisition. After a market research it was chosen the sensor from JR3, model 75E20A-I125-D (Figure 2 b).

2.3 Tool Change

Instead of using a single/universal gripper difficult to build, was selected an automatic tool change system. The selected system was from Schunk (SWS – 100).

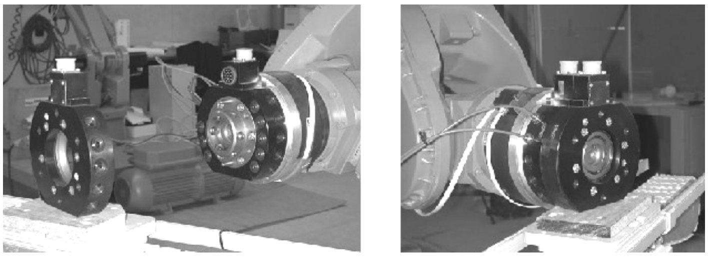


Figure 3 - Tool Change

2.4 The Artificial Vision System

To implement this system were acquired monochromatic cameras with a CCD of one third of an inch (1/3"). The cameras resolution is 760x568 points. The used lenses possess a focal distance of 8mm. The image frame grabber is *Matrox Meteor II* that can work with both monochromatic and color images, using PCI as interface. The card includes a functions library that makes it possible to control and initialize the frame grabber, acquire, visualize and manipulate images.

2.5 Table of Coordinates

The table to bear the pieces was developed by MAQUISIS. A model where the piece is placed and then transported to the working table by the robot composes the table. Figure 4 shows a drawing of the "*Gabari*" used for one of the pieces to deburr (the plait), and presents a Figure of the table that will bear the "*Gabari*" with the piece to deburr.

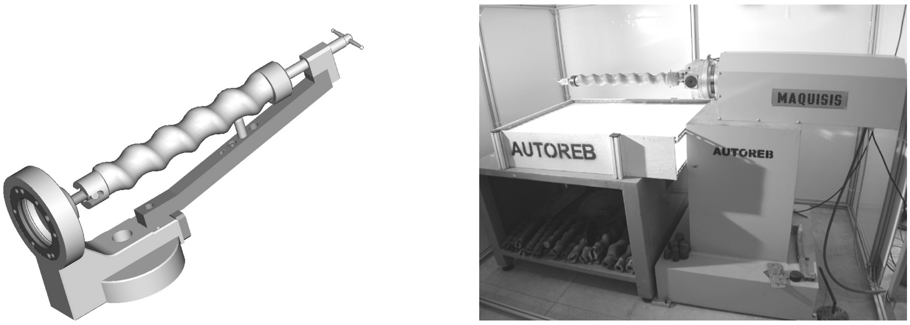


Figure 4 – "*Gabari*" and table to bear the models

2.6 Deburring Tool

When choosing the deburring tool was decided that the network frequency tools (50Hz) were not appropriated to the accomplishment of this task, because when subjected to an effort it would not maintain a constant speed and the option was to obtain a high frequency tool. After a market study was chosen a tension converter and a feeding frequency (200V/ 300Hz), with a 4kVA power, since it was only necessary to keep one machine working at a time. The acquired tool was a Bosch model HGS 85/80 (Figure 5).

Figure 5 – Bosh straight grinder

3 Robotization Development

The robotization process was divided in three subsystems: 1) identification subsystems; 2) force's control subsystem; 3) pieces quality/inspection control subsystem. The first one's function is to identify and examine the pieces and determine where edge exists. The second executes the deburring process based on the data coming from the vision complemented with information from the force sensor in real time. On a final stage, it will be executed an inspection in order to determine whether the piece was properly deburred, relying on the comparison between the information gathered on a database and the updated information obtained by the vision system. Notice that an inspection is accomplished before the deburring is executed, aiming to verify if the piece needs to be deburred.

In order to develop these subsystems it was necessary to choose a modular and flexible platform that would make possible an easy integration of the software modules to be developed. It was chosen the programming tool *LabView* from *National Instruments* (*NI*). *LabView* has the ability to quickly develop acquisition and data analysis systems, as well as, easiness of communication and connection with other applications using *ActiveX*, DLLs (*Dynamic Linked Libraries*), *DataSocket*, TCP/IP protocol and many other protocols. It has also the advantage of being multiplatform, with the possibility to be used in several platforms as *Windows*, *Mac Os* or *Linux*.

3.1 Identification subsystem

The identification process is one of the most important aspects of the entire process because the determination of unconformities, quality control and deburring depends on a good identification of the piece. This process works based on the agreement between the information collected, in real time, from the piece and the information concerning a correctly deburred piece previously stored in a database. The characteristics stored in the database used for a good identification and later inspections of the piece are the following: area; perimeter; maximum diameter; mass centre; piece's weight; number of interlaces; image localization; transponder identification; image of a well deburred piece.

Considering the validation of the previously mentioned characteristics the process of and pieces inspection is accomplished through the interconnection of three modules:

- The first module is composed by a radio frequency identification system whose main function is to determine which family the piece belongs to. Each model has a transponder that identifies it univocally. Since each model is able to transport a determined family of pieces, the identification of a given group of pieces is immediately restricted to one family. The main advantage of the radio frequency system, when compared with other automatic identification systems, such as bars code, is related with the fact that transponders can be re-used and it is possible to effectuate a reading even if there is no vision line between the reader and the transponder. Basically, a radio frequency identification system is composed by an interrogator element (reader with an antenna) and an interrogated element. The interrogator module has a transmitter/receiver circuit that issues a radio signal and receives, from the interrogated element, an answering signal. The questioned element is called transponder, or just tag because it is used on the objects that must be identified. The dispatch of the information is made through the PC's serial door (RS-232).

- The second module consists on the use of a load cell (force sensor linked on the robot's wrist) in order to calculate the weight of the piece to process and enable the selection of pieces with similar weight. The characteristic weight of the piece will be determined by the force sensor placed on the robot wrist when it holds the piece placed in the rest table.

- Finally, a module that using image digital processing techniques withdraws some characteristics from the piece, in order to obtain an unequivocal identification. The identification process is made by the vision module based on the comparison between the acquired image and the image of the piece without edge existing on the database.

On the development of this module was used a packet named *National Instruments Vision* and *Image Processing Software*. The use of *Matrox Meteor II* frame grabber on *LabView* environment required the development of the necessary *drivers* to run the card since it is not an NI product.

The information deriving from the three modules is compared in order to identify the piece with the smallest error probability. After the identification process the vision module draws out the information related with the edge. That information is afterwards sent to the force control subsystem to execute the deburr.

3.2 Force control subsystem

The robot's force control industrial manipulator from ABB is achieved throughout the conjugation, on the remote Personal Computer, of the data proceeding from the force/moment sensor and the robot movements (Figure 6). The PC analyses the real time values of the force and, according to it, are sent the necessary corrections for the robot's position so that a desirable unchanging force is maintained. The force sensor can also be used to detect an unexpected crash and, therefore, alert the system for something out of place or an abnormal event happening on the work cell. Thus, when including an external ring for force control it is possible to adjust the robot's position to the sensorial information of force/movement and the intended objectives.

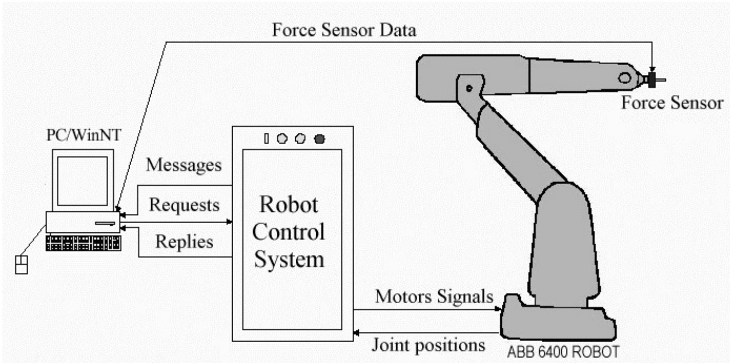


Figure 6 – Sensorization System

The basic structure of the software used for application to the industrial robot and the sensor (Figure 7) is divided in two separated parts:

1 – A set of functions that effectuate all communication operations with the robot's controller, as well as the access to the remote services it makes available (ActiveX PCROB). The communication with the robot is established through Ethernet.

2 – A set of functions destined to shape and access to the force/moment sensor (ActiveX NP_JR3).

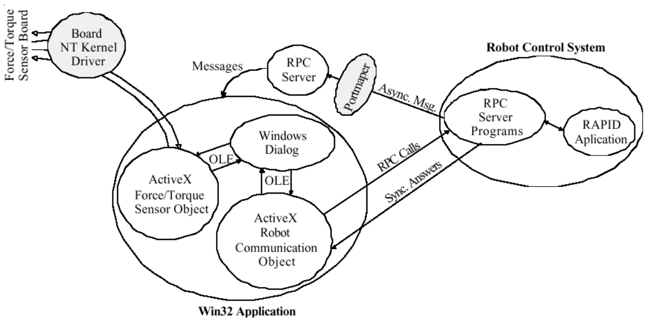


Figure 7 – Software structure for interaction with the industrial ABB robot and the force sensor.

The purpose of the force control is to keep constant the deburring force. Because it is a non-linear system, without an acceptable mathematical model, it was decided to implement a fuzzy PI controller, so the human knowledge of the deburring process could be reproduced.

The implemented controller has two inputs and one output as the next table exhibits:

	Variable definition
Input	Force Error ⇒ e(k) = f_a (k) - f_d (k)
	Error Variation ⇒ de(k) = e(k) – e(k-1)
Output	Control Variable ⇒ du(k)

Table 1: Inputs and outputs of fuzzy controller.

Fuzzy-PI controller was implemented through a 2D table, generated by Matlab program, using it's toolbox with fuzzy logic, being the basic knowledge rules obtained using a similar strategy to the one employed by J. Norberto Pires (J. Pires 1999) in his work.

The generation of that table was based on triangular membership functions with modal values corresponding to 9 linguistic variables: Big Negative (BN), Big Average Negative (BAN), Average Negative (AN), Small Negative (SN), Zero (ZR), Small Positive (SP), Average Positive

(AP), Big Average Positive (BAP), Big Positive (BP). When generating the table was considered the force/moment sensor used and the effectuated calibration tests, dividing the sensors doe in 19 zones, obtained from percentage error quotients (e(k) / fd) and the error difference (d e(k) / fd) in function of the desired force (Table 2).

$\frac{e(k)}{f_d}(\%)$	$\frac{de(k)}{f_d}(\%)$	**Level**
< -0.99	< -0.85	-9
[-0.85, -0.99]	[-0.75, -0.85]	-8
[-0.70, -0.85]	[-0.65, -0.75]	-7
[-0.55, -0.70]	[-0.55, -0.65]	-6
[-0.45, -0.55]	[-0.45, -0.55]	-5
[-0.35, -0.45]	[-0.35, -0.45]	-4
[-0.25, -0.35]	[-0.25, -0.35]	-3
[-0.15, -0.25]	[-0.15, -0.25]	-2
[-0.10, -0.15]	[-0.10, -0.15]	-1
]0.10, -0.10[	]0.10, -0.10[	0
[0.10, 0.15]	[0.10, 0.15]	1
[0.15, 0.25]	[0.15, 0.25]	2
[0.25, 0.35]	[0.25, 0.35]	3
[0.35, 0.45]	[0.35, 0.45]	4
[0.45, 0.55]	[0.45, 0.55]	5
[0.55, 0.70]	[0.55, 0.65]	6
[0.70, 0.85]	[0.65, 0.75]	7
[0.85, 0.99]	[0.75, 0.85]	8
> 0.99	> 0.85	9

Table 2 – Corrections Levels

On Table 2 zero level (shaded) represents the dead zone, that is, the zone were no increment is sent to the robot and where the controller must remain if the measured force is equal to the desired force.

3.3 Pieces quality/inspection control

The purpose of the inspection/control applications was to verify the defects, to effect dimensional measurement and characteristics verifications. When the inspection/quality control process is performed manually there is the possibility of occurring a human error and, because of the process slowness, the inspection is frequently executed by sampling. The use of an automatic system, like this one, enables the control of all the pieces, using less time and keeping the same criteria homogeneity, eliminating human subjectivity.

The quality control is executed every time that a new piece arrives to the deburring cell and every time that the deburring process is finished.

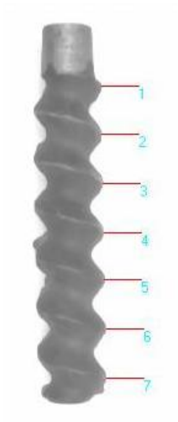
The first control process aims to verify if the new piece presents the acceptable quality levels (edge < 0,5mm). If it is not under the accepted levels the deburring is effectuated. Otherwise, the piece is removed from the deburring cell and the processing of a new piece begins. The quality control is fulfilled using the values are retired during the process to determine the dimension and localization of the edge. As in the developed functions are obtained the values of the biggest edge existing in the piece, these values are used to determine the result of the control quality process. Thus, if the value of the biggest edge is superior to the quality value (0,5mm) the piece is rejected and must be deburred again. Otherwise, the piece is considered good and removed from the deburring cell. It was defined that one piece could pass a maximum of three deburring operations. If, even with these three operations the quality control is negative, the piece is definitively rejected. This procedure avoids also that the time for deburring process becomes elevated.

4 Tests and conclusions

4.1 Pieces identification and inspection subsystem

The performed tests made possible to effectuate a pre-evaluation of the vision module viability in tasks as identification and extraction of relevant information afterwards sent to the control module that will execute the deburring process. These tests enabled an evaluation of the *LabView* tool, namely its packet IMAQ *Vision*.

Figure 8 shows as an example the result of the comparison between the piece kept in the database and a piece with deburr.



[X]	[Y]	[D]
619,000	343,000	6,000
620,000	343,000	6,000
621,000	343,000	7,000
622,000	343,000	8,000
623,000	343,000	8,000
624,000	342,000	8,000
625,000	342,000	9,000
626,000	341,000	9,000
627,000	340,000	9,000
628,000	340,000	9,000
629,000	340,000	10,000
630,000	339,000	10,000
631,000	340,000	11,000
632,000	340,000	12,000
633,000	340,000	13,000
634,000	340,000	13,000
635,000	340,000	14,000
636,000	340,000	15,000
637,000	340,000	16,000

Figure 8 – Determination of the edge dimension

From the edge image, it is possible to built a table with the edge dimensions, where X and Y are the coordinates concerning the image referential and D the size of the edge.

After the deburring, takes place the acquisition of a new piece that will be compared with the image of the one existing in the database. If the edge dimension is minor than 0, 5 mm the piece is considered good. Otherwise, it will be deburred again on the points where the condition (<0,5mm) is not verified. With these tests it was possible to infer that this simple approach makes it possible to determine, with the necessary strictness, the edge dimension, as it is possible to settle the characteristics of the piece such as the area, the perimeter, the maximum diameter, the mass centre and the number of interlaces, that will contribute to a strict identification and inspection of the pieces. It must be noted that the LabView tool potentialities concerning image acquisition and process has made it easy to obtain the intended information.

4.2 Force control subsystem

With the available prototype were made some tests to the modules that implement this subsystem in order to make a survey of the possible problems that could come up during de deburring process. For such purpose it was used a metallic structure linked to the robot wrist enabling the simulation of the tool position when it strikes the pieces. With this structure was possible to fulfil the first tests simulating the course that the tool must accomplish to execute the interlaces deburring (Figure 9). For the robot to follow the piece outline it was developed software to communicate with the robot, enabling the position corrections, based on the information received from the real time force sensor.

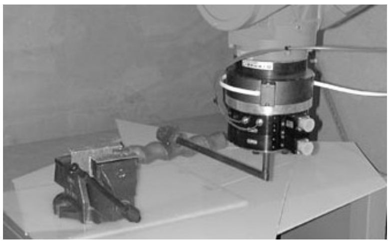


Figure 9 – Simulation of the trajectory following throughout the piece

The first controller used in this simulation was the ON-OFF with scales. That is a very simple controller with a division for twelve correction steps. This test allowed the test of three modules of the control and supervision system:

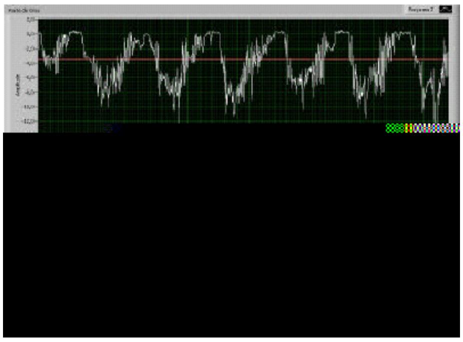
- Management of the force sensor module;
- Module of communication with the robot;
- Module of robot control during the deburring process.

Table three indicates de force values obtained by the sensor, the force breaks resulting from subtraction of the desired force value (15KgF in this case), as well as the correction in millimetres sent to the robot. In bold are the breaks that form the dead zone.

Force values sent by the sensor	Force breaks	Sent corrections
< 0	> 15	0.9
[0,3[	[15,12[	0.8
[3,5[	[12,10[	0.7
[5,7[	[10,8[	0.6
[7,9[	[8,6[	0.5
[9,11[	[6,4[	0.4
[11,12[	[4,3[	0.3
[12,13[	[3,2[	0.2
[13,14[	[2,1[	0.1
[14,15[	**[1,0[**	**0**
[15,16[	**[0,-1[**	**0**
[17,16[	[-1,-2[	-0.1
[17,18[	[-2,-3[	-0.2
[18,19[	[-3,-4[	-0.3
[19,21[	[-4,-6[	-0.4
[21,23[	[-6,-8[	-0.5
[23,25[	[-8,-10[	-0.6
[25,27[	[-10,-12[	-0.7
[27,30[	[-12,-15[	-0.8
> 30	< -15	-0.9

Table 3 – Force correction scales

This first test was useful to acquire information about the force control system in order to make it easy to develop the Fuzzy-PI controller. The already performed tests did not permit the evaluation of its potentialities since it has not been possible to perform such test on a real deburrign process. However, the effectuated test demonstrated that was necessary an improvement because the force control was still exhibiting excessive oscillation as it is shown in Figure 10 a.



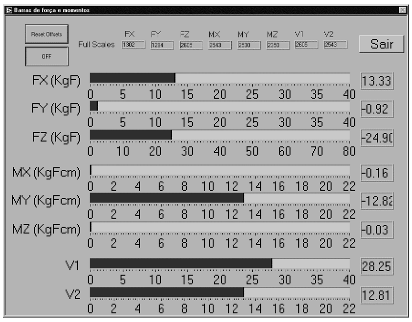


Figure 10 – a) Force graphic following a deburred piece b) Indication force/moments

It was concluded, in consequence of these, tests that the structure idealized for this system is a valid one and indicates success probabilities in the deburring of this type of pieces. On the other hand, the *LabView* was easy to use, enabling the utilization with simplicity of the force sensor management modules and the communication with the robot using Ethernet on it's own environment. Notice that was easy to bring up a monitorization environment that allows us to know at each instant the state of the progress, such as the forces/moments measured by the force sensor (Figure 10 b).

5 Future work

From the points mentioned before, the vision identification and inspection techniques using computer could be developed using complementary sensorization, backed by sensorial fusion techniques.

The optimisation of the deburring algorithm throughout the improvement of the fuzzy-PI controller and experimentation of new controlling approaches.

The development of the system control and supervision/decision, with a higher hierarchic level, in order to optimise the global factory process. Example: tele-maintenance and tele-service using web.

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