# Report on Bristol RIF visit outcome

*- DEBUR Experiment -*
*Automated robotic system for laser deburring of complex 3D shape parts*

Author 1 (TEKNIKER FOUNDATION)

Author 2 (IDELT S.L.)

**Version 1**

**Submission date: 18.11.2016**

## Minutes of the meeting

| Date | Place | Start | Duration | Responsible |
|---|---|---|---|---|
| 2016/10/28 | Bristol Robotics Laboratory<br>UNIVERSITY OF BRISTOL | 9:00 | 2h | Farid Dailami |
| **Assistants (Entity)** | | | | |
| ▪ Dr. Farid Dailami (Bristol RIF Coordinator)<br>▪ Dr. Sam Forbs (University of Bristol)<br>▪ Mr. Carlos Soriano (IK4-Tekniker)<br>▪ Mr. Ramon Arana (IK4-Tekniker)<br>▪<br>▪ | | | | |

# 1. Meeting Content

1. Presentation of Debur project
2. Discussion
3. Next Actions

# 2. Presentation of the experiment

The meeting started with a presentation of the objectives and main achievements of the Echord ++ Debur experiment by Mr. Ramon Arana and Mr. Carlos Soriano. The overall objective of the experiment was to design and set up an automated robotic station for laser deburring of metal casting 3D parts. It was intended to develop a flexible, low-maintenance and environmentally friendly prototype, able to improve the quality, cost and cycle time of aluminium injected components.

To achieve this goal, there were the following particular objectives:

– Development of a laser deburring process of 3D aluminium casting parts, able to replace the current hydraulic deburring and manual sanding operations of casting industries, for components with different geometry and burrs thickness (< 2.0 mm).

- Development of a highly adaptive cognitive robotic system, to carry out the process of deburring and manipulating the parts autonomously, and providing overall process inspection using 2D and 3D machine vision techniques. This system will correct the predefined trajectory, implementing a burr tracking system based on machine vision techniques, and finally determining the optimum cutting path. This system will also be capable to operate at maximum processing speed (> 150 mm/s), according to the performance of the selected laser source (maximum power, spot diameter, etc.).
- Identify and specify the most appropriate individual elements of the laser deburring station, as the laser source, optical beam path, laser head, clamping tools, monitoring and control devices and algorithms.

The expected results were:

- High precision deburring process of complex 3D parts with burrs thickness up to 2 mm, at high processing rates (> 150 mm/s) and cycle times per piece below 90 s, maintaining low roughness cutting edges (Ra ~ 1 µm).
- Prevention of physical lesions of the workers due to the final sanding process, which involves repetitive and intensive manual operations.
- Automatic detection and handling of medium sized parts (400 x 200 x 200 mm) using machine vision techniques.
- 3D measuring for precise burr characterization: locations and height, in tenths of millimetres.
- Automatic processing of the part for burrs removal depending on the previous results of the 3D measurement step. Adaptable processing approaches will be programmed, depending on the existence and location of the burrs. The proposed station design has the laser cutting head fixed in space, while the handling and relative movement with the part is performed by a 6 axes robot.

The presentation was actively followed by Dr. Farid Dailami and Dr. Sam Forbs, making a lot of questions in a very fruitful discussion that served to clarify and understand the research activities done during the execution of this project. Finally the work carried out was recognized by Dr. Farid Dailami.

The presentation is also included with this report.

## 3. Discussion

The main concerns were related with the precision of the robot cell as a whole and whether it will accomplish the deburring process requirements. These requirements, at the deburring operations, are around of a few tenths of a millimetre of accuracy. Normal robots, as the one used on the development of this experiment, do not fulfil this precision on its full working area. About this point, it was argued that even though robots cannot guarantee a very good precision in all the working area, its precision can be highly improved when process path trajectories are restricted to small volumes on the working areas, as it occurs in the Debur experiment. The trajectory is defined at a local coordinate origin. The obtained trajectory is relative, not absolute respect to robot coordinate system, so precision is improved.

Another comment of Dr. Farid Dailami was related with flexibility of the whole deburring cell. The grasping point is based on the acquired 2D image and is defined in the CAD of the part.

In this station the coordinate system is also defined on the conveyor and is common to the robot and the camera.

Same schema was used for the 3D measurement system, where a common coordinate system was defined for both the camera and the robot. It is important to mention that one of the main objectives of the 3D station, besides the burrs detection, was to correct the differences on grasping.

Finally, the laser deburring trajectory is defined on the CAD of the part and it is referred to an origin that must be found on the local coordinate system defined for the deburring process. In this way the trajectory is based on small movement's relatives to that origin.

Therefore, at Debur experiment the coordinates systems of the three developed stations are defined locally and robots points and trajectories are relative to these coordinate frames and defined on the CAD.

At the discussion it was pointed out by all the assistants the need of automatization of the deburring operation of casting parts. Several technologies are on the market like cutting presses abrasive tools and even milling processes. However, the automated mechanical deburring of casting parts, in a precision way with reduced consumptions of spare parts and without tool wear, is a pendent industrial matter. Actually, there are many companies that have inverted a lot of money on these conventional solutions that did not fulfilled their expectations. Laser deburring is a well-positioned process for deburring of casting parts since it is a non-contact technique, there is not a tool wear and the thermal effect on the material surface after the deburring process is very low. In addition, it is a high flexibility and ease of automation technology.

## 4. Next actions

Finally the meeting was focused on the exploitation of the DEBUR experiment results.
It was agreed by participants the difficulty to exploit the cell as a whole, since it would require a more precise and expensive robot system, limiting the benefits of the intended flexible and low cost solution for the deburring of casting parts proposed by the DEBUR experiment.

Analysing the different developments done it seems clear that elements like the laser head and monitoring devices as well as the 3D measurement system are also suitable for exploitation independently.

The 3D measurement system was developed using commercial and economical components in order to achieve a competitive solution. It was analysed whether it could be patented, but faces the inherent difficulty of being mainly a software development. IK4-Tekniker will spread its use to companies that produce robotic cells and automatic lines allowing them integrating a 3D measurement system on its developments. Usually, the automation solution is developed in collaboration with the client, including them in the design and development process, allowing IK4-Tekniker to transfer its knowledge. Automation and robotic solutions incorporate technologies that allow improvements in the efficiency of the processes by optimizing the operation, reducing times and costs and increasing reliability.

Between the actions that may carry out to reach the market the Madrid Global Robot Expo, to be held on Madrid, February 2-4th 2017, being a Business platform for the robotic industry may be a good opportunity to show the results carried out on Debur Project.

# DEBUR experiment:
# Automated robotic system for laser deburring of complex 3D shape parts

Bristol RIF, October 28th 2016

# Contents


1. Introduction to DEBUR experiment
   - Objective and Motivation
   - Work-packages
2. Main results
3. Experiment impacts
4. Exploitation activities

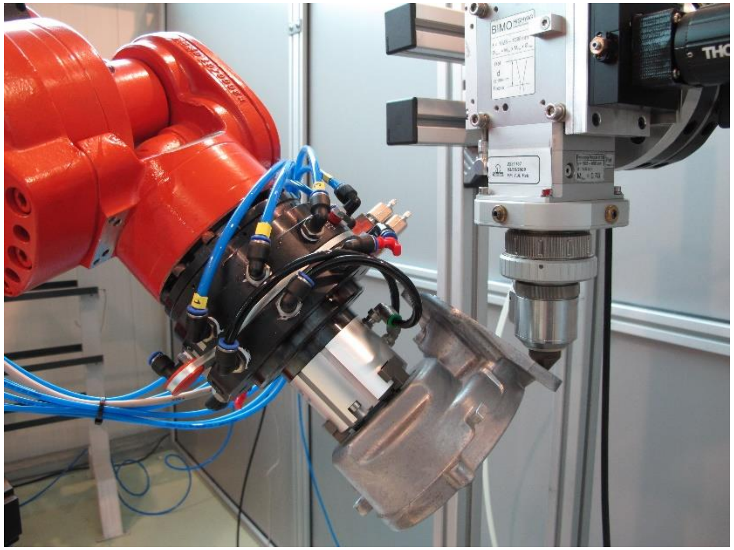
## Experiment objectives

**Main objective**: To design and set up an automated robotic station for laser deburring of aluminium casting parts.

**Particular objectives**:

Development of the laser deburring process

Devlopment of an adaptive cognitive robotic system



## Experiment motivation

Deburring process: finishing operation for casting parts

The use of cutting presses and robotized abrasive tools implies:

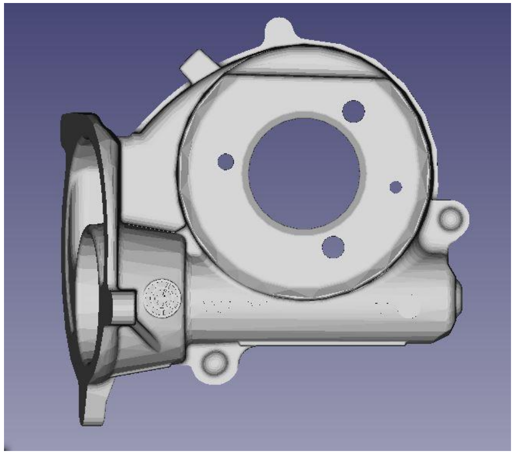
- Imprecise cutting and unwanted geometric deviations for complex parts
- Additional operations (inspection, manual deburring) and slower production (extra costs)
- Cutting dies and tools for each part geometry
- Tool wear

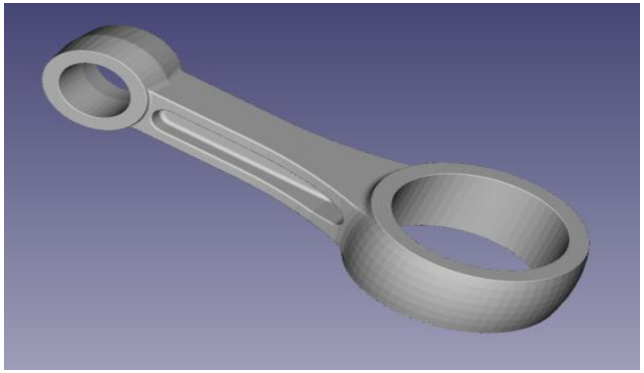
Current trend in new markets is the production of short series

# Experiment Workpackages

| GANTT | | M1 | M2 | M3 | M4 | M5 | M6 | M7 | M8 | M9 | M10 | M11 | M12 | M13 | M14 | M15 | M16 | M17 | M18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Task 1 | Design and development of the laser deburring station. | | | | | | | | | | | | | | | | | | |
| Task 2 | Design and development of the different workstations of the cell: grasping, trajectory tracking and laser adaptive control. | | | | | | | | | | | | | | | | | | |
| Task 3 | Cell integration and testing. | | | | | | | | | | | | | | | | | | |
| Task 4 | Validation and experimentation. | | | | | | | | | | | | | | | | | | |

- Definition of the deburring process requirements





## Main results: WP1

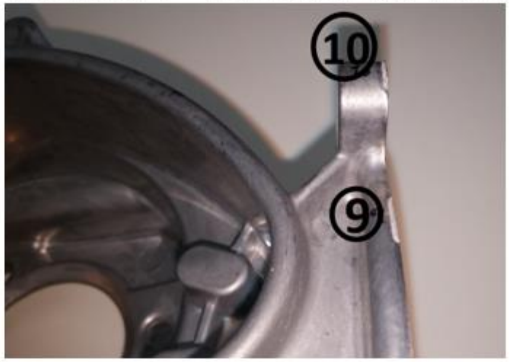

Reference 1 – Burr Zone 1


Reference 1 – Burr Zone 2


Reference 1 – Burr Zone 3

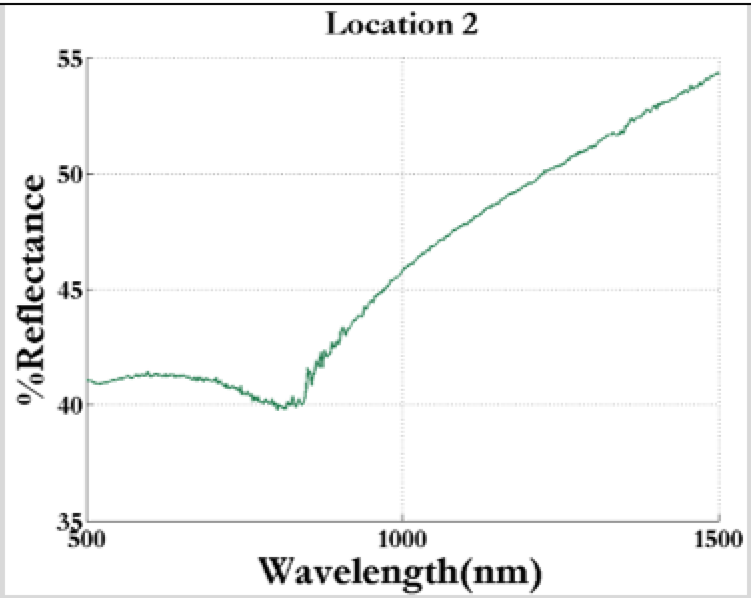

Reference 1 – Burr Zones 4, 5 and 6


Reference 1 – Burr Zones 7 and 8

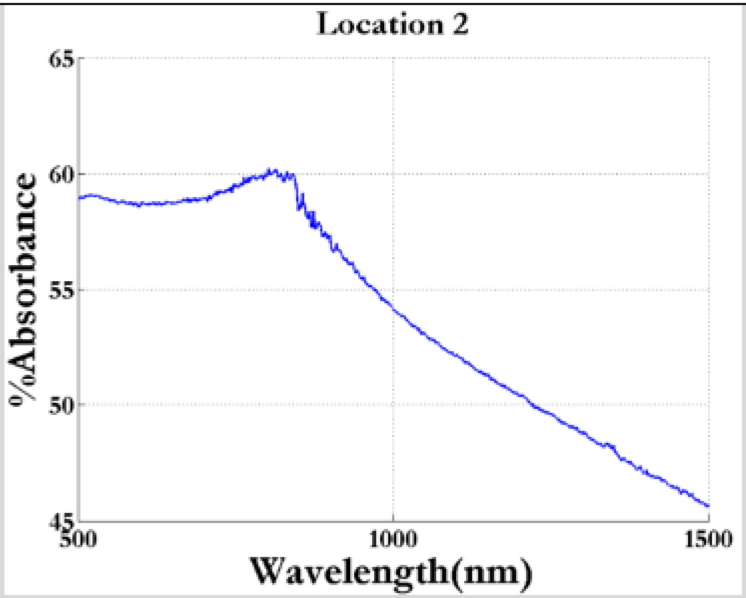



Reference 1 – Burr Zones 9 and 10

- Measurement of the optical properties of the Al casting parts




Reflectance at position 2

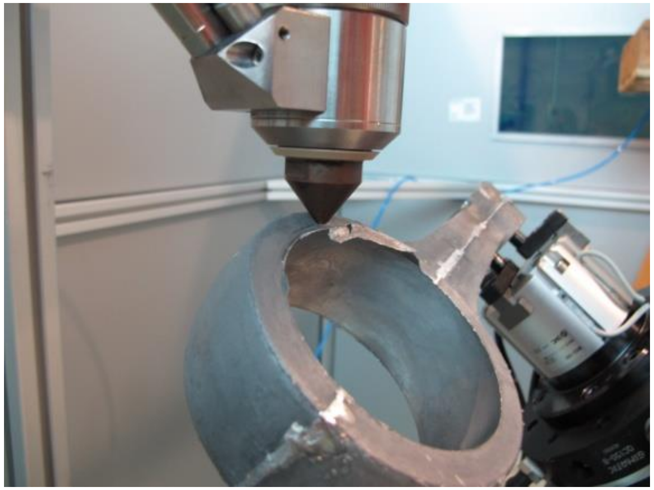


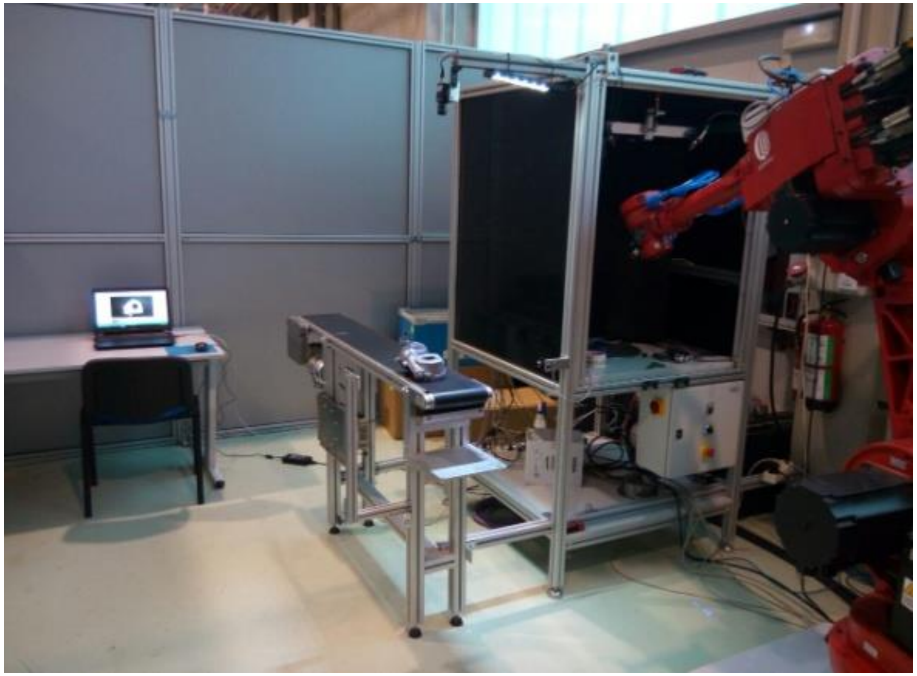

Absorbance at position 2

## Laser deburring cell

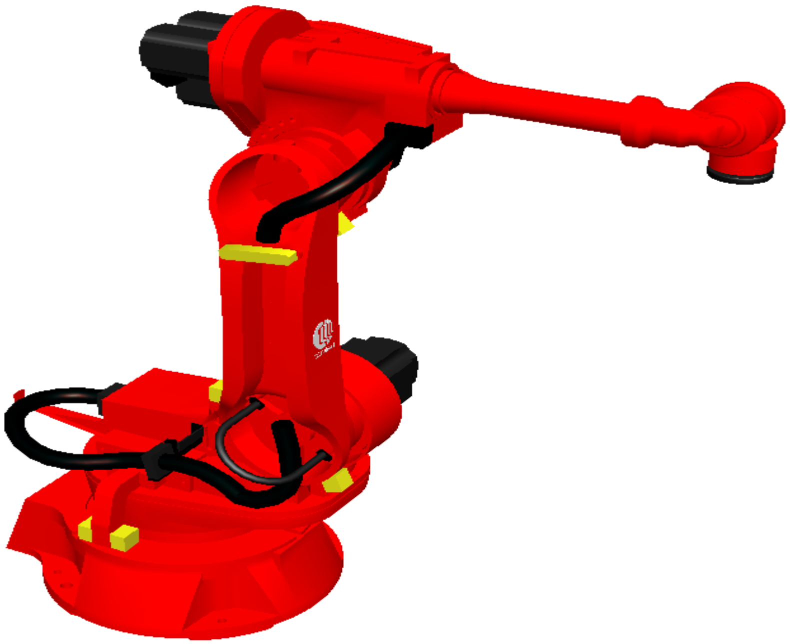
The automatic laser deburring cell consists of the following components:

- Conveyor belt and grasping workstation
- Burr measurement by 3D workstation
- Lase deburring process workstation





## Robot

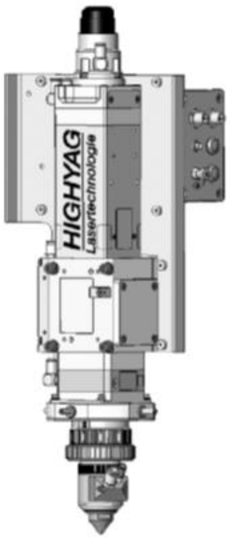


COMAU MN45-2:

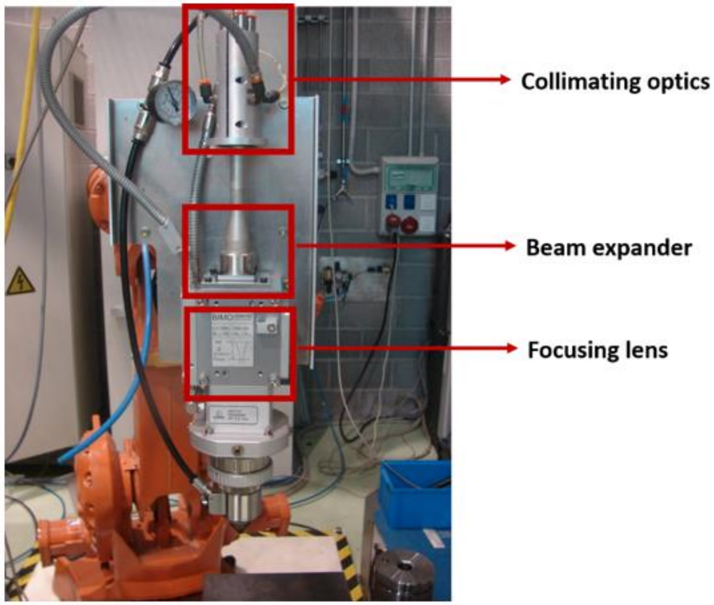
- 6 axis
- Payload 45 Kg
- PC interface
- Ethernet connection
- Multitasking

# Laser source and cutting head

| Maximum Power (W) | 200 |
|---|---|
| Operating wavelength (nm) | 1070 |
| Beam quality ($M^2$) | < 1,1 |
| Fibre optic length (m) | 5 |
| Pulse repetition frequency (kHz) | 0 - 100 |
| Maximum pulsed energy (mJ) | 2,0 @ 100 KHz |
| Pulse duration (ns) | >10 |
| Power stability (%) | <0.5 |
| Weight (Kg) | 45 |
| Dimensions W x L x H (mm) | 483 x 507 x 221 |

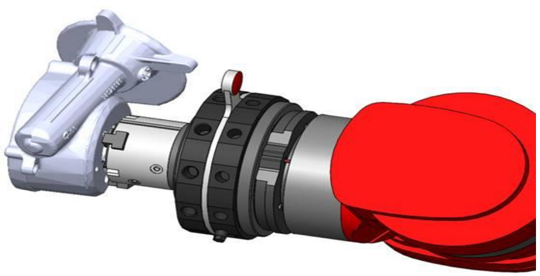




a) Original configuration



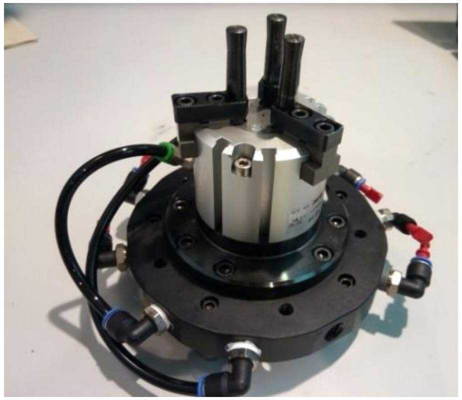

b) Modified configuration

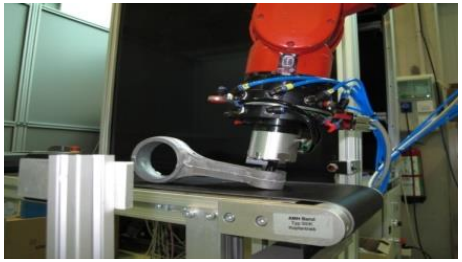
## The gripper system



Components:

- Gimatic tool exchanger: QC150-B & A
- Gripper: SMC MHS3-80S 3 fingers gripper





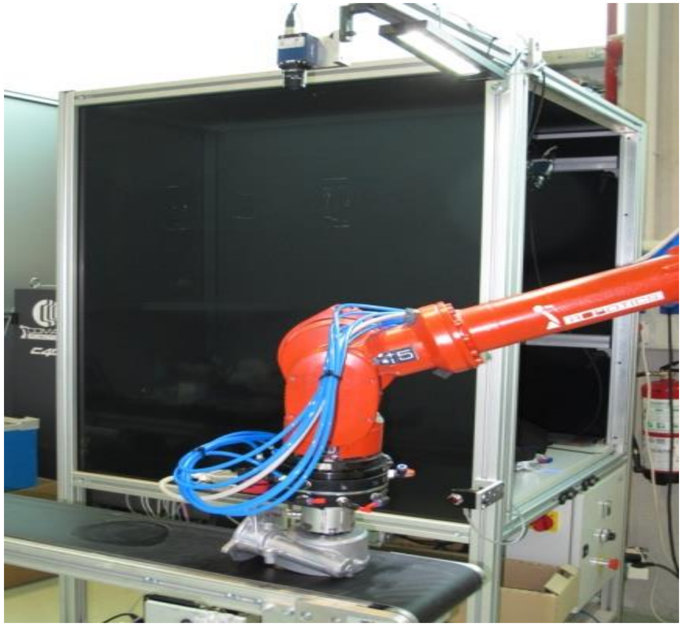
Major developments:

- Design and manufacturing of the flange
- Design and manufacturing of the fingers
- Easy tool change system for testing the laser head or the gripper system independently, allowing the optimization of robot working

# Main results: WP2

## Grasping workstation

- Camera Genie C1280 1/3” 1280x960 CMOS
- Optics F1.4/16 mm
- 24 fps
- 3.75 x 3.75 µm size sensor
- Lighting by leds



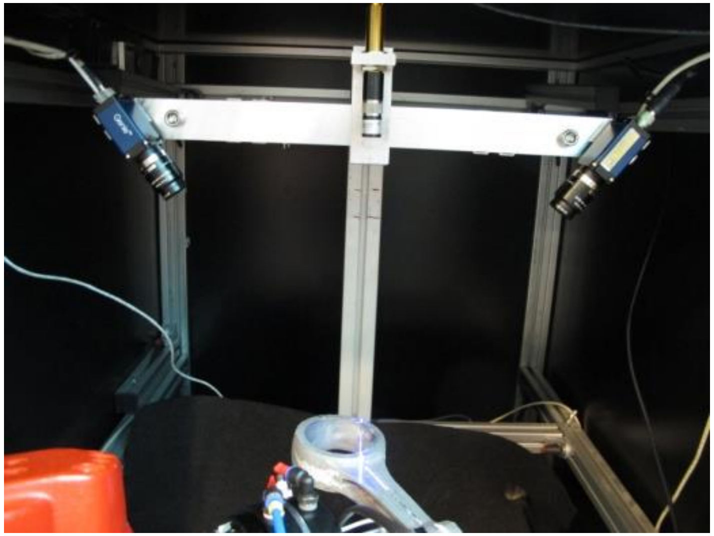
Main developments:

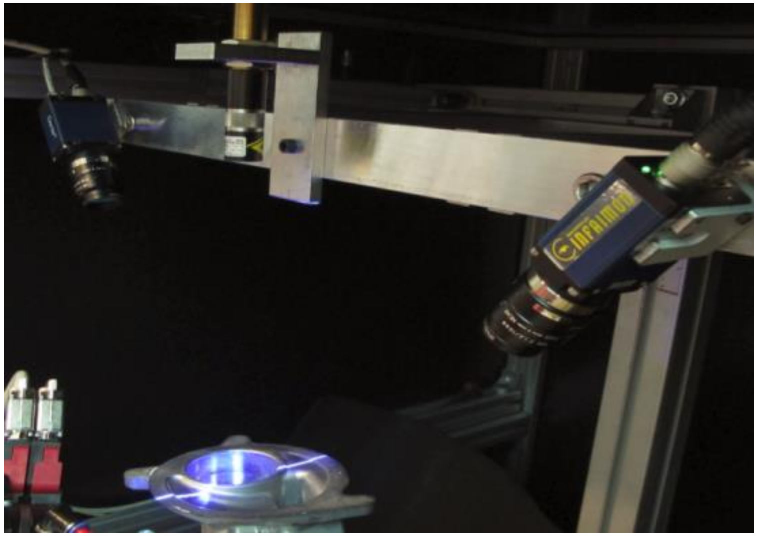
- Generation of the shape model for 3D pose estimation from the 2D image
- Unification of the coordinates systems
- Measured pose is sent by TCP/IP and transformed in the robot from XYZ to ZYZ Euler representation

## 3D WorkStation: Components

Elements used in this station are:

- Two Cameras Genie HM1400 monochrome 1400x1280 CMOS
  - Optics F1.4/16mm
  - 64 fps
  - 7.4 x 7.4 µm size sensor
  - Band pass filters: IBP470 centred at 470 nm
- Sheet of light laser generator: Z-Laser Z030M18H-F450LP30 (blue, 30 mW, 450 nm and with a LP30 optic)

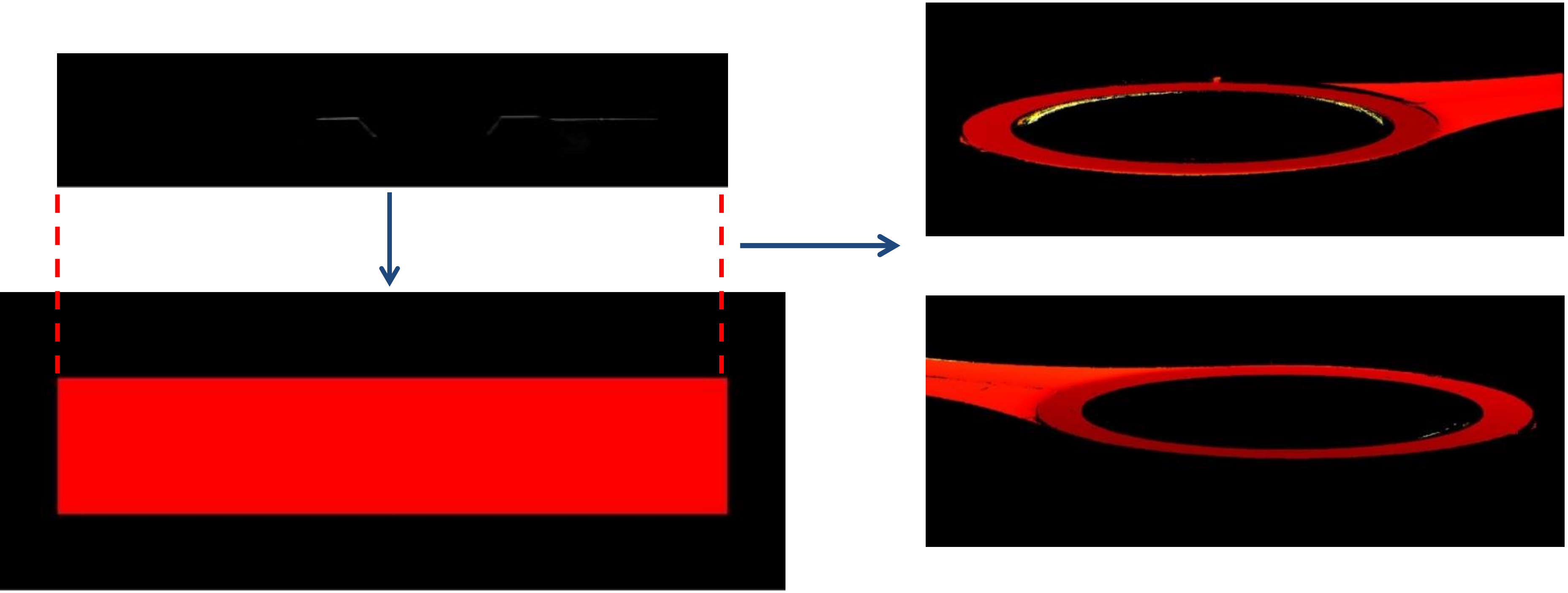




## 3D WorkStation: acquisition

Main Developments:

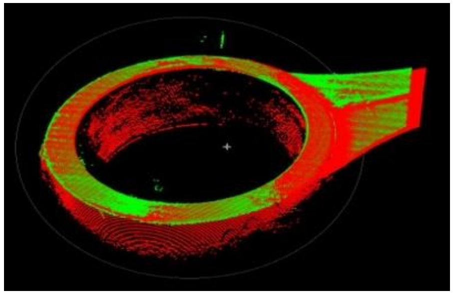
- Calibration of both cameras
- Positioning of cameras, laser beam and robot trajectory
- Triggered by the robot through a socket
- The frame size has been reduced to the sheet of light ROI to increase acquisition speed



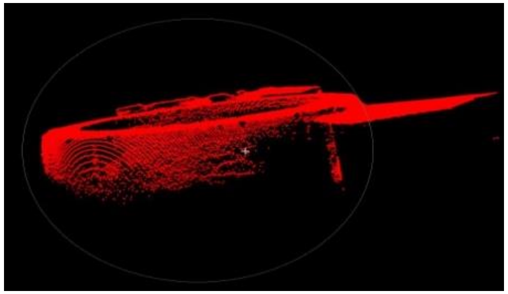
## 3D WorkStation: Analysis

Developments:

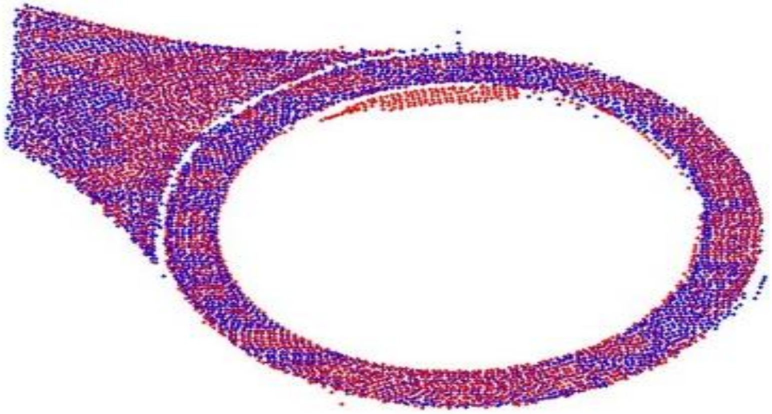
- Registration of both partial reconstructions by matching both points cloud (red and green)
- Improvement of the points cloud by outlier removal, down-sampling and smoothing
- Overlapping between the reference (blue) and the measured parts (red)
- As a result it is obtained:
  - The position of the burrs
  - Pose difference between the reference and the grasped part



Registration



Smoothing



Overlapping

## Cell integration and testing

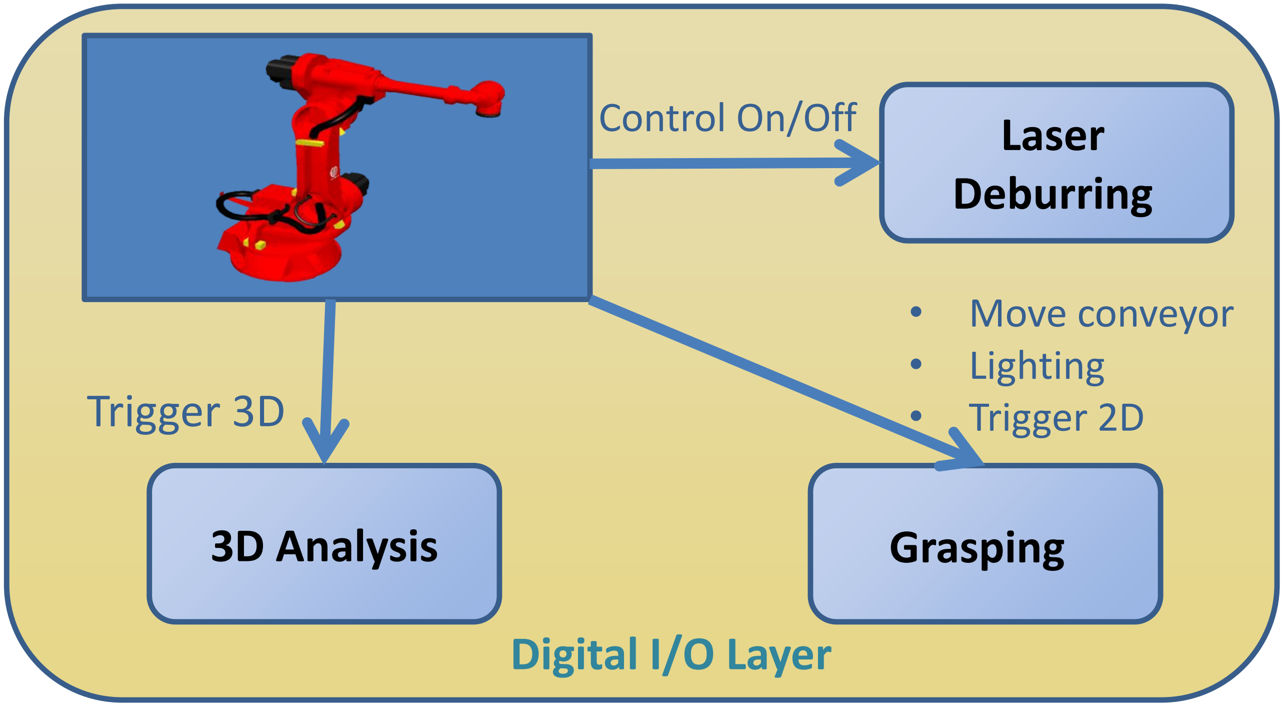

**User interface**

Main developments:

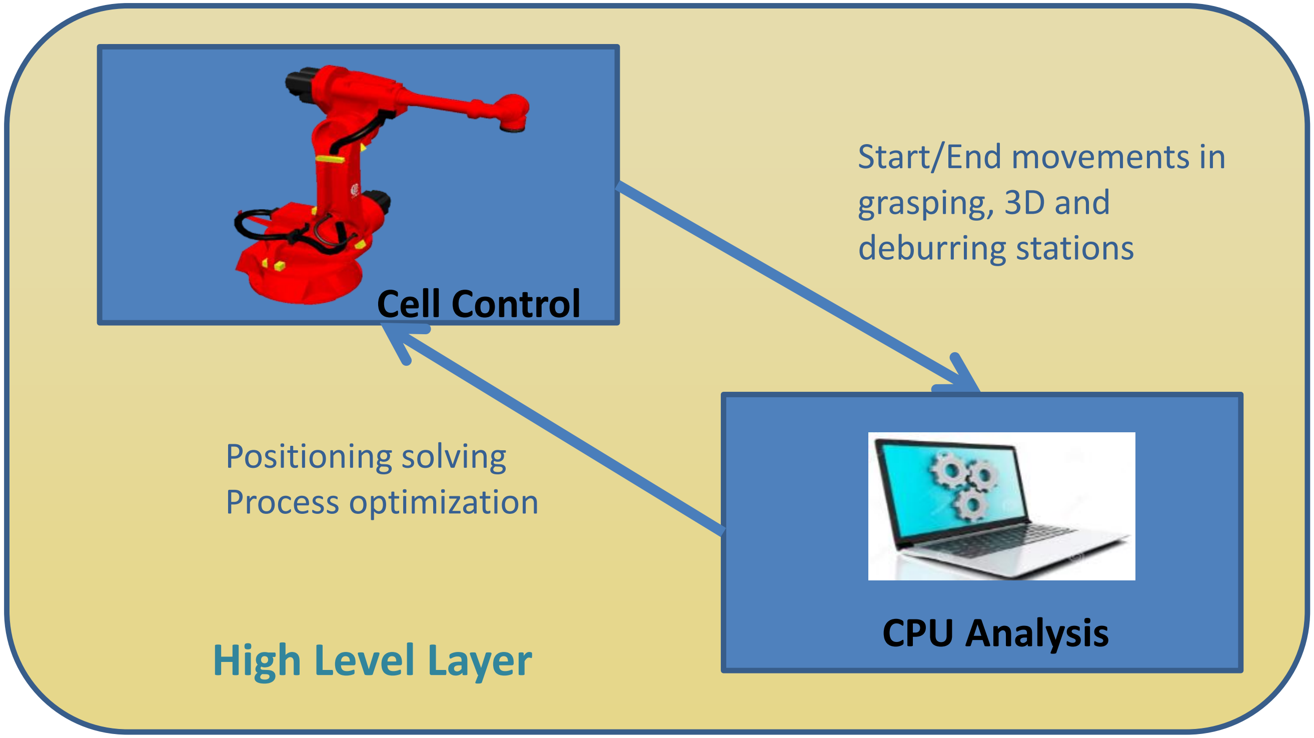
- Robot architecture
  - Thread for I/O and for Ethernet communication with the PC
  - Thread for path trajectory

- Central unit of analysis (CPU)
  - 2D and 3D analysis
  - Communication with the robot by TCP/IP to send results
  - HMI

## Cell integration and testing: Robot



# Cell integration and testing: Robot & CPU relation



## Cell integration and testing: Validation of the acquisition

Repeatability validation of the Robot / 3D acquisition system was made.

The part of the first acquisition is used as reference. Afterwards the part is passed again through the system several times and the result is compared against the reference.

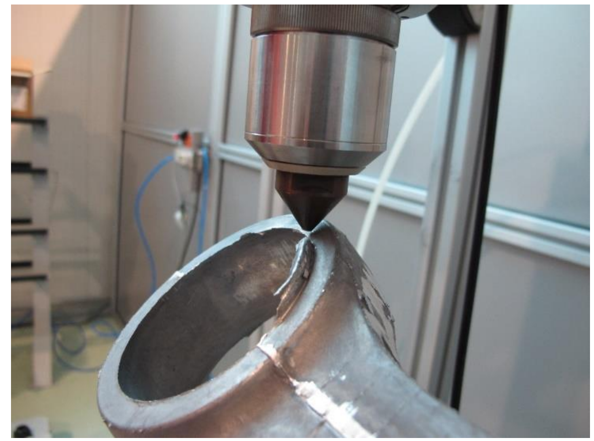
At the end, obtained objects should result equivalents.

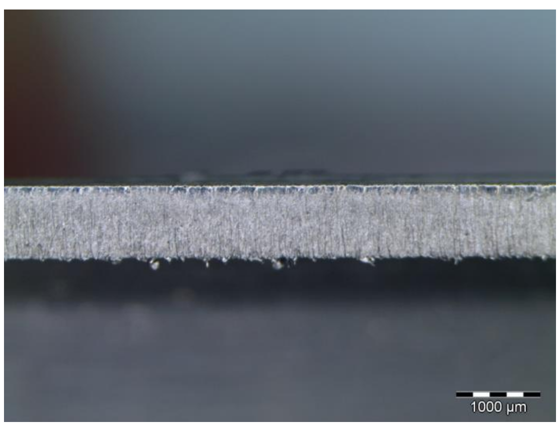
The following table resumes the achieved results. It shows the differences between the acquired models given by its poses. On the table appears the mean value and the standard deviation of those differences.

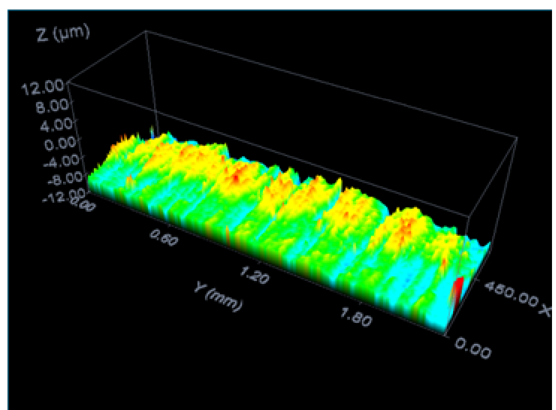
| | x | y | z | alfa | beta | gamma |
|---|---|---|---|---|---|---|
| mean | 0.004 | -0.143 | 0.008725 | -0.001 | -0.007 | 0.1575 |
| std dev | 0.734199 | 0.322765 | 0.015069 | 0.004 | 0.004062 | 0.165304 |

# Cell integration and testing:  Laser deburring process

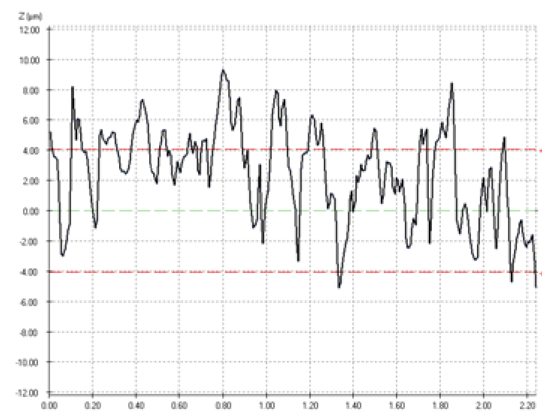
| Parameters | Value |
|---|---|
| Laser power | 200 W |
| Processing speed | 100 mm/min |
| Laser tip diameter | 2 mm |
| Type of gas | Ar |
| Gas pressure | 10 bar |
| Laser spot diameter | ~ 30 µm |
| Rayleigh length | 0.7 mm |





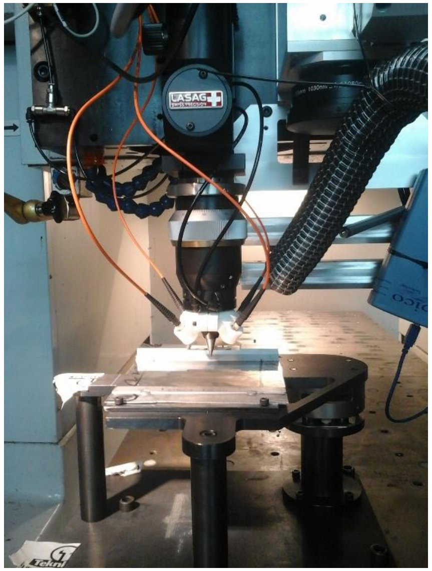



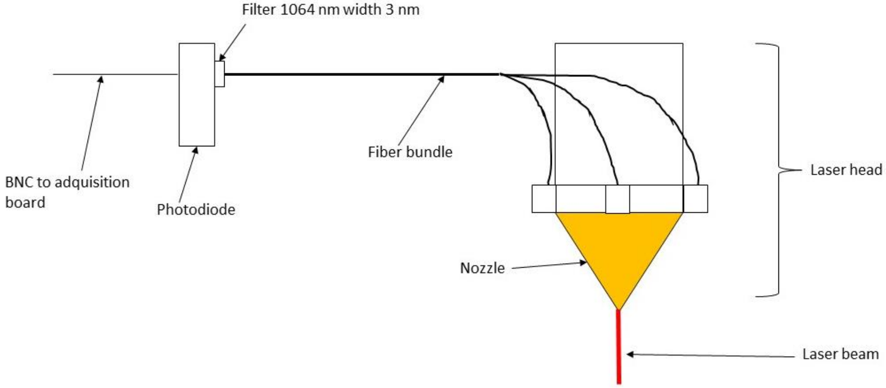

Topography

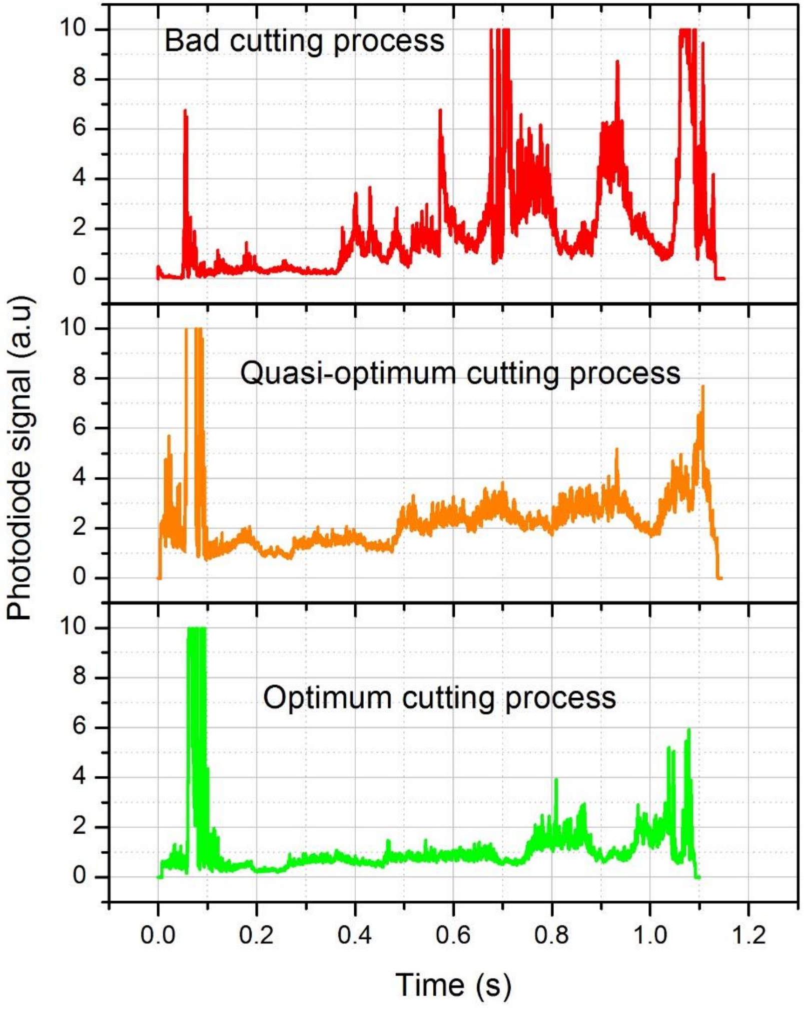


burr profile

# Cell integration and testing: monitoring of the laser deburring process



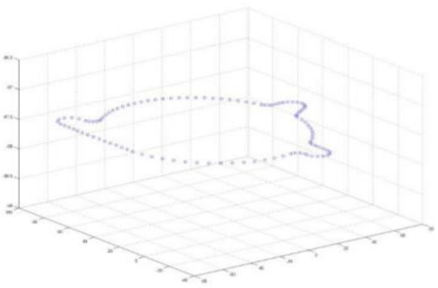


# Cell integration and testing: Laser deburring process optimization

Designed strategy:

- 3D Model sets corrections to path points.
- Change speed between speed1 (slow) / speed2 (fast).
- Activate (burrs area) / Deactivate (no burs) laser.



Robot path from CAD: burrs area

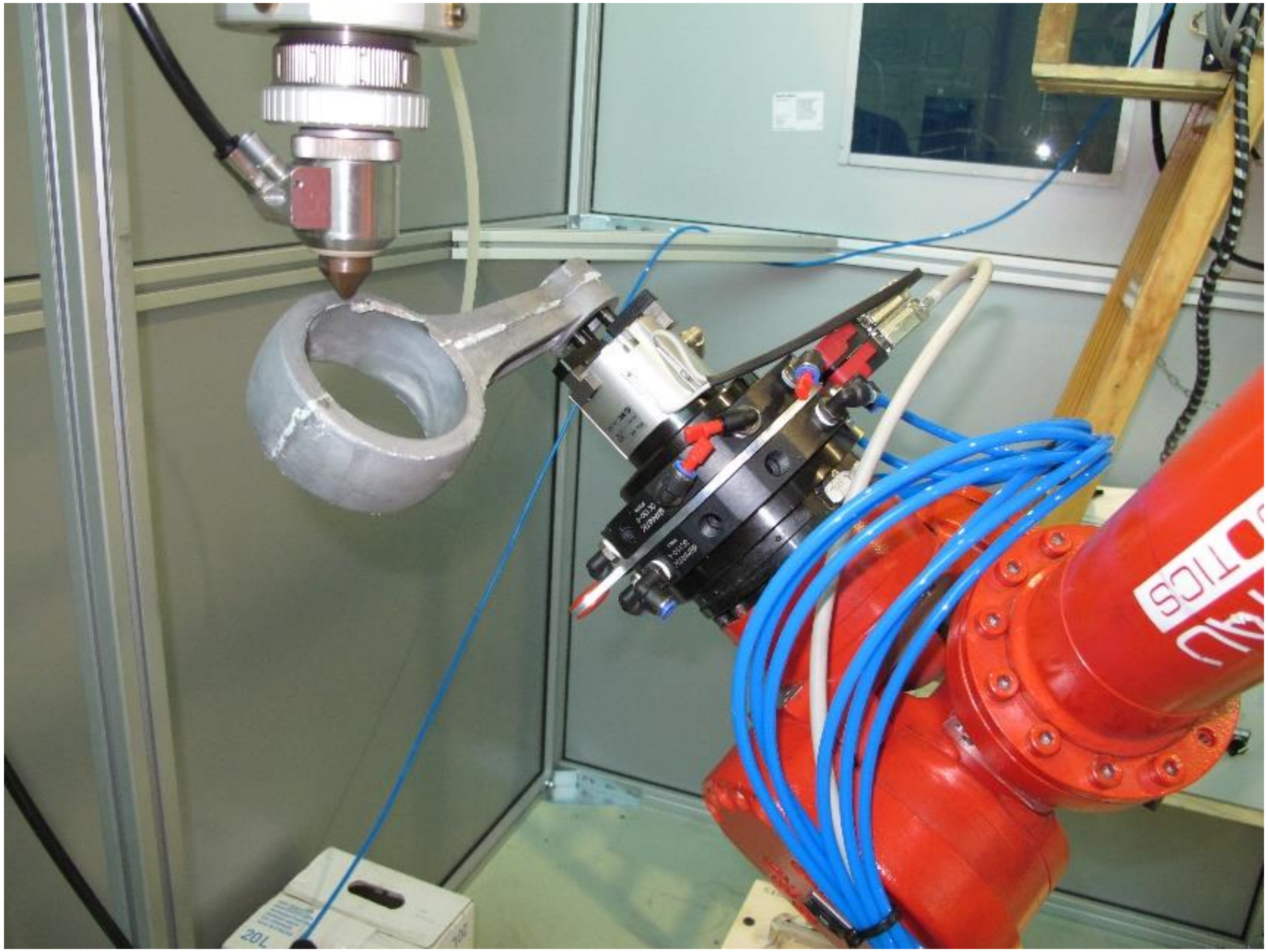
| | x | y | z | descriptor |
|---|---|---|---|---|
| Point 1 | -100.33 | -24.76 | 40.65 | d1 |
| Point 2 | -100.72 | -24.33 | 42.85 | d2 |
| Point 3 | -101.07 | -23.21 | 44.80 | d3 |
| Point 4 | -101.33 | -21.51 | 46.30 | d4 |
| Point 5 | -101.48 | -19.41 | 47.17 | d5 |
| Point 6 | -101.51 | -17.14 | 47.34 | d6 |
| Point 7 | -101.41 | -14.94 | 46.78 | d7 |
| Point 8 | -101.20 | -13.03 | 45.55 | d8 |
| Point 9 | -100.89 | -11.63 | 43.78 | d9 |
| Point 10 | -100.51 | -10.87 | 41.67 | d10 |
| Point 11 | -97.19 | -25.42 | 22.80 | d11 |
| Point 12 | -97.54 | -25.35 | 24.78 | d12 |
| Point 13 | -97.89 | -25.27 | 26.77 | d13 |
| Point 14 | -98.23 | -25.20 | 28.75 | d14 |
| Point 15 | -98.58 | -25.13 | 30.73 | d15 |
| Point 16 | -98.93 | -25.05 | 32.72 | d16 |
| Point 17 | -99.28 | -24.98 | 34.70 | d17 |
| Point 18 | -99.63 | -24.91 | 36.68 | d18 |
| Point 19 | -99.98 | -24.84 | 38.67 | d19 |
| Point 20 | -100.33 | -24.76 | 40.65 | d20 |
| Point 21 | -90.36 | -24.39 | -15.93 | d21 |
| Point 22 | -91.11 | -24.50 | -11.63 | d22 |
| Point 23 | -91.87 | -24.62 | -7.33 | d23 |
| Point 24 | -92.63 | -24.73 | -3.02 | d24 |

Robot path points definition plus descriptor

## COMAU programming

```
$SPD_OPT := SPD_LIN
if code[1] = 1 THEN
        $DOUT[12] := ON   --Laser ON
        $LIN_SPD := 0.025
        MOVEFLY CIRCULAR TO point[3]:correction[3] VIA point[2]:correction[2] ADVANCE
else
        $DOUT[12] := OFF   --Laser Off
        $LIN_SPD := 0.2
        MOVEFLY CIRCULAR TO point[3]:correction[3] VIA point[2]:correction[3] ADVANCE
endif
```

# Laser deburring cell validation



https://www.youtube.com/watch?v=2KqTBzxh7kU

## Experiment impact

- Cost reduction up to 20% per part for the deburring operation
- Volume of lubricants and abrasives reduced by 30%
- Reduction of scrap parts by 30%
- Improved quality of the resulting parts, lower protrusion and smoother surface (roughness)
- Reduction of manual operations and therefore increased safety for the workers (less injuries)
- Environmentally friendly process: No need for abrasives and lubricating oils for the deburring process
- New jobs at industrial partner at the end of the project

# Thank you

Contacts:

Ramón Arana (ramón.arana@tekniker.es)
Carlos Soriano (carlos.soriano@tekniker.es)