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Abstract	Description of the DEMONSTRATOR that has been designed and will be presented in the SIMAC trade fair in October 2012

Document History			
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Content

1   List of figures and tables

1.1   *Figures*

1.2   *Tables*

No se encuentran elementos de tabla de ilustraciones.

2 Introduction

The SIMAC Trade Fair is the most important fair in the footwear sector. It takes place every two years in Bologna. ROBOFOOT will present a demonstrator of some of the results achieved during the first months of the project in that fair.

This document describes the elements that are part of the demonstrator:

- A robotic cell with inking, polishing and last opening operations
- Path programming environment:
  - Basic CAM
  - Off-line path adjustment
- Bimanual, multifinger robotic packaging

3 Demonstrator description

The key element of the DEMONSTRATOR is the robotic cell, based on that implemented for PIKOLINOS, i.e. the cell including inking, polishing and last removal operations.

3.1 Stand description

A stand has been allocated for the presentation of ROBOFOOT results. The main element of the stand is the robotic cell. The stand will be presented in a specific area devoted to robotic applications.

The layout of the cell is presented in the following pictures:

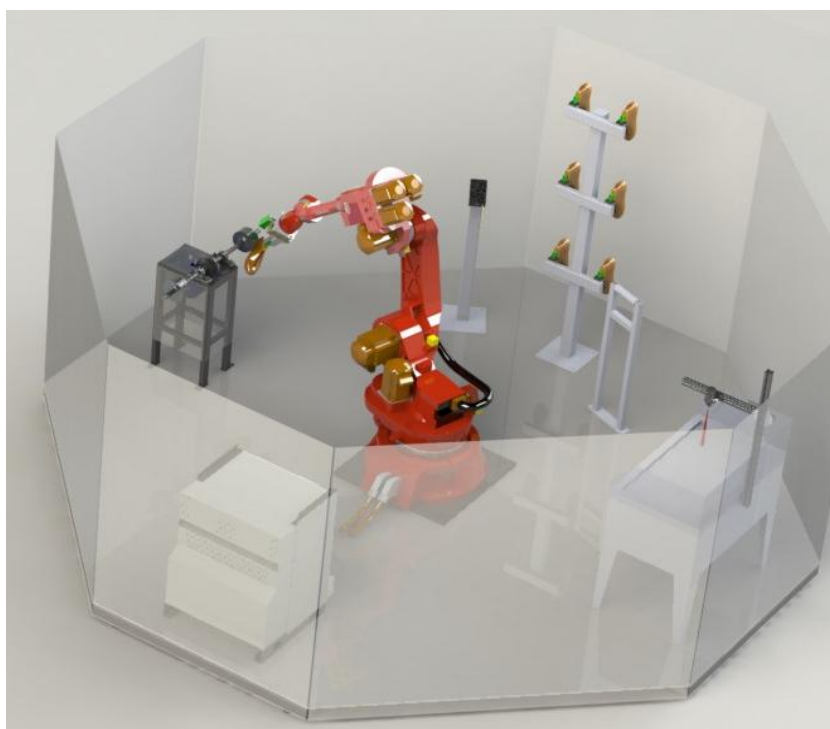**Fig. 1 General overview of the robotic cell (I)**

Fig. 2 General overview of the robotic cell (II)

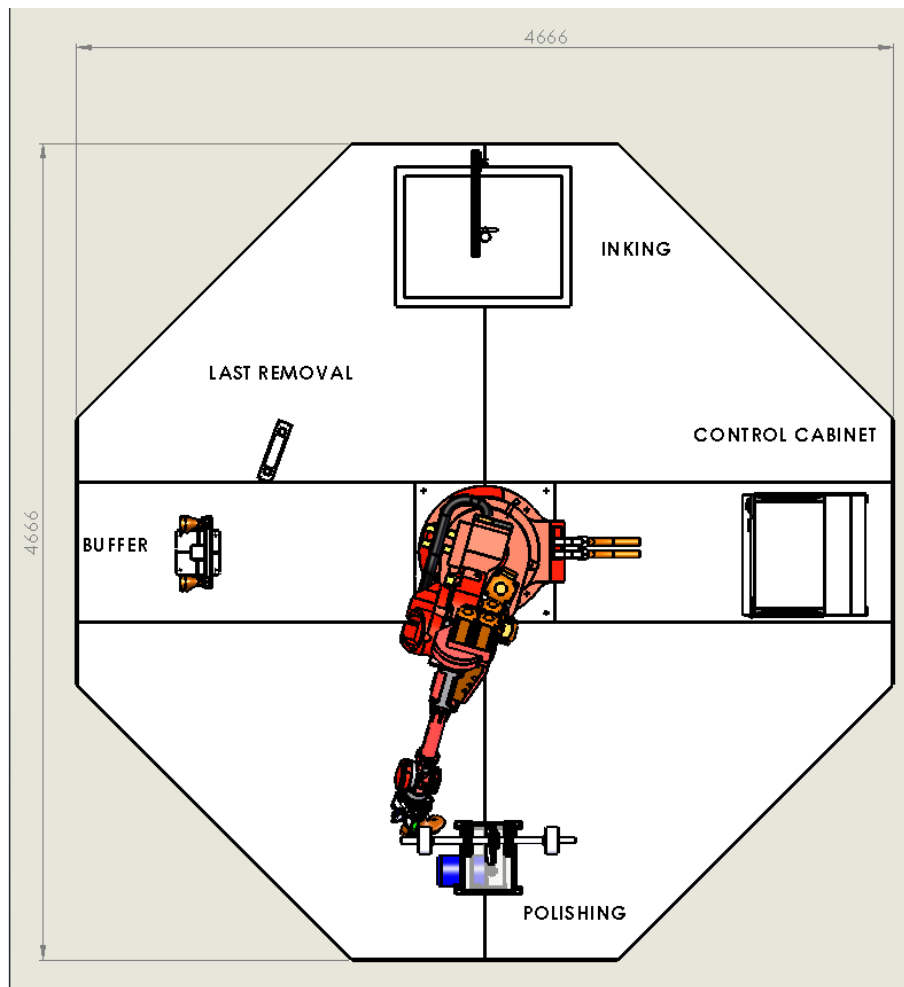**Fig. 3 Layout of cell, dimensions**

3.2 Cell description

Inking cabinet

A new cabinet has been designed for the Demonstrator to facilitate visitors having a good vision of the inking process. It includes a new air suction system.
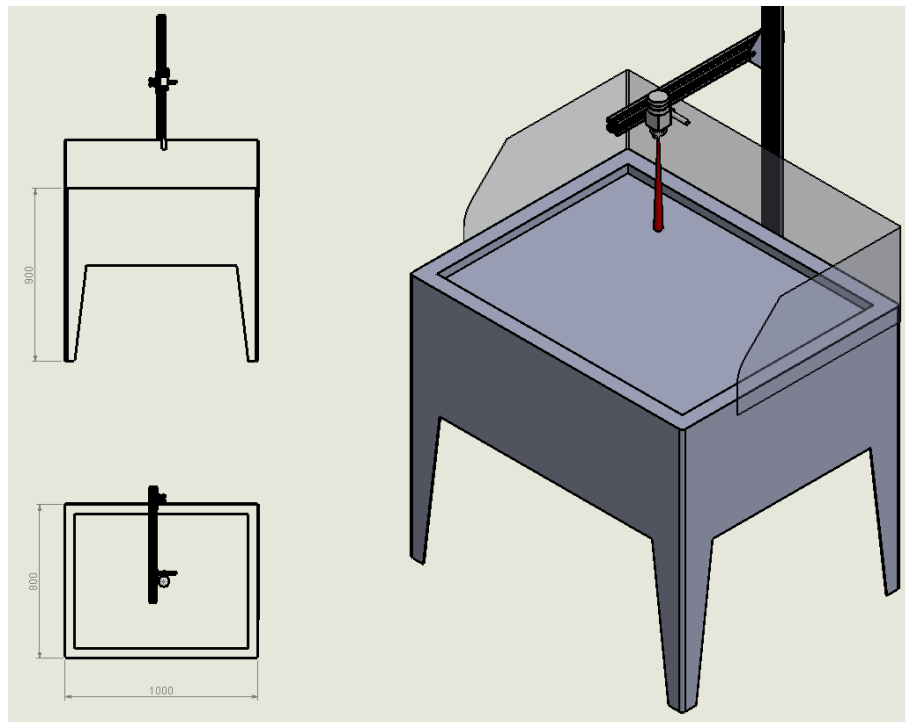
Fig. 4 Inking cabinet for the Demonstrator

Ink drying Buffer

An 8 position buffer will be used to allow drying the ink before polishing.
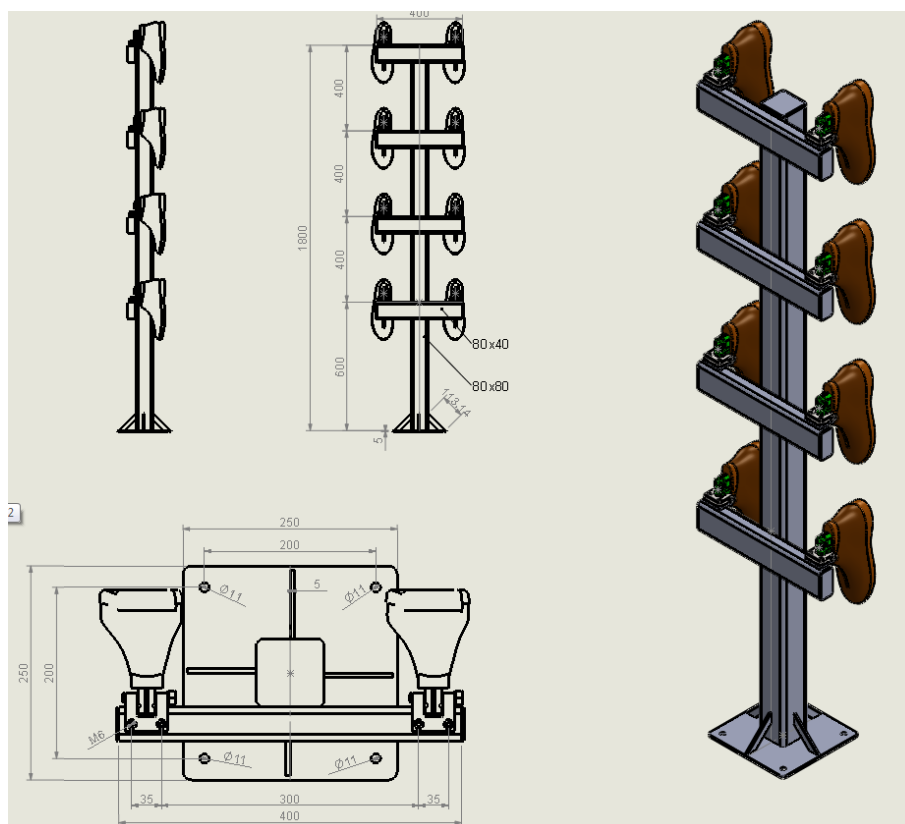

Fig. 5 Ink drying buffer

Polishing machine

A special polishing machine has been designed and manufactured to be integrated in the cell. This new machine is designed without protections in order to allow seeing the full process during the exhibition.
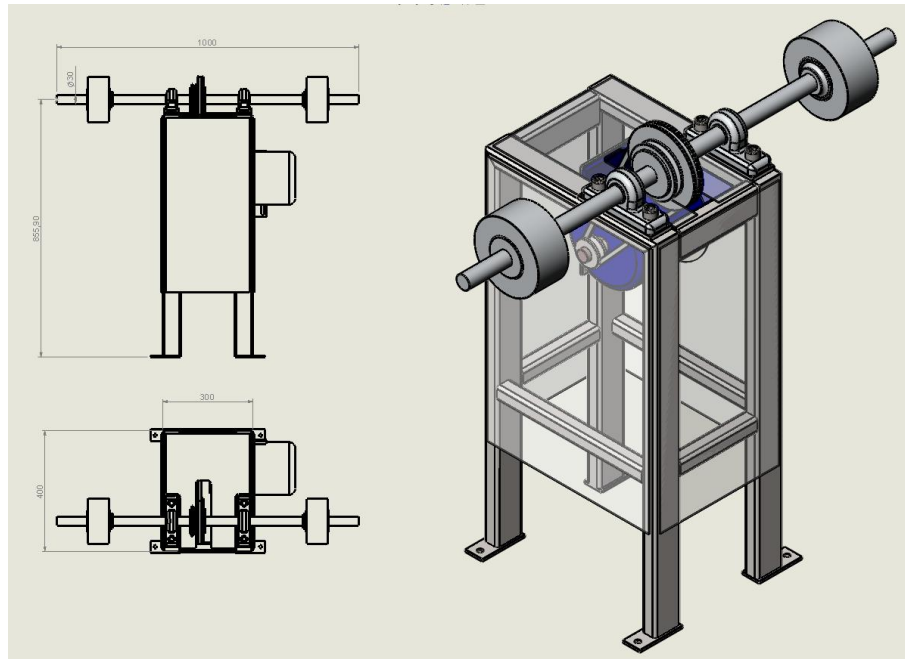
Fig. 6 Polishing machine

Last opening station

At the end of the polishing process the last will be opened in the workstation designed to this aim.

As it will be presented in a fair, in order to be an unattended process that repeats cyclically, instead of leaving in a conveyor as would be the real process the robot will close the last and put it again in the buffer.

Fig. 7 Last opening station

3.3   Sequence of operations

As explained before, the sequence of operations will be cyclic for the eight shoes:

- Take the shoe from the buffer (8 positions)
- Inking
- Polishing
- Last opening (and close)
- Take it back to the buffer

Fig. 8 Sequence of operations

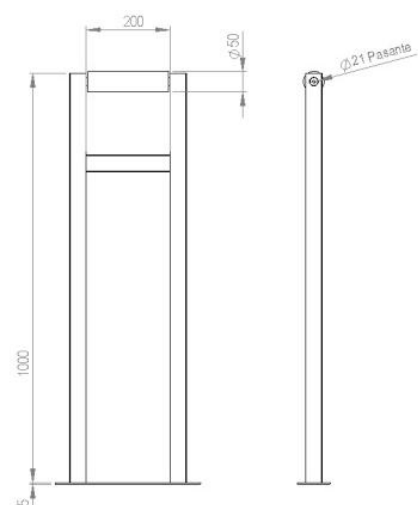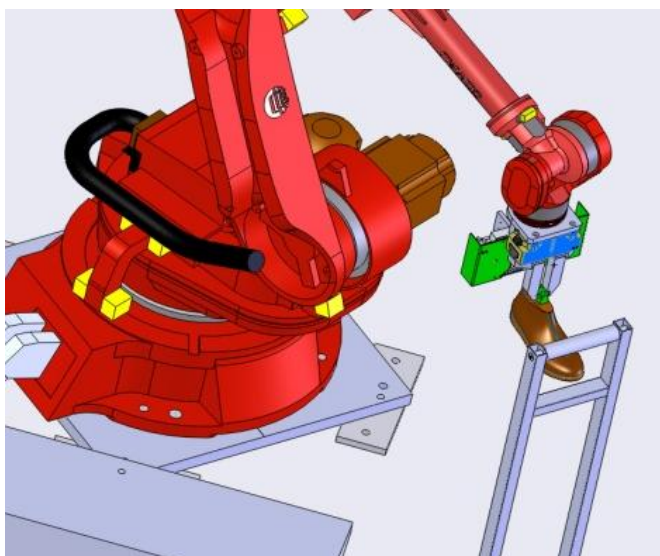# 4 Other elements presented

4.1 Programming environment

It will be presented the programming approach adopted by ROBOFOOT, described in D4.1, in particular the trajectory definition, the postprocessor and the OFF-line program adjustment using the 3D laser scanner.

Fig. 9: **General scheme for trajectory generation/control**

4.1.1 Off-line programming: BasicCAM

BasicCAM is a software developed in the project to help users defining the path the robot has to follow to perform different operations as well as some parameters related with the operation.

It will be presented how this software is used for inking and polishing operations.

Fig. 10 Path definition for inking

Fig. 11 Path definition for polishing
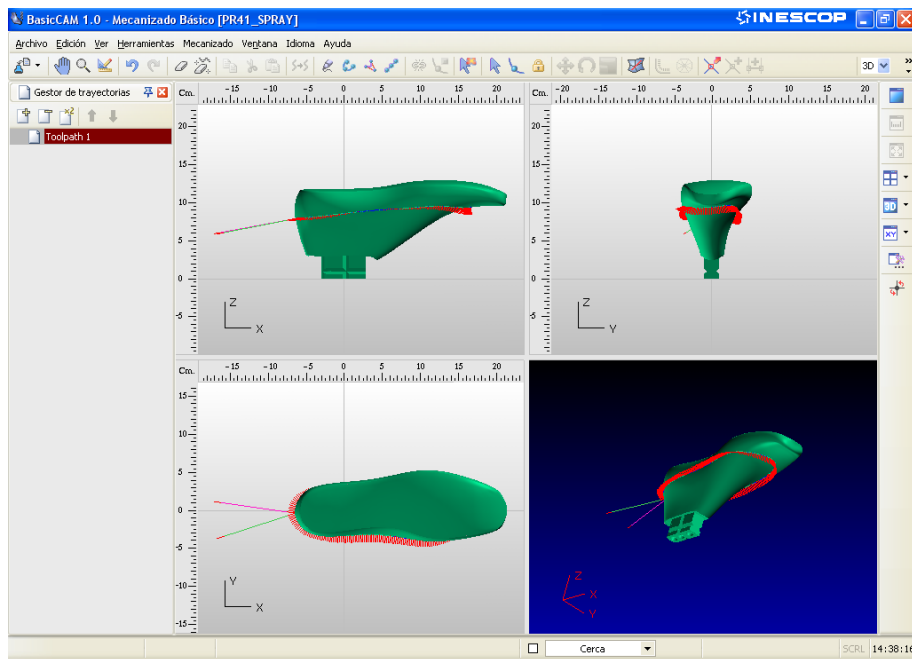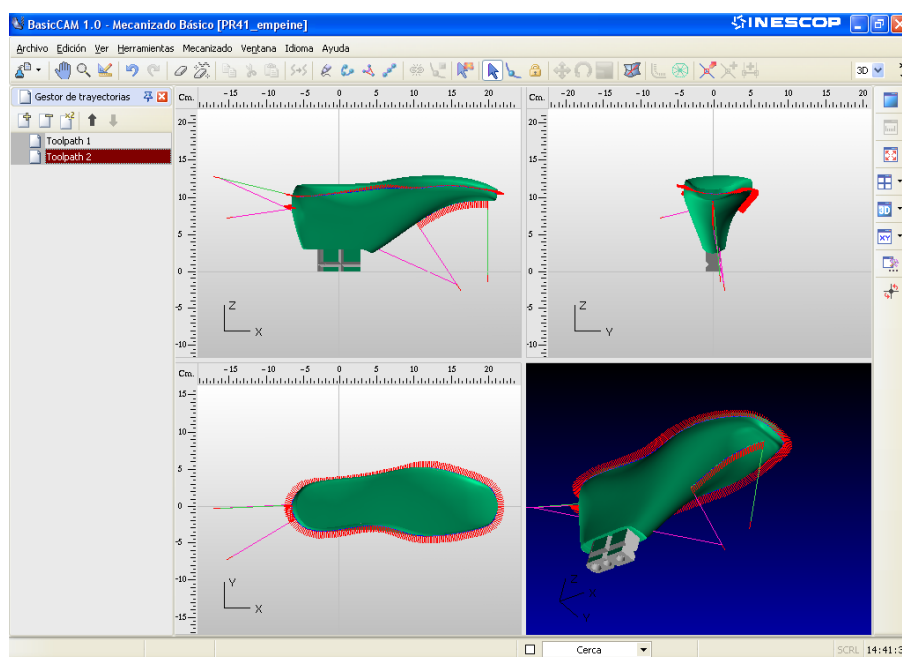
4.1.2 *ROBOmove postprocesor*

The path generated with BasicCAM is translated in an executable program in the robot language, in our case in PDL2 format. This process is done by means of the ROBOmove postprocessor created by QDESIGN.

ROBOmove takes care of:

- Robot kinematic and reachability:

    The translation of a point in the space into a point reachable by the robot tool means the solution of the inverse kinematic of the robot model, i.e., the mapping of that point in the space into a set of 6 joint angles (one for each robot axis). The solution to the inverse kinematic equations is provided by ROBOmove. If at least a solution exists

the point is reachable by the robot and ROBOmove informs the user about it, as well as if any point is outside the robot working area.

- Management of the robot redundancy:

The relationships between joint space and Cartesian space coordinates of the object held by the robot are in general multiple-valued: the same pose can be reached by the serial arm in different ways, each with a different set of joint coordinates. In other words, the solution of the kinematic chain of the robot gives more than one solution for the 6 joint angle values the robot must have to reach a point in the space. ROBO-move solves the kinematic of the robot giving an unique solution. This is done managing the redundancy, acting on the **wrist pose**. Given a point and a direction for the tool, the robot can move the tool to that position/orientation in more than one pose: Controlling the pose of the wrist (the 4th, the 5th and the 6th angles), this redundancy can be managed.

The solution suggested by ROBOmove to manage this 6th DOF is the rotation around the axis of the tool. The following pictures show the example of a robot holding the last to be milled. The tool touches the same point (near the last-tip) in the 4 different pictures, but in each picture the posture of the robot is different and is controlled by a different value of rotation around the tool axis.
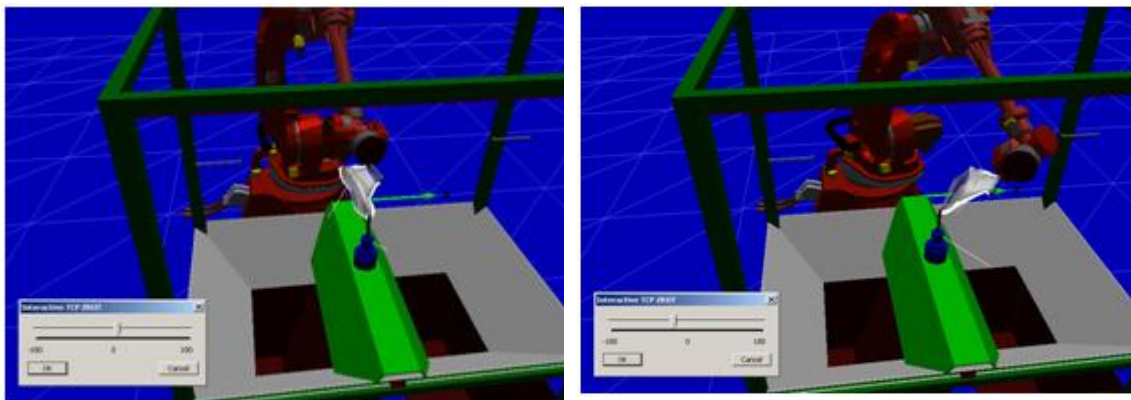

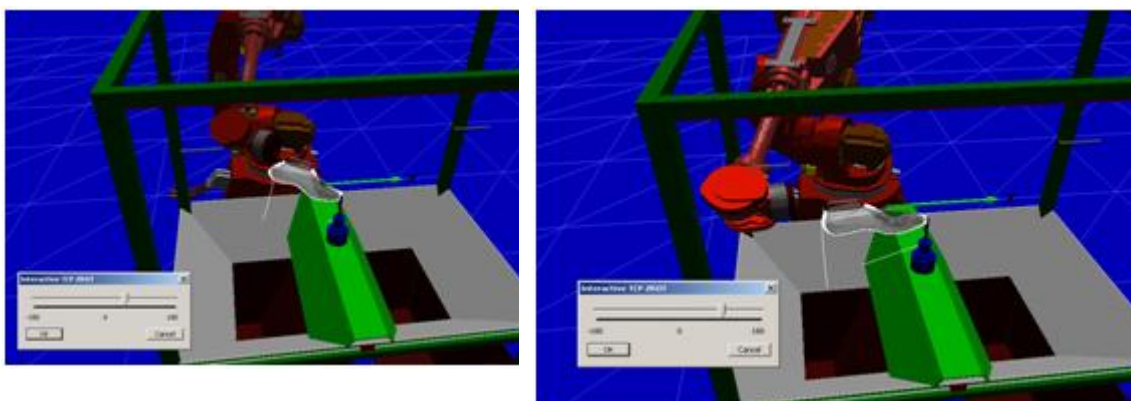**Fig. 12 ROBOmove simulation (I)**

Fig. 13 ROBOmove simulation (II)

- Management of singularities:

Some robot poses cannot be reached in a unique way because there are infinite solutions of the kinematic chain in that point. If the robot path pass near one of this singular points the behavior of the movement can't be predictable around it. ROBOmove avoids moving the robot in the vicinity of those points.

- Simulation and Collision Detection:

The offline simulation of the machining is important in order to detect possible collisions between the robot and/or end effector and/or other part in the environment. ROBOmove offers a 3D simulation of the plant scenario: robot, external axes, spindle, tool, workpiece, any fixture and any other significant element of the robotic cell.

The user has the opportunity to introduce new graphics on the scene.

Moreover, the ROBOmove simulation windows gives other important information:

- The machining cycle time.

- The displayed tool path is colored depending on if the points are reached by the robot or not, as well as if the points match the conditions of singularities of the robot.

ROBOmove has got some Settings Tool and Utilities by which:

- The user can set:
  - o Piece Positioning Frame
  - o Initial robot posture
  - o Velocity setting

- The user can:
  - o modify the points coordinates /normal set by BasicCAM, if needed
  - o add some points useful for the machining (i.e, transition points).
  - o use appropriate strategies for reducing the number of points in the APT / ISO language program.

- Robot code Output
- Customization

ROBOmove has been customized in order to managed special commands (not foreseen in the standard APT language) needed to manage particular operation. For instance, some non-standard special commands can be used to insert some robot-language-instructions directly in ROBOmove in operations as polishing and roughing.

4.1.3 3D Scanner

The LSS developed allows the instrument for "last+gasper" digitalization, both HW and SW, it has been fully and internally developed; the solution is a laser scanner able to work, in a reliable way, in an uncontrolled environment and characterized by an open and modular architecture.

The solution is a linear scanner; the multiple head allows the whole acquisition of the subject under digitalization in only one linear movement; a single scan is enough for digitalizing the subject entirely.

For the acquisition of the last coupled with a gripping device the requirements were:
- working volume equal to 300x300x600 mm3
- accuracy equal or less than 0.1 mm

- acquisition time equal or less than 30 sec.

To reach the final configuration different conceptual designs of LSMs and LSS have been developed and different tests for the identification of suitable components (laser, optic, camera etc.) have been performed. The optimal solution selected consists of:

- LSMs: each LSM is provided by one camera (752 x 480 pixels) and a laser emitter (Class 3R)
- 1 linear axis that moves the target (last coupled with the gripping device)

The target motion and the acquisition are synchronized and managed by the same PC embedded.
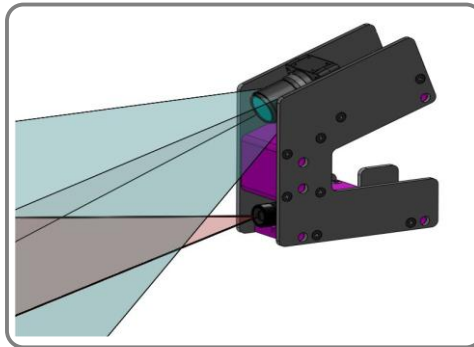

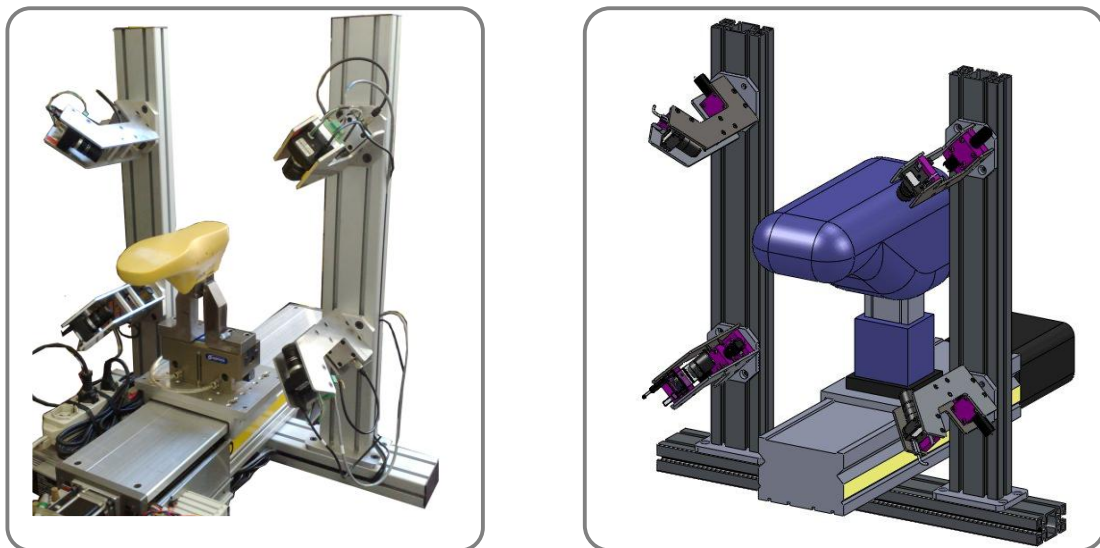**Fig. 14 Laser scanner 3D single module model with working area**

Fig. 15 ITIA-CNR Laser scanner system 3D

Final solution:
- 4 linear laser scanner heads with:
  - Cam Pt Grey Fire-Fly MV Usb 752 each
  - Optic Fujinon da 6mm DF6HA-1B each
  - Filtri Midwest BP660- 27 each
  - Laser Globallaser Lyte-MV 660, 5mW each
  - Interax Cam-laser 150mm
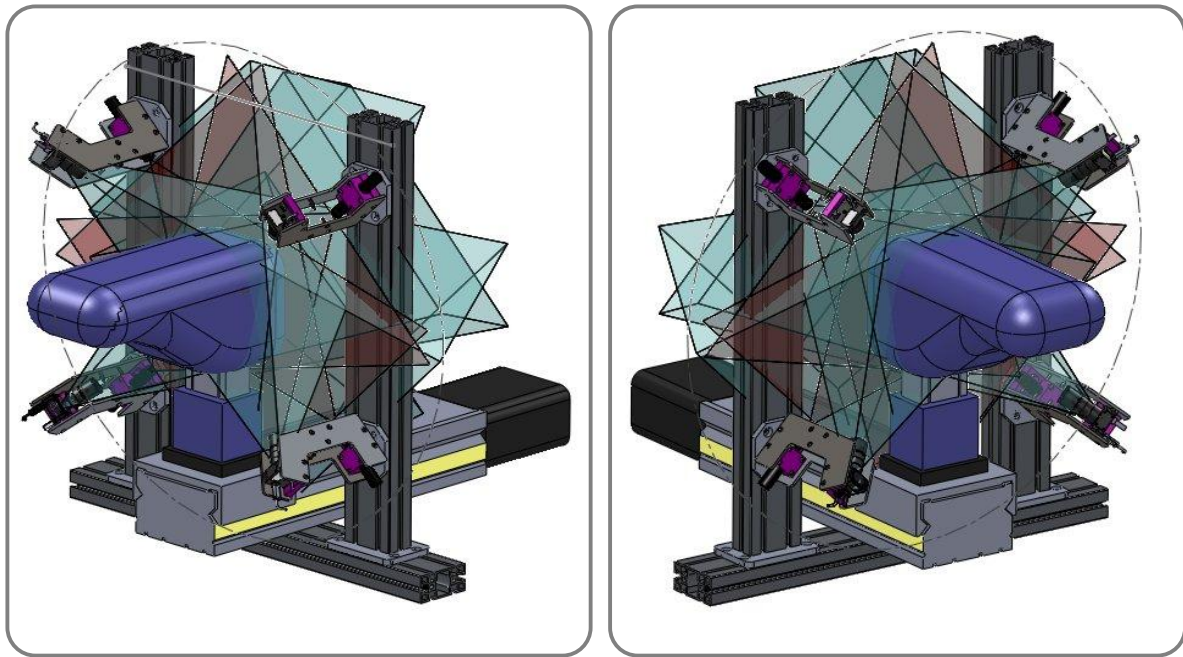- 1 linear axis run 1000mm

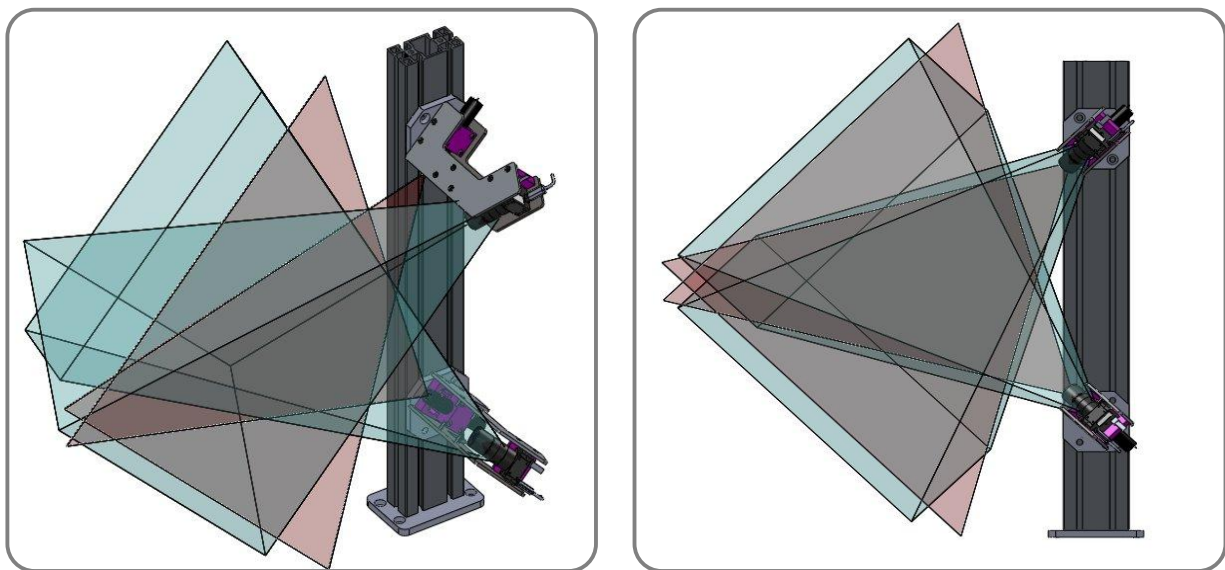**Fig. 16 ITIA-CNR Laser scanner system 3D with working volume**

Fig. 17 laser scanner 3D single column with working volume

Thus, measuring the single-shoe or the single-last in the production system seems, by now, the only solution in order to allow the introduction of robot inside the production line, paving the path for autonomous adaptation of the nominal robot part program to the actual geometrical characteristics of the shoe being manufactured

The design followed is based on modular design, allowing the use of low-cost components, and directly customized on the specific application's requirements. The laser scanner system has solved the problem of the measure of the actual coupling between the last and the gripping device that is usually characterized by a poor accuracy.

To perform the alignment between the CAD model and the acquired cloud of points a procedure, based on Iterative Closest Points (ICP) optimization methods, has been developed and directly integrated in the laser scanner device. As a result of this procedure a roto-translation matrix is communicated directly to the robot controller.

The two sets of data input are:

- the 3D points of the last coupled with the gripping device in the CAD model Xpc-cad;
- the 3D points acquired by the LSS Xpc-laser

The goal of the alignment procedure, consists of identifying (registration process) the 3D rigid transformation (rotation Rpc-cad and translation Tpc-cad) between the CAD nominal model and the 3D object reconstructed by the LSS (each point is expressed in the same Cartesian frame).

Iterative algorithms allow an easy and cost-efficient solution; target accuracy can be fixed by defining a user-selected tolerance threshold $\tau > 0$ that identify the exit condition for the algorithm (iteration terminates when the mean-square error is below the threshold).
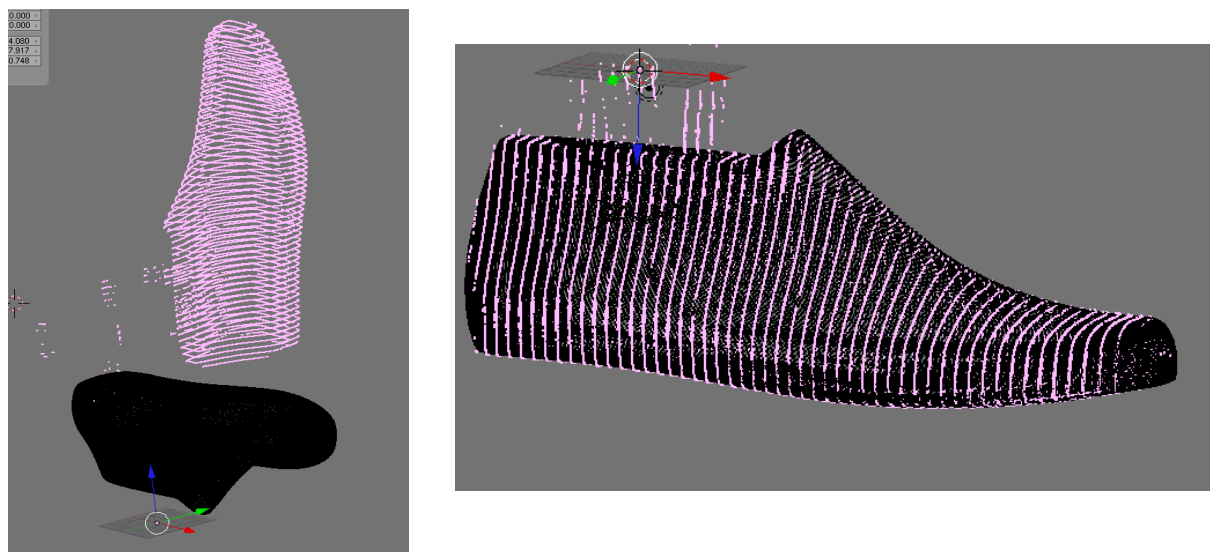

Fig. 18 point clouds on cad reference system (black) and on scanner reference system (pink) before and after registration procedure

An automatic procedure that modifies off-line the robot part-program allows higher accuracy in the tool path planning so reducing the unwanted-constraint forces when the shoe is brought in contact with tools by a robot.

For the evaluation of the efficacy of this method many test have been performed; the experiments consist on moving shoe in contact with different tool with and without the off-line correction of the path and performance evaluation is given by the measurement of the contact forces. Results and more details can be found in D5.1.

4.2 AILA

DFKI will provide project flyers for the Fair which explain the contribution of DFKI to the project ROBOFOOT in terms of non-rigid part manipulation by means of multifinger-dual-arm robots.

Moreover, a video will be shown in which the contribution of DFKI to the project is demonstrated. In this case, the video will show the dual-arm robot AILA autonomously packing a pair of shoes into a box. The robot learned to perform this task after a few demonstrations given by a human operator. The approximately 3-minute video will consist of real sequences of the robot at DFKI Laboratories combined with screen captures of the simulations performed during the learning process.

5   Supporting material

Different dissemination material will be ready for distribution and presentation in the fair

-Poster and leaflet

-Videos of partial results