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Abstract	Description of the prototype developed integrating the inspection algorithms described in D2.4. It includes both software application and hardware used.

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No se encuentran elementos de tabla de ilustraciones.

2 Introduction

The introduction of robots in the footwear production implies handling the last with the shoe to execute some production tasks currently done by operators. In order to guarantee that these tasks are properly done the quality of the execution is going to be assessed.

Artificial vision has been decided as technology for the quality inspection. This allows taking advantage of the robot having the last grasped by putting the shoe in front of a camera to evaluate whether the operation has been correctly done.

Quality inspection will be focussed on the following operations:

- Quality of roughing operation
- Detection of remaining staples/nails
- Assurance of correctly applied adhesive
- Detection of surface defects

1. Quality of roughing operation

Once the leather has been put on the last with the insole (toe lasting) it is necessary to prepare the surface of the leather covering the insole to receive the adhesive material. In a later operation this part will be stuck on the sole.

Due to the smooth texture of the plain leather surface, this is not normally good enough to be substrate for a long lasting junction with the sole so a roughing operation is required. This operation has two main objectives: to prepare the surface for a better acceptance of the adhesive and to flatten it because of possible folds.

The roughing operation has to be done carefully since the leather used in footwear industry is thin. Typical defects that appear in roughing operations are: excessive roughing, lack of roughing and rough out of the limits. Excessive roughing creates a zone with lack of material. In case of lack of roughing the original surface remains unchanged. If roughing has been done out of the limits the shoe is defective.

Artificial vision has been used to ascertain that the operation has been correctly done. Images of the bottom of the shoe have been taken and analyzed to detect lack of material in the zone where the adhesive has to be present. Lack of rough is also detected. To know whether the roughing operation has been done within the expected limits, images of the shoe sides might also be needed.

2. Detection of remaining staples/nails

Staples or nails are used to fix the insole to the last. They are just fixtures for intermediate operations during the footwear manufacturing process that have to be removed before sticking the sole to the shoe. It is very important that no staple/nail remains in the final product otherwise it could hurt the person who wears it.

To detect the presence of remaining staples/nails images of the shoe bottom are taken after the operator has removed them. The objective is to know whether all of them have been removed prior to the roughing operation.

3. Assurance of correctly applied adhesive

After the roughing operation adhesive will be put on the bottom of the shoe around the border profile. The spread of adhesive has to be continuous along the profile and with the required width. Depending on the models, adhesive has to be applied in the lateral of the shoe. In this case, care has to be taken in order not to put the adhesive out of the limits. Both type

of errors have to be detected: lack of adhesive and presence of it outside the limits. Artificial vision will be in charge of checking whether both conditions are met.

4. Detection of surface shoe defects

Once the shoe has been completely manufactured it is necessary to assure that it has no surface defects. Examples of defects are scratches, wrinkles or scares that can appear in the leather surface, making it a defective product. These defects are intended to be detected by using artificial vision, focusing on different characteristics such as changes in texture or colour, among others.

This document contains a description of the prototype for the implementation of the aforementioned inspections to assure quality in the new manufacturing environment. The scenario, i.e., devices, machines, software and other components taking part in the evaluation of the operations, and working operative will be described in next chapters.

The description of the algorithms used is available in D2.4.

3 The prototype

Quality inspection has been designed to be included in the two robotic cells developed in the project: the roughing, gluing and last milling cell and the inking and polishing cell. In the former the roughing operation is done and checked, the adhesive is spread throughout the shoe bottom and checked and the remaining staples/nails are detected. In the latter the detection of surface defects and of adhesive out of the boundaries, when required, are done.

Both cells are formed by a robot, operation stations, an artificial vision system and a PC with two applications; an application is in charge of the general control of the cell and another one of the image acquisition and analysis. Cameras are connected to the PC. The vision system works synchronised with the robot.

This chapter contains the description of the prototype used for quality inspection in both cells. This includes the description of the hardware and software used in each quality evaluation as well as how they work.

3.1 Components of the quality inspection system

3.1.1 Hardware

Hardware components (**Fig. 1**) are those needed for shoes handling (with last) and those used for the images acquisition of the zones to inspect.

- For shoes handling a Comau NM 45-2.0 model with a payload of 45 kg and a reach of 2000mm is used. A more detailed description of its characteristics can be found in Deliverable D2.2, chapter 2. The robot has at its flange a grasping tool for shoe handling and a vision system (camera and lighting) for dynamic positioning (visual servoing) of the tool.
- Depending on the type of inspection, a colour camera and different lighting devices are used. Images are acquired and analyzed according to each quality inspection. There is different lighting for each inspection as the observed objects present different characteristics.

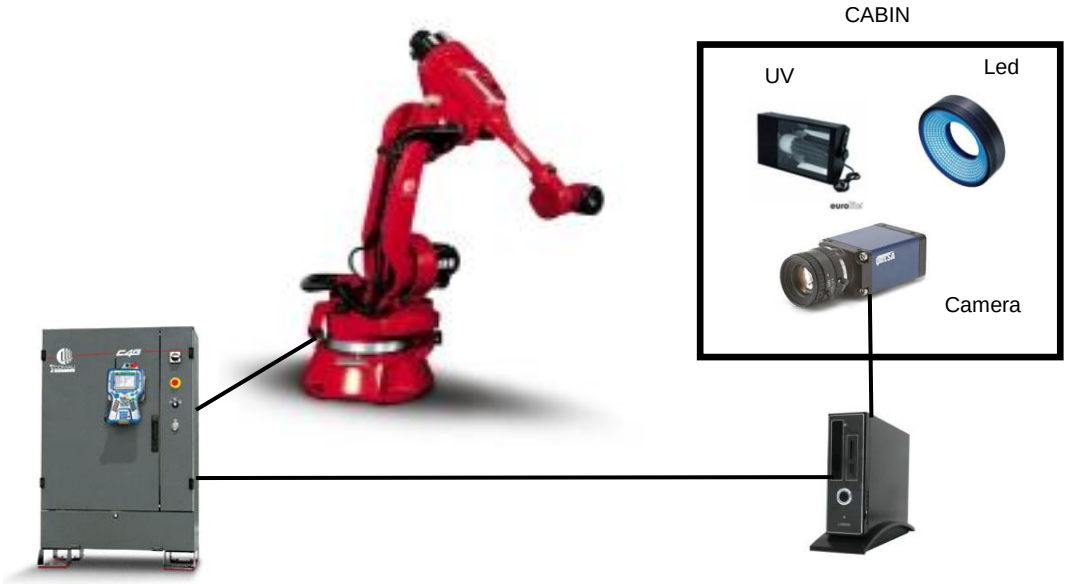

Fig. 1 Quality inspection system hardware components

The artificial vision devices used in the prototype are:

- Colour camera of 1280x960 pixels, 24 fps
- Lighting
    - Diffuse white colour lighting
    - Ultraviolet lighting
- Nearly closed cabin to avoid ambient light influence
- Band pass green filter ring (for adhesive detection)

Care has to be taken to avoid interferences of the ambient lighting. For that purpose a nearly closed cabin has been used. This cabin has at the front side a curtain of black plastic strips in order to allow the robot to get in with the lasted shoe. Inside the cabin the camera and the required illumination is installed. **Fig. 2** shows the devices and their main characteristics.

Lighting plays a key role in the quality evaluation. It has to contribute to highlight the characteristics that facilitate the detection of defects. Depending on the type of inspection these characteristics are:

- Quality of roughing operation: lighting has to highlight differences among roughed and not roughed leather and insole. This could be difficult when the colour of the roughed and the non-roughed leather is very similar or due to the presence of certain zones of the insole.
- Detection of remaining staples/nails: the brightness of metal has to be highlighted from the rest. It is also suggested to use coloured staples/nails in order to improve their detection in the insole.
- Assurance of correctly applied adhesive: since normally the adhesive used is transparent, it is difficult to assess whether it has been applied along the whole shoe profile when illuminating with conventional lighting. The problem is that the glue is not detected because of its transparent nature. In order to avoid the drawback of transparency an additive that reacts to the ultraviolet light is added to the adhesive. By illuminating with ultraviolet light the adhesive becomes visible and this allows detecting the lack or excess.
- Detection of surface defects: there are different types of defects and the illumination conditions have to be adapted to the requirements of each case. The leather can be of different colours and defects can appear everywhere in the shoe. A valid illumination for all cases is not feasible, so fault detection success will depend mainly on image analysis techniques.

Equipment	Characteristics
Cabin	- Minimum Dimensions of the upper cube (w-h-d) mm: 100-110-100 - Total height: 200 mm - Mobile rods inside for adaptable fixtures - Black plastic strips curtain in the front
Camera	- Color camera Genie C1280 - Number of pixels 1280x960 - Connection GigE
Lighting	- Ultraviolet light - Diffuse white color lighting - Band pass green filter ring

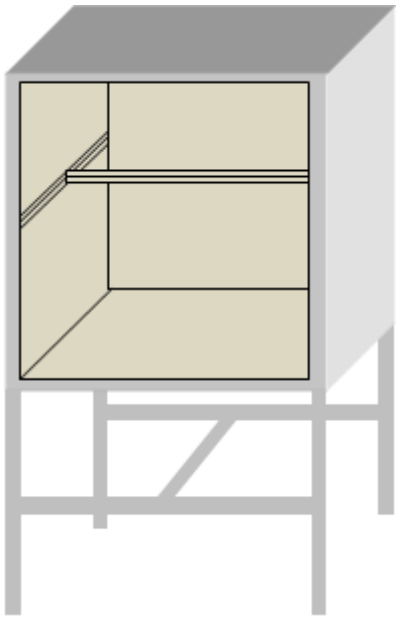

Fig. 2 Cabin for quality inspection and its characteristics

3.1.2 Software

Several software applications are need in the full process of quality inspection. The applications is used to:

- define and configure the inspection operations for each shoe model and
- execute the inspection according to the defined configuration, in synchronisation with the robot.

These software tools are:

- CAM tool
- Configuration application
- Inspection application

3.1.2.1 CAM tool

BasicCAM has been developed in the Robofoot project. This tool is used for the definition of the robot trajectories for several operations such as polishing, roughing or inking . Additionally, a new functionality has been added to allow the definition of masks for the quality inspection operations.

The definition of masks is done by using the 3D model of the shoe. First, the view of the shoe where the mask has to be defined is selected. The mask is formed by curves that are built from a sequence of interpolated points. Next figure shows a mask defined for a roughing operation. More information about the definition of masks can be found in deliverable of the BasicCAM tool (D4.1).

With BasicCAM masks are generated to focus the inspection on specific zones of the image. Masks are assigned to inspection operations with the configuration application. The inspection application applies these masks to the acquired images in order to extract the area of the image to focus the analysis on.

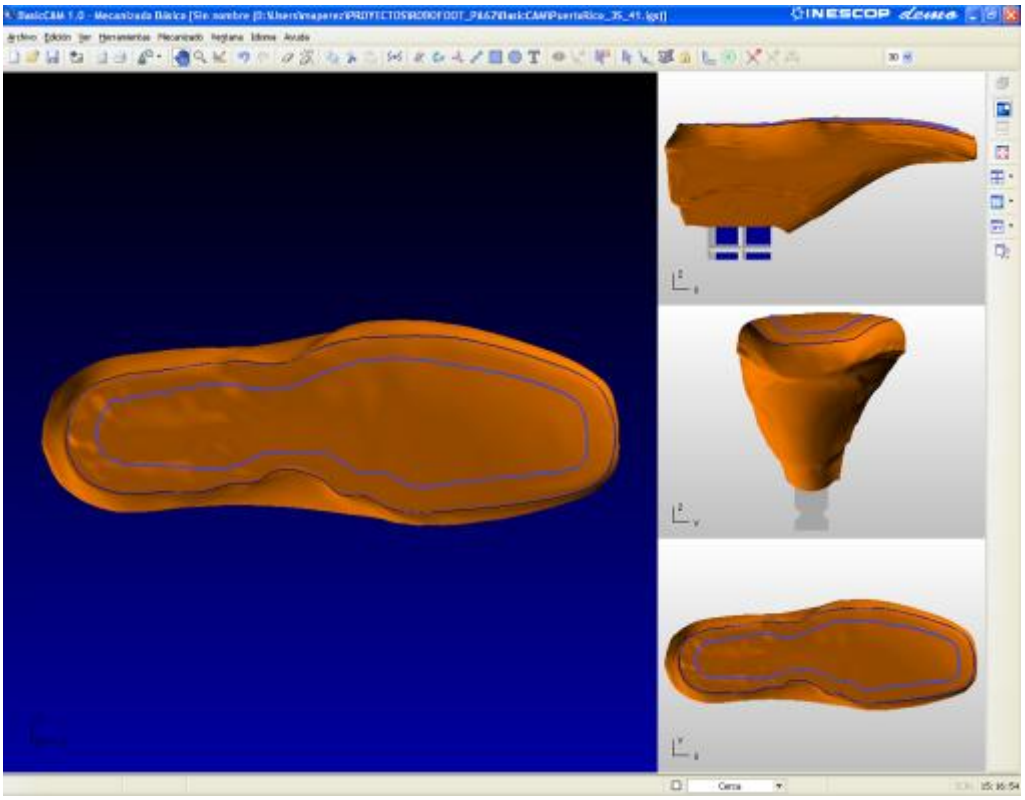

Fig. 3 Definition of mask for the roughing operation

Masks are used in all quality inspections: detection of staples, roughing operation, correct adhesive application and detection of surface defects. These masks are defined according to the requirements of the algorithm and the operation. For instance, when looking for seam defects the mask has to be defined along the seam and not much wider than it. This is because the algorithm used (LBP) searches for particularities in a generality. Here the generality is the seam and the particularity is the defect. On the other hand, when looking for scratches or thin cuts the mask can cover a wide area provided that it has the same texture.

3.1.2.2**Configuration application**

Each shoe model requires quality inspections according to its characteristics of shape, size, colour, components, etc. As there is a great diversity of shoe models, inspection operations have to be particularised for each one. A configuration application has been developed to help defining the parameters to be used for each inspection and shoe model.

The configuration of an inspection operation implies providing the necessary information that allows carrying it out. This information is related to image acquisition parameters (gain, shutter speed), the selection of the mask, the type of inspection, etc.

The configuration application is in charge of allowing defining all information required for each inspection operation for a shoe model. This information is stored and it is later used by the inspection application itself.

The application has two different working environments, one for general configuration of cameras and image acquisition and another one for the definition of inspections. It is possible to select from different types of cameras and to save images that later can be used to test inspections. **Fig. 4** shows the configuration of a camera.

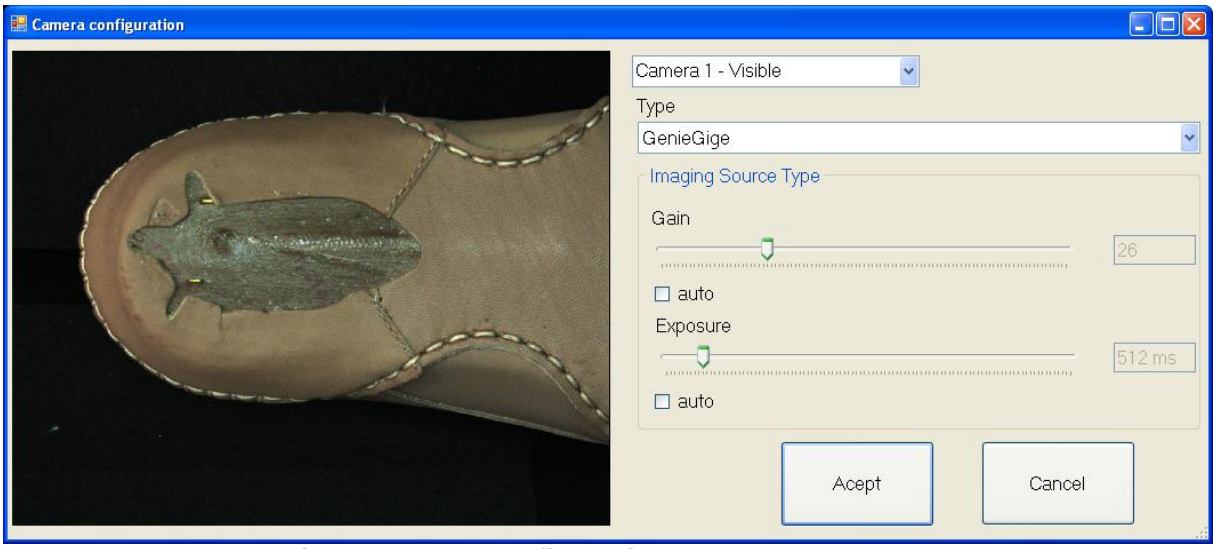

Fig. 4 Camera configuration

Configuration of inspections is done at shoe model level. The information managed for a shoe model that differentiates it from the rest corresponds to:

- Shoe model: model of the shoe for which the configuration is going to be done.
- Last identification: allows accessing the information of the last that will be used each time a last is taken by the robot, i.e. shoe size and foot (left or right) and corrections in the positioning of the grasping device.
- Colour: this information is considered as necessary since different leather colours can imply different lighting conditions even for the same model and size.

These three data are required to identify the configuration of the inspections to be applied to a shoe model.

The individual inspection operations to parameterise for a shoe are:

- Detection of remaining staples
- Quality of the shoe´s bottom roughing
- Quality of the shoe´s left side roughing
- Quality of the shoe´s right side roughing
- Quality of the shoe´s bottom adhesive application
- Quality of the shoe´s left side adhesive application
- Quality of the shoe´s right side adhesive application
- Detection of surface defects by pattern
- Detection of surface defects: scratches
- Detection of adhesive

All of them have some parameters in common, such as those related to the mosaic generation, mask and camera used, but can have other parameters specific to the particular inspection. **Fig. 5** and **Fig. 6** show the parameterisation of two inspection operations: detection of staples and quality of the shoe´s bottom adhesive application.

Fig. 5 Configuration for the staples inspection

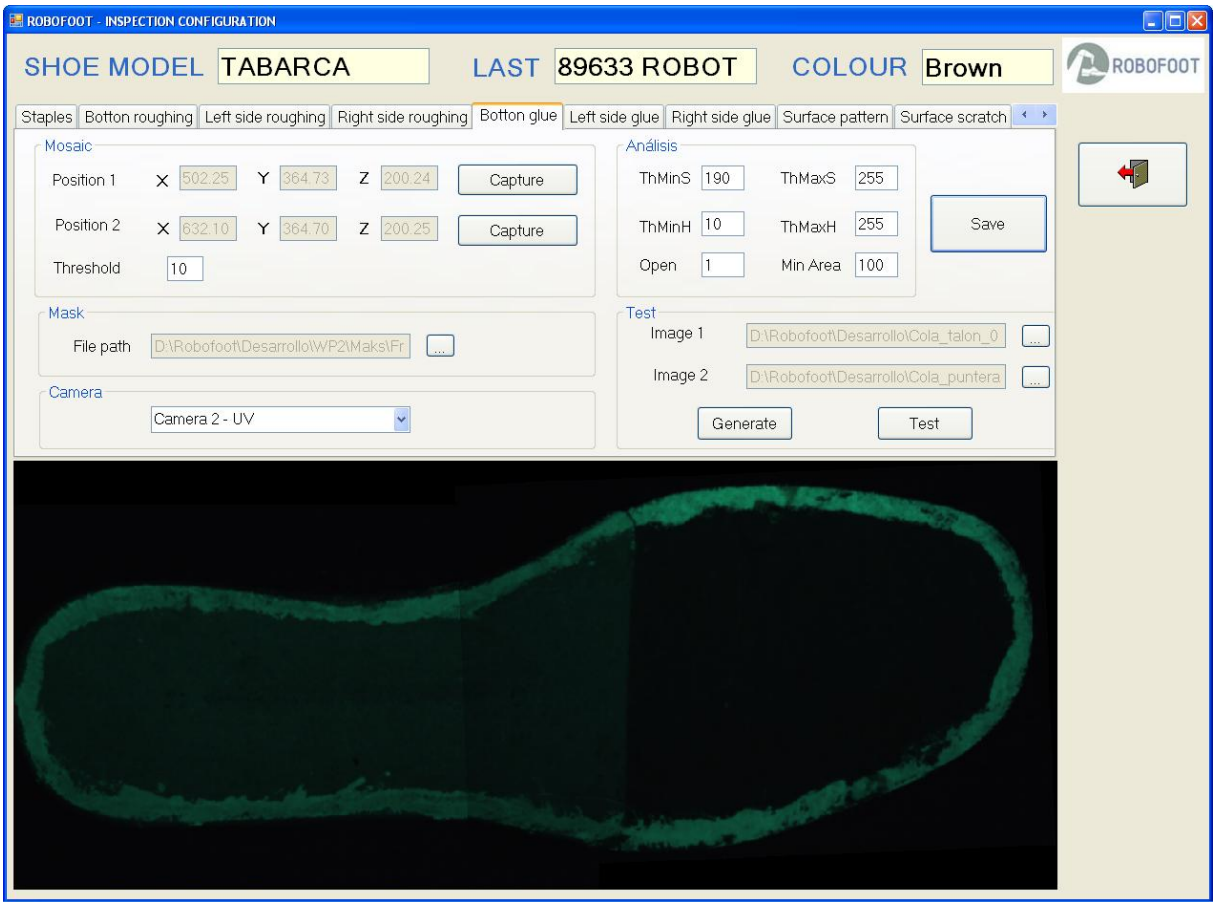

Fig. 6 Configuration for the bottom adhesive inspection

3.1.2.3 Inspection application

The inspection application is in charge of executing the quality inspections procedure defined for a shoe model with the configuration application, i.e. it is in charge of the acquisition and processing of images to decide whether the operation has been correctly done or whether there are defects on the shoe. It works in synchronisation with the hardware and software components that constitute the manufacturing cells.

Once the shoe is identified (shoe model, last and colour) the application loads all information required to carry out the inspections and applies the algorithm (see D2.4). This information is used to synchronise robot movements, image acquisition, analysis and decision taking.

Fig. 7 Inspection result for surface defects detection

3.2 Quality inspection procedure

The general procedure is: the robot takes the shoe from the feeding line (manovia) and then executes a predefined sequence of movements for shoe inspection or to perform the manufacturing operation.

When the shoe is in the right position with respect the lighting system, it is triggered the image acquisition.

The general software application is the control centre of all tasks in the cell. It works in coordination with the robot program and with the inspection application. A configuration file contains the sequence of actions (shoe grasping, inspections, operations, ..) to be done in the cell. The general application triggers robot programs as well as the inspection application when required.

The inspection application decides when to take pictures and what to do with the grasped shoe once the inspection has been finished. Taking pictures implies preparing the lighting conditions for a better image acquisition; thus the appropriate illumination is activated depending on the inspection to be done.

For the synchronisation between robot and inspection application there is a protocol that makes feasible the coordination. The initiative is at the application's side since the robot program only executes the requested movements and actions. When a quality inspection has to be one the procedure followed is:

- The general software application informs the inspection application which inspection has to be done, for instance, detection of staples.
- Depending on the type of inspection, the inspection application sends commands to the robot for lighting activation/deactivation.
- The inspection application sends positioning requests to the robot according to the configuration file and once the position has been corrected according to the specific last the shoe in mounted on.
- The inspection application takes pictures once the robot has reached the requested positions and proceeds with the algorithms defined for the inspection.
- Once the result of the inspection is known, the control software triggers the next action: moving to the manovia, to a buffer or triggers a new operation. If inspection is not successful the shoe is marked as defective for future re-working.

3.2.1 Roughing, gluing and last milling cell

Shoes arrive to the roughing, gluing and last milling cell after toe lasting and staples/nails removal. Once the robot takes the shoe three types of inspections and two operations are done in this cell. These are:

- Inspections
    - Detection of remaining staples and nails
    - Roughing quality assessment
    - Adhesive presence
- Operations
    - Roughing
    - Gluing

Last milling has not been included as it is an auxiliary operation that will be used only on idle time of the robot.

The elements that form the cell are:

- Manovia, for shoe transportation from one station to another
- Robot, with a grasping tool for shoe handling and a camera for a dynamic positioning of the tool
- Roughing station with the corresponding devices for bottom and side roughing
- Gluing station
- Vision system, for images acquisition, consisting of:
    - 2 colour cameras: one for the detection of remaining staples and roughing evaluation; the other one for checking the presence of adhesive
    - Diffuse white colour lighting for detection of staples and roughing evaluation
    - Ultraviolet light for checking adhesive presence. A band pass filter ring is put on the lens to extract just the green colour component reflected by the adhesive
    - Nearly closed cabin to avoid ambient light influence. Cameras and lightings are placed inside.
- PC with the application for image acquisition and analysis

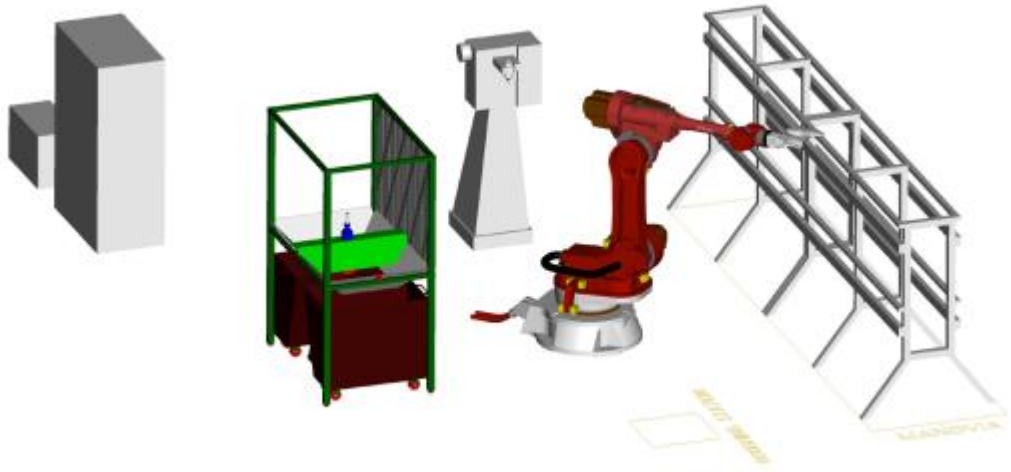

Fig. 8 General overview of the roughing and gluing cell

The general application manages the sequence of actions and coordinates with robot and inspection application. The sequence is (see **Fig. 9**):

1. The robot takes the shoe from the manovía. At this stage the shoe is identified by the general application (currently this is manually done because it is out of the scope of the project) and all configuration data for inspections and operations are loaded. The robot program also controls the locking/unlocking mechanism of the trolley in the manovia.
2. The general application passes control to the inspection application. The shoe is put into the cabin for staples detection. The white lighting is turned on, UV lighting is off. One or two pictures are taken depending on the distribution of staples on the insole. Once the robot has reached the position it sends the corresponding code to the application. A picture is taken and the application sends a new command to the robot to continue to a new position for another image. The application generates the composed image and analyses it. The result of the inspection is sent to the general application that recovers the control. If no staple is detected the robot proceeds to the next step, otherwise the shoe is left for corrective actions. During this step images are taken (if required) before roughing; they will be used for the roughing assessment algorithm as described in D2.4 (substration)
3. Roughing operations are done. Bottom roughing is always done; side roughing depends on the shoe model. The robot executes the movements of the operations.
4. Control is passed to the inspection application. The shoe is put into the cabin for roughing quality assessment. Diffuse white lighting is switched on. For bottom roughing the robot puts the shoe in two positions. In each position an image is acquired in coordination with the robot movements. After the analysis, the application proceeds to the next step. This step can include additional positions for side roughing or the next operation, gluing. In case of side roughing the same sequence of bottom roughing is repeated for right and left side.
5. Adhesive is spread on the corresponding areas at the bottom and at the sides when required.
6. Control is passed to the inspection application. The shoe is put into the cabin for checking of adhesive presence. The UV lighting is turned on; white lighting is off. Two

pictures of the shoe bottom are taken in coordination with robot movements. They are analysed and the robot proceeds to check for adhesive on the sides if required (two pictures, composition and analysis for each one).

7. If inspection is successful the process continues, otherwise the shoe is marked as defective for future re-working.

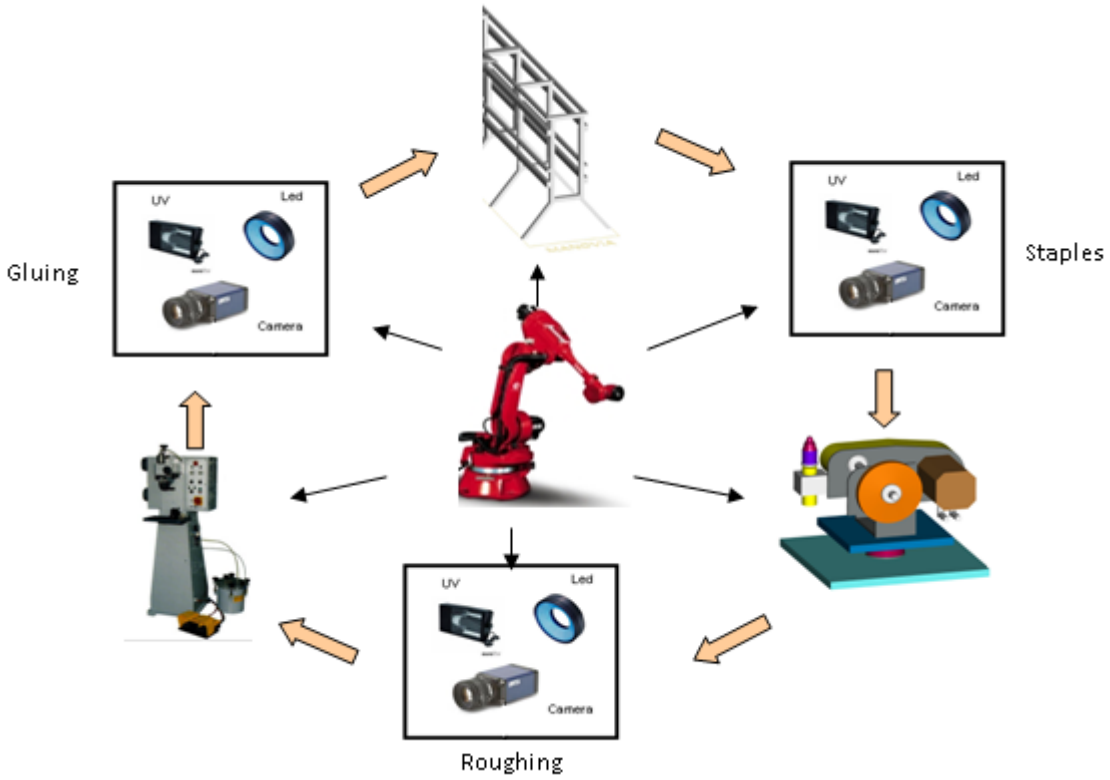

Fig. 9 Sequence at the roughing and gluing cell

3.2.2 Inking and polishing cell

Shoes arrive at the inking and polishing cell after the sole is stuck on the shoe. Once the robot takes the shoe two operations and two inspections are done in this cell. These are:

- Inspections
  - Detection of adhesive out of boundaries
  - Detection of surface defects
- Operations
  - Inking
  - Polishing

The elements that form the cell are:

- Manovia, for shoe transportation from one station to another
- Robot, with a grasping tool for shoe handling and a camera for a dynamic positioning of the tool
- Inking station
- Polishing station
- Vision system, for images acquisition, consisting of:

- 2 colour cameras: one for surface defects detection; the other one for checking the presence of adhesive
- Diffuse white colour lighting for surface defects detection
- Ultraviolet light for checking adhesive presence. A band pass filter ring is put on the lens to extract just the green colour component reflected by the adhesive
- Nearly closed cabin to avoid ambient light influence. Cameras and lightings are placed inside.

- PC with the application for image acquisition and analysis

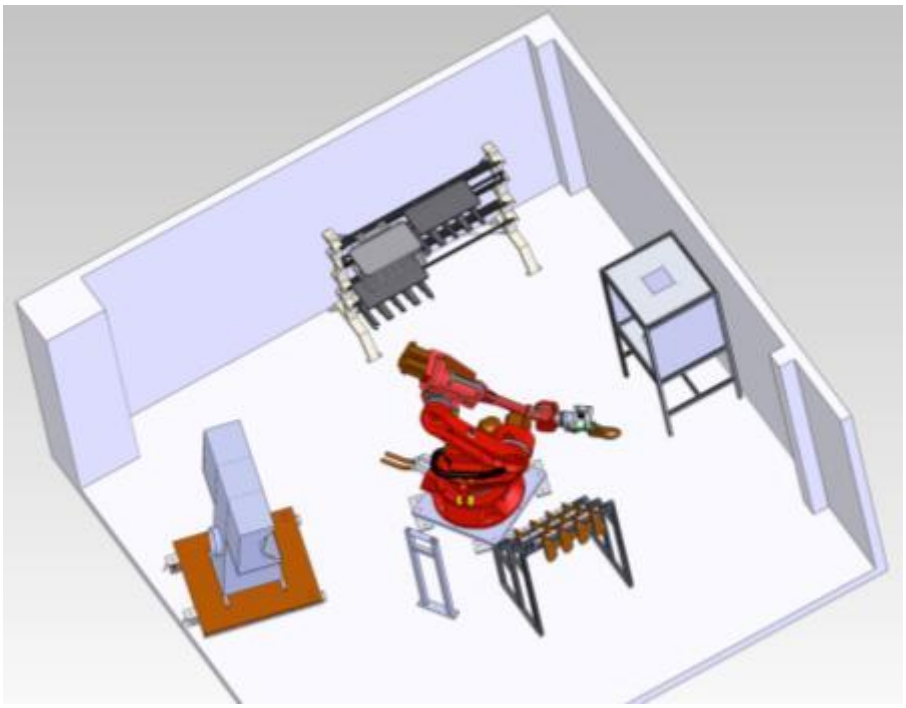

Fig. 10 General overview of the inking and polishing cell

The sequence is the following:

1. The robot takes the shoe from the manovia. At this stage the shoe is identified by the general application (currently this is manually done because it is out of the scope of the project) and all configuration data for inspections and operations are loaded. The robot program also controls the locking/unlocking mechanism of the trolley in the manovia.
2. The general application passes control to the inspection application. The shoe is put into the cabin for checking of **adhesive presence** at shoe sides. The UV lighting is turned on; white lighting is turned off. Two pictures of a shoe side are taken in coordination with robot movements. The composed image is analysed and the result is sent to the general application. If the shoe is correct the robot proceeds to the next step, otherwise it is left for corrective actions.
3. The general application passes control to the inspection application. The shoe is kept into the cabin for **surface defects** detection at shoe sides. The white lighting is turned on, UV lighting is turned off. Two pictures of a shoe side are taken in coordina-

tion with robot movements. The composed image is analysed and the result is sent to the general application.

4. If inspection is successful the process continues, otherwise the shoe is marked as defective for future re-working.
5. If successful, the process continues with the inking, polishing and last removal operations.

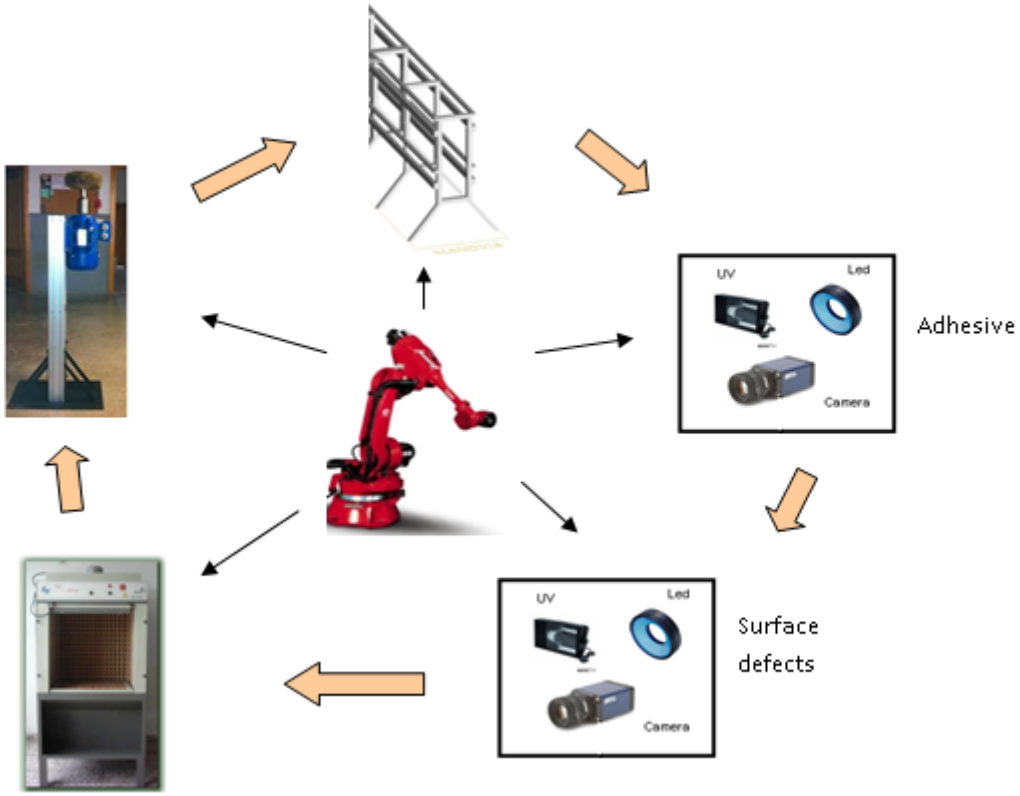

Fig. 11 Sequence at the inking and polishing cell