Project ref. no.	**260159**
Project acronym	**ROBOFOOT**
Project full title	**Smart robotics for high added value footwear industry**
Type	Deliverable
Dissemination level	PU
Contractual date of delivery	M4
Actual Date of Delivery	M14
Title of document	**D1.2 Scenarios definition and validation plan**
Version	V3.0
Number of pages	45
Partner Responsible	TEKNIKER
Other Contributors	ROBOFOOT Consortium
Author	TEKNIKER
Keywords:	Scenario, validation
Abstract	This document summarizes the process followed and decisions taken by the consortium to select the target operations in the project and the mechanisms that will be used to validate the results obtained.

Document History			
Ver.	**Date**	**Changes**	**Author**
0.1	08.11.2010	Structure of document	TEKNIKER
0.2	21.01.2011	Contribution of partners	TEKNIKER
1.0	31.01.2011	First consolidated version	TEKNIKER
1.1	01.05.2011	Minor corrections and request for contributions	TEKNIKER
1.2	24.05.2011	Contributions from partners	TEKNIKER
2.0	31.05.2011	New release	TEKNIKER
3.0	30.10.2011	New release	TEKNIKER

Content

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2 Introduction

This document summarizes the process followed and decisions taken by the consortium to select the target operations in the project and the mechanisms that will be used to validate the results obtained.

In the project proposal, some initial footwear manufacturing processes were identified for the introduction of robotics:

- *Heat-setting (Shoe heat forming):* It is currently done in continuous ovens, where heat air is used for heat forming of the lasted shoes. The project proposed using robots to manipulate the last in the vicinity of a controlled heat source in order to optimize the process, heating only those parts that need to be fitted, within the temperature limits that materials properties impose.
- *Leather ironing:* It is done before brushing by means of a vapour flow that follows shoe's upper 3D geometry.
- *Final ironing:* It is also made using vapour flow but in this case the operation is much more complicated and worker skill demanding due to the fact that there is not last to support the manipulation.
- *Finishing:* it is completely done by hand through the use of chemical finishing-products dye-spraying on the leather surface.
- *Final inspection and Packaging*: They are manually done by operators at the end of the production line. Workers take the shoes, visually inspect them and if everything is fine and no defect is identified, proceeds with the packaging process, i.e. introducing a soft piece into the shoe (usually a simple piece of crumpled paper plus a plastic rib), and finally introducing the pair of shoes into the box..

A deeper analysis has been carried out in order to define the final sub-tasks that will be implemented in each scenario and how they should be scheduled through the project, according to the impact in the whole industry and scientific innovation criteria. This will be achieved in a progressive approach using three different implementation phases: basic, intermediate and final.

The second objective has been to define the variables/characteristics to be measured during the validation process in order to determine the success of the project.

Metrics have been identified at two levels:

- At component level: positioning, manipulation and grasping of flexible parts.
- At system level. It includes robotic system performance in quantitative terms: cost, productivity, MTBF, etc., but also qualitative, i.e., to measure and to evaluate systematically the quality of the user-system interaction.

This document has to be considered as a starting point for the rest of workpackages.

The content of this document can be summarized as follows:

In “Chapter 3 Operation selection process” it is described the process followed and criteria adopted for the selection of operations.
In “Chapter 4 Brief description of operations analysed” we briefly describe the main operations and the technical considerations when deciding the introduction of robots to support them. References to videos are provided.
In “Chapter 5 Operations selected and high level planning” it is provided the roadmap of prototypes including the relationship with workpackages.
Finally, In “Chapter 6 Validation procedure” we describe the validation procedure of the results.

3 Operation selection process

3.1 Description of the procedure to select operations

The selection of operations is the result of a deep analysis carried out by all partners involved in the project. In summary the process has been the following:

- Phase 1: Workshop hold in PIKOLINOS (7th of September 2010).

After the visit to PIKOLINOS facilities, we split up the participants into two groups, in such a way that representatives of all stakeholders were present in each of them:

	Group 1	**Group 2**
End Users	ROTTA	PIKOLINOS
Footwear Sector	INESCOP, CNR-ITIA	INESCOP
Technology Providers	TEKNIKER, COMAU, ROBOTNIK DFKI	TEKNIKER, COMAU, ROBOTNIK DFKI
System Integrators	QDESIGN	AYCN

Tab. 1: Workshop organization

In order to make the selection process easier, it was agreed to classify the operation in two main groups according to the manipulation mechanism/complexity:

- The lasted shoe
- The shoe once the last has been removed

In this workshop we agreed on the selection criteria (see chapter 3.2) and worked on the operations that were included in the DoW plus others that participants proposed as possible candidates (open-minded discussion).

- Phase 2: Elaboration of an initial proposal.

An initial document with the insights of all partners on the operations analyzed in previous workshop was prepared for later discussion.

- Phase 3: Workshop hold in ROTTA (8th of November 2010)

The consortium met at ROTTA's facilities to select the operations based on the previous report.

- Phase 4: Consensus meeting in CNR-ITIA (26th January 2011)

  A final meeting took place between partners to consolidate the scenario selection and validation plan.

Pictures and videos were recorded during both visits and the result of this process is compiled in this document.

3.2 Selection criteria

The criteria that have been taken into account in the selection of operations are as follows:

- Has it a positive impact in initial requirements? (see Deliverable D1.1)
  - Improvement of the final product quality
  - Minimal modifications in current production means
  - Reduction of manufacturing time
  - Increase of production flexibility
  - Robotic / Manual production compatibility (it is easy to shift from robotized to manual operations)
  - Reduction of workforce
  - Improvement of working conditions
  - Overall production cost reduction
  - The system has to be easy to use
  - The system has to be easy to maintain
  - Robots might be used for other operations during idle periods (for instance at night for last manufacturing, ...)
- Novelty: is the operation already done by robots?
  - In the Footwear Industry
  - In other applications
  - As industrial solution or just research?
- Does it mean an innovation in the field of robotics? In any of the key topics addressed by ROBOFOOT
  - Programming
  - Control
  - Manipulation
- Does it mean an innovation in the process?
- Is the operation applied in most shoe types?
- Are there many variants in the way of doing the process? Can we cope with most of them?
- Is the solution proposed suitable to be used in other operations?
- Does it seem feasible to be done in the timeframe of the project?
- Is it suitable to be introduced in a demonstrator?

4 Brief description of operations analysed

A short introduction of most relevant manufacturing operations is presented in this section. A detailed description of selected operations can be found in Deliverable D2.1

4.1 Operations with last

They share the way the part (last) has to be grasped. It should be introduced a mechanism to guarantee a steady, fast and accurate grasping procedure, although small correction of co-ordinates might be needed each time a last has been grasped.

4.1.1 Op01: Heat-setting

Support material

- ..\Videos\087 -horno-estabilizado pequeño-dvd.wmv
- ..\Videos\087.a-horno-estabilizado grande-dvd.wmv
- ..\Videos\095-reactivado-dvd.wmv

Fig. 1 Heat setting

Analysis

The most important parameters in the process are time (higher priority) and temperature.

If we consider the operation itself, the impact on workforce reduction is very low because people doing the operation of loading and unloading parts into/from the oven perform other operations at the same time, so it should be considered in a comprehensive way, including those other operations.

The initial opinion of end-users is that the process itself (the heat-setting) will not be improved by the fact of using a most selective heat application (compared to the current approach, i.e. using the oven to heat all the surface of the leather in a homogenous way).

Some materials might be affected by the process. However in these cases the velocity of the belt is changed, but not the temperature. Furthermore in case of having decorative pieces that don't support the temperature, they are covered with pieces of cardboard.

There are some concerns also about the productivity of the new approach: currently it is normal having 8 pairs of shoes simultaneously in the oven, how can this productivity be reached by means of robots?.

The role of the robot manipulators here could be just to load and unload the oven. The possibility to use the robot in the process itself cannot be considered feasible as a shoe takes about 1 minute and half in the oven. So, it would mean an underutilization of robots.

The real improvement and impact of using a robot here can be given by the assumption that the robot will be used to accomplish other tasks.

Although technically feasible, it seems not suitable to be included in the final selection for the limited impact on process efficiency and mainly because of the well-founded doubts about the impact on shoes' final quality. Nevertheless, this operation can be included in the group of operations where the robot is aimed to pick a shoe, load/unload a machine and finally leave the shoe in the manovia. As a consequence, the solution proposed for other operations will be reusable in the future if end-users decide to implement it.

Technical considerations and initial ideas

OFF-Line programming

Theoretical information on the components of shoe design, last, heels, soles, any part of the cutting edge positions, union positions and position of trims could be available. Keep in mind that this information may differ from the theoretical to the real due to many factors so the information must be taken as a basis but it might be needed a real position feedback using artificial vision, proximity sensors or other techniques.

Sensor based programming

For loading/unloading the oven, a more intuitive programming interface (Manual Guidance Device) can be used by workers without particular experience on the robot programming.

Sensor based robot control

It requires adapting the velocity according to the temperature.

4.1.2 Op02: Leather ironing

The supporting material and analysis is similar to Op31: Ironing, although the manipulation is easier due to the presence of the last.

Fig. 2 Leather ironing

4.1.3 Op034: Inking and waxing (Finishing)

Support material

- ..\Videos\PIKOLINOS_EnceradoManual.AVI
- ..\Videos\PIKOLINOS_AbrillantadoSpray-ZonaTrabajo.AVI
- ..\Videos\PIKOLINOS_EstabilizacionTunelFrio-Salida-SprayManual.AVI
- ..\Videos\107 -acabados-pulverizados-dvd.wmv
- ..\Videos\107.1-manchadores-dvd.wmv

Fig. 3 Inking station at pikolinos

Analysis

We include in this section those operations that are done to provide ink or wax to the leather or to the shoe (It is usually followed by a polishing operation).

Although it is done either with the last or once the shoe has been un-lasted, it is considered that the application with the last might have more impact.

This operation can be split into different phases, spray application, waxing, and buffing-polishing

The end users' interest was medium (ROTTA) and high (PIKOLINOS). In the last case only if we consider the combined operation: spray application + polishing.

There is a similar operation developed by CNR-ITIA at its plant in Vigevano, although with a different approach.

The role of the robots here is to combine their versatility together with the need of a fast process. The flexibility of the robot can assure the possibility to do operations as inking or waxing and to combine them with the polishing operation (see below).

Technical considerations and initial ideas

The initial design idea is to create a small cell (spraying and polishing) wherein the shoe is manipulated by the robot.

OFF-Line programming

The models of the shoe from the CAD can be efficiently used to define the robot trajectory.

4.1.4 Op04: Inspection

Support material

- ..\Videos\108.5-envasado-dvd-soloinspeccion.wmv
- ..\Videos\104-repasado-dvd.wmv
- ..\Videos\PIKOLINOS_AcabadoFinal-1.AVI
- ..\Videos\PIKOLINOS_AcabadoFinal-2.AVI
- ..\Videos\PIKOLINOS_AcabadoFinal-3.AVI
- ..\Videos\101-limpieza-dvd.wmv

Fig. 4 Inspection

Fig. 5 Reworking operation in final inspection

Analysis

In the DoW, the operation described as Inspection is that performed at the end of the production process, just before the packaging process. However once it has been observed at PIKOLINOS' facilities (and later at ROTTA), it seems not realistic to focus on this kind of inspection process due to the fact that it is done at the same time than final manual rework and it affects to more than 80% of the shoes.

These reworking operations are hard for automation because they have multiple variants in the tools (paintbrushes, burins, scissors,...) and products (inks and waxes of different colours and nature) utilized, there is not any kind of repeatability and they require human perception and dexterity (this is way it is always done by hand).

However, the idea of inspection is still relevant so it is proposed to focus in the intermediate manufacturing operations, where similar inspection technologies can be applied to assess intermediate process quality.

Technical considerations and initial ideas

Vision based inspection might be used.

4.1.5 Op05: Roughing

Support material

- ..\Videos\092 -cardado-automatico-dvd.wmv
- ..\Videos\091-lijado-a-mano-dvd.wmv
- ..\Videos\123.03-cardado-automatico m. giratoria-dvd.wmv
- ..\Videos\ROTTA_OUTSOLE ROUGHING.wmv
- ..\Videos\089.5-rebatido-dvd.wmv

Fig. 6 Roughing

Analysis

Integrated in the CNR-ITIA "Design &Mass Customisation Laboratory" (D&MC Lab) located in Vigevano there is a robotic cell for roughing and gluing/cementing of shoe uppers that was developed by CNR-ITIA within the framework of the FP6 EUROSHOE project [EURОShoE: "Development of the processes and implementation of the management tools for the Extended UseR Oriented Shoe Enterprise", 6th FP]. The robotic cell integrates CAD-CAM generated tool paths with the use of a redundant force controlled head, mounted at the manipulator wrist, which allows real-time adaptation of the trajectory in order to ensure continuous and stable contact between the tool and the shoe to be processed, regardless, to a certain extent, of the inaccuracies in the path specification.

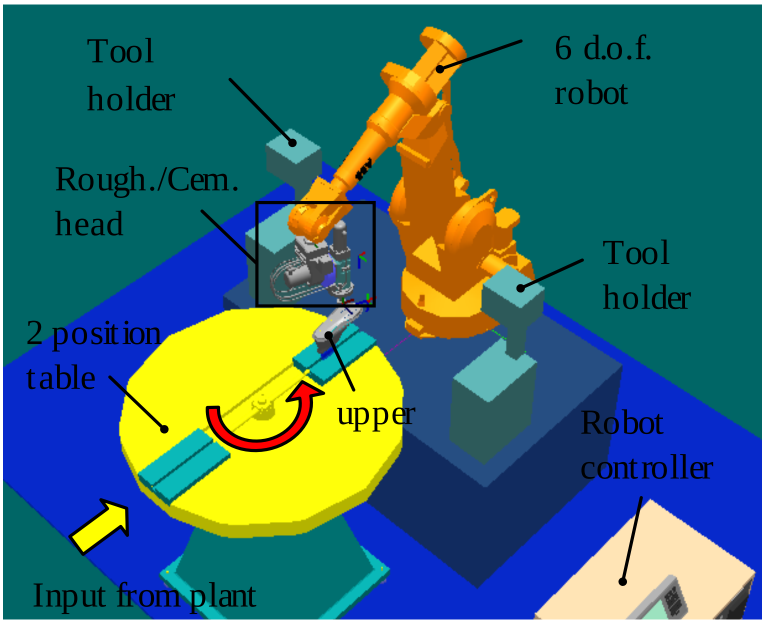


Fig. 7 Roughing cell at Vigevano plant

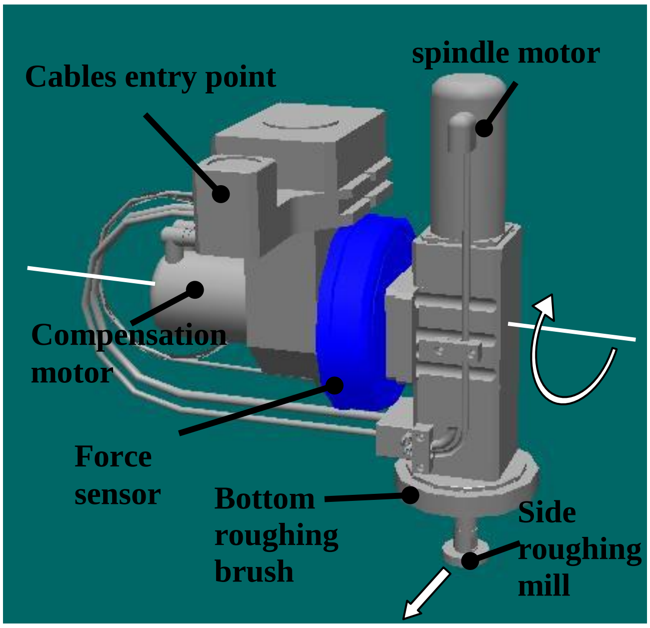


Fig. 8 Roughing device used at Vigevano plant

The head is made up of two main groups: the first one (that from now on will be referred to as "spindle axis") rotates the shaft on which either the side roughing mill or the bottom roughing brush are mounted. A second motor ("compensation axis") rotates the whole spindle axis and has the aim of keeping the working tool steadily attached to the upper by continuously controlling the contact force between the tool and the upper. Force/Torque measurement is available through a proper force/torque sensor.

Within the scope of the ROBOFOOT project the cell will be re-designed eliminating the redundant force controlled head mounted at the wrist and implementing a force control strategy directly on the COMAU C4G Open Control Platform

The thickness of the leather used is crucial for the acceptance of fashion shoes by the market: the more sophisticated the shoe is, the thicker leather is required in order to best fit the style. For that reason the range thickness of leather used is very tight: 0,6 mm up to 1,2 mm in the case of ROTTA (more than 80 % of production corresponds to thickness below 1,0 mm), 1 to 1,4 mm in the case of PIKOLINOS. In summary, the process of roughing has to be done with extreme care due to such a thickness of the leather.

It is of high interest for ROTTA. They know some experiences but they foresee potential problems with thin thickness of the leathers they use, so there is a high risk of damaging them during the automatic process.

Lateral roughing is of higher interest than sole roughing for PIKOLINOS.

Technical considerations and initial ideas

OFF-Line programming

Information about the cut remaining on the sole is not considered in the CAD system. The trajectory can be described using the CAD model, although it will be necessary on line adjustment to deal with assembly inaccuracy and leather thickness.

Sensor based programming

The C4G Open in the Cartesian modality can be used to program the robot with the aid of force control in order to perform the roughing task taking into account the uncertainties relative to thickness, leather type and so on.

Sensor based robot control

The importance of sensor based robot control and programming here is fundamental, as the process needs a high level of flexibility (due to the use of leathers of different materials and thickness); in order to cope with the uncertainty of a lot of parameters, the use of sensors might be needed.

It is suggested the use of force feedback to control/adjust the trajectory of the robot. This trajectory control/adjustment can be done in real-time with the C4G Open Control platform.

The vision system can be used in order to detect the areas with different roughing needs or (mainly) just to assess that the process has been properly done. These areas must be selected and a mechanism must be studied to modify the robot path program in order to perform the process on the areas to be correctly roughed. These areas (translated in a robot-like language as PDL2) can be sent to the robot controller and then the intelligent engine will be in charge of managing the modified path to be followed by the robot. However, the fact that the roughing is done with a robotized approach, makes this final inspection less challenging and even necessary.

4.1.6 Op06: Gluing

Support material

- ..\Videos\094.1-encolado-suelas-dvd.wmv
- ..\Videos\094.2-cola-montado para suelas-dvd.wmv

- ..\Videos\082.0 -cola palmillas para centrar-dvd.wmv
- ..\Videos\PIKOLINOS_EncoladoCorte-y-Palmilla-1.AVI
- ..\Videos\PIKOLINOS_EncoladoCorte-y-Palmilla-2.AVI
- ..\Videos\PIKOLINOS_EncoladoSuela-y-CorteMontado.AVI
- ..\Videos\093-halogenado-dvd.wmv (this is in fact halogenization, but is a done in a similar way)

These other gluing operations seem to be too much complexes for robotic application

- ..\Videos\082.2-cola-cortes-a-maquina-dvd.wmv
- ..\Videos\082.1-cola-cortes-a-mano-dvd.wmv
- ..\Videos\102-poner-adornos-dvd.wmv

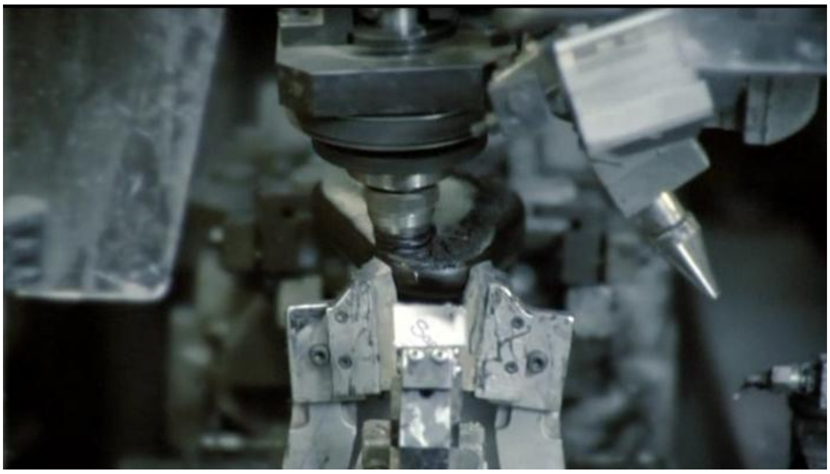


Fig. 9 Gluing

<u>Analysis</u>

There is a similar operation developed by CNR-ITIA at its plant in Vigevano.

If combined with the roughing operation (they are sequential) it could be a good improvement for the general efficiency of the process.

And additional challenge is related with the gluing process itself (selecting the proper gluing mechanism). It is of high interest for ROTTA.

<u>Technical considerations and initial ideas</u>

OFF-Line programming

The CAD models could be used to determine the path to be followed by the robot during its gluing process on the shoe. It will require modifications in the CAM application.

Sensor based robot control

Vision system can be use to inspect the boundaries of glued zone.

4.1.7 Op07: Polishing

Support material

- ..\Videos\PIKOLINOS_Abrillantado-EliminaciónCeras.AVI
- ..\Videos\109-cepillado-abrasivo y abrillantador-dvd.wmv
- ..\Videos\110- cepillado-abrillantador suela-dvd.wmv
- ..\Videos\110.1-cepill-abrill-corte-dvd.wmv
- ..\Videos\107.2-cepillado tacones suela-dvd.wmv
- ..\Videos\PIKOLINOS_Pulido-y-Deshormado.AVI

Fig. 10 Polishing

Analysis

See finishing operation (the two processes can be combined). See also Last Removal as the three operations (inking, polishing and last removal) can be combined also.

Sensor based robot control

It has to be double-checked the need of force control for polishing.

4.1.8 Op08: Last removal

Support material

- ..\Videos\PIKOLINOS_Pulido-y-Deshormado.AVI
- ..\Videos\099-sacar-hormas-dvd.wmv

Fig. 11 Last removal

Analysis

During this operation operators have to exert a force to open the last before pulling the shoe. Avoiding this effort is of interest from the point of view of working conditions of operators.

This process can be linked to that of shoe inking and polishing. Due to risk of damaging the leather in contact with the un-lasting tool this element has to be designed with care. It is also possible to think on an operation wherein humans and robots cooperate (the robot holding the last and the human removing the shoe from it).

Technical considerations and initial ideas

A new way of removing the last should be designed.

4.1.9 Op09: Combined operation: nail/staple removal and vapour application on the contour

Support material

- ..\Videos\PIKOLINOS_EliminacionGrapasPlantillaMontaje.AVI (It is missing the vapour application on the contour.
- ..\Videos\079 -clavar-palmillas o plantas-dvd.wmv
- ..\Videos\079.1-clav.y rondar palmillas-dvd.wmv (it includes the sole rounding operation)

Fig. 12 Nail/staple removal

Analysis

The robot could be used to perform the combined operations and to achieve a good through-put.

It is technically complex, but it can be of some interest because leaving nails in the shoe is unacceptable for shoe manufacturers.

Currently, it is the same worker who takes the last from the oven, removes the nail (or staple) from the last and uses a vapour flow to enhance the contour of the shoe. It is accepted that all operations might be done by the same robot, although it would be also possible to do the nail removal at a different stage, combining with another operation.

Although we did not see at PIKOLINOS, it is worth analysing to include the rounding of the sole, an operation that (when necessary) it is done just after the sticking of the insole to the last (see video).

It is of interest for ROTTA.

Technical considerations and initial ideas

Vision can be used to detect the nail (before removal) and assess that it has been effectively removed.

Sometimes they use nails with coloured heads for easier recognisance.

4.1.10 Op10: Combined operation: roughing and gluing

Support material

Fig. 13 Roughed sole

Analysis

It would have a high impact in terms of taskforce reduction, because there are three operations (drawing, roughing and gluing) that are currently done in different workstations and can be reduced (if combined) to a single robotic operation. It is of high interest for both end users.

Technical considerations and initial ideas

See individual operations

4.1.11 Op11: Marking

Support material

- ..\Videos\ROTTA_355 - Rev 0 - presa e segnatura con laser.wmv
- ..\Videos\ROTTA_356 -file riferimento segnatura con laser.MOV

Analysis

It is technically complex but feasible.

The main challenge is the accuracy in the movements required.

It is a similar process to gluing but with tighter tolerances.

It is of interest for ROTTA.

Technical considerations and initial ideas

It makes no sense if roughing is done automatically.

In other cases OFF-Line programming might be the key (when available).

OFF-Line programming

CAD model must be used to generate the trajectory that the robot has to follow to perform the marking operation.

Sensor based programming

The C4G Open controller can be used to provide the robot with the force sensor, which enables the robot trajectory to be changed and corrected in real-time (useful if the marking process is not done with laser, but with other tool which need a direct contact with the leather. This is the case of using a tool similar to a ballpoint pen to mark the leather using ink).

4.1.12 Op12: Last Manufacturing

Support material

- ..\Videos\ROTTA_357 - Rev 0 - fresatura forma.MOV
- ..\Videos\ROTTA_LAST TRACKING & GRABBING.wmv (It is not clear what the operations consist on)

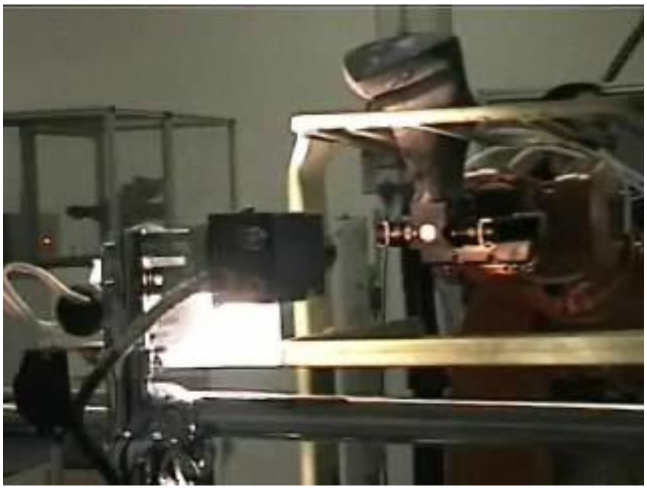


Fig. 14 Tracking and grabbing

Analysis

This operation is currently done with dedicated milling machines and/or turning lathes. Although technically feasible, the operation is rarely performed using robots due to the high loads at robot wrist and the need of dedicated and quite complex post processors to optimize both the geometric and process parameters.

This operation is not currently done by the end users (it is outsourced). However it is suggested as a possible operation that can be done by robots in idle periods (at night or when the production demand is low) during collection preparation or whenever the designers need a last for doing some trials.

A potential idea would be that the robot which performs other operations, either during idle periods of time or at night could perform the last manufacturing.

It is one of the research activities of INESCOP and QDESIGN. It can be considered for short term scenarios.

It is of high interest for ROTTA.

Technical considerations and initial ideas

OFF-Line programming

The CAD model of the last is used in the process to define the robot trajectory.

Sensor based programming

The C4G Open Control platform can be used to implement force control that can be inserted in the process of the creation of the last, giving a step towards innovation in the process.

Sensor based robot control

Force control might needed

Visual inspection

Final 3D inspection might be needed to double check the correctness of the machining

4.1.13 Op13: Insole sticking

Support material

- ..\Videos\PIKOLINOS_GrapadoPalmilla-1.AVI
- ..\Videos\PIKOLINOS_GrapadoPalmilla-2.AVI

Fig. 15 Insole sticking

Analysis

The breakthrough would be to find a method of sticking the insole without using nails. The operation requires high dexterity in the manipulation and placement of the insole before and meanwhile sticking.

PIKOLINOS: Medium interest

4.1.14 Op14: Machine feeding

Support material

Reactivating:

- ..\Videos\083-reactivado-dvd.wmv
- ..\Videos\095-reactivado-dvd.wmv

Fig. 16 Reactivating

Moulding:

- ..\Videos\103.5-conformado-dvd.wmv

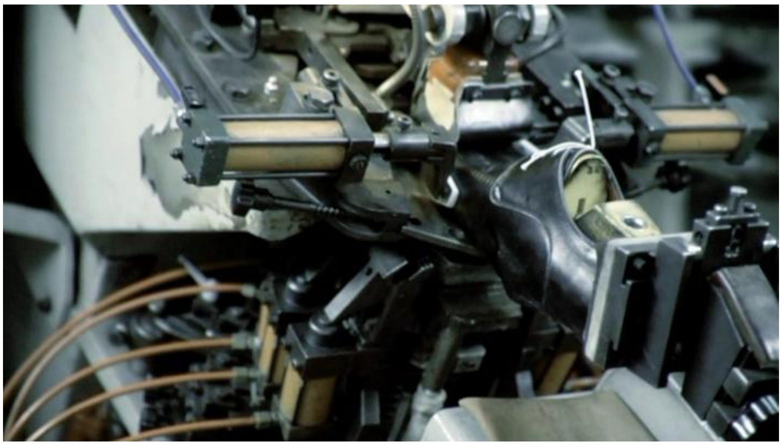


Fig. 17 Moulding

Chiller (stabilization):

- ..\Videos\097-horno-estab. con frio-dvd.wmv
- ..\Videos\PIKOLINOS_EstabilizacionTunelFrio-Entrada-Contorneado.AVI

Heel re-sticking (it is done without the last):

- ..\Videos\097.2-reclavar-tacones-dvd.wmv

Fig. 18 Heel re-sticking

Heel mounting:

- ..\Videos\086.2-montar-talones-dvd.wmv

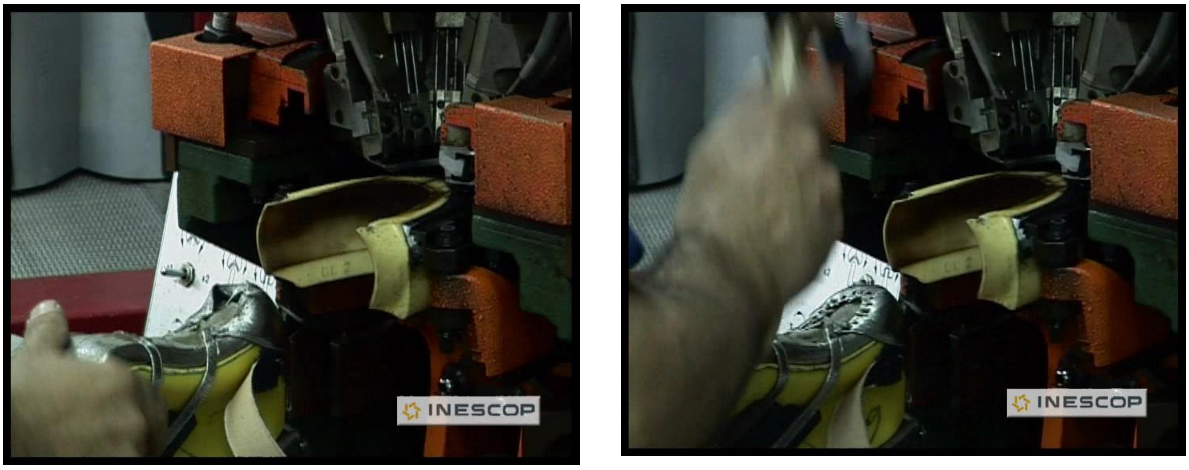


Fig. 19 Heel mounting

Heel mounting

- ..\Videos\092.5-montar-pestañas-talon-abierto-dvd.wmv

Fig. 20 Heel mounting

Heel marking

- ..\Videos\092.6-marcar-talones-talon-cerrado-dvd.wmv

Fig. 21 Heel marking

Analysis

It includes all kind of operations in which the worker introduces a shoe in a machine (or removes from it) and usually pushes a button to start the process in such a machine. It should be taken into account that in most of cases the worker does additional operations, no just the feeding of the machine.

Low (PIKOLINOS) to medium (ROTTA) interest.

4.1.15 Op15: Heel piece (tap) sticking

Support material

- ..\Videos\097.1-clavar-tapas-dvd.wmv
- ..\Videos\092.7-prefijar-tacones-dvd.wmv

Fig. 22 Heel piece sticking

Comments

High interest for PIKOLINOS. It would be possible in styles with prefixed heels.

Technical considerations and initial ideas

Visual inspection

Nail presence after the operation.

4.2 Operations without last

These are the most challenging operations from the point of view of grasping and manipulation, as they demand the development of a new gripper that can manipulate the shoe without damaging it and a vision system to identify the pose of the shoe.

4.2.1 Op31: Ironing

Support material

- ..\Videos\105-planchado-dvd.wmv
- ..\Videos\108 -ultimo-planchado-dvd.wmv

Fig. 23 Final ironing

Analysis

It corresponds to the operations Leather Ironing and Final Ironing described in the DoW, according to both operations the robot/operator can perform: in the first method, the robot can take the vapour flow on its flange, so the shoe is fixed and the robot will perform operations directly on it. In the second hypothesis, the robot must be able to manipulate the shoe without the last with a high level of dexterity as there are no references to grasp the shoe. The process does not need a very high level of precision.

It is important to emphasize that this operation is very much dependant on the type of shoe and the assembly process, i.e. it is not done in all shoes produced.

The challenges are similar to those of side roughing (although without the need of force control), inking or gluing in terms of program generation.

4.2.2 Op32: Packaging

Support material

- ..\Videos\108.5-envasado-dvd.wmv
- ..\Videos\PIKOLINOS_Empaquetado-1.AVI
- ..\Videos\PIKOLINOS_Empaquetado-2.AVI

Fig. 24 Packaging

- ..\Videos\106-rellenos-de-soporte-dvd.wmv

Fig. 25 Packaging

Analysis

It is one of the operations with higher workforce impact. Workers verify the correspondence in the pair (numbers), they write the pair number on the box, the pair of shoes is put into the box (sometimes having to introduce some piece of paper (or similar) to separate them and the box is closed with the lid.

In the scope of the project, the packaging process will not include any further operation to classify the box or to build a pallet.

High (PIKOLINOS) and medium (ROTTA) interest.

Technical considerations and initial ideas

It has to be integrated with order management.

It will require re-designing the conveyor control, box feeding and palletizing.

Manipulation

Design a gripper that can manipulate the shoe without the last. Design a gripper to manipulate the piece of paper. The manipulation of the paper has a high level of complexity.

OFF-Line programming

The CAD system doesn't include information on this process.

4.2.3 Op33: Cutting

Support material

- ..\Videos\PIKOLINOS_CortePielTroquel-1.AVI
- ..\Videos\PIKOLINOS_CortePielTroquel-2.AVI

Fig. 26 Cutting

Computer assisted Cutting and manual cutting:

- ..\Videos\PIKOLINOS_CortePielOrdenador-PreparacionPiel.AVI
- ..\Videos\PIKOLINOS_CortePielOrdenador-Proceso-1.AVI
- ..\Videos\PIKOLINOS_CortePielOrdenador-Proceso-2.AVI
- ..\Videos\PIKOLINOS_CortePielManual-1.AVI
- ..\Videos\PIKOLINOS_CortePielManual-2.AVI

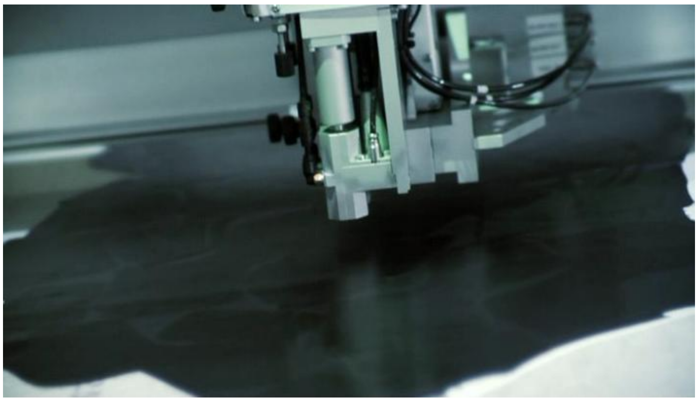


Fig. 27 Computer assisted cutting

Analysis

Positioning the die on the leather and controlling any defective zone in it.

In an initial analysis, it has not interest for end users, although it has scientific and technology interest: the vision system can be used for identifying different zones in the leather and a classification algorithm can be used to select those zones that are more suitable for the different upper parts. The robot could be used for picking the proper die in the right position and orientation and remove the cut leather part.

Technical considerations and initial ideas

Manipulation

Design a gripper to take the dies and remove the cut pieces.

4.3 Initially discarded other operations

4.3.1 Sole and Upper assembly

Support material

- ..\Videos\PIKOLINOS_EnsambladoSuelaCorte-y-Reactivacion.AVI (plus reactivation machine feeding)
- ..\Videos\096 -pegado-suelas m. membrana-dvd.wmv
- ..\Videos\096.a-pegado suelas m. tacos-dvd.wmv

Fig. 28 Sole assembly

4.3.2 Tacking

Support material

- ..\Videos\080-embastado-dvd.wmv

Fig. 29 Tacking

4.3.3 Preforming of upper

Support material

- ..\Videos\081-moldeado-dvd.wmv

Fig. 30 Performing of upper

4.3.4 To pull over and tack on to the last

Support material

- ..\Videos\084-centrado-dvd.wmv
- ..\Videos\CENTRAR CON REACT. EN L.wmv
- ..\Videos\PIKOLINOS_MontajePuntera-y-NudoCordones.AVI
- ..\Videos\PIKOLINOS_MontajeTalon.AVI

Fig. 31 Pulling over the last

4.3.5 To last the side leather

Support material

- ..\Videos\085.0-montar-lados-a-mano abierto-dvd.wmv
- ..\Videos\085.1-montar-lados-a-mano cerrado-dvd.wmv
- ..\Videos\086.1-clavar-lados-dvd.wmv

Fig. 32 To last the side leather

4.3.6 To cut-out the leather

Support material

- ..\Videos\100.6-calados-maquina-dvd.wmv

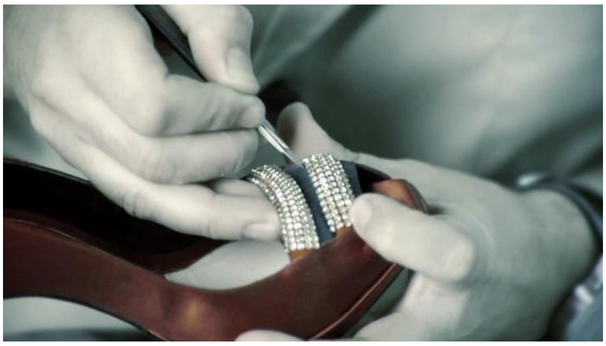


Fig. 33 Cutting out the leather

4.3.7 Stitching

Support material

- ..\Videos\122.15-cosido-con-ranura-dvd.wmv
- ..\Videos\PIKOLINOS_Aparado-OperariaMaquinaCosiendo.AVI

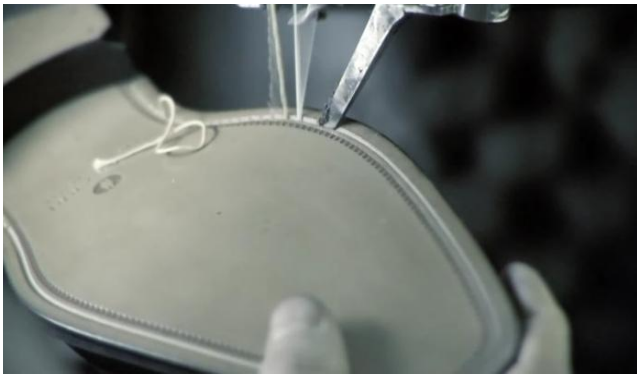


Fig. 34 Stitching

4.3.8 Lining preparation

Support material

- ..\Videos\PIKOLINOS_PegadoForros-1.AVI
- ..\Videos\PIKOLINOS_PegadoForros-2.AVI

4.3.9 Leather skiving

Support material

- ..\Videos\PIKOLINOS_Rebajado.AVI

4.3.10 Insole assembly

Support material

- ..\Videos\103 -poner-plantas-dvd.wmv
- ..\Videos\PIKOLINOS_PlantillaInterior.AVI

Fig. 35 Insole assembly

4.3.11 Channel opening, blake stitching, gluing and finishing

- ..\Videos\122.08-abrir-hendido y sacar horma cro.-dvd.wmv
- ..\Videos\122.10-cosido-blake-de-hendido-dvd.wmv
- ..\Videos\122.11-cola-hendido-dvd.wmv
- ..\Videos\122.12-pegar-hendido-dvd.wmv

Fig. 36 Opening channel

5 Operations selected and high level planning

According to the criteria established and the analysis of operations, it has been established a ranking of operations. They will be scheduled in the timeframe of the project and delivered in three prototype releases:

- Basic prototype
- Intermediate prototype
- Final prototype

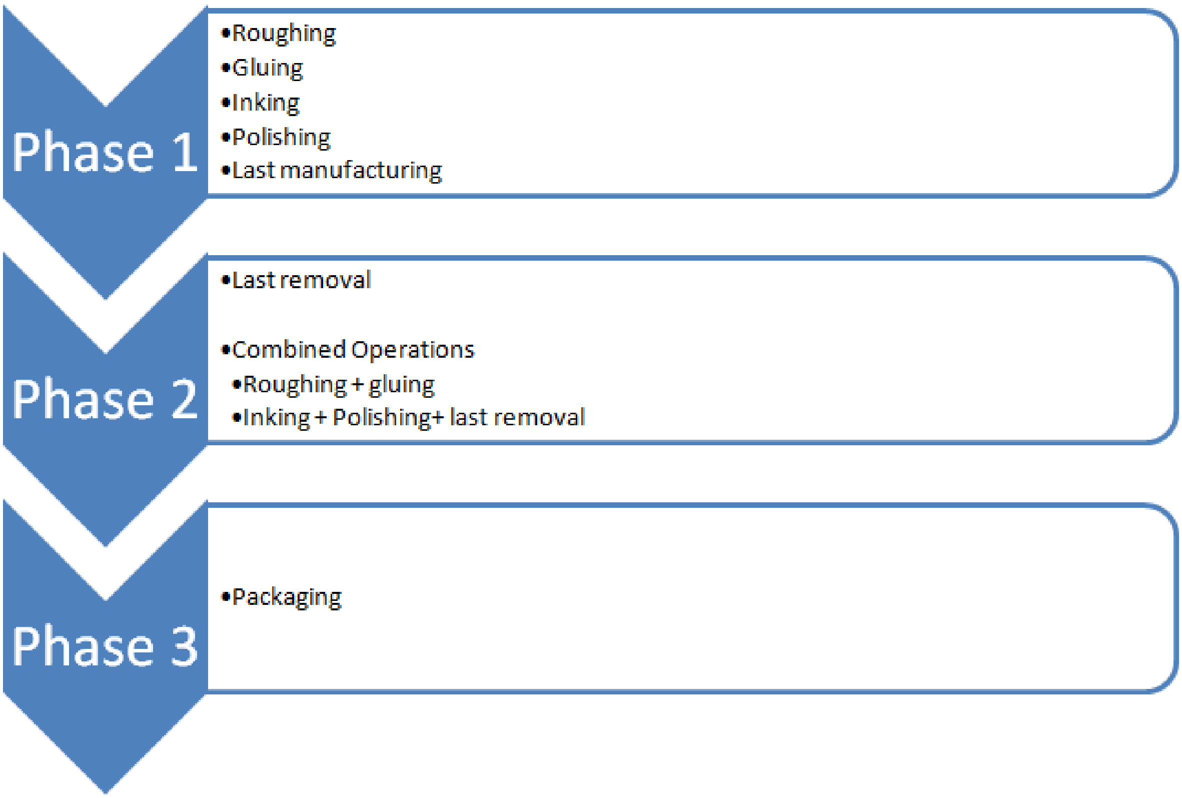


Fig. 37 Roadmap of prototypes

This approach corresponds to the three prototypes development approach that was set-up in the DoW.

The development and validation of the project results is scheduled according to the following approach:

- Component development and testing

  The technology providers (TEKNIKER, CNR-ITIA, ROBOTNIK, INESCOP, COMAU and DFKI-RIC) will develop partial solutions in the context of WP3 and WP4.

  System integrators will work in parallel in the manufacturing process adaptation.

- Testbed validation

  Before testing at shoemaker facilities, there will be an integration of results in CNR-ITIA/QDESIGN, TEKNIKER and INESCOP.

- Shoemaker validation

Final validation will be carried out at end-user facilities, although it is not discarded to use system integrators workshops to this aim in order not to interfere in the real production lines. The validation process is defined in next.

This process will be used for each of the three prototypes.

- Demonstrator

  It is scheduled (WP6) to develop a physical real demonstrator integrating some of the operations for dissemination activities and presentation at SIMAC.

5.1 Basic prototype: single operations

They correspond to some operations that have been already tackled for some of the partners in previous research activities, but providing a different approach. These operations are:

- Roughing (CNR-ITIA)
- Gluing (CNR-ITIA)
- Polishing (CNR-ITIA)
- Last Manufacturing (CNR-ITIA, INESCOP)

It includes also the inking process.

This basic prototype is scheduled by Month 18.

The steps needed to setup this basic prototype are:

- Process redefinition

  It will be analysed the following aspects of the production:
    - Last holding piece design and interferences with existent machines
    - Via redesign
    - Workstation redesign
    - Safety means
- Gripper design for last manipulation
- Visual inspection
    - Nail removal
    - Gluing
    - Roughing
- Programming
    - Path and process parameter definition (CAD/CAM)
- Sensor based control
    - Cartesian Space modality
    - Visual servoing to grasp the last
    - Force control in roughing

5.2 Intermediate prototype: combined operations

They correspond to some operations that can be combined in the same robotic cell, as explained in previous chapter.

- Roughing+ Gluing
- Inking+ polishing+ last removal

It includes also the availability of safety related outcomes.

This Intermediate prototype is scheduled by Month 24.

The additional steps needed to setup this intermediate prototype are:

- Process redefinition
  - Last removal workplace
  - Combined operation workplace layout redesign and development
- Safety
  - Human-robot space sharing
  - Collision avoidance

5.3 Final prototype: packaging

It corresponds to the most challenging operation, i.e. packaging.

This final prototype is scheduled by Month 30.

The additional steps needed to setup this intermediate prototype are:

- Process redefinition
  - Packaging workplace layout redesign (box, bag, vision system, conveyor)
- Manipulation
  - Bimanual, multifinger manipulation (visionary approach)
  - Industrial gripper
- Visual inspection
  - Shoe identification (model, left/right, number)

6 Validation procedure

Currently there is no specific protocol for measurement and validation in the footwear industry.

6.1 Component level

The validity of the COMAU C4G robot control and mechanics (related to NM 45-2.0) have been widely tested and validated to comply with the International Standard ISO 9283 (in relation to the Repeatability). The value of Repeatability ISO 9238 is 0.06 mm, with a maximum horizontal reach of 2000 mm, protection class IP65/IP67 @ wrist. The operating areas of the robot are depicted in the following picture:

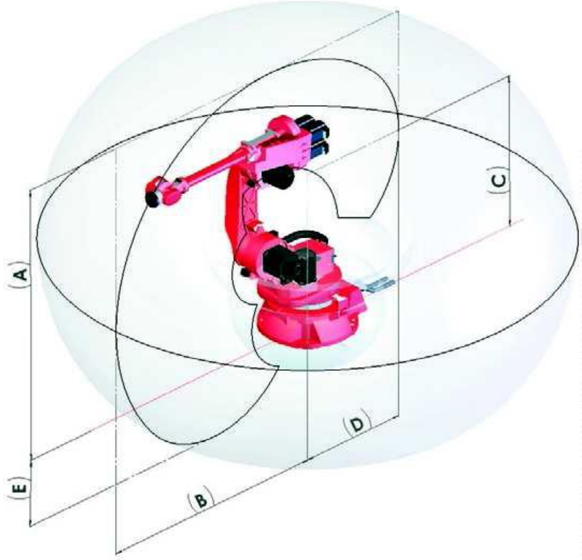


Fig. 38 ***NM 45-2.0 Operating Area***

Where:

- A = 2350 mm
- B = 2000 mm
- C = 1307 mm
- D = 952 mm
- E = 582 mm

The robot high repeatability and precision is the basis to support the manipulation of lasted shoes; in addition to that, the operating area of the robot has a good reach, compared to the application to be developed in ROBOFOOT.

6.1.1 Manipulation

Two different categories have been considered:

- Manipulation of the last.
- Manipulation of the shoe (without last).

1) Manipulation with Last

The precision in manipulation is the key point to achieve a correct operation in the rest of processes. During picking, last grasping requires high position and orientation accuracy and repeatability. Additionally, it needs to be firm to ensure that this position and orientation do not change during the manufacture processes and the manipulation of the last.

Fig. 39 Example of Gripping Method adding a fixture on top

To validate the grasping method, 3 different tests will be used:

- **Pick**: A shoe with Last is placed in the pick/dock area. The system identifies the position of the Last and the Robot grasps it. The robot moves the grasped Last to a defined position for measurement.

  To measure the picking process two benchmarks proposed in EURON[1] for Visual Servoing are being used as well as another one related with the accuracy:

  - The capability of grasping (pass/fail). Several tries will be done placing the shoe in the pick area with different positions and orientations. The difference between these positions/orientations and the theoretical picking point will be the same that in a normal manufacturing process, that it is expected to be of a few millimetres/angular degrees.
  - Time and computational cost. The seconds elapsed in the whole picking process are measured as well as the computational cost of the position corrections.
  - Position/orientation repeatability. Once the robot moves the Last to the Measurement place, position and orientation are measured. To measure this positioning, the lasts used for the tests need to have special marks or calibrated surfaces, and then the measure can be done by contact micrometric systems (gauges or similar) touching the surfaces; or by high resolution vision system detecting the marks. This measure will include the error due to robot repeatability in the related work area.
- **Hold:** The grasped last is moved in different directions (axis) with high accelerations rates (as proposed in several robotic projects). After a set of movements the last is measured again to check the position and orientation.
- **Operation:** It is also necessary to measure the impact of the different operations in the holding process. To this end different forces and torques, equivalent to the one applied in the different operations selected, will be applied to the last grasped by the robot. This test will measure the stiffness of the grasping when forces are applied in the last.

[1] http://www.robot.uji.es/EURON/en/visual.htm

2) <u>Without last: use of multi-fingered hand</u>

Evaluation of the selection of grasp points

This test is concerned with evaluating the selection of appropriate grasping points on the shoe. For every shoe, areas will be defined apriori in which the robot is allowed to grasp and areas in which it is not allowed. Thus this test aims at evaluating the ability of the robot hand for achieving a grasp, in which the fingers do not occupy non-allowed regions. Basically, the allowed regions are the sole and the inside part of the shoe.

The measure will be the finger occupancy on allowed regions, penalising for occupancy on non-allowed ones. The test will just consider successful grasps and not invalid ones.

Grasp performance evaluation

This test is primarily concerned with the evaluation of the performance of a multi-fingered grasp for different types of shoes. To this aim, the hand will be presented with different shoes and the algorithm will be tested according to the success achieved by grasping and moving the shoe from point A to point B.

This test is subdivided into two evaluations.

- The first one which evaluates the global performance of the robot hand for moving a shoe from A to B. This evaluation will not consider which the type of grasping is but whether the task is achieved or not. That is, this experiment evaluates the ability of the robot to select the most appropriate grasping method.
- The second test will evaluate the different types of grasping for each of the shoes. That is, this second test will evaluate specifically the success rate of a specific type of grasping.

The measurement in both experiments is the success rate of grasping the object at point A and moving it to point B.

Grasp dexterity evaluation

This test is primarily designed to evaluate the dexterity of the hand to move an object from an initial pose to a target pose. That is, the test aims at evaluating the in-hand dexterity and the selection of proper grasp points to achieve the task. The test will check whether the robot is able to maintain a certain target pose for the shoe by accounting for possible shoe deformations.

The measurement is the orientation error in degrees with respect to the target pose.

Grasp stability evaluation

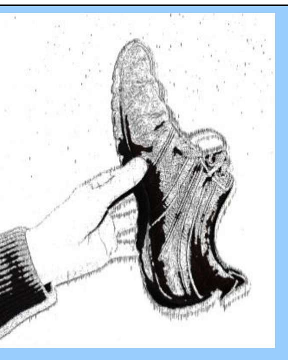
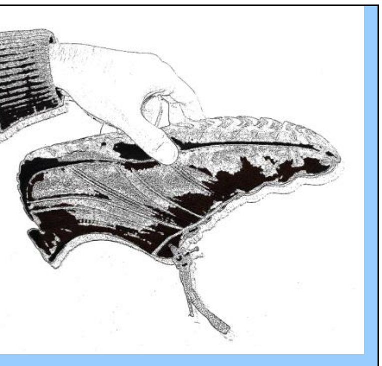
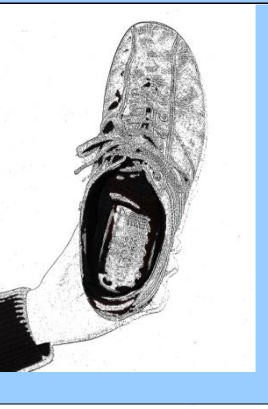
This test is primarily designed to evaluate the stability of a given grasp. Once a shoe is grasped, a high acceleration will be applied to the arm in different directions to check whether the shoe pose is kept.

The main measurement is the success rate on holding the shoe after the arm movements. A secondary measure is the average of the contact forces used for grasping and moving the shoe. The best result is achieved for the grasp that holds the object with the minimum contact forces.

Grasp planning time evaluation

This test will evaluate the time required for planning and selecting a particular grasp for different types of shoes.

The main parameter to measure is the time in seconds to plan and decide for a certain grasp.

Grasp for stability/dexterity evaluation		
Grasp for stability/dexterity evaluation		
Grasp used in the performance/dexterity evaluation		
Grasp used in the performance/dexterity evaluation		

Tab. 2: Some of the pre-defined grasps used for evaluation

6.1.2 Robot programming and control

Off-line programming

Two different measuring mechanisms are foreseen, one for milling of the last and the second for the rest of operations where OFF-Line programming is used.

- **Roughing/Gluing/Inking and Polishing trajectory definition**

  These operations can be faced by three approaches:

  - Generation of a different part program for each different sample, that is, each different shoe with upper mounted is acquired and digitalized by a laser scanning device already available for the partners. On the acquired CAD model, the CAM system developed in ROBOFOOT will calculate the sample-customized trajectory (*that is, the calculated trajectory lies in the actual bottom of the leather of the shoe*).
  - Generation of a part program for each model and size of the shoe by the CAD model of the last and CAD model of the leather (thickness and technological parameter as equivalent stiffness). On the basis of this complete CAD model, the CAM developed in ROBOFOOT by INESCOP will calculate the shoe-customized trajectory (*that is, trajectory that lies in the theoretical bottom of the leather of the shoe*).
  - Generation of a part program for each model and size of the shoe by the CAD model of the last. On the basis of the CAD model of the Last, the CAM developed in ROBOFOOT will calculate the last-customized trajectory (*that is: trajectory that lie in the sole of the last*).

  Common to all the strategies, the post-processor will generate the tool trajectory for a virtual tool (a pen). The robot will execute this program, drawing a profile on the surface of the same shoe (to isolate from other parameters as scaling).

  The shoe will be digitalized and the theoretical and real profiles will be compared using the CAD.

  In addition, assessment criteria for the evaluation of performances of the different available approaches will be:

  - Influence of solutions in the production time
  - Correlation of the performance of the different solution with the performance of the corresponding off-line and on-line path adjustment strategy. In fact, different solution requires a different adaptation control strategy.

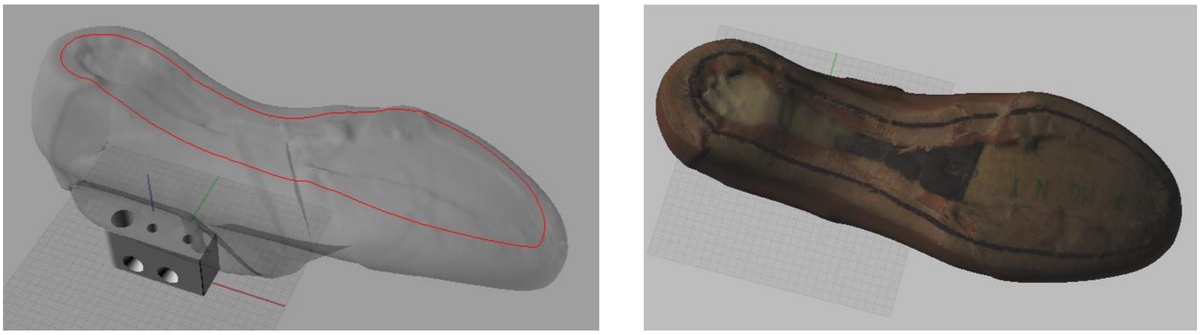


Fig. 40 Left: the trajectory defined in the CAD. Right the obtained trajectory using a pen as tool

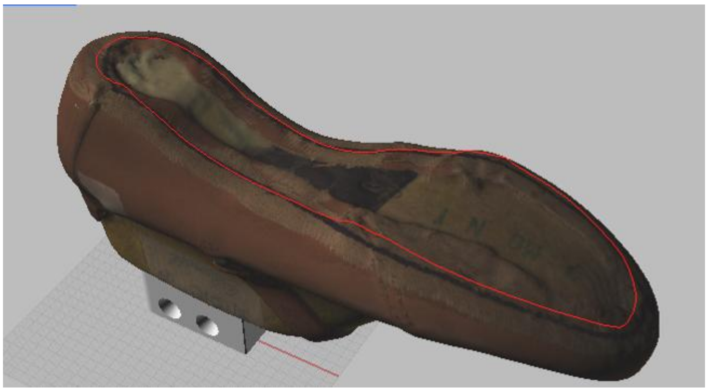


Fig. 41: Comparison of both trajectories

- **Last milling trajectory definition**

  A last will be machined using postprocessor and the trajectory defined in the CAD/CAM system developed by ROBOFOOT.

  The resulting LAST will be digitalized and compared with the expected geometry using the software InfoHorma, developed by the University della Marche in Italy and the program Forma3D.

Off-Path Adjustment

To meet the goals of robotized shoe manufacturing the robot program generated using off line programming techniques has to be adjusted due to different reasons:

- The path generated using off line programming techniques have to be adjusted to account for geometric differences between the digital data and the actual physical scenario (inaccuracies in the grasping device fixation on the last)
- There should be the possibility to change the path e.g. for a new, almost identical work piece.

The objective of the ***Robofoot*** project is to develop Innovative solutions for smart adaptation of off-line automatic robot part program generated from digital data (CAD). The success of this activity will be measured with two aspects:

- The precision of adjusted path regarding position and orientation will be **at least 10 % better**.
- The need for manual intervention will be **almost reduced to zero.**

On-line Path Adjustment

Roughing trajectory correction

With respect to different scenarios (see previous paragraph), different control strategies can be implemented. Simple position control can be implemented only if the roughing path is known exactly for each shoe. Performance is correlated to dynamic performance of the COMAU robot.

In the case the roughing path is referred to nominal Last, force control strategies will be implemented. These on-line adaptations of the robot part program generated from digital data (CAD) are possible thanks to the advance functionalities of the COMAU-C4GOPEN robot controller.

The objective of the ***Robofoot*** project is to develop innovative control strategies that will preserve the time cycle of the application and at the same time they allow an efficient roughing of the leather. The success of this activity will be measured based on:

- The performance of the force-based robot controller: the delay in deviation command, the bandwidth, the stiffness-equivalent stability, the following error, the presence of vibrations.
- The technological performance in the roughing with respect to industrial standard application. Different kind of shoes, leather and soles will be taken into account for the comparison.

Manual guidance

Robofoot project will use and validate an already existing manual guidance device developed by CNR-ITIA for COMAU. The same MG device will be used and improved in an ECHORD experiment (EASYPRO) by some of the partners of ROBOFOOT with the objective of facilitating robot programming by combining hand guided end-effector rough movement planning and 3D visual servoing. In the same experiment safety for the use of the device will be taken into account. In EASYPRO the process (laser cladding) is basically different from the shoe manufacturing processes but the synergy between the applications of the MG device is given by its flexibility of programming in heterogeneous processes.

The success of this activity will be measured with four aspects:

- The programming time for a typical pick and place operation will be at least 20% shorter for the improved MG device in comparison to the use of COMAU teach pendant
- The training time for a non skilled operator will be **almost zero.**
- The non skilled operator can focus his attention on the process regardless programmatic aspects; this results in a substantial increase in benefits in the quality of the process.
- The extreme flexibility of the MG device is a key aspect to allow the programming of different and heterogeneous shoe manufacturing processes.

6.1.3 Inspection

- Nail detection: the aim is to detect that there aren't nails left in the sole of the shoe once the operator has done this operation manually. The process to be follow includes using different type of soles (different colours and with different textures) and placing nails in different parts of the sole. The system has to be able to detect 100% of the visible nails.
- For gluing defect detection, we should consider two objectives:
  - Glue present outside the edges of the area
  - Lack (partial or total) of glue in the predefined gluing area.

  In both cases a set of experiments using a combination of different leathers will be performed. It will be defined the gluing area and it will be applied glue in the area creating artificial errors (both by excess and defect of glue). The system has to be able to detect all defects according to the parameters defined by end users (size and number of errors).
- Roughing inspection. Two different objectives: to control the boundaries of the roughed area and to verify that the leather has not been damaged due to over-roughing.
- Assembly errors. We refer with them to defects on the surface of the shoe. A collection of defects will be collected for the validation. The system has to be able to detect them and open to include new kind of defects in an easy way.

6.2 System level

6.2.1 Manufacturing related metrics

To understand the complexity of the shoe and the problems that we come across when we define a measurement and validation protocol in the footwear sector it is enough to have a look at something as simple at first glance as the shoe size, which cannot be measured accurately. In whatever other industrial sector it is very simple to know the nominal bolt width of a screw by just measuring and validating it. However, the size of a shoe cannot be accurately determined.

As regards the wide range of operations that are performed throughout the shoe manufacturing process there is no literature referring to how to measure and validate these processes. Only for some operations within the manufacturing process there are estimated data concerning time and temperature, as is the case of setting and activation ovens.

However for the majority there is not a founded measurement procedure. For instance, if we look at the process of applying adhesive onto the shoe sole, we find that there is no information concerning the amount of adhesive to be applied and how it should be done, or the type of applicator to be used, the application rate needed, etc. All these data are dependent on many factors including material type, adhesive type, shoemaker's expertise, etc

Nevertheless, the parameters that will be measured are:

- Accomplishment of the average production time in the line that allows combining manual process with the robotized operations.
- Time need to shift from manual (traditional) operation to robotized one (and vice versa).
- ROI of the proposed solution.
- Reduction on defective parts (defects due or produced during roughing, gluing, inking, polishing).

6.2.2 Safety

The overall objective of the ***Robofoot*** project with respect to safety issues is to develop safe and high performance human robot cooperation in shoe manufacturing. The success of this activity will be measured according to:

- The **cost** of the demonstrator will be **at maximum 10% higher** for the fenceless solution in comparison to the conventional solution.
- The **footprint** of the robotized cell will be **at least 8-10% lower** for the fenceless solution in comparison to the conventional solution.

COMAU Robots are compliant to the safety norms of the International Standard ISO 10218 which specifies requirements and guidelines for the inherent safe design, protective measures, and information for use of industrial robots. Since it describes basic hazards associated with robots, and provides requirements to eliminate or adequately reduce the risks associated with these hazards, it can be said that the Comau Robot is safe. The safety is guaranteed by the fact that the ISO 10218 is respected even in presence of external sensors and this is particularly true if we consider the automatic state of the robot.

For what concerns the manual state, in the classical configuration COMAU Robots respect the norm, with a maximum velocity of 250 mm/s; however there is the possibility to use devices directly connected to the end-effector, to move the robot (as Manual Guidance Device); in these cases, there is the need to do a specific risk analysis for the robot system in order to comply with safety norms.

Furthermore COMAU robots have a specific security option, called IEAK. It is a safety interlock module used to disable in safety one or more axes associated to independent arms, at the same time allowing the remaining arms to operate. This option is useful in order to allow the load/unload of pieces directly mounted on the robot tool. This can be used in the context of footwear production, for instance to allow the human worker to have a visual check on the shoe in a safe way. Using this option, however, requires a specific risk analysis.

6.2.3 Easy to use and maintain

It will be measured by means of:

- Observation of operators
- Survey to be answered by operators (on usability aspects)

As a result a report on usability of the system will be generated.