Implementation and testing of a shoe polishing process with a collaborative robotic system

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Abstract. Nowadays, automated processes in manufacturing industries are on the rise due to the need to increase productivity and product quality, but also to reduce operator cognitive-physical fatigue. This need is more felt in companies, such as footwear companies, where production is done entirely by hand and the success of the product relies totally on the skill of experienced artisans. The work presents the automation with a collaborative robot of the shoe polishing. This process is very delicate because of the high variability of leather types and the maximum quality to be achieved, as well as very tiring for the operator. An operational methodology for carrying out the polishing of a real leather shoe is proposed. Starting from the design of polishing trajectories, implementing them on UR5e, controlling the contact force of the tool, toe shoe polishing is performed, achieving a good quality standard. Experimental tests and their results are presented.

Keywords: Leather shoe polishing · Collaborative robotic application · Human robot collaboration.

1 Introduction

At the moment many manufacturing companies feel the need to automate processes, in order to have better results in terms of quality and higher production, decreasing the possibility of errors [1]. The operator performs high value-added tasks that machines would not be able to do, decreasing their physical and cognitive stress . In this regard, collaborative robots [15], which are machines that can automate a production process but also work alongside the operator by interacting with it, are becoming increasingly popular in recent years [2]. This can improve the psychophysical well-being of the operator and reduce his cognitive stress [6]. For example, in the footwear industry, most production processes are carried out by hand, and only a few processes are dedicated to specialized machinery, such as cementing and cutting operations [8]; while the use of robots is generally dedicated to ordinary repetitive tasks, such as pick and place [9], glue deposition on the sole [3], and robotic grip of the sole during assembly operations [11]. The use of robots and profound industrial automation is limited in this industry by the fact that products with considerable variability and totally different processing requirements are handled, and the finished products must have high precision, quality and comfort. Only human labor can guarantee these targets, making the company competitive. Characteristic aspects of shoe companies operating in the luxury sector that stand in total opposition to the possibility of automating a process are: low productivity due to artisanal activities [10], high levels of customization and with the management of micro-lots [17], difficulty in managing and transmitting knowledge of skilled artisans [13]. A central process in the production of shoes is the polishing of them. Polishing is almost always done by hand, takes a long time of 20 min or more for shoe, and is a very delicate operation. The ability and manual dexterity of the operator is crucial to achieving a quality polish. It is a difficult process to automate because each individual shoe has different polishing behaviour since it depends on multiple factors, such as leather color, type of leather, leather processing, and so on. Fundamental parameters to be kept under control to achieve good polishing through a robot are the contact force between tool and shoe, which must always be the same and not too high. The robot must be compliant in the direction perpendicular to the surface by always applying the same force. The force control can be implemented by passive compliance control or active force control [5, 7]. In passive compliance control, the polishing tool is deformed and adapts to the surface, absorbing him the deformation energy and always providing the same force to the surface. In active control, on the other hand, thanks to sensors, the force applied is measured and kept constant [14]. Today, such operation is possible thanks to the use of collaborative robots, which are characterized by high mobility, and control of the force exerted on the workpiece thanks to high-tech sensor technology. There are studies in the literature on polishing operations of objects with even complex surfaces using robots [16, 12] but polishing of shoes is lacking. In [4] preliminary tests for a shoe polishing are presented. The objective of this paper is to propose an operational methodology to achieve high quality shoe polishing using a collaborative robot. This methodology starts with the definitions of polishing trajectories on a software cam and then moves on to their implementation on a collaborative robot. An active control of the polishing force was implemented, allowing for an optimal result in terms of product quality. The implementation of this methodology allows for the total automation of shoe polishing achieving good results, which is today performed by hand. No such solution exists in the literature, which could be innovative for the entire footwear sector. The whole process has been tested on a real shoe form and then the quality of the polishing has been analyzed by a chemical laboratory of a footwear company. Some of the following figures present blurred zones, which aren't essential to the correct comprehension of the work, due to company confidentiality agreement. The paper is organized as follows: Section 2 describes the polishing process, Section 3 illustrates how the process has been implemented, Section 4 discusses the experimental tests and the results obtained. Finally, concluding remarks and future works are summarised.

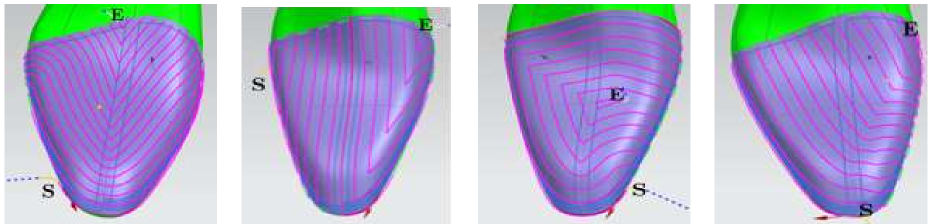
2 Polishing Process for Leather Shoes

The purpose of this section is to illustrate the process performed by hand by the operators and then in later sections will be automated and replicated on tests shoe. Polishing starts with visual inspection of the pair of shoes allows one to understand what color of polish is needed for that shoe, how many times the operation needs to be repeated to give uniformity of polish. A last is then inserted into the shoe to give rigidity. The first step consists of four main operations. The operator places the cloth on his fingers and picks up the polish by applying pressure with his fingers inside the container. The withdrawn excess polish is deposited by rubbing the cloth on a white tap. In such way is possible to avoid staining the shoe on first contact, which could compromise the success of the entire process. The application of polish on the shoe should always be done starting from different points depending on the shade and tone you want to give the shoe, because these are the points where the shade will be most pronounced. In the second phase, the same operations are performed, but a polish with a different consistency and viscosity is used. Step 1 and step 2 are repeated n and m times, respectively, where n and m are defined from time to time based on the goodness of the polishing process.

Starting from here, the exact same process was replicated, taking all these cautions into consideration, with a collaborative robot to complete the first polishing step, which is the most delicate and exhausting for the operator. Next, the operator must complete the polishing with the finishing step. The workstation of the robot and the polishing tool are defined in [4]. It was chosen to use the polishing tool with a 30 mm diameter backing pad with fixed rotation axis and angular velocity of 3000 rpm. In this article only the toe part of the shoe has been polished through the use of a rigid last covered with leather. Such a last is the same one that is used to manufacture the shoe and polish it.

A fundamental step is to define the trajectories for the robot to perform the polishing. The robot has to polish the same area several times but cannot do it by performing the same trajectories otherwise it would leave streak signs on the leather. In order to avoid this phenomenon, 16 different types of trajectories were designed to work the toe area, thanks to NX manufacturing software and "Multi-axis-deposition" processing, which allows creating and simulating the deposition of a polishing layer on the surface. The 3D CAD of the shoes was divided into several zones, one for the toe. We designed several paths on the toe surface starting from guide lines, for example, the edge line of the shoe sole. The different types of trajectories are shown in Figure 1. Only the 4 most representative of the 16 are reported, the others have slightly different shapes with different start and end points.

As can be seen, the trajectories are organized so that they never have the same start and end points (indicated by the letters S and E). In addition, the first trajectories all start from specific points, to give that shade of tone described earlier. There are different paths, either zigzag or spiral. The step between two adjacent lines is 5 mm for the first path after resuming polished and the last path before resuming polish, for the others it is 8 mm. In the cycle presented in



(a) (b) (c) (d)

Fig. 1: Four different types of trajectories

the Figure 2, the polish is taken twice: before trajectory 1 and before trajectory 9. The polish is dispensed in a precise amount from a dispenser into a container,

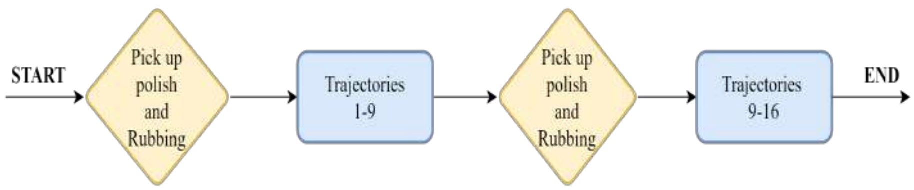


Fig. 2: Experimental polishing process

the robot with its tool goes to the position of the container, gets in contact with the container for two seconds, and picks up the polish with the rotating backing pad. The precise amount of polish dispensed cannot be reported here for confidentiality reasons. Next this operation, the robot switches to the hemispherical surface to rub off excess polish and homogenise it. Then the polishing starts with the different trajectories.

3 Implementation of the Process on a Collaborative Robot

To implement the polishing process on a collaborative robot, in this case UR5e, we had to generate the robot program from the trajectories generated by NX manufacturing. After setting the path in NX multi-axis-deposition, it is possible to export a .cls file, in which there is a list of path poses with orientation perpendicular to the shoe surface. The robotic system is replicated in ROBODK software, with the UR5e in an upside-down configuration and 3D CAD of the shoes (Figure 3).

The .cls file of the trajectory was imported to ROBODK thanks to the "Robot Machining Project," setting the correct parameters such as tool, reference frame,

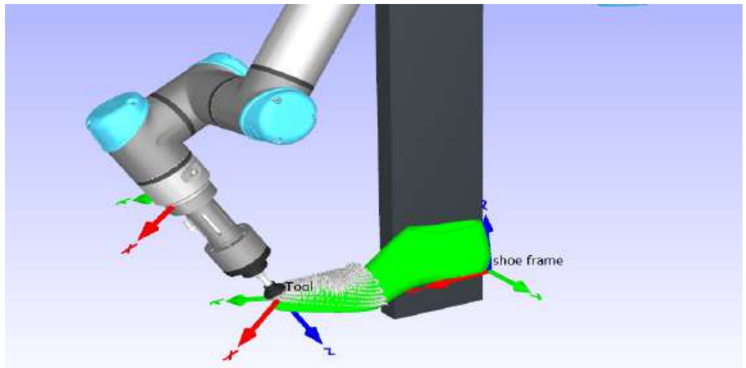


Fig. 3: Robodk station to obtain an executable trajectory from the robot

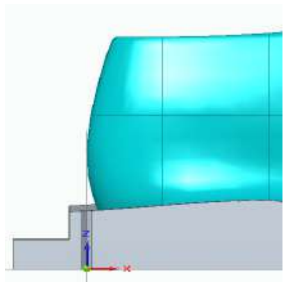
preferred tool orientation and robot configuration, and so on. This made it possible to run the polishing process designed in NX with the UR5e. The compiled URscript from ROBODK Universal Robot post processor was exported and further command such as the control force setting was added. A URscript was generated for each trajectory, then implemented and executed on the real robot. All the poses of the trajectory are referred to the shoes frame

The contact force is controlled through UR5e force torque sensor installed on the robot flange. This sensor ensures a good sensibility at the contact with the leather. To realize a control force along the direction of the tool, which changes continuously during the execution of the task, a thread operating with a frequency of 100 Hz was implemented that updates the tool position from time to time and activates the force on the direction of the tool, pushing on the surface with 5 N. This value was chosen by trial and error after several tests, it allows good quality. At the end of the tool, there is a spring before the backing pad that contributes to compliance movement of the robot in the perpendicular direction of the surface and helps keep the force constant.

4 Experimental Tests and Results

To perform the experimental tests, the shape of the shoe was placed on a specially constructed support that exactly replicates the shape of the shoe heel. The reference system in the Figure 4 is the reference system of the shoe. In this way, by knowing where the reference system of the support is positioned in the workspace, automatically the position of the reference system of the shoe is known, which is otherwise difficult to measure because it is in a position that is not known at the beginning. To measure the support reference position and orientation respect to the robot base, three different point are taken with the robot. These three points define the support reference system.

After this setup, knowing the position of the shoe reference, the polishing process has been started as shown in Figure 2. The goodness of polish is given



(a) *Shoe support*

(b) *Shoe position during polishing*

Fig. 4: Last shoe with its support

by the right compromise between three main parameters, which are the force with which the shoe is worked, the number of repetitions of trajectories that are performed, and the speed of the movements. The first two are discussed in Sections 2, 3 the latter can neither be too high otherwise the polish is not deposited and neither too low otherwise the cycle time is compromised. For footwear company confidentiality agreement, the speed value used cannot be given. The necessity to perform different trajectories of polishing on the toe, repeated several times with not too high speed constrains the cycle time of the operation. However, it is a fair compromise to achieve the excellent quality that is mandatory in this scenario. In Figure 5, in the area bounded by the red rectangle, the polish on the surface of the shoe, left by the rotating backing pad, is clearly visible.

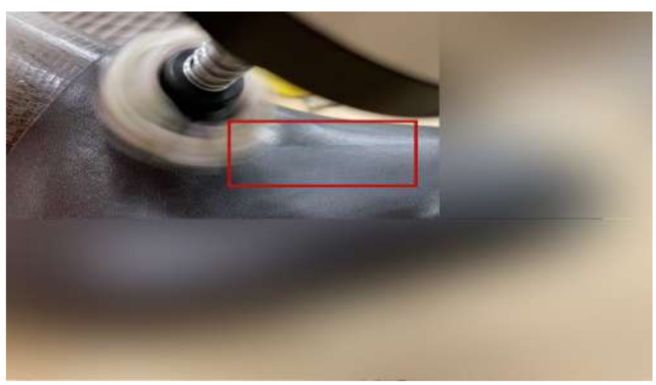


Fig. 5: Polishing operation

After the entire polishing process was completed, the polished toe was examined by a chemical laboratory, experienced in leather polishing, with a careful visual inspection of the shoe and other chemical tests that cannot be reported here due to confidentiality agreements. The polishing satisfies the quality standard for shoe polishing and it can be equated with an handmade polishing obtained before the second phase of finishing. At the moment, by choice of the footwear company, human and robot work in separate areas monitored by a laser scanner, but collaboration between them is also possible. Figure 6 shows the region of the polished toe at the end of the process. The difference between the polished and unpolished area is clearly visible.

Fig. 6: Shoe polished after the entire process

5 Conclusions

This work addressed the need by a shoe company to automate a shoe polishing process, that was previously done totally by hand, in order to decrease the physical stress on the worker. An operating methodology was implemented to automate a shoe polishing process using a collaborative robot. The results obtained in terms of polishing quality are satisfactory, demonstrating the feasibility in automating this procedure. The only limitation concerns the cycle time, which is around 20 min to perform the shoe toe polishing. This time is caused by the large number of polishing passes to be made to achieve optimal polishing quality that meets the high quality standards of the handmade luxury footwear industry. The toe area is the most important area of the shoe because it is the most visible. However, this time is comparable to the time it takes the operator to polish a shoe. Thanks to this solution, the operator will no longer perform this repetitive and tiring operation, but will be able to check whether the automated polishing achieves good quality and simply finish the polishing, allowing him to spend his time on high value-added activities. As next developments, to reduce the cycle time, we will adjust the polishing speed and optimize the number of polishing. Considering the good results found on the toe, this methodology will be adopted to polish a whole shoe.

References

1. Axmann, B., Harmoko, H.: Robotic process automation: An overview and comparison to other technology in industry 4.0. In: 2020 10th International Conference on Advanced Computer Information Technologies (ACIT). pp. 559–562. IEEE (2020)
2. Callegari, M., Carbonari, L., Costa, D., Palmieri, G., Palpacelli, M.C., Papetti, A., Scoccia, C.: Tools and methods for human robot collaboration: Case studies at i-labs. Machines **10**(11), 997 (2022)
3. Castelli, K., Zaki, A.M.A., Dmytriyev, Y., Carnevale, M., Giberti, H.: A feasibility study of a robotic approach for the gluing process in the footwear industry. Robotics **10**(1), 6 (2020)
4. Chiriatti, G., Ciccarelli, M., Forlini, M., Franchini, M., Palmieri, G., Papetti, A., Germani, M.: Human-centered design of a collaborative robotic system for the shoe-polishing process. Machines **10**(11), 1082 (2022)
5. Dong, Y., Ren, T., Hu, K., Wu, D., Chen, K.: Contact force detection and control for robotic polishing based on joint torque sensors. The International Journal of Advanced Manufacturing Technology **107**(5), 2745–2756 (2020)
6. Gualtieri, L., Rauch, E., Vidoni, R.: Emerging research fields in safety and ergonomics in industrial collaborative robotics: A systematic literature review. Robotics and Computer-Integrated Manufacturing **67**, 101998 (2021)
7. Lakshminarayanan, S., Kana, S., Mohan, D.M., Manyar, O.M., Then, D., Campolo, D.: An adaptive framework for robotic polishing based on impedance control. The International Journal of Advanced Manufacturing Technology **112**(1), 401–417 (2021)
8. Maurtua, I., Ibarguren, A., Tellaeche, A.: Robotic solutions for footwear industry. In: Proceedings of 2012 IEEE 17th International Conference on Emerging Technologies & Factory Automation (ETFA 2012). pp. 1–4. IEEE (2012)
9. Méndez, J.B., Perez-Vidal, C., Heras, J.V.S., Pérez-Hernández, J.J.: Robotic pick-and-place time optimization: Application to footwear production. IEEE Access **8**, 209428–209440 (2020)
10. Mosca, F., La Rosa, E.: 4.0 technology within fashion and luxury production. Symphonya. Emerging Issues in Management (2), 82–94 (2019)
11. Oliver, G., Gil, P., Gomez, J.F., Torres, F.: Towards footwear manufacturing 4.0: shoe sole robotic grasping in assembling operations. The International Journal of Advanced Manufacturing Technology **114**(3), 811–827 (2021)
12. Perez-Vidal, C., Gracia, L., Sanchez-Caballero, S., Solanes, J.E., Saccon, A., Tornero, J.: Design of a polishing tool for collaborative robotics using minimum viable product approach. International Journal of Computer Integrated Manufacturing **32**(9), 848–857 (2019)
13. Rossi, M., Papetti, A., Germani, M., Marconi, M.: An augmented reality system for operator training in the footwear sector. Comput. Des. Appl **18**, 692–703 (2020)
14. Tian, F., Lv, C., Li, Z., Liu, G.: Modeling and control of robotic automatic polishing for curved surfaces. CIRP Journal of Manufacturing Science and Technology **14**, 55–64 (2016)
15. Vicentini, F.: Collaborative robotics: a survey. Journal of Mechanical Design **143**(4) (2021)
16. Wang, K.B., Dailami, F., Matthews, J.: Towards collaborative robotic polishing of mould and die sets. Procedia Manufacturing **38**, 1499–1507 (2019)
17. Zhang, C., Chen, D., Tao, F., Liu, A.: Data driven smart customization. Procedia CIRP **81**, 564–569 (2019)