Automation in Shoe Assembly

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Abstract: *The paper describes three applications of industrial robot in shoe production. Two of them – automation of shoe lasting machine and automation of finishing process are extremely difficult to automate and are according to our knowledge first successful automation of the above processes. The focus of the paper is on automatic robot trajectory generation directly from CAD shoe design data. The paper shows also how kinematic redundancy resolution approach was used in order to design fault tolerant robot trajectories.*

Keywords: *Robot Applications, Trajectory Optimization, Redundancy Resolution*

I INTRODUCTION

Shoe production is most likely labour intensive; the rate of automation is usually low. Therefore it is considered as industry suitable for counties with low labour cost, typically Far East countries [1, 2]. In last years new aspect in shoe production is arising – custom made shoes [3]. Customization in mass shoe production requires complex information system and fully automation of all planning, production and distribution processes. In the paper we deal with three applications in shoe assembly that are difficult to automate. The main objective was to generate robot trajectories base solely on the CAD model of the shoe. Manual teaching and trajectory testing phases were not acceptable.

II SHOE LASTING MACHINE AUTOMATION

One of the most critical aspects in shoe production automation is the lasting machine automation. Manual operation required in shoe lasting is correct positioning of both sole and upper coat on the last and feeding the lasting machine. The shoe lasting machine then glues shoe upper and shoe last. There were several attempts how to automate shoe lasting machine. In most cases they tried to align shoe upper directly in the lasting machine, but they were less successful due to the inability of the vision systems to determine correct position of the shoe upper. Shoe upper differ in size, color and design. Our fully automated shoe lasting work-station setup consists of the lasting machine, 6 DOF industrial robot equipped with special gripper and upper and sole positioning device [4]. Lasting work-cell is presented in Fig. 1. Positioning device is stand alone machine. It consists of 9 pneumatic cylinders for fixing and gripping, servo axis for shoe upper positioning and vision system for determination of the correct positioning of shoe upper and sole. In contrary to the previous attempts, we perform positioning on the reversed shoe. The required position of the shoe upper signed with a marker in the interior of the shoe upper. This marker is detected by the vision system and aligned with the shoe last axis using servo positioning device. Once the shoe upper and the shoe are aligned, the robot hand grips the shoe last, shoe upper and shoe sole and takes it to the existing shoe lasting machine. Using this approach we increased the productivity of the lasting work cell, increased reliability and avoided nailing of the sole on the last, which is required in manual operation.

Figure 1
Automated lasting cell

III AUTOMATED CELL FOR GLUING OF SHOE SOLES

The main focus is on generation of appropriate robot trajectories. During the glue application with an industrial robot, the shoe is inserted in a special clamping device, as seen in Fig. 2. The jaws of the clamping device fix the shoe rather than shoe last. Namely, in current production line, shoe lasts do not posses a reference plane, which could be used for shoe grasping. The problem arises from the fact that the clamping device holds shoes in different position, depending on shoe shape and size.

Figure 2
Automated gluing cell

Therefore, only manual teaching of robot trajectories was applicable. We developed a special CAD system, which virtually clamps the CAD shoe model in the clamping device using appropriate 3D fitting. Although shoes are now days designed using CAD system, the only reliable data in our case was CAD model of the shoe last. Another problem arises from the fact, that the CAD model is available only for the reference shoe size. Shoe lasts for different sizes are made using different grading tables. Unfortunately, the shape of the shoe does not depend uniformly on the shape of the shoe last. An expert system was developed in order to establish the relation between the shoe shape and shoe last shape. Fig. 3 shows an example how the gluing trajectory is defined. Using the described approach, we are able to automatically determine the gluing path of the shoe in the clamping device. The resulting trajectory is automatically downloaded to the robot controller.

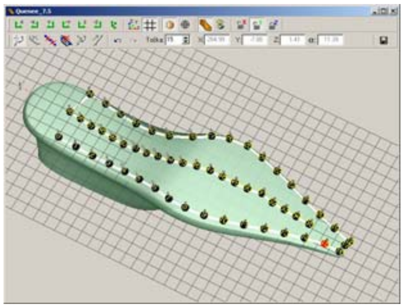

Figure 3
CAD system for robot gluing

IV AUTOMATED CELL FOR FINISHING OPERATIONS

Finishing operations in shoe manufacturing process comprises operations such as application of polishing wax, polishing cream and spray solvents, and brushing in order to achieve high gloss. These operations require skilled worker and are generally difficult to automate due to the complex motion trajectories. After previous analyses of the manual finishing, which include trajectory and force capturing using calibrated video cameras and force sensors, the layout of the cell was defined. The finishing cell consists of the shoe polishing machine, machine for application of polishing creme, spray cabin for application of the polishing solvents and an industrial robot, as seen in Fig 4. The 6 DOF robot is a commercially available product from ABB, rest of the cell components were not available and had to be developed especially for this purpose. Customized mass production differs from the mass production because virtually any product item can differ from the previous one. Therefore, manual teaching and manual preparation of the manufacturing programs is not acceptable. The customized mass production requires that all production

Figure 4
Finishing cell

phases are prepared in advance during the design phase of the specific shoe model. Modification of the part programs for the specific shoe model, required for the customization, has to be done automatically without any human intervention. Therefore, new CAD tools for finishing operations had to be developed. (Fig. 5)

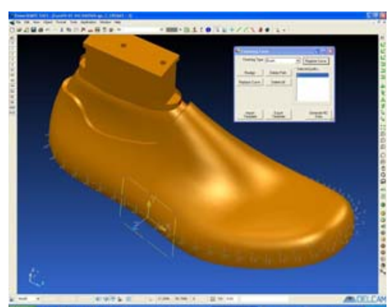

Figure 5
CAD system for defining polishing trajectories

One of the main problems in automatic trajectory generation is the inability to assure that the generated trajectory is feasible using a particular robot, either because of possible collisions with the environment or because of the limited workspace of the particular robot.

Limitations in the workspace are usually not subjected to the tool position, but rather to the tool orientation. Another sever problem are wrist singularities, which can not be predicted in the trajectory design phase on a CAD system. A widely used solution is such cases is off-line programming with graphical simulation, where such situation can be detected in the design phase of the trajectory. Unfortunately this is a tedious and time consuming process and therefore not applicable in customized production, where almost each work piece can vary from the previous one [5]. The problem was efficiently solved using the trajectory optimization based on kinematic redundancy of the manipulator [6]. For a given task, the obstacle avoidance can be accomplished only if the robot is kinematicaly redundant. Note that the degree of redundancy depends on the task the robot is performing. For example, a 6 DOF robot is kinematicaly redundant for spraying and creaming operations in shoe production. Due to the circular shape of the cream application brush and spray beam, roll angle or the robot is free to choice. For brushing operations, there is another type of redundancy due to the circular shape of felt rollers, as illustrated in Fig. 6.

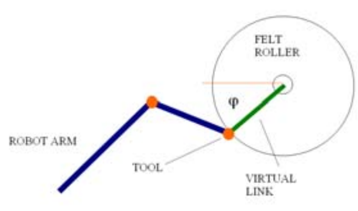

Figure 6
Kinematic redundancy due to the circular shape of the brush tool

Namely, the tool centre point is not restricted to be a fixed point, rather it can be freely chosen at the circumference of the tool. Unfortunately, in general one degree of redundancy is not enough to satisfy simultaneously all secondary tasks – obstacle avoidance, singularity avoidance and preserving the joint angles within their physical limits. More flexibility is offered by the fact that for some tasks it is not necessary to assure strict orientations of the tool. This can be interpreted as two additional degrees of redundancy. In robot trajectory generation, we define primary and secondary task. Primary task is position of the TCP of the robot. We have multiple secondary tasks, such as

a) Maximizing the distance between the robot joins and the environment objects-obstacles. This task prevents the robot to collide with the obstacles.
b) Maximizing the distance between the joint position and join limits. This task prevents the robot to come to the join limits.
c) Maximizing the distance between the actual and singular pose, which avoids wrist singularity.
d) Minimizing the difference between the desired and actual tool orientation.

Secondary tasks generate robot tool orientation based on gradient optimization in Jacobian null-space. This approach could be used also on-line on the robot control level. We implemented it as a batch procedure in the trajectory optimization module. The benefit of this approach is that the optimization is performed in each trajectory frame until the desired secondary task is fulfilled, which can not be guaranteed in on-line implementation. Due to the physical limitations of the robot it is possible that the procedure does not converge. In such a case the optimization stops and off-line programming system is used to check and verify the robot configuration and the desired task trajectory. In most cases after the successful accomplishment of the trajectory optimization the verification with off-line programming system is not necessary and the trajectory can be downloaded directly to the robot controller. This approach was implemented in the automated cell for finishing operation in a custom shoe production line in Vigevano, Italy [2].

Conclusion

The paper describes three applications of industrial robot in shoe production. Automation of shoe lasting machine and automation of finishing process are extremely difficult to automate and are according to our knowledge first successful automation of the above processes. In design we focused on automatic robot trajectory generation directly from CAD shoe design data. The main problem with this approach is to assure fault tolerant robot trajectories. We proposed an efficient solution to this problem using kinematic redundancy resolution approach.

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