Development and Testing of a Semiautomatic Gluing Machine

S. Pagano, R. Russo, S. Savino

***Abstract*—The paper describes the development of a semi-automatic gluing machine to be adopted to glue the shoe upper to its sole.**

The experimental machine consists in a cartesian robot that drives a glue gun and by a vision system that can recognize the sole placed on a worktop allowing the planning of the glue gun trajectory. In this paper it is first described the machine hardware assembly and the developed procedures that allows the object recognition and the robot planning trajectories. Then, there are reported the results of several tests to check to procedure goodness.

***Index Terms*— Arduino, footwear manufacturing, Microsoft Kinect sensor, semi-automatic gluing machine.**

I. Introduction

In the last 50 years, shoes have undergone considerable evolution, both in terms of materials and fixing systems for their parts; in a recent past, the soles were mainly made of leather, sometimes with a lower rubber lining and the upper was fixed to the sole by means of hooks and seam.

Currently the large series production provides shoes made with increasingly lighter materials and equipped with soles made of deformable material that are, at the same time, comfortable, breathable, durable and able to provide good thermal protection. Great importance is given to the sole cushioning function, especially for sports shoes that, in some cases, are equipped with gas-filled bag, inserted in the sole to prevents impacts [1]. Soles are mostly made of synthetic materials belonging to the following groups or their combination [2, 3]:

- thermoplastic rubber (TPR) and thermoplastic polyurethane (TPU);
- two-component polyurethane materials: polyether-based PUR, polyester-based PUR;
- copolymers such as rubber and EVA (Ethylene vinyl acetate).

The soles for footwear must comply with the requirements indicated by various international standards to be labeled as quality sole.

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The standard establishes the tests to be performed to assess resistance to bending, abrasion, de-lamination, slip, water penetration, dimensional stability, compressive and splitting tensile strength, of the stitching point and to bonding capacity.

When uppers and soles (Fig.1) are joined by gluing, in the junction zone a combination of stress is involved including tensile, shear and peel (or splitting); the most critical stress is the peel one. For this reason, special instruments are adopted to test the strength of adhesion between upper/outsole and sole. The load causing the separation can be measured or alternatively, a pass load can be applied to check that the sole adhesion is satisfactory. This second operation method is the more useful in the shoe factory since it can be applied to ordinary shoes from the production line.

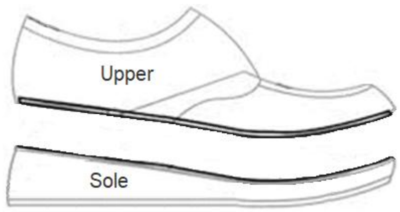

Fig.1 – Shoe upper and sole

In the standard EN 15307 there are reported the minimum shoes peel strength for different kind of shoe. For example, it must be greater than 3.0 N/mm^2 for men town footwear; 2.5 N/mm^2 for women town footwear; 5.0 N/mm^2 for mountain footwear.

This paper refers to a gluing machine prototype allowing to connect the uppers to the soles; the gluing operation must be carried out with great care in order to meet the current standards of resistance; at the same time, it must be carried out as quickly as possible to contain production costs. The semiautomatic machine prototype uses a vision system to recognize the sole to be glued and allows to plan the trajectory of a cartesian robot that drives a glue gun. The developed prototype should improve all the parameters of the production tetrahedron. In fact, it allows to improve:

a) the production costs; the machine may be produced by means of cheap preassembled components and does not require operators having specific skills;
b) production time; the developed procedures allow to arrange the objects to be glued in an arbitrary position on the worktop and does not require preliminary operations such as storing the sole geometry;
c) production flexibility; the prototype can operate on objects having different sizes and shapes;

d) production quality; it is possible to control the glue dispensed by adjusting the glue gun velocity, the distance from the object and the glue flow rate, allowing to guarantee the required adhesion resistance.

II. Prototype Description

The gluing machine prototype (Fig.2), called *Ulisse* [4], was made up with pre-assembled and low-cost elements. It mainly consists of a closed cabin containing a worktop on which are placed the objects to be glued, a vision system (Microsoft Kinect) able to recognize the shape of the objects placed on the worktop, a Cartesian robot whose end-effector is a glue gun and an aspirator to suck the glue vapors avoiding their dispersion in the work environment.

A. The cabin

The frame of the cabin structure was realized by means of a modular system of standard aluminum components having many constructive advantages like the simplicity and speed of assembly that allows even to modify the structure geometry to adapt it to the variations that arise during the prototype set-up activity and to adjust its stiffness so that it can bear the robot weight preventing vibrations that could arise due to the rapid robot movements.

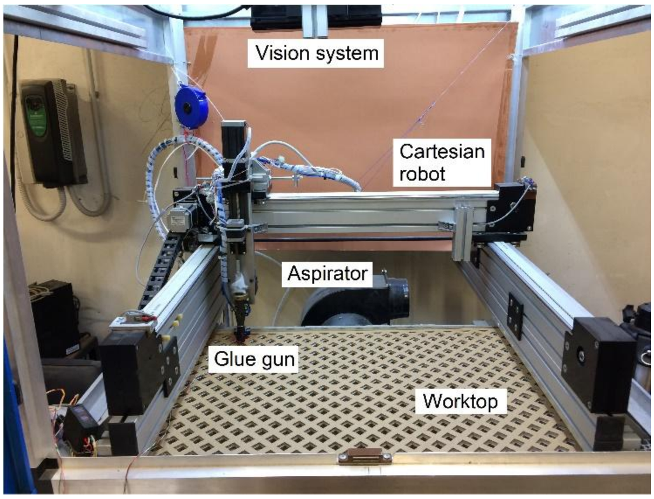

Fig. 2 – Gluing machine prototype

B. The worktop

The worktop on which are placed the object to be glued has an area of 550x650 mm; it is constituted by a permeable plane so that the suction action, carried out by an aspirator located under the worktop, may convey and remove the glue vapors from the cabin. For this reason, the worktop consists of a pressed cardboard grid, covered with a fabric (not present in Fig.2); both elements must be periodically replaced as they can be impregnated by the glue vapors crossing them.

The suction action also realizes a restrain function for the objects placed on the worktop.

C. The robot

In the cabin there is placed the cartesian gantry robot, having the task of driving the glue-gun end-effector. The cartesian robot is made of pre-assembled elements easily available on the market and ready-to-install. The translational motions, along the three orthogonal axes, are obtained by means of linear modules whose slides are composed of a steel plate translating on idler wheels. The horizontal slides are driven by a toothed belt transmission (Fig. 3,4), while the vertical slide, supporting the glue gun, is driven by a trapezoidal screw-nut transmission.

The belt transmissions allow to perform rapid planar movement with maximum speed and acceleration equal to about 3 m/s and 7 m/s^2, respectively. The vertical positioning does not require rapid movements and high precision; for this reason, a screw-nut transmission is adopted; thanks to its low efficiency (30% or less), this transmission does not allow the slide to move downwards under the effect of its weight so that the end-effector can be maintained at a constant height without energy consumption. In any case, adopting a screw pitch of 2 mm and driving it with a stepper motor with a step-angle of 1.8°, the vertical displacement accuracy may be lower than 1/100 mm.

The assembly of the linear modules is simple and inexpensive but may involve errors in the end-effector positioning due to inaccurate components assembly, backlashes between the moving parts and deformability of some components.

To limit the positioning errors, some mechanical precautions must be provided:

- by means of the wheels eccentric pins it is possible to adjust the preload between wheel and rail in order to remove the backlash and to prevent the wheel-rail sliding; this operation minimizes the rolling friction thus improving the mechanical efficiency;
- to reduce the belts deformability, the driven pulleys of the planar linear modules are mounted on an eccentric pin allowing the belt tensioning; in this way it is possible to guarantee a positioning repeatability of ± 0.1 mm;
- as the first translation motion is obtained by means of two parallel guides, the two driving pulleys are connected by means of a transmission shaft (Fig. 4) so that the same motor drives both the slides assuring the synchronization of the movements.

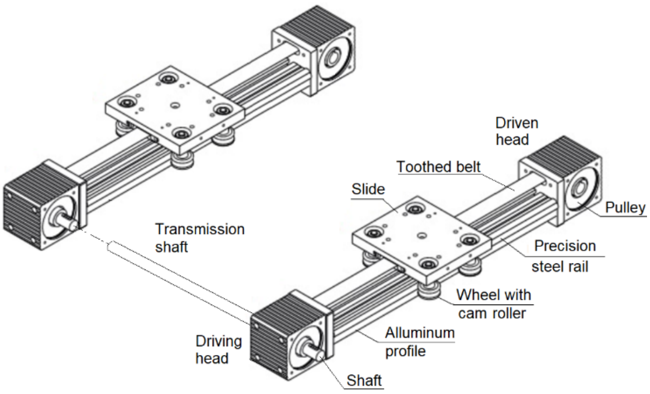

Fig. 3 - Linear modules with toothed belt drive for the first translational motion

The stepper motor adopted for the three translations can provide a maximum torque of 3.2 Nm; torque and power curves are shown in Fig. 5. The glue gun nozzle is adjusted with a stepper motor whose maximum torque is equal to

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0.5Nm.

The robot is controlled by a microcontroller Arduino UNO board, managed by GRBL Software [5, 6]; it controls the motor drivers, the end-stroke of the linear modules and the glue gun opening/closing valves.

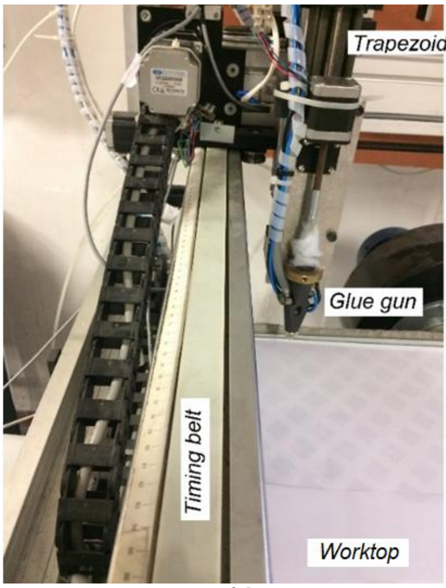

Fig. 4 – Linear motion systems of the prototype

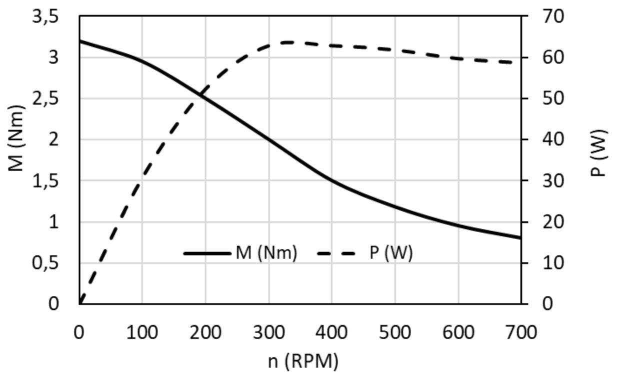

Fig.5 – Stepper motor characteristic curves (LAM Tech., mod. NEMA17: 3.2 Nm bipolar static torque, 4.2 Arms bipolar phase current, 24 Vdc)

D. *The vision system*

The 3D vision system allows the recognition of objects to be glued, in order to detect their position on the worktop, their dimensions and the contour along which the glue must be dispensed. The Ulisse prototype is equipped with a *Microsoft Kinect V2* that is a camera, integrated with an infrared sensor, that allows to measure the sizes of the framed objects [7]; the vision system is positioned on the ceiling of the cabin to frame the entire worktop. It consists of an RGB camera, whose resolution is 1920x1080 pixels, and an infrared emitter combined with an IR camera with a resolution of 512x424 pixels; the elaboration of the IR signals allows to define the depth map.

The vision system reliability was checked for objects placed at distances from the camera included in the range 0.50-0.80 m; the tests stated that it is reliable and repetitive from 0.60 m; it was therefore fixed on the cabin ceiling at the distance of 0.75 m from the worktop.

III. Calibration procedure

Two fixed frame references are defined for the prototype Ulisse: the first one (*Rr*) has its origin in the robot base; the other one (*Rc*) in the vision system camera. The two frames have different origin position and different orientations. To transform the coordinates detected by the vision systems from *Rc* to *Rr* reference, it must be defined a homogeneous transformation matrix [T]:

$$\{x\}_r = [T] \cdot \{x\}_c \tag{1}$$

being: $\{x\}_r$ and $\{x\}_c$ the coordinate vectors expressed in the *Rr* and *Rc* references, respectively. The homogeneous matrix:

$$[T] = \begin{bmatrix} C_{11} & C_{12} & C_{13} & V_x \\ C_{21} & C_{22} & C_{23} & V_y \\ C_{31} & C_{32} & C_{33} & V_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{2}$$

contains the C_{ij} elements of the rotation matrix and Vi elements to define the *Rc* origin position in *Rr* reference. The matrix contains six unknowns: three rotations and three displacements.

The calibration procedure allows to identify this matrix by means of the following procedure that adopts a tool that allows the system vision to identify the position of the glue-gun nozzle. This tool is constituted by a plastic disk that can be fixed on the glue gun with its centre coincident with nozzle centre (Fig.6a). The disk is covered with a cyan fabric on which there are five circles made of black fabric. The centres of the black circles are arranged on a circumference whose centre coincides with the centre of the cyan disk and therefore with the position of the glue gun nozzle.

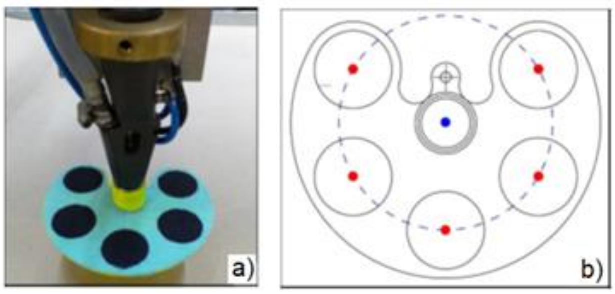

Fig.6 – Disk adopted for the calibration procedure

The calibration procedure requires the positioning of the glue gun nozzle in different points of the volume framed by the camera. In each position the camera recognizes the visible black circles (at least three); by adopting classical computer vision algorithms [8-11] , the positions of the centres of the black circles are first identified and subsequently the position of the centre of the circumference passing through these points is defined that, as said above, coincides with the glue gun nozzle position.

For each robot configuration the nozzle position is detected in both, *Rr* and *Rc* references; by means of an optimization algorithm the transformation matrix is identified.

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IV. ROBOT PLANNING TRAJECTORY

Starting from the recognition of objects to be glued, a data processing procedure has been developed in order to implement the trajectory that the glue gun must follow.

The gluing of an upper shoe to its sole consists in depositing the glue along the contour of the sole upper surface that often differs from the sole top view contour (image counter) since the soles can have a tapered shape (Fig.7).

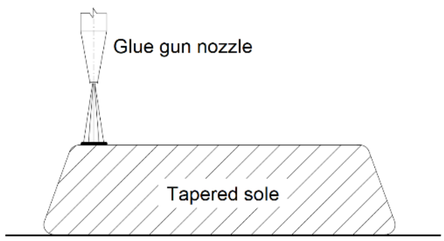

Fig. 7 – Cross-section of a tapered sole

To define the object contour, the three-dimensional information provided by the points cloud matrix, are used.

Starting from points cloud matrix D, containing the coordinates of the point in the *Rc* reference, the procedure transforms the coordinates in the *Rr* reference, obtaining the D1 matrix.

Then, to consider only the cloud points related to the object, the points belonging to a predefined volume, are selected. The volume is defined by a base surface equal to the worktop and height of 150 mm; it is slightly raised form the worktop so that even the points belonging to the worktop are discharged. With this operation, the D1 matrix is converted in a new logical matrix S that, for each point, contains "true" value if the point belongs to the parallelepiped, "false" value in the contrary case. As the camera frames the worktop from the cabin ceiling, this last matrix can be seen as a B/W image that allows to identify the "top view" of the object.

By means of the classical image processing algorithms, from the S matrix it is possible to extract the object silhouette contour. Moreover, it is possible to evaluate the local slope of the points in the neighbour of the object contour, by computing the local normal vectors, [9].

With reference to the gluing of a sole, the system must discharge the points having high local slope because they belong to the lateral tapered surface where the glue must not be laid (Fig.7). Therefore, only the points arranged on the upper surface of the sole are considered to identify the upper surface contour; to drive the glue gun, the contour coordinates are moved toward the inside of the surface and fitted with a continuous function, in order to obtain a gluing trajectory that is slightly inside the defined contour. The glue gun trajectory is therefore obtained by means of an "offset" of the contour line to prevent the glue gun sprays on the lateral tapered surface.

The processing time for the trajectory calculation dependents on the hardware performance and is independent on the number of objects to be analysed. The prototype hasn't real-time procedures, but the developed algorithms are executed with waiting times that are compatible with production.

V. EXPERIMENTAL RESULTS

The procedure was tested adopting a sample having a frustum of a cone shape (Fig.8).

The sample was positioned on the worktop and framed by the camera (Fig.9). The detected cloud points (Fig.10) are elaborated to define the contour of the upper surface of the sample (blue line in Fig. 9) which is fitted with a continuous function (red line in Fig10).

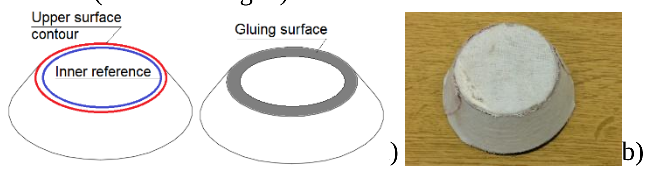

Fig. 8 – Sample adopted to test the procedure: a) reference entities; b) the sample (D = 70 mm; d = 50 mm; h = 30 mm)

Fig. 9 – Elaborated camera image containing the upper surface contour of the sample (blue line)

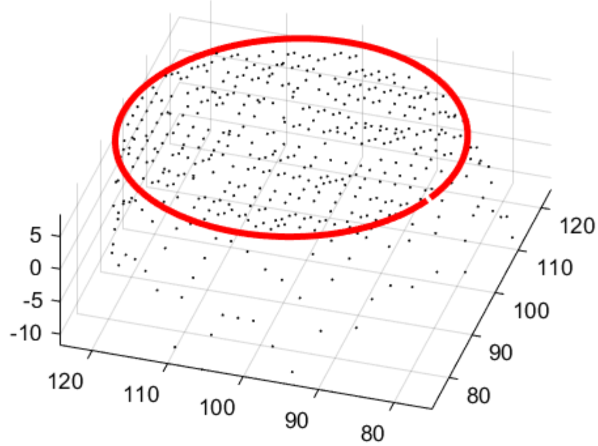

Fig. 10 – The cloud points and the estimate contour of the upper sample surface

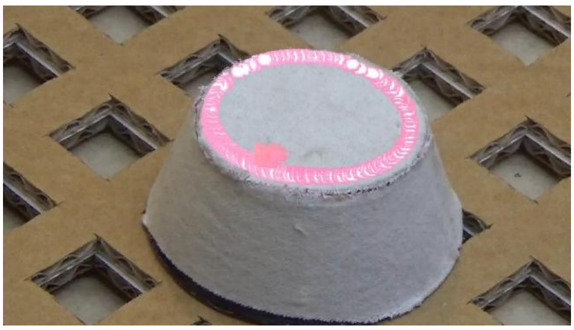

Fig. 11 – Video elaboration allowing the visualization of the glue path

To highlight the machine behaviour, of the nozzle, a led laser was placed in correspondence of the glue gun nozzle,

whose laser beam simulates the glue spray. The gluing machine is observed during the execution of a gluing test by means of another fixed vision system to record the video of the luminous point path. The laser beam path was isolated performing an analysis on successive frames, based on the normalized cross-correlation of matrices, [12]. In particular, by means of correlation coefficient, a target sub-matrix of a frame “i”, containing the laser mark on the object, was searched in the successive frame “i+1”, the submatrix found becomes the target for the following frame “i+2”; this procedure was repeated for the whole video sequence; the video elaboration allows to visualize the glue path, as it is possible to observe in Fig. 11 where the laser produces a mark on the object constituted by a central area with a strong brightness and a red halo.
The procedure was then tested on a shoe sole, as represented in Fig.12. In this case the gluing surface is comprised between the raised sole contour and the lightened area of the sole.
It was found that the procedure allows to identify the outline of the sole; then, through the evaluation of the local slope of the points, it excludes the outermost part, which has a raised border and the lightened internal one. The trajectory of the glue gun was defined by offsetting the contour towards the inside of the sole.

Fig. 12 – Glue gun trajectory highlighted by means of a laser light connected to nozzle.

VI. Conclusion

The prototype of gluing machine has been presented; it has the possibility to recognize the object to be glued by means of a Microsoft's Kinect vision system and to locate the gluing surface if it is arranged in the neighbourhood of the object contour as it happens for the gluing operation of shoe soles. This information is adopted to estimate the glue gun trajectory and therefore to drive the cartesian robot that move it.
The procedure is based on a preliminary calibration procedure that allows to identify the transformation matrix adopted to transform the coordinates detected by the vision systems in the robot reference.
The proposed procedure was verified by fixing a LED laser pointer to the glue gun nozzle and recording the track described by the luminous point projected on the gluing surface. This result confirms the goodness of the procedure that appear to be suitable for the footwear industry.
The adption of better performing hardware can produce an improvement in the performance of the machine regarding the execution time and the trajectory precision.

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