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Automatic Robot Path Planning for a GRC Spraying Cell

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Abstract

This paper deals with the automatic path planning modules of a robotized system for the production of Glass Reinforced Cement (GRC) panels of any geometry. The robot paths generated take into account several criteria including space and time optimisation of the paths, non-roll up the glass fibre, avoidance of the singular positions of the robot and collision avoidance. The experimental results demonstrate high quality and uniformity in the manufactured panels together with high productivity.

1. INTRODUCTION

A pre-manufacturing automatic system for GRC panel production has been previously reported [1]. This system described has been installed in the Dragados, S.A. factory near Zaragoza. The main features of the automatic spraying cell are shown in fig. 1. It comprises a 6 dof ASEA IRb3200 type robot, a PLC controlled spraying pump, a cement-fibre concentric spraying gun and a mortar hopper and mixer.

The GRC panels, which are manufactured by casting, have such common applications as wall units, urban furniture and ornamental motives. The high strength/weight ratio and excellent surface finish of these products makes them very useful nowadays, as explained in [2].

Until this system was developed, the manufacturing process was performed manually, with the operator holding the spraying gun without mechanical aid. The quality and thickness of the layers thus greatly depended upon his expertise and ability. One of the objectives of the automation was to obtain a product of almost perfect uniformity and excellent quality, as shows in [3]. The path-planning presented below is part of a whole CIC concept [4], this taking into account the experience gained through years of manual production.

There are three different stages within the CAD-CAM concept of the system. First of all we have the definition module, in which each panel to be manufactured and its mould are designed by an operator under a CAD environment.

This facility is menu driven in order to introduce the drawings and the spraying parameters in easy and safe way.
In the second stage, working with the information transmitted from the previous one, it generates the optimum robot paths in respect to time and space in terms of the manufacturing parameters. In this module, a graph search is made covering kinematics and the requirements for collision-free paths for the robot.
Finally, the third module provides real-time control for all the factory cell equipment including the robot and the PLC controlled spraying-pump.

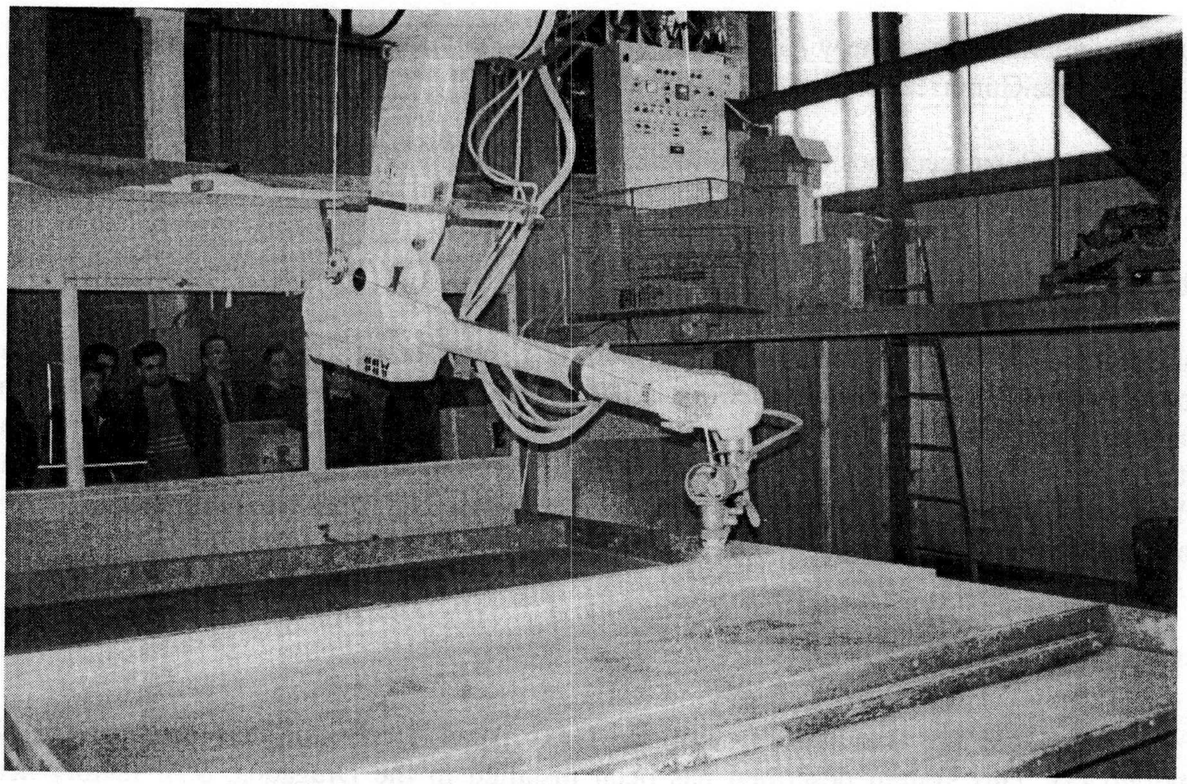

Figure 1. GRC spraying cell.

2. MANUFACTURING RULES AND PARAMETERS

The first point of system specification to consider is the panel type we are dealing with. There are five basic panel types as shown in fig 3., these distinguished by the number and type of the layers to be applied. The first layer is common to all types of panels and is done with mortar only. Subsequent layers vary with the types as follows:

(i) *Plain shell* - two layers of mortar and fibre to a total thickness of 10 mm.
(ii) *Stud frame* - same a *plain shell* but with a steel frame.
(iii) *Shell with ribs* - same as *plain shell* but with stiffening ribs.
(iv) *Shell with insulation* - same as *plain shell* but with a few isolation sheets.
(v) *Sandwich* - same as *shell with insulation* but with an additional GRC layer.

Some spraying rules, based on the manual experience, have been established and subsequently adapted to accommodate peculiarities of the spraying operation by the robot:

(i) Spraying has to be done perpendicular to surface whenever is possible.
(ii) The surface to be sprayed is divided in parallel paths, and the width of these paths are adjusted by modifying the distance of the spray projection to give a whole number of paths. ***D***, the projection distance is given by $D = A/(2.\tan(\alpha/2))$, where A is the path width and α the cone angle (Fig. 3 a).
(iii) The robot does not re-orientate for perpendicularly where a slope has a length of less than 7 cm (Fig. 3 b).
(iv) The linear speed V of the robot is given by $V= F/(E*A)$, where F *is* the mortar flow rate and E the layer thickness.
(v) The bottom and the sides of the mould are produced as different stages.
(vi) Spraying of the bottom is done by alternate traversing in perpendicular directions in consecutive layers (Fig. 3 c).
(vii) The projection direction of the gun in the bottom is set on the bisection of the angle between the bottom planes when this greater than 60° (Fig. 3 d).

3. CAD UTILITIES

This module gets data from 3D AUTOCAD drawings of the mould as needed to produce a panel such as that shown in Fig. 4 a). In order to facilitate the design process, a series of utilities are included as a menu bar in AUTOCAD. These utilities include dialogue boxes which enable the user to interact with a series of easy instructions to start the panel generation process and to specify the process parameters such as spraying cone angle, projection distance, layer thickness and concrete flow rate.

For the mould, a solid modelled representation is required and this is achieved using AUTOCAD's Advanced Modelling Extension (AME) [5]. This is necessary in order to obtain automatically the information needed in the rest of the off-line process.

This information consists of parallel straight segments forming a grid over each automatically generated panel layer. It is over that grid that we afterwards perform the optimum path planning.

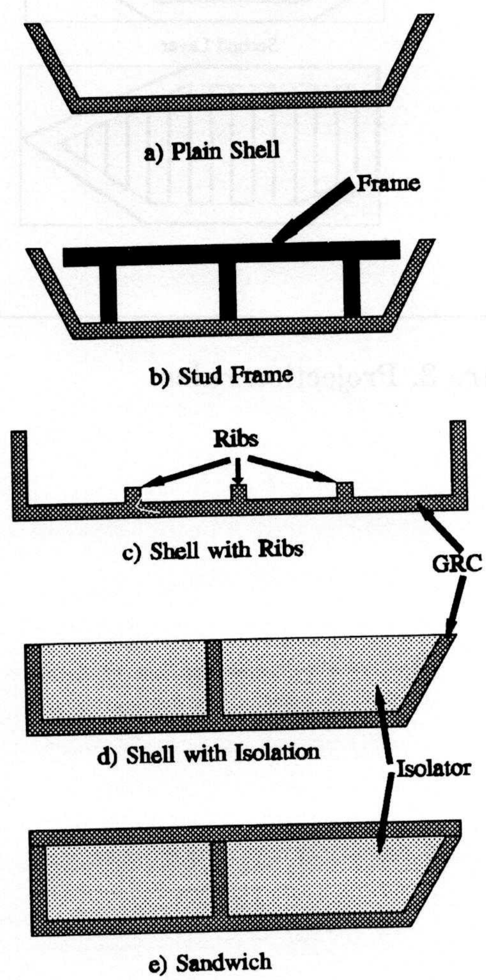

Figure 2. GRC panel types.

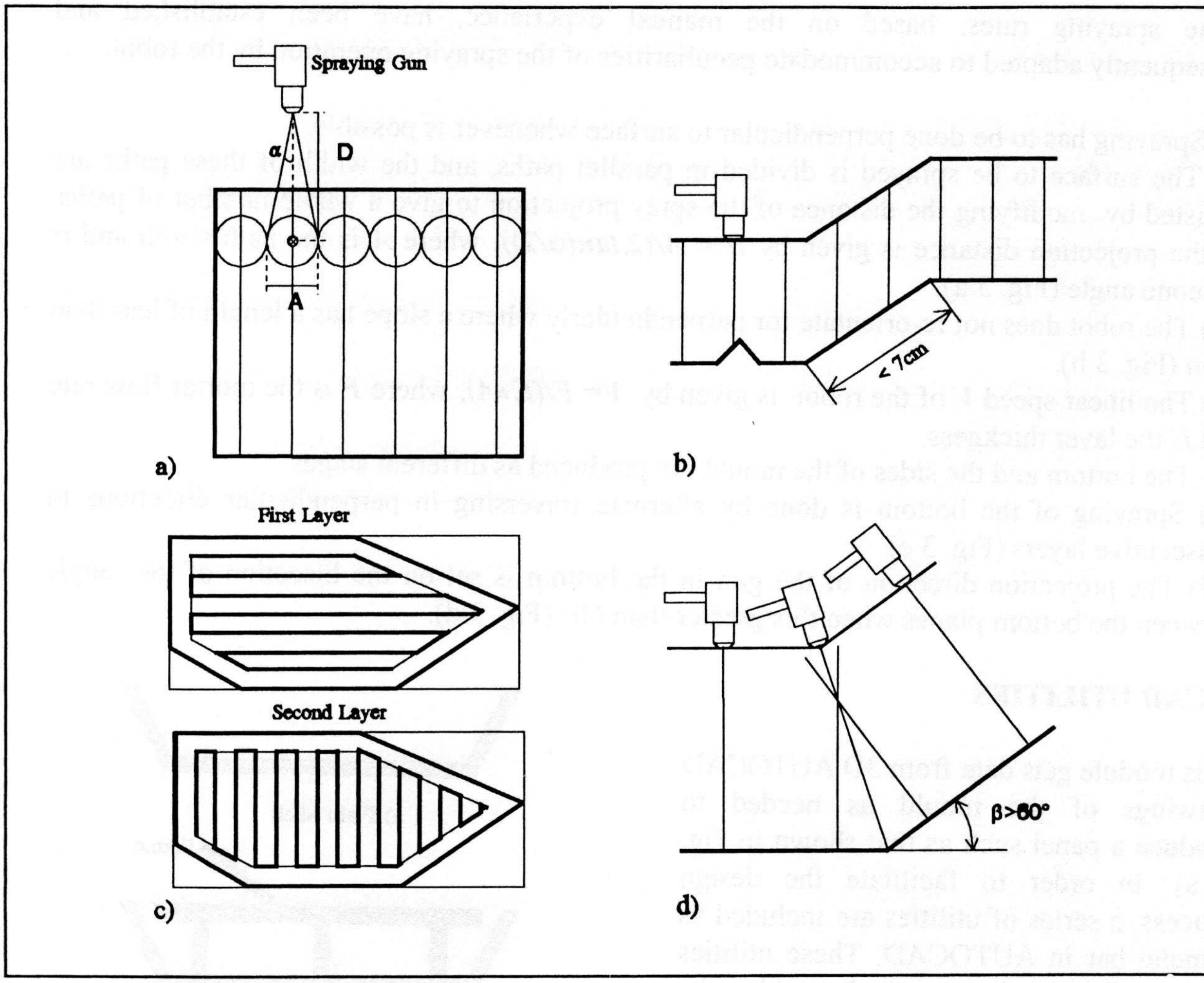

Figure 3. Projection rules.

4. GENERATION OF THE PROJECTION LINES

Since the trajectories of the robot are parallel lines, in order to ensure the homogeneity of the projected layer, any straight segment can be defined by its two extreme points. This information would be enough to specify the positions, but we also need the orientation and the distance projection from the mould to the gun.
From the AUTOCAD representation of the panel, these straight segments are generated automatically, keeping the distances between them within defined margins and calculating projection distances and orientations of the gun (Fig. 4 b).

5. OPTIMUM PATH PLANNING

Once the straight segments needed to project a whole panel are obtained, the optimum sequence to follow them are generated (Fig. 4 c). To establish the best solution, we have to follow some rules which are similar to those given elsewhere [6].

(i) *Minimum gun stops* - the robot can go from a segment to the next one without stopping the gun but it must not project over windows or connect distant segments. This is the most important condition of all.
(ii) *Minimum robots configuration changes* - these are require to stop the gun, to withdraw the robot from a panel, to rotate one or more joints of the robot, to change configuration and to approach a panel again and re-start the gun.
(iii) *Vertical progress of the path* - For panel sides the projection must be done mainly upwards

All these conditions, and a few more that were discovered in the use of the prototype cell, are used to select the best path from all feasible paths. The optimum path is found by means of an exhaustive graphical search process. Some of the weights of these conditions change dynamically according to the specifications. In order to avoid the singular positions of the robot, some modifications to the paths are made (Fig. 4 d). In such areas of conflict the orientation of the gun is changed and the resulting path is termed the *theoretical robot path.*

6. KINEMATIC STUDY OF THE PATH

Once the theoretical robot path has been generated, a kinematic study of the robot's motion is initiated as shown in Fig. 4 e). The objective of this analysis is to position the robot at each point with the appropriate orientation over the panel. Three additional restrictions, one static and two dynamic, have to be taken into consideration for the manufacturing process:

(i) The last joint of the robot must be always in a range of $\pm 20°$. This is caused by the extremely fragile nature of the glass fibre roving that is fed to the spray gun along the arm of the robot.
(ii) The path must be continuous in the sense that there can't be sudden changes in the orientation of the spray gun.
(iii) The robot must move in most cases by describing straight lines by Cartesian co-

ordinates. This implies the existence of multiple singular points.

The study is divided into various sequential steps. First of all comes the Transformation of Orientation Algorithm which is designed to fulfil condition (ii). This transforms each robot to panel vector $V_{(r-p)i}$ into a vector $V_{(r'-p)i}$ by means of the relationships:

$$\vec{W}=\frac{\sum_{j=i-k}^{i+l} a_j*\vec{V}_{(r-p)j}}{\sum_{j=i-k}^{i+l} a_j} \quad l,k>0 \qquad \vec{V}_{(r'-p)i}=\vec{P}_{(x,y,z)}-D*\frac{\vec{W}}{\|\vec{W}\|} \tag{1}$$

,where P is the position on the panel and the values of coefficients $\{a_j,l,k\}$ have been obtained through factory tests and are fixed for each specified geometry[7]. It is important to note that only the robot position is modified ($r \neq r'$). This transformation makes the path continuous in orientation.

The next two steps cover the calculation of the robot position, orientation coefficients and treatment of singular points. They are executed sequentially for each pair of robot-panel points. In this, the elbow selection is conditioned by the theoretical robot path. Vector a of the $\{n,o,a\}$ system is calculated as the axis of rotation and the algorithm begins an iteration to make θ_6 as low as possible in accordance with condition (ii). This is accomplished by rotating the $\{n,o,a\}$ system about vector a. It is noted that the step in the iteration changes dynamically with the linear function:

$$F(\theta_6)=a_i*\theta_6 \qquad 0<a_i\leq 1 \tag{2}$$

as θ_6 is updated after each inverse kinematic transformation. Coefficient a_i varies with the relative positions of the three last axis. After iteration, the wrist that best fits a series of conditions is chosen. If no solution is found with either wrist an orientation redefinition has to be made.

Finally, if we are dealing with an extended singular point specific to the robot, such as a change of sign of θ_5 or a rotation of θ_4 more than 90°, the robot must make its move to that point in robot co-ordinates. This complies with restriction (iii).

7. TRAJECTORY CONNECTION ALGORITHM

The generation of trajectories that connect the individual portions of the robot path is the last link in the path planning chain (fig. 4 f). All the movements of the robot, apart from the proper projection path have to be collision free. Examples of these trajectories are the approach to the first spraying point, the retreat from the last work position and the connection of two distant path points without spraying The only information about the environment we work with is that the moulds are always at a fixed location relative to the robot base and that the mathematic function that defines each portion of the surface is always injective with a few inflexion points. The C-space proposed elsewhere [8] was studied and found to be feasible

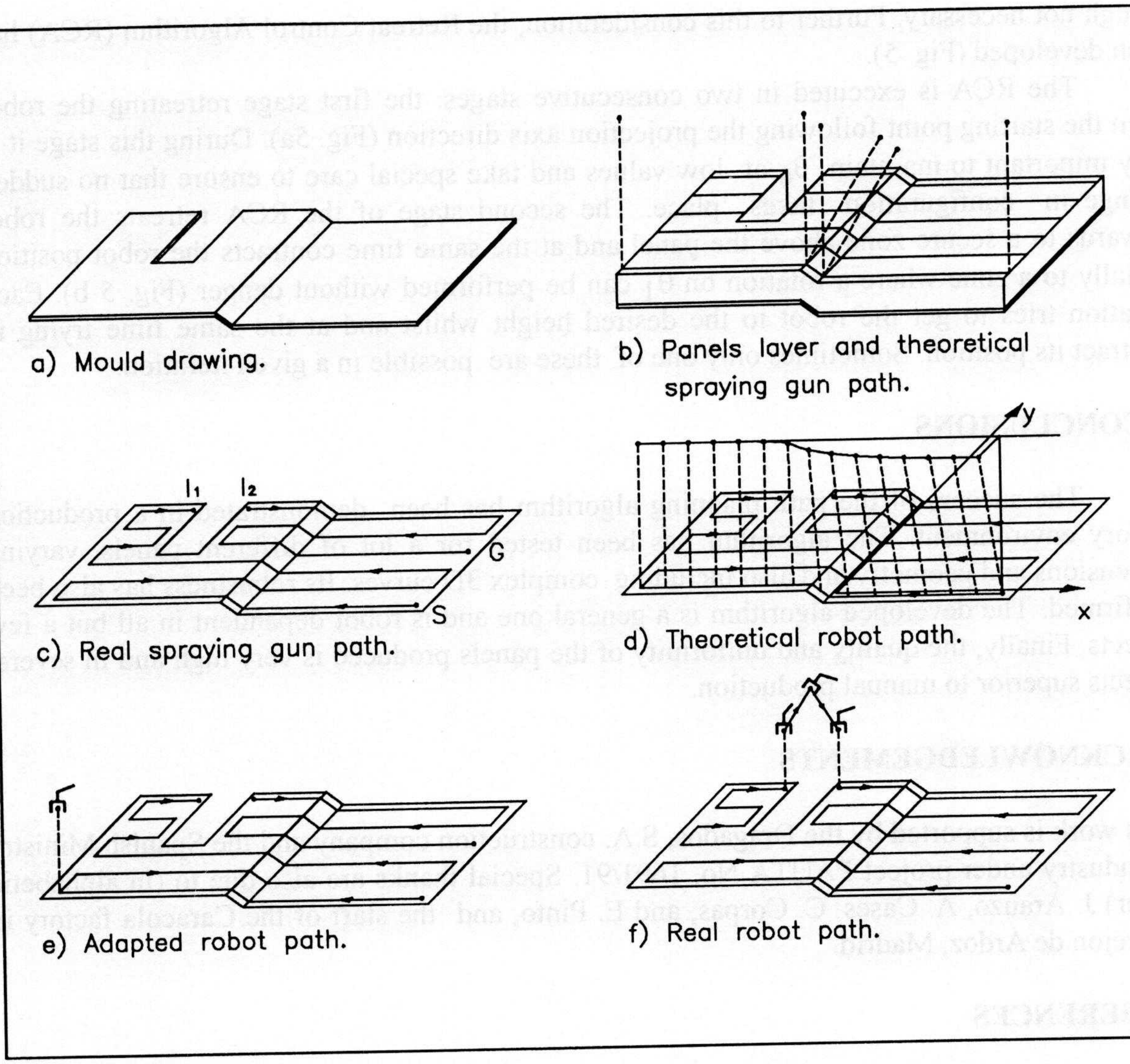

Figure 4. Path planning generation steps.

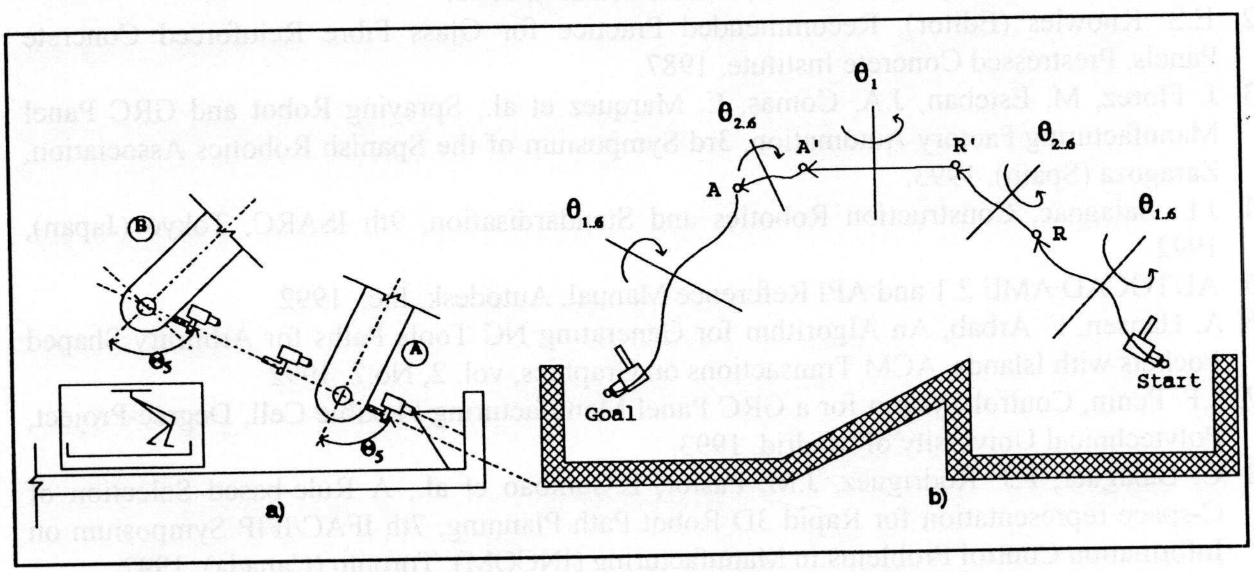

Figure 5. Retreat control algorithm.

though not necessary. Further to this consideration, the Retreat Control Algorithm (RCA) has been developed (Fig. 5).

The RCA is executed in two consecutive stages: the first stage retreating the robot from the starting point following the projection axis direction (Fig. 5a). During this stage it is very important to maintain θ_6 at low values and take special care to ensure that no sudden change in configuration takes place. The second stage of the RCA retreats the robot upwards to a secure zone above the panel and at the same time contracts the robot position radially to a zone where a rotation on θ_1 can be performed without danger (Fig. 5 b). Each iteration tries to get the robot to the desired height whilst and at the same time trying to contract its position. Sometimes only one of these are possible in a given iteration.

8. CONCLUSIONS

The success of the path planning algorithm has been demonstrated in a production factory environment. The algorithm has been tested for a lot of different panels, varying dimensions and geometry and also including complex 3D curves. Its robustness has also been confirmed. The developed algorithm is a general one and is robot dependent in all but a few aspects. Finally, the quality and uniformity of the panels produced is very high and in several aspects superior to manual production.

9. ACKNOWLEDGEMENTS

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