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VIRTUAL PROTOTYPING AND PROGRAMMING OF A ROBOTIC MANUFACTURING CELL FOR WOOD MACHINING

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Abstract: *This paper presents the virtual prototyping and simulation of a robotic manufacturing cell for machining wood panel doors. The machining task is focused towards performing milling and drilling operations for hinge slots and door lock cavity. First, based on a study regarding the state of the art in this field, the most efficient structure of the flexible manufacturing cell was chosen. Thus, the cell included a roller conveyor which provides input and output to the cell, a gantry robot for door handling, a three axis workpiece positioner and an articulated arm robot equipped with self-driven tools and tool changer for machining operations. The layout of the application was then modeled as a 2D top view of the robotic cell. The 3D virtual model of the entire application was then developed using Catia V5 software. Validation for the layout of the cell, robot integration and system functionality were performed through kinematic modeling in Catia's DMU Kinematics module. In the final stage of the project, the structure of the required programming for the flexible manufacturing cell was developed, showing the logical structure and signal configuration of the application. The signals were correlated with application events, ensuring communication between the various cell components.*

Key words: *robotic machining, wood panel door, flexible manufacturing cell, virtual prototyping, robot programming.*

1. INTRODUCTION

Wood processing is one of the oldest industrial branches. Since the dawn of civilization, wood was always available and required almost no technology to be used or processed. Obviously, since then, the wood industry had grown, evolved, and with progress came the need of new technologies to be integrated. But woodworking has always been a manually intense labor. Even today, in major wood industry branches, such as furniture or construction materials, industrial equipment merely assist human labor, and many of the operations are done manually.

One of the wood processing methods is machining. Robots that are integrated in industrial applications in order to directly perform machining operations are facing certain disadvantages when compared to machine tools, mainly regarding stiffness, precision and power. But they also have advantages, such as flexibility and better sensor integration. Regarding wood machining applications, these offer good opportunities for robotic integration. First of all, wood is a relatively soft material, with very good machinability when compared to metals. Also, because robots are well equipped to replace manual labor, they can provide better productivity and more reliable results [1]. On the other hand, taking into consideration its structure (illustrated in Fig. 1) [2], wood is a material with a very high level of inconsistencies. Knots and different vegetal tissues are important issues when it comes to machining. But even in this case, industrial robots have certain advantages, having flexible programming and making good use of sensors such as artificial vision and force feedbackto identify the structural variations of wood materials.

Besides structural inconsistencies, one of the main issues for robot integration in wood machining applications is linked to economic considerations. Thus, efficient robotic application design is required for robotic market growth in this field.

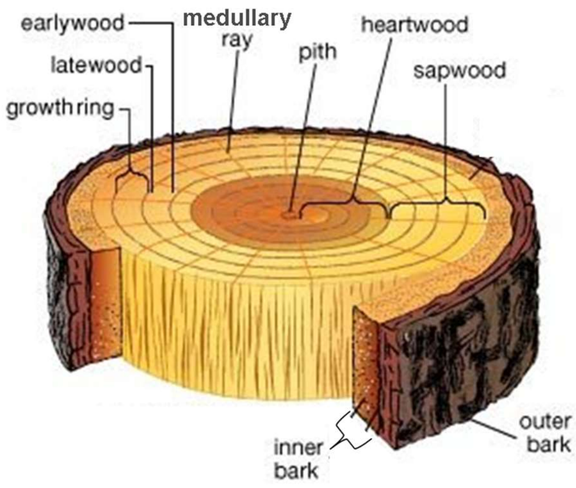

Fig. 1. Wood internal structure.

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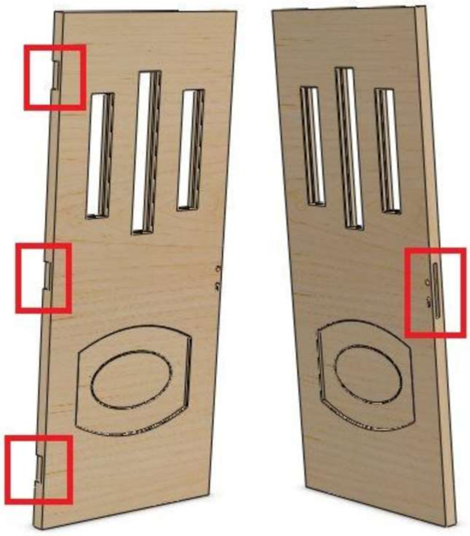

Fig. 2. Door manufacturing features.

Wood processing is a wide term that includes all operations from wood cutting, de-barking, initial treatment, to assembly, painting and finishing. These operations are performed in various places, such as the forest or in factories. Generally, at this moment only the factory based operations are suitable for robotic integration.

Essentially, the operations performed by industrial robots integrated in wood processing applications fall into three categories: material handling, assembly and machining [3]. This article is focused towards the machining segment, developing a virtual prototype and application programming for an efficient manufacturing cell for wood panel doors. The doors enter the cell with the features of the panel already processed. The operations performed inside the cell are focused towards machining the hinge slots and lock cavity of the door, as illustrated in Fig. 2.

2. STATE OF THE ART

In order to find an efficient layout for the proposed application, on which the 3D modelling of the application was based, a comparative analysis of several wood machining applications was made.

Fig. 3. The MAKA M ROB 60 flexible manufacturing cell.

Fig. 4. Wood beam cutting robotic cell.

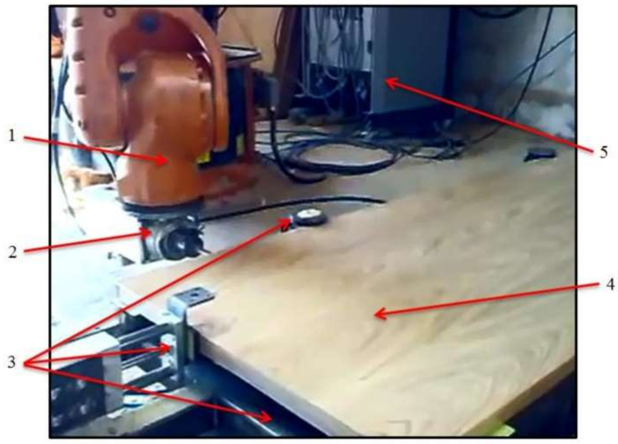

Fig. 5. The EUROBOTS door machining cell.

The MAKA M ROB 60 is a flexible manufacturing cell for wood prototyping [4]. The cell includes a floor-mounted six axis Kuka articulated arm robot. The application structure is presented in Fig. 3. A self-driven tool (2), mounted on the Kuka robot (1), machines wood parts that are clamped to the two workstations of the cell (4). The end-effector is also equipped with an automatic tool changer. The tool stand (3) is placed in the upper part of the cell for more convenient access and provides eight tool positions. The tool changing is pneumatically actuated. The workstation are manually loaded and do not provide axes for part orientation.

Another flexible manufacturing cell integrating a Kawasaki articulated arm robot is illustrated in Fig. 4 [5]. The cell is designed to cut wood beams. The Kawasaki ZX200S articulated arm robot (1) is equipped with a self-driven tool (2) which cuts the wood beams (5). The end-effector is also equipped with an automatic tool changer. The application can use up to six tools, stored in the tool stand (4). The beam is automatically introduced into the cell, and after cutting is evacuated through the output section (3).

The EUROBOTS flexible manufacturing cell is designed for wood doors machining [6]. The operations performed by this cell are similar to those proposed in this article – the machined areas are the hinge slots and the lock cavity of the door. The cell was developed in order to improve these operations that were previously done manually. In this case, good precision and reliability is required, since the operations are close to the end of the door manufacturing process, and the added value is already high. The cell, illustrated in Fig. 5, integrates a KukaKR360Fortec articulated arm robot (1) equipped with a self-driven tool (2) which machines a wooden door panel (4) which is clamped to a pneumatically-driven workpiece holder (3). In this case, tool changing is done manually, as there is no tool stand. Also, the loading and unloading of the door is done manually (although assisted by other mechanical systems).

Based on the preliminary study of comparative analysis, the following conclusions can be drawn regarding the structure of the flexible manufacturing cell:

- For the machining operations an articulated arm, six axis industrial robot should be used. This robot architecture benefits from good kinematic flexibility, ensuring access even to complex shaped parts.
- The application should be equipped with a tool changing system. This feature can be in the form of a tool changer mounted on robot’s flange or can be provided as an end-effector functionality. The machining operations performed on the same part can vary, and the ability to automatically change the tool during the work cycle improves productivity.
- Many of these applications replace manual labor. In order to be efficient and completely automated, both the input and the output of the parts should be done automatically. This can be achieved by other robots or by conveyors.
- In order to increase the productivity and reduce cycle times, as well as further increase the kinematic flexibility of the application, the part should be clamped on a workpiece positioner with two workstations and axes for part orienting. The double side of the positioner ensures that the changing of the part being machined is done automatically and as fast as possible. The part orienting axes of the positioner contribute to a less complex trajectory for the robot and easier access to complex shaped part features.
- Clamping of the part to the positioner workstations should be done through pneumatically actuated modular fixturing components. These are well suited for automated systems, provide fast and repeatable clamping.

3. CELL COMPONENTSAND LAYOUT

Taking into account the above aspects, for performing the machining operations, an ABB IRB 2600 articulated arm industrial robot was chosen – version with 20 kg payload and 1.65 m reach. The main advantages of this model are the compact design – which improves accessibility – as well as suitable reach and payload. The IRB 2600 robot is illustrated in Fig. 6. The specific dimensions and the workspace of the robot are illustrated in Fig. 7. Regarding the end-effector, the chosen model was TMA4 produced by ELTE. This is a self-driven end-effector with tool changing capabilities, dedicated to wood machining applications. The end-effector is illustrated in Fig. 8. The dimensions of the end-effector – including clearance dimensions and mounting holes – are illustrated in Fig. 9. The specifications of the end-effector are shown in Table 1.

Fig. 6. ABB IRB 2600.

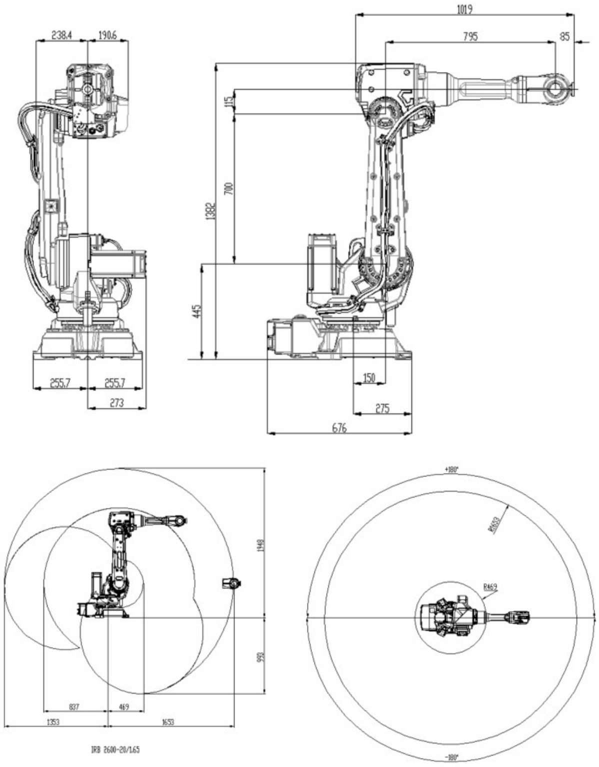

Fig. 7. ABB IRB 2600 dimensions and workspace.

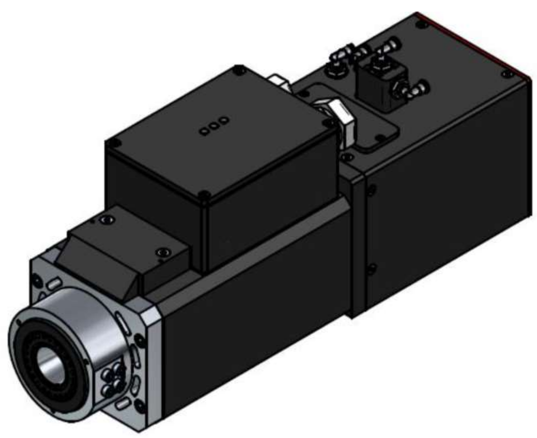

Fig. 8. The TMA4 end-effector.

Table 1

TMA4 end-effector parameters

Name	TMA4	
Manufacturer	ELTE	
Type	Self-driven tool	
Features	Automatic tool changing (pneumatic, 5.5 bar), electrical fan	
Power	3.6 kW@20000rpm	
Speed	2000-24000 rpm	
Torque	0.55 Nm@20000rpm	
Stiffness	Radial 93 N/μm	
	Axial 44 N/μm	
Weight	13 kg	
Current	360 V	
Frequency	400 Hz	
Materials	Wood, plastic, composites, aluminium	

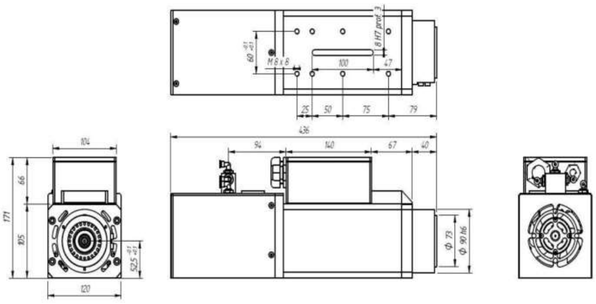

Fig. 9.TMA4 end-effector dimensions and mounting holes

Based on the previous considerations, a completely automated cell layout was developed (see Fig. 10). The cell includes the ABB IRB 2600 industrial robot (13) equipped with the TMA4 end-effector, a tool stand with seven tool positions (14) and an ABB IRBPK300/1000 workpiece positioner with two workstations (2). This section has controlled environment, as the dust resulted from the machining process is filtered (5) and not released into the atmosphere. The workpiece is brought into the cell by a Bosch-Rexroth TS5 roller conveyor (1), halts into a pneumatically driven stopper (8) and is centered by a pneumatically actuated pusher (6). The part is then automatically loaded onto workstations by a GudelZP4 two axis gantry robot (4) using a vacuum gripper (7) and clamped to the workstations (15). The cell is enclosed by fences (12) to prevent access inside during operation. All pneumatically driven equipment is actuated using a KaeserSX8T compressor (9). The ABB IRB 2600 industrial robot and the workpiece positioner are controlled by an ABB IRC5 controller (10).

The layout of the flexible manufacturing cell was developed taking into account the clearance dimensions of the component systems and the workspace of the industrial robots and workpiece positioner at a 1:1 scale. Thus, the spatial distribution of the component equipment on the floor and clearance dimensions of the entire cell were determined. The cell has a footprint of 7916 × 6133 mm.

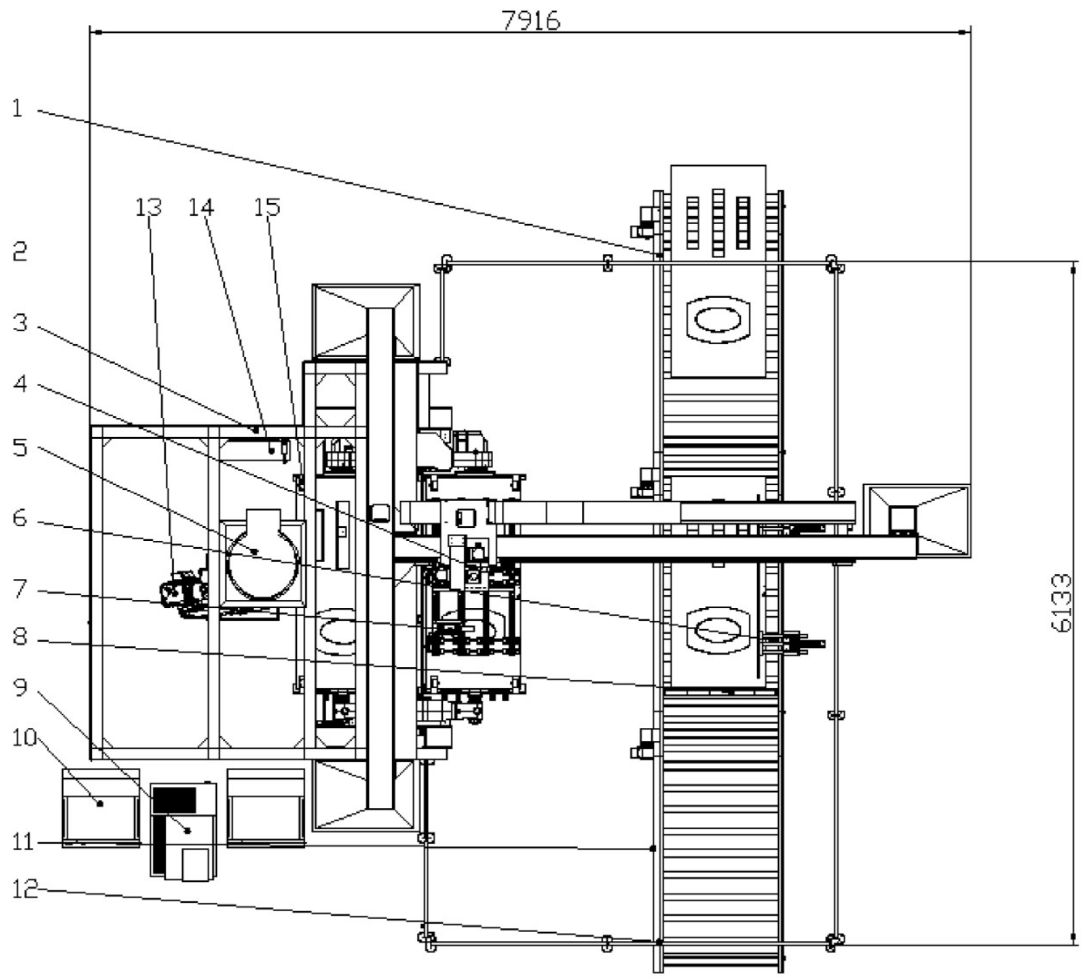

Fig. 10. Flexible manufacturing cell layout.

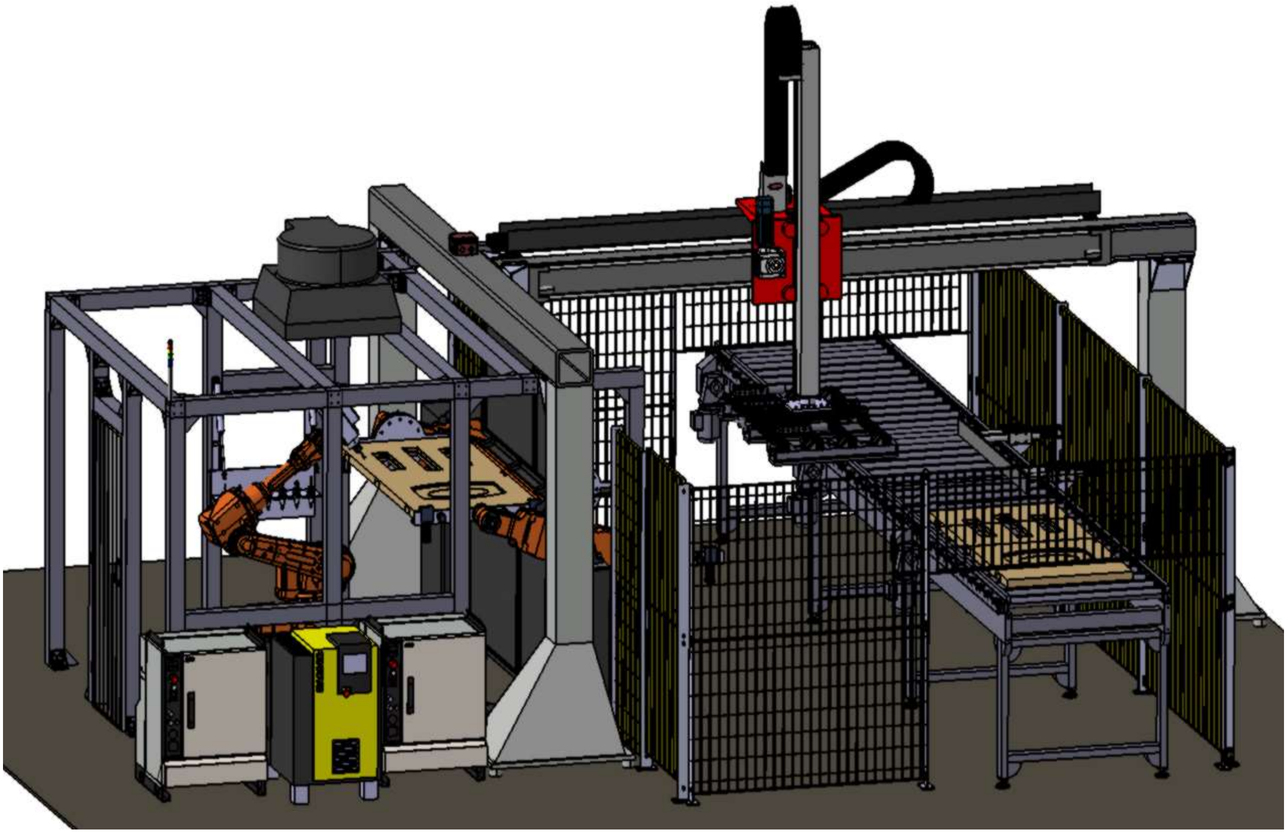

Fig. 11. Flexible manufacturing cell 3D virtual model.

4. MANUFACTURING CELL VIRTUAL MODELING AND PROGRAMMING

Based on the previous layout, the virtual 3D model of the manufacturing cell was developed using Catia V5 software. The virtual 3D model of the cell is illustrated in Fig. 11.

The TS5 conveyor provides the inputs and outputs of the cell. The conveyor has three sections, each with its own drive unit. After the door stops and is positioned against the conveyor edge by the pusher, it is transferred to the workpiece positioner by the GudelZP4 gantry robot. The door is clamped to the workstation by four pneumatically actuated swing clamps. This section is illustrated in Fig. 12.

The ABB IRBPK300/1000 workpiece positioner has two workstations, with a horizontal axis for part orienting on each workstation. The switch between workstations is done by rotation around a horizontal axis. The workpiece positioner has two major functions: providing part orientation functionality and automated part switching.

The door machining section includes a tool stand with seven tool positions and an air control unit which filters the wood particles. The tool stand has a pneumatically actuated cover in order to protect the tool positions from dust and particles. This section is illustrated in Fig. 13. The tool stand and the air control unit are illustrated in Fig. 14.

In order to validate the layout of the application and the functionality of the flexible manufacturing cell, the operation flow was analyzed using Catia DMU Kinematics module.

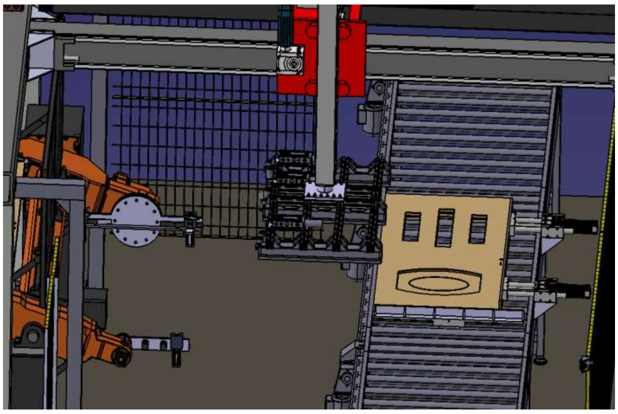

Fig. 12. Door transfer section.

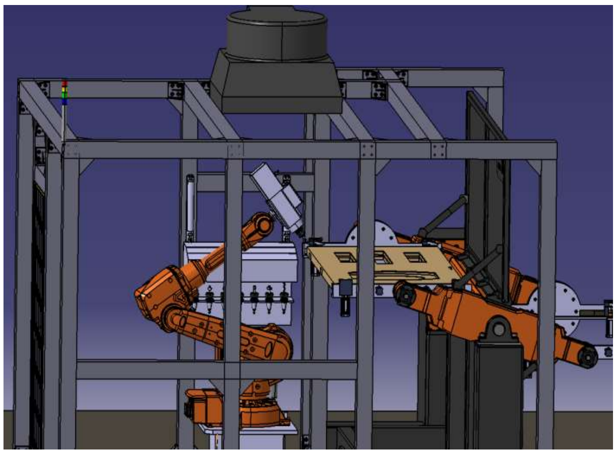

Fig. 13. Door machining section.

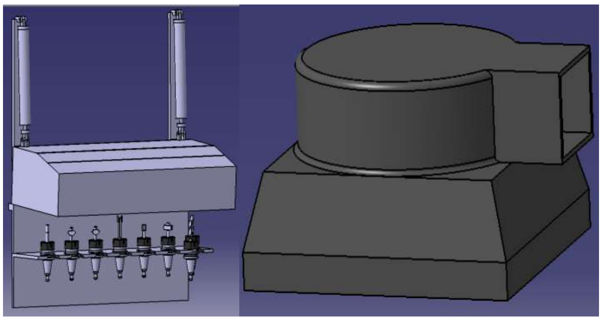

Fig. 14. The tool stand and the air control unit.

In order to develop the programming structure and signal logic of the application, the functional events must be identified:

1. The door advances on the conveyor until it halts on the stopper. The door stop represents the first event.
2. The door is then positioned against the edge of the conveyor by the pusher. This is the second event.
3. The third event is the door transfer from the conveyor to the workpiece positioner.
4. The clamping of the door on the workstation represents the fourth event.
5. The workstation switch represents the fifth event.
6. The start of machining represents the sixth event.
7. The tool changing represents the seventh event.
8. The part reorientation represents the eighth event.

Then, considering the above events, the application signals must be established. The required signals and their role are shown in Table 2.

Table 2

Application required signals

Signal	Role	Robot
MC1	Activates the drive unit for the first conveyor section	Gudel – 1
MC2	Activates the drive unit for the second conveyor section	Gudel – 2
MC3	Activates the drive unit for the third conveyor section	Gudel – 3
SC1	Detects the doors that enter the cell	Gudel – 1001
SC2	Detects the doors that reach the stop gate	Gudel – 1002
SG	Activates the stop gate	Gudel – 4
COM	Activates the pusher	Gudel – 5
SP1	Activates the first wotkstation	Gudel – 1010 ABB – 1010
SP2	Activates the second wotkstation	Gudel – 1020 ABB – 1020
SPP1	Activates the part clamping on the first wotkstation	Gudel – 11 ABB – 11
SPP2	Activates the part clamping on the second wotkstation	Gudel – 12 ABB – 12
ES	Tool changing	ABB – 10
MS	Opens the tool stand cover	ABB – 30
Gudel-ABB	Signals the end of door transfer	Gudel – 100 ABB – 1200
ABB-Gudel	Signals the end of machining operations	Gudel – 1100 ABB – 200

The application programming was developed as follows:

```
PROGRAM Robot_Portal
;variable declarations
LOCAL MC1, MC2,MC3,SC1,SC2,SG,COM
GLOBAL SP1,SP2,SPP1,SPP2
;vacuum gripper activation and 100% speed
PARAMETER HAND.TIME=0,5
SPEED 100 ALAWAYS
;the robot is sent to the SAFE pose
MOVETsafe,7
;the signal variables are initialized
SP1=1010
SP2=1020
SPP1=11
SPP2=12
MC1=1
MC2=2
MC3=3
SC1=1001
SC2=1002
SG=4
COM=5
;a timer is initialized – if after 60 sec. no door enters the cell, a message is displayed
100 TIMER1=0
;the drive units for the first two conveyor sections are started
SIGNAL (MC1)
SIGNAL (MC2)
;a door detection is expected or the timer expiration
WAIT ( SIG (SC1) OR TIMER (1)>=60)
;if the timer expires, the conveyors are stopped and the following message is displayed : ”There are no doors on the conveyor!”
IF TIMER (1)>=60 THEN
;the conveyor stops
SIGNAL (-MC1)
SIGNAL (-MC2)
TYPE ”There are no doors on the conveyor!”
;the program stops
GOTO 200
ELSE
;the stop gate signal is activated
SIGNAL(SG)
;a door detection in the pick-up position is expected
WAIT (S2)
;the pusher is activated and the conveyor is stopped
SIGNAL (COM)
SIGNAL (-MC1)
SIGNAL (-MC2)
;the system waits for the door to be positioned
TIMER (T2)=0
WAIT (T2)>=10
;the stop gate and the pusher are reverted to the original position
SIGNAL (-COM)
SIGNAL(-SG)
;the transfer program is called
CALL P_P( conveyor, positioner)
;the workpiece positioner is activated
SIG (200)
```

```
;a signal from the ABB robot is awaited before part pick-up
WAIT SIG (1100)
;the door transfer program is called
CALL P_P(positioner,conveyor)
;the third conveyor segment is activated and a 10 sec. wait is inserted
SIGNAL (MC3)
TIMER (T3)=0
WAIT (T3)>=10
SIGNAL (-MC3)
;the program is resumed
GOTO 100
;the program stops
200 MOVE SAFE
.end

.PROGRAMp_p(pick,place)
;the robot is moved 100 mm above the pick-up position
APPROpick,100
BREAK
;the speed is reduced to 50%
SPEED 50
;the robot is moved towards the pick-up position
MOVES pick
;the gripper is activated
CLOSEI
;the speed is kept at 50%
SPEED 50
;the robot is moved above the pick-up position
DEPARTS 50
BREAK
;the robot is moved 100 mm above the drop position
APPROplace,100
BREAK
; the speed is reduced to 50%
SPEED 50
;the robot is moved towards the drop position
MOVES pick
;the gripper releases the part
OPENI
;the workstation clamps are activated
SIGNAL (11)
; the speed is kept at 50%
SPEED 50
;the robot is moved above the drop position
DEPARTS 50
BREAK
;return to the main program
RETURN
.END

.PROGRAMRobot_ABB
;variables declaration
LOCAL ES,MS
GLOBAL SP1,SP2,SPP1,SPP2
;the tool attachment is configured at 0.5 sec., speed at 100%
PARAMETER HAND.TIME=0,5
SPEED 100 ALAWAYS
;the robot is sent to the SAFE pose
MOVETsafe,7
;the signal variables are initialized
SP1=1010
SP2=1020
SPP1=11
SPP2=12
ES=10
MS=30
;a timer is initialized
100 TIMER1=0
; the system awaits a signal from the gantry robot regarding part placement or the 60 sec. timer expiration
WAIT ( SIG (100) OR TIMER (1)>=60)
;if the timer expires, the system stops and the following message is displayed: ”There are no parts on the positioner!”
IF TIMER (1)>=60 THEN
TYPE ”There are no parts on the positioner!”
;the program stops
GOTO 200
ELSE
;the tool changing program is called
CALL tool_stand(0,S1)
;the desired tool is declared
TOOL S1
;the trajectory is configured
SET loc.start=Safe
SET loc.final=Safe
;the tool is activated
SIGNAL(ES)
;machining
APPROloc.start,100
SPEED 20
MOVE loc.start[i]
DURATION 1/50 ALAWAYS
FOR i=0 to last.punct
x=DX*loc.x
y=DY*loc.y
END
;the robot is sent to the SAFE pose with the tool stopped
SIGNAL(-ES)
MOVE SAFE,1
;part reorienting
P3=P3:90
;machining
APPROloc.start,100
SPEED 20
MOVE loc.start[i]
DURATION 1/50 ALAWAYS
FOR i=0 to last.punct
x=DX*loc.x
y=DY*loc.y
END
200 MOVE,SAFE
.END

.PROGRAMtool_stand(0,S1)
;the robot is sent 10 mm under the tool change position
APPRO0,-100
BREAK
;the speed is reduced to 50%
SPEED 50
```

```
;the robot is moved towards the tool change position
MOVES pick
;the tool is picked up
CLOSEI
;the speed is maintained at 50%
SPEED 50
;the robot is moved above the tool change position
DEPARTS 50
BREAK
;the robot moves 100 mm above the tool drop position
APPROS1,100
BREAK
;the speed is reduced to 50%
SPEED 50
;the robot is moved towards the pick-up position
MOVES pick
;the tool is stopped
OPENI
;the clamping system is activated
SIGNAL (11)
;the speed is maintained at 50%
SPEED 50
;the robot is moved above the drop position
DEPARTS 50
BREAK
;return to the main program
RETURN
.END
```

5. CONCLUSIONS

The preliminary study regarding the state of the art provides an essential background for developing an optimized structure for a flexible manufacturing cell for wood machining. The goals of the study was complete automatization of the process and efficient programming, as well as developing a compact cell design.

The layout of the manufacturing cell respects the preliminary conclusions drawn after the comparative analysis performed earlier. It completely replaces manual labor for this segment of wooden door manufacturing and provides a flexible solution that can be adapted to any door configuration. The kinematic flexibility of the IRB 2600 articulated arm industrial robot is complemented by the workpiece positioner's part orienting axes.

The impact of the study in the field of door manufacturing is important, as it draws several guidelines regarding application design and industrial robot integration. The study presented in this article provides a frame for faster and more efficient application development in this field. It also underlines the essential equipment required in a robotic wood machining application.

Further studies in this field will be focused on robot trajectory planning for the machining operations, as well as machining parameters optimization. This represents the next step towards robotic machining optimization in the field of wood industry.

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