Fundamentals of Robotics Practical Exercise 5: *Simulation of a Painting Process using COSIMIR*

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***Abstract*—This report summarizes the steps and results obtained during programming simulation of painting process using COSIMIR. In this lab session, we perform the control of external devices such as conveyor belt, a rotary table and a paint gun using predefined instructions and subroutines in the program. To accomplish this, we program the appropriate Control Signal Connection between the robot and the conveyor belt. Another aim is to familiarize with the use of different end-effectors, for instance grip or a paint gun.**

I. INTRODUCTION

The COSIMIR Simulator will be used to simulate the execution of a painting task with the Mitsubishi RV-E4NM robot. Programming using the Movemaster Command language is used, therefore a MRL control program will be generated to accomplish the task algorithm (to obtain a position list and define the transitions between the positions).

II. CONTROL INSTRUCTIONS

At the beginning, all the needed preparation steps were made concerning simulation software setup. To develop and to check the program, a carrier should be imported with the pillar. Each time program is started, it is mandatory to import the model that includes the part that is going to be painted: File/Import, and load the file "WPCWithPillar.mod". Next step is to establish connection of the robot with different devices, in this case conveyor belt. The connection between the robot and the conveyor belt is established by dragging appropriate components to their right location in the "Model Explorer" window. It is necessary to trail (using the mouse) the "StartBelt" and "ReverseBelt" outputs of the robot RV-E4NM to the "On" and "Reverse" inputs of the conveyor belt, respectively.

Digital Inputs of the Robot are specified in appendix figure 10, while Digital Outputs of the Robot are specified in appendix figure 11. MRL Position list (list of positions used in the algorithm) is shown in appendix figure 12.

III. ALGORITHM DESCRIPTION

The robot program executes the laquering of a workpiece - the object. The workpiece is delivered by the autonomously guided vehicle (AGV). The robot has to place the workpiece upon a rotary table. Using a gripper exchange system the robot has to change its tool to several paint guns and laquer the workpiece. The program contains the connection to the overlayed plant control (appendix, figure 10 and figure 11) and the movement program for laquering of the workpiece. The program uses programming language MRL.

A. Workcell Paintshop - Components

The workcell CheckPack contains the following components:

- Mitsubishi Robot RV-E4NM
- Rotary Table
- Gripper Exchange System
- Tool Rack with gripper and blue, green and red paint gun
- Conveyor Belt as connection to AGV

B. Painting process

The painting process is decomposed into the following stages:

- The conveyor belt approaches the specific part to be painted to the working area.
- The part moves to the rotary table.
- The end-effector is changed, replacing the grip by a paint gun.
- The painting process starts, setting the paint gun and applying several coats to the part. Once the first side of the part is painted, it is necessary to turn the rotary table and paint the other side of the part.

- The end-effector is changed again, replacing the painting gun by the grip.
- The painted part is located at the conveyor belt and returned to the original position.

Step	Comment
Main Program	Calls subroutines.
WPC to robot	Transportation of workpiece carrier by conveyor belt.
Grasp workpiece	Picks workpiece and moves it upon rotary table.
Deposite gripper	Deposites parallel gripper.
Take red paintgun	Attachs red paintgun to robot's endeffector.
Laquering	Laquers the workpiece and controls the rotary table.
Deposite red paintgun	Deposites red paintgun.
Take green paintgun	Attachs green paintgun to robot's endeffector.
Laquering	Laquers the workpiece and controls the rotary table.
Deposite green paintgun	Deposites green paintgun.
Take blue	paintgun Attachs blue paintgun to robot's endeffector.
Laquering	Laquers the workpiece and controls the rotary table.
Deposite blue paintgun	Deposites blue paintgun.
Take gripper	Attachs parallel gripper to robot's endeffector.
Grasp workpiece	Picks workpiece and move it upon workpiece carrier.
WPC to AGV	Transportation of workpiece carrier by conveyor belt.

IV. IMPLEMENTATION

Move Master Command Program for painting is designed using subroutines that accomplish a particular task of the algorithm. Each of the algorithm stages is presented with code, comments for the code and simulation result. Main program is divided into subroutines. Each time a particular task has to be done, a subroutine is called, using function GS. The MRL code for the main program is shown in figure 1.

```
45 ' Set distance from the base to the end-effector
50  TL 139.0

55 ' Move workpiece carrier (WPC) to robot
60 GS 150
61 ' Stop the table turn
62 OB -6

65 ' Move workpiece to laquering station
70 SP 30
80 GS 290

85 ' Deposite gripper
90 GS 410

95 ' Laquering
100 GS 1000

105 ' Take gripper
110 GS 1840

115 ' Move workpiece to workpiece carrier
120 GS 1890

125 ' Move workpiece carrier to Automated Guided Vehicle (AGV)
130 GS 220
135 'End painting
140 ED
```

Figure 1. MRL code of the main program.

1) `The conveyor belt approaches the specific part to be painted to the working area.` First, program needs to deactivate robot output bit (output bit 0) that defines reverse transportation direction of the belt and to start the belt movement (output bit number 1). These actions, similarly to the other commands for setting output bits are accomplished using command OB. Once belt is started, robot waits for input bit (index 1) to become active - saying that there is a carrier upon the conveyor belt at the position of the robot. This was realized through the loop in which command TBD returns to its beginning until input bit is set to desired value, in this case 1 - signalling that the object has reached robot. After the belt was activated, there was some waiting time (0.1 sec) set using command TI, so that sensing starts with a bit of delay. The same pattern of usage of TI and TBD instructions to generate conditional waits with input bits, is used at several places later in code where it was needed to work with conditional bits. Figure 2 presents the code used for this task, and figure 2 shows simulation result.
2) `The part moves to the rotary table.` This step is realized as subroutine called from the main program. Gripper approaches the object, takes it at position 2, by closing the gripper and brings to position 5 (appendix figure 12 contains table with details about positions) where it is left for further processing. Figure 3 presents the code used for this task, and shows simulation result.
3) `The end-effector is changed,`

```
55 ' Move workpiece carrier (WPC) to robot
60 GS 150
.
.
.
150 ' Control conveyor belt: WPC to robot
160 OB -1
170 OB 0
180 TI 1
190 TBD -1, 190
200 OB -0
210 RT
```

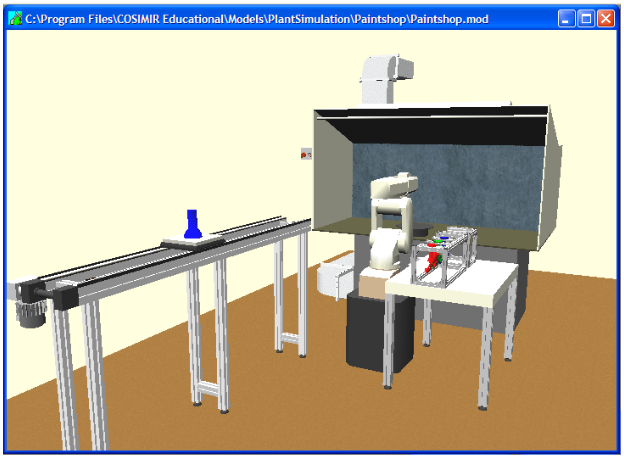

Figure 2. Algorithm step 1: MRL code (top) and simulation results (bottom frame) - object approaches robot over belt.

```
85 ' Deposite gripper
90 GS 410
.
.
.
410 ' Deposite gripper
420 MO 7
430 MS 8
440 MS 7,O
450 RT
```

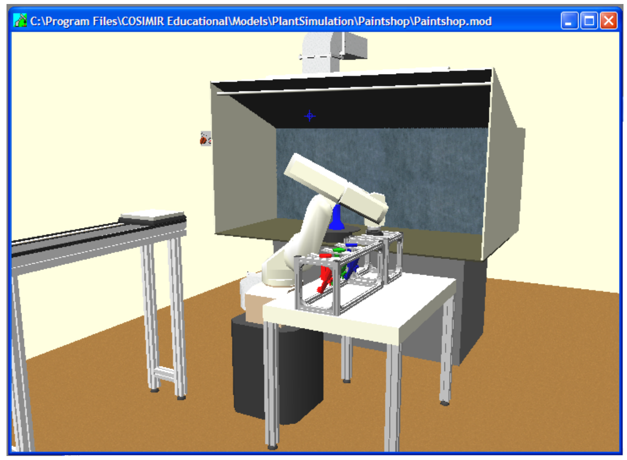

Figure 4. Algorithm for step 3: MRL code (top) and simulation results (bottom frame) - deposit gripper.

```
65 ' Move workpiece to laquering station
70 SP 30
80 GS 290
.
.
.
290 ' Grasp workpiece and move it to laquering station
300 MO 1
310 MS 2
320 OB 2
330 MS 3
340 MO 4
350 SP 10
360 MS 5
370 OB -2
380 MS 4
390 SP 30
400 RT
```

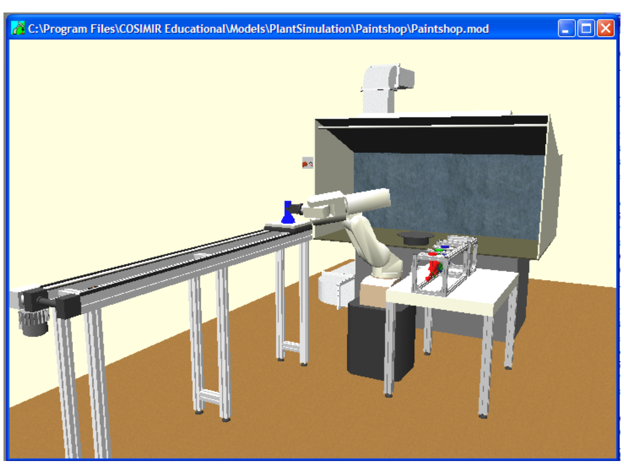

Figure 3. Algorithm for step 2: MRL code (top) and simulation results (bottom frame) - object is transferred to the rotary table.

`replacing the grip by a paint gun.` As soon as the positioning of the object at the table is over, gripper reaches position 8 where the gripper is left, using command MS. MS instruction moves to position 8 by linear interpolation, because it guarantees correct insertion. It is also used in order to replace the end-effector during the movements since next position, number 7 is reached using the same command, but with gripper opened (code in figure 4).

Next step is to take the paint gun before doing the painting itself. Taking the paint gun, whether it is red, green, or blue is arranged as a separate subroutine, defined for each of the colours, with code shown in figure 5. It is called from subroutine Laquering explained in next section. Similarly to deposit gripper routine, we approach the paint-tools using MS (linear interpolation) and similarly use C to grab the tool (figure 5).

4) `The painting process.` The painting is localized in subroutine called Laquering. It consists of taking the paint gun subroutine (code shown in figure 5), passing it over to the object that is being painted, doing the painting itself and returning the painting gun to its place. This process is repeated for all three colours using appropriate routines. Separate routines are designed and called

```
460 ' Take red paintgun
470 MO 9
480 MS 10,O
490 MS 11,C
500 MS 12
510 MS 13
520 RT
.
.
.
610 ' Take green paintgun
620 MO 14
630 MS 15,O
640 MS 16,C
650 MS 17
660 MS 18
670 RT
.
.
.
760 ' Take blue paintgun
770 MO 19
780 MS 20,O
790 MS 21,C
800 MS 22
810 MS 23
820 RT
```

Figure 5. Algorithm for step 3: MRL code (top) and simulation results (bottom frame) - deposit gripper.

for taking the tools and returning them, they are symmetrical with used commands.

Painting algorithm consists of several elements:

- Moving the gripper in front of the object slower than usual, while taking several positions around the object that is being painted. Positions (25, 26, 27 - red; 28, 29, 30 - green; 31, 32, 33 - blue) are reached after the speed is redefined (lowered) using command SP 5. Speed can be set on range $1 \leq speed \leq 30$ (figure 6).
- Taking different height levels for different colours. Each set of painting positions is defined for different height (figure 12).
- Rotating the table 180°. After finishing with the first side of the object, table is rotated. Code that accomplishes rotation is shown in figure 7. Previously explained method for waiting for input bit to become activated (when waiting for the belt to bring the object) is used (commands TI, TBD and OB used). At first, output bit (number 6) that starts rotation of a rotary table is activated. Program waits in a loop for the flag "TurnTable:Ready" (input bit 4) activation two consecutive times. Each time, after activation, one quarter of a full circle is measured ($\frac{\pi}{2}$) so that eventually algorithm waits for the table to rotate for π radians enabling painting of the other side of the object.

```
1000 ' Laquering
1010 ' Red paintgun
1020 GS 460
1030 MO 24
1035 ' Small speed for painting action
1040 SP 5
1050 MS 25
1060 OB 5
1070 MS 26
1080 MS 27
1090 MS 25
1100 OB -5
1105 ' Back to old speed
1110 SP 30
1130 ' Rotate table
1140 OB 6
1150 TI 1
1160 TBD -4,1160
1170 OB 6
1180 TI 1
1190 TBD -4,1190
1191 OB -6
1195 ' Small speed for painting action
1200 SP 5
1210 OB 5
1220 MS 26
1230 MS 27
1240 MS 25
1250 OB -5
1255 ' Back to old speed
1260 SP 30
1270 MS 24
1280 GS 530
```

```
1290 ' Green painting
1300 GS 610
1310 MO 24
1320 MS 28
1325 ' Small speed for painting action
1330 SP 5
1331 OB 4
1340 MS 29
1350 MS 30
1360 MS 28
1370 OB -4
1375 ' Back to old speed
1380 SP 30
1390 ' Rotate table
1400 OB 6
1410 TI 1
1420 TBD -4,1390
1430 OB 6
1440 TI 1
1450 TBD -4,1420
1451 OB -6
1455 ' Small speed for painting action
1460 SP 5
1470 OB 4
1480 MS 29
1490 MS 30
1500 MS 28
1510 OB -4
1520 ' Back to old speed
1530 SP 30
1540 MS 24
1550 GS 680
```

```
1560 ' Blue paintgun
1570 GS 760
1580 MO 24
1590 MS 31
1595 ' Small speed for painting action
1600 SP 5
1610 OB 3
1620 MS 32
1630 MS 33
1640 MS 31
1650 OB -3
1655 ' Back to old speed
1660 SP 30
1670 ' Rotate table
1680 OB 6
1690 TI 1
1700 TBD -4,1620
1710 OB 6
1720 TI 1
1730 TBD -4,1650
1731 OB -6
1735 ' Small speed for painting action
1740 SP 5
1750 OB 3
1760 MS 32
1770 MS 33
1780 MS 31
1790 OB -3
1795 ' Back to old speed
1800 SP 30
1810 MS 24
1820 GS 830
1830 RT
```

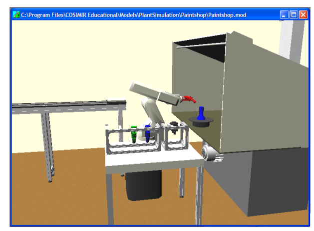

Figure 6. Algorithm for step 4: MRL code and simulation results (frame figure) - deposit gripper.

```
1130 ' Rotate table
1140 OB 6
1150 TI 1
1160 TBD -4,1160
1170 OB 6
1180 TI 1
1190 TBD -4,1190
1191 OB -6
```

Figure 7. Algorithm for step 4: MRL code for table rotation.

As stated, the tools (paint guns in this case) are returned back to their place after painting job is done.

5) `The end-effector is changed again, replacing the painting gun by the grip.` Subroutine 'Take gripper' is used for this purpose. Its code is shown in figure 8. It is executed after subroutine Laquering. Used commands are similar to those used previously for gripper deposit, just that instead of motion with opened grip, we have transition to position using command MS, with gripper closed.
6) `The painted part is located at the conveyor belt and returned to the original position.` Two subroutines, one for taking the object back to the conveyor belt,

```
105 ' Take gripper
110 GS 1840
.
.
.
1840 ' Take gripper
1850 MO 7
1860 MS 8,O
1870 MS 7,C
1880 RT
```

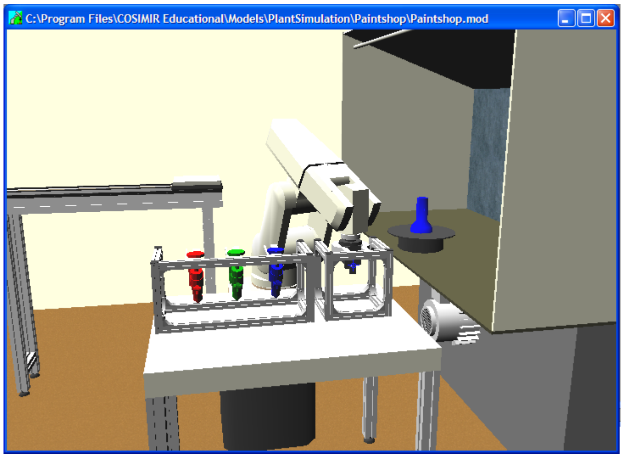

Figure 8. Algorithm for step 5: MRL code (top) and simulation (bottom frame) for taking the gripper again after painting.

and one for returning it to the original position manage final stage of the painting algorithm.

V. CONCLUSIONS

In this lab session, we implemented an algorithm for programming painting workcell, emulation of industrial usage of robot for painting. The following tasks were accomplished: communication of robot with sensors (digital inputs) and digital outputs, usage of gripper tool, usage of rotary tables, usage of conveyor belts, programming in MRL.

```
115 ' Move workpiece to workpiece carrier
120 GS 1890

125 ' Move workpiece carrier to Automated Guided Vehicle (AGV)
130 GS 220
135 'End painting
140 ED
.
.
.
1890 ' Grasp workpiece and move it to WPC
1900 MO 4
1910 SP 10
1920 MS 5
1930 OB 2
1940 SP 10
1950 MS 4
1960 SP 30
1970 MO 3
1980 MS 2
1990 OB -2
2000 MS 1
2010 MO 6
2020 RT

220 ' Control conveyor belt: WPC to AGV
230 OB 1
240 OB 0
250 TI 1
260 TBD -2, 260
270 OB -0
280 RT
```

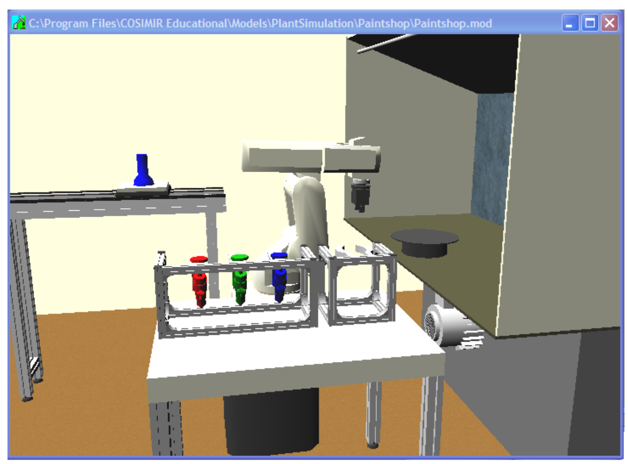

Figure 9. Algorithm for step 6: MRL code (top) and simulation (bottom frame) for returning object to conveyor belt and returning back to initial position.

APPENDIX A
DIGITAL INPUTS AND OUTPUTS OF THE ROBOT

Nº	Object : Input	connected to Object : Output	Comment
0	RV-E4NM : GESIsClosed	GripperExchangeSystem : State	TRUE: The gripper exchange system is closed.
2	RV-E4NM : WPCAtAGV	IFS579AGV : On	Sensor: There is a carrier upon the conveyor belt at the position of the AGV.
1	RV-E4NM : WPCAtStorage	IFS579Robot : On	Sensor: There is a carrier upon the conveyor belt at the position of the robot.
3	RV-E4NM : GripperIsClosed	Gripper : IsClosed	TRUE: The gripper is closed.
4	RV-E4NM : TurnTableIsReady	TurnTable : Ready	The rotary table stands still.

Figure 10. Digital Inputs of the Robot.

Nº	Object : Output	connected to Object : Input	Comment
0	RV-E4NM : StartBelt	ConveyorBelt : On	Starts the conveyor belt.
1	RV-E4NM : ReverseBelt	ConveyorBelt : Reverse	Toggles the transportation direction of the conveyor belt.
2	RV-E4NM : CloseGripper	Gripper : Close	Closes the gripper.
3	RV-E4NM : PaintBlue	PaintgunBlue : On	Activates blue paintgun.
4	RV-E4NM : PaintGreen	PaintgunGreen : On	Activates green paintgun.
5	RV-E4NM : PaintRed	PaintgunRed : On	Activates red paintgun.
6	RV-E4NM : StartTurnTable	TurnTable : RotateOnce	Starts rotation of rotary table about 90°.
901	RV-E4NM : HClose1	GripperExchangeSystem : Close	Closes the gripper exchange system.

Figure 11. Digital Outputs of the Robot.

APPENDIX B
RECORDED POSITIONS, THEIR COORDINATES, COMMENTS AND COMPLETE CODE

1	-320.0, 500.0, 655.0	-90, 0, 0,R,A,F,C	Gripping approach
2	-320.0, 615.0, 655.0	-90, 0, -0,R,A,F,C	Gripping position
3	-320.0, 615.0, 675.0	-90, 0, 0,R,A,F,C	Raise the object from WPC
4	650.0, 0.0, 675.0	-90, 0, -90,R,A,F,C	Place the object above turn table
5	650.0, 0.0, 475.0	-90, 0, -90,R,A,F,C	Place the object on turn table
6	346.5, 0.0, 497.3	178, 0, -90,R,A,N,C	Neutral position
7	205.0,-440.0, 475.0	180, -0, -90,R,A,N,C	Approach gripper
8	205.0,-440.0, 347.0	-180, -0, -90,R,A,N,C	Take gripper
9	-336.1,-430.0, 345.0	180, 0, 0,R,A,N,C	Approach red pistol
10	-336.0,-430.0, 315.0	180, 0, 0,R,A,N,C	Take red pistol
11	-336.1,-430.0, 325.0	180, 0, 0,R,A,N,C	Raise red pistol
12	-336.1,-290.0, 325.0	180, 0, 0,R,A,N,C	red - move out
13	-336.1,-290.0, 515.0	180, 0, 0,R,A,N,C	red - move out
14	-199.0,-430.0, 345.0	-180, 0, 0,R,A,N,C	Approach green pistol
15	-199.0,-430.0, 315.0	-180, 0, 0,R,A,N,C	Take green pistol
16	-199.0,-430.0, 325.0	180, 0, 0,R,A,N,C	Raise green pistol
17	-199.0,-290.0, 325.0	-180, 0, 0,R,A,N,C	green - move out
18	-199.0,-290.0, 515.0	180, 0, 0,R,A,N,C	green - move out
19	-61.0,-430.0, 345.0	180, 0, 0,R,A,N,C	Approach blue pistol
20	-61.0,-430.0, 315.0	-180, 0, 0,R,A,N,C	Take blue pistol
21	-61.0,-430.0, 325.0	180, 0, 0,R,A,N,C	Raise blue pistol
22	-61.0,-290.0, 325.0	-180, 0, 0,R,A,N,C	blue - move out
23	-61.0,-290.0, 515.0	180, 0, 0,R,A,N,C	blue - move out
24	523.9, 7.7, 686.2	93, 0, 91,R,A,F,C	Laquering - initial position
25	523.9, 7.7, 614.7	93, 0, 91,R,A,F,C	Red laquering
26	523.9, -25.1, 614.7	93, 0, 91,R,A,F,C	Red laquering
27	523.9, 38.0, 614.7	93, 0, 91,R,A,F,C	Red laquering
28	509.8, 7.5, 502.9	68, 0, 91,R,A,F,C	Green laquering
29	509.8, 87.7, 502.9	68, 0, 91,R,A,F,C	Green laquering
30	509.8, -88.3, 502.9	68, 0, 91,R,A,F,C	Green laquering
31	523.7, 7.7, 458.5	86, 0, 91,R,A,F,C	Blue laquering
32	523.7, 66.6, 458.5	86, 0, 91,R,A,F,C	Blue laquering
33	523.7, -62.8, 458.5	86, 0, 91,R,A,F,C	Blue laquering

Figure 12. Recorded positions, their coordinates and comments.

```
10 '    COSIMIR® Educational
20 '    Plant Simulation
30 '    Laboratory Exercise
40 '    Laquering of Workpieces

45 ' Set distance from the base to the end-effector
50  TL 139.0


55 ' Move workpiece carrier (WPC) to robot
60 GS 150

65 ' Move workpiece to laquering station
70 SP 30
80 GS 290

85 ' Deposite gripper
90 GS 410

95 ' Laquering
100 GS 1000

105 ' Take gripper
110 GS 1840

115 ' Move workpiece to workpiece carrier
120 GS 1890

125 ' Move workpiece carrier to Automated Guided Vehicle (AGV)
130 GS 220
135 'End painting
140 ED

150 ' Control conveyor belt: WPC to robot
160 OB -1
170 OB 0
180 TI 1
190 TBD -1, 190
```

```
200 OB -0
210 RT

220 ' Control conveyor belt: WPC to AGV
230 OB 1
240 OB 0
250 TI 1
260 TBD -2, 260
270 OB -0
280 RT

290 ' Grasp workpiece and move it to laquering station
300 MO 1
310 MS 2
320 OB 2
330 MS 3
340 MO 4
350 SP 10
360 MS 5
370 OB -2
380 MS 4
390 SP 30
400 RT

410 ' Deposite gripper
420 MO 7
430 MS 8
440 MS 7,O
450 RT

460 ' Take red paintgun
470 MO 9
480 MS 10,O
490 MS 11,C
500 MS 12
510 MS 13
520 RT
```

```
530 ' Deposite red paintgun
540 MO 13
550 MS 12
560 MS 11
570 MS 10
580 MS 9,O
590 MO 13,O
600 RT

610 ' Take green paintgun
620 MO 14
630 MS 15,O
640 MS 16,C
650 MS 17
660 MS 18
670 RT

680 ' Deposite green paintgun
690 MO 18
700 MS 17
710 MS 16
720 MS 15
730 MS 14,O
740 MO 18,O
750 RT

760 ' Take blue paintgun
770 MO 19
780 MS 20,O
790 MS 21,C
800 MS 22
810 MS 23
820 RT

830 ' Deposite blue paintgun
840 MO 23
850 MS 22
860 MS 21
```

```
860 MS 21
870 MS 20
880 MS 19,O
890 MO 23,O
900 RT

1000 ' Laquering
1010 ' Red paintgun
1020 GS 460
1030 MO 24

1035 ' Small speed for painting action
1040 SP 5

1050 MS 25
1060 OB 5
1070 MS 26
1080 MS 27
1090 MS 25
1100 OB -5

1105 ' Back to old speed
1110 SP 30

1130 ' Rotate table
1140 OB 6
1150 TI 1
1160 TBD -4,1160
1170 OB 6
1180 TI 1
1190 TBD -4,1190
1191 OB -6

1195 ' Small speed for painting action
1200 SP 5

1210 OB 5
1220 MS 26
```

```
1220 MS 26
1230 MS 27
1240 MS 25
1250 OB -5

1255 ' Back to old speed
1260 SP 30

1270 MS 24
1280 GS 530
1290 ' Green painting
1300 GS 610
1310 MO 24
1320 MS 28

1325 ' Small speed for painting action
1330 SP 5

1331 OB 4
1340 MS 29
1350 MS 30
1360 MS 28
1370 OB -4

1375 ' Back to old speed
1380 SP 30

1390 ' Rotate table
1400 OB 6
1410 TI 1
1420 TBD -4,1390
1430 OB 6
1440 TI 1
1450 TBD -4,1420
1451 OB -6

1455 ' Small speed for painting action
1460 SP 5
```

```
1470 OB 4
1480 MS 29
1490 MS 30
1500 MS 28
1510 OB -4

1520 ' Back to old speed
1530 SP 30

1540 MS 24
1550 GS 680
1560 ' Blue paintgun
1570 GS 760
1580 MO 24
1590 MS 31

1595 ' Small speed for painting action
1600 SP 5

1610 OB 3
1620 MS 32
1630 MS 33
1640 MS 31
1650 OB -3

1655 ' Back to old speed
1660 SP 30

1670 ' Rotate table
1680 OB 6
1690 TI 1
1700 TBD -4,1620
1710 OB 6
1720 TI 1
1730 TBD -4,1650
1731 OB -6

1735 ' Small speed for painting action
```

```
1740 SP 5

1750 OB 3
1760 MS 32
1770 MS 33
1780 MS 31
1790 OB -3

1795 ' Back to old speed
1800 SP 30

1810 MS 24
1820 GS 830
1830 RT

1840 ' Take gripper
1850 MO 7
1860 MS 8,O
1870 MS 7,C
1880 RT

1890 ' Grasp workpiece and move it to WPC
1900 MO 4
1910 SP 10
1920 MS 5
1930 OB 2
1940 SP 10
1950 MS 4
1960 SP 30
1970 MO 3
1980 MS 2
1990 OB -2
2000 MS 1
2010 MO 6
2020 RT

2030 ED
```

Figure 13.   Complete MRL program code for the painting algorithm.