Automatic Applicator
Requirement Specifications

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1 Introduction

This document lays out the specifications for the *Automatic Applicator* being built to fulfill the need of replacing human operator from the job of spray painting plastic parts in order to increase safety, consistency, production throughput and reduce operation costs and wastages of the painitng process.

2 Environment

The layout of the Paint shop at Port Qasim Plant of Auvitronics is as shown in figure 1. The sequence of operations is: Cleaning, Painting, Baking, Stacking in racks, Drying in racks for 24 hours, Quality Assurance, Reworking if needed and Packaging. A video clip giving a tour of the paint shop can be found here[1]. A similar layout is also present in the Hub Plant of Auvitronics and is shown in figure 2. Its video can be found here[2]. Marks A, B, C and D on the figures are the locations where human painters currently operate. Those are the locations at which the robot arm needs to be installed. A number of human operators are moving around these spots for the purpose of moving in the cleaned parts from the Cleaning area and taking out the painted parts from painting area to the baking area. So it is important that the machine is stable in response to any collisions from walking humans. Also, it should have hard safety limits so as to avoid any harm in case of machine error causing parts to go out of the operating zone. These limits should be present in the hardware and not just at the software level. Also, the machine should have protection from paint particles. The temperature of the paintshop is maintained around 25^oC.

3 Performance

3.1 Speed of Operation

Current production throughput of one spraybooth is 400 jobs a day or 50 jobs an hour for the wheel cap. A similar rate is there for all other parts where each job comprises of spray-painting one set arranged on a jig. The speed of

[1] https://drive.google.com/file/d/0B0hRGVYqXqmJWUFpQk9kdjBxNXM/view?usp=sharing

[2] https://drive.google.com/file/d/0B0hRGVYqXqmJbUg4R2wxZ3BZelU/view?usp=sharing

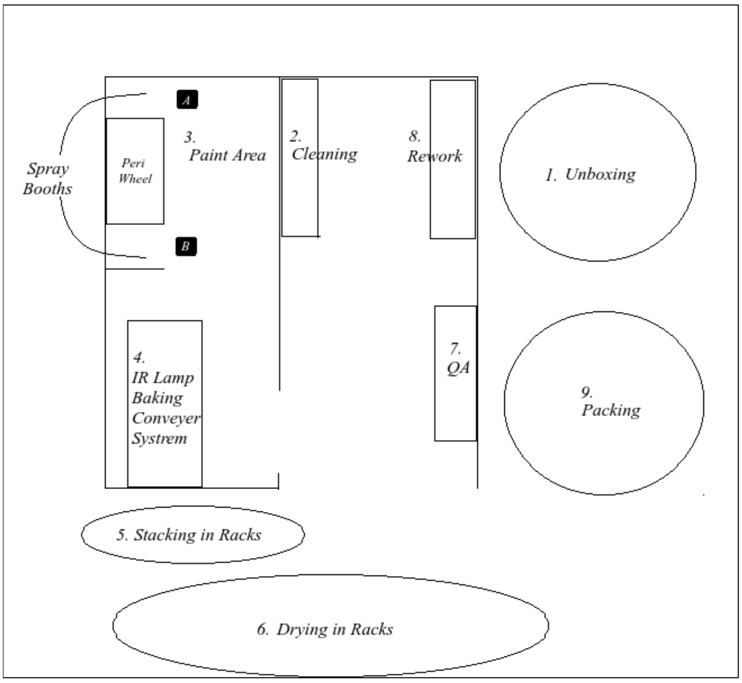

Figure 1: A rough drawing of the existing layout of the paint shop at Port Qasim

horizontal motion based on the maximum sizes of the jigs (5ft $\times$ 4ft) assuming full coverage will be attained by forty-eight 5-feet lines separated by one inch along the breadth. The required speed can be calculated as follows:

$$\begin{aligned} v_{max} &= \frac{\text{motion giving full coverage}}{\text{time per job}} \\ &= \frac{5\text{ ft } \times 48}{1\text{ minute}} \\ &= \frac{240\text{ ft}}{60\text{ sec}} \\ &= 4ft/s \\ &= 1.2m/s \end{aligned} \tag{1}$$

3.2 Spraying Gun Paths and Contours

The parts being painted currently are shown in figure 3. Apart from the wheel-cap all parts are painted in sets arranged in the form of an array fixed on a jig. Figure 4 shows two such jigs. It is important for the purpose of the design to know what the sizes of these jigs are and how many pieces are present in the set of each of these parts when arranged on the jig before painting. Table 1 shows the names of these parts numbered according to the labels present in figure 3 along with the sizes of the Jigs and the count of parts per set. A video showing the human operator painting a robot can be found here[3].

[3] https://drive.google.com/file/d/0B0hRGVYqXqmJWnU3NXE0R1hPODA/view?usp=sharing

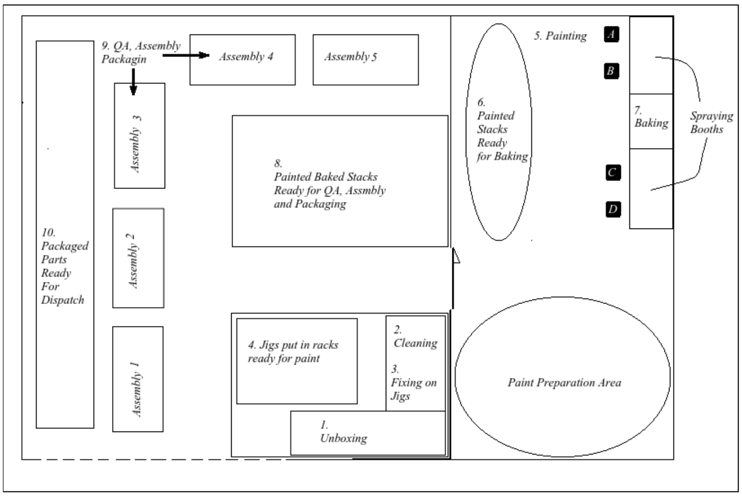

Figure 2: A rough drawing of the existing layout of the paint shop at Hub

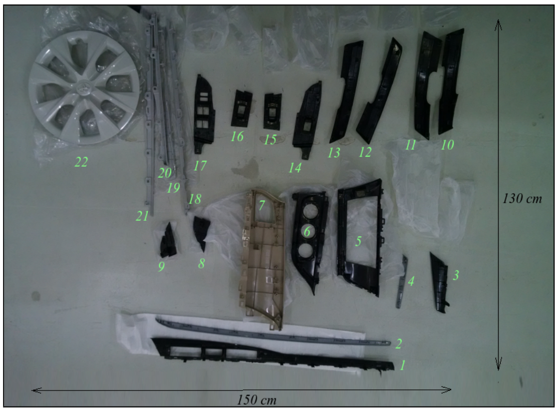

Figure 3: A snapshot of the collection of parts being painted currently

Figure 4: A. Jig for part no. 18—Cover FR Door Trim RH B. Jig for part no. 3—Garnish S/A Inst Panel

S.No.	Part Name	Jig Size	Set Size
1	Garnish S/A Instr. Panel	3 ft × 19 in	5
2	Panel, Instr. CSTR Fin., CTR LWR	3 ft × 14 in	5
3	Garnish S/A Inst Panel	2 ft × 19 in	14
4	Panel Inst Lwr LH	2 ft × 20 in	20
5	Panel S/A Instrument Cluster Finish (BLACK PIANO)	2 ft × 22 in	3
6	Panel S/A Instrument Cluster Finish LWR CTR	2 ft × 20 in	4
7	Garnish Assy, Instrument Cluster Finish Panel	2 ft × 2ft	3
8	Panel RR Door Armrest Base, UPR LH	2 ft × 20 in	18
9	Panel RR Door Armrest Base, UPR LHR	2 ft × 20 in	18
10	Cover Door Assist Grip, RH	2 ft × 20 in	6
11	Cover Door Assist Grip, LH	2 ft × 20 in	6
12	Cover Door Assist Grip, RH (low)	2 ft × 20 in	6
13	Cover Door Assist Grip, LH (low)	2 ft × 20 in	6
14	Switch Set Power Window LH	2 ft × 20 in	10
15	Switch Set Power Window RH	2 ft × 20 in	20
16	Switch Set Power Window LH	2 ft × 20 in	20
17	Switch Set Power Window Master LH	2 ft × 20 in	10
18	Cover FR Door Trim RH	2 ft × 20 in	10
19	Cover FR Door Trim, LH	29 in × 22 in	10
20	Cover RR Door Trim, RH	29 in × 22 in	10
21	Cover RR Door Trim, LH	29 in × 22 in	10
22	Wheel Cap (Radius: 16 in)	N/A	1

Table 1: Parts Being Painted along with Jig Sizes and Part Count per Set

3.3 Programming

The machine should have the ability to be programmed easily as parts are changed. It should have the ability to remember the planned paths programmed with regards to each new part. Its memory should be scaleable and should be able to accomodate any number or type of parts.

3.4 Reach and Precision

The sizes of parts and jigs on which the arm will operate shown in table 1 indicate that the maximum length of the jig is 3 ft and the maximum width is 2 ft. Adding one foot on either side for tolerance, we say the total coverage on the horizontal plane (say XY-plane) should be 5 ft × 4 ft (figure 5). In addition to this, the spray gun should be able to rotate about the X-axis and the Y-axis. This is important in order to allow the spray to access tilted surfaces on the inside of the parts. Since most parts also have near-vertical surfaces, only allowing for the afore-mentioned rotations will not be enough, so we need the end-effector to be able to move vertically (that is, along the Z-axis), such that the spray direction can be made perpendicular to such vertical surfaces on the side of a part. Since the parts are no more than 5 inches long along the Z-dimension and the spray should be 6–8 inches away from the surface, the vertical range should be $1ft + 5in + 8in + 1ft = 3ft1in$ where a one-foot tolerance is added to either side. Also, the range of rotation about the X and Y axes should be $\pm 90^o$ when 0^o indicates the orientation where the spray direction is along the Z-axis. Current wastage of the paint is significant owing to the fixed fluid flow and spread from the spray-gun. If the spread is made narrower wherever needed, wastage can be minimized. This also means that the control of position and orientation of the end-effector should be precise. Better precision will result

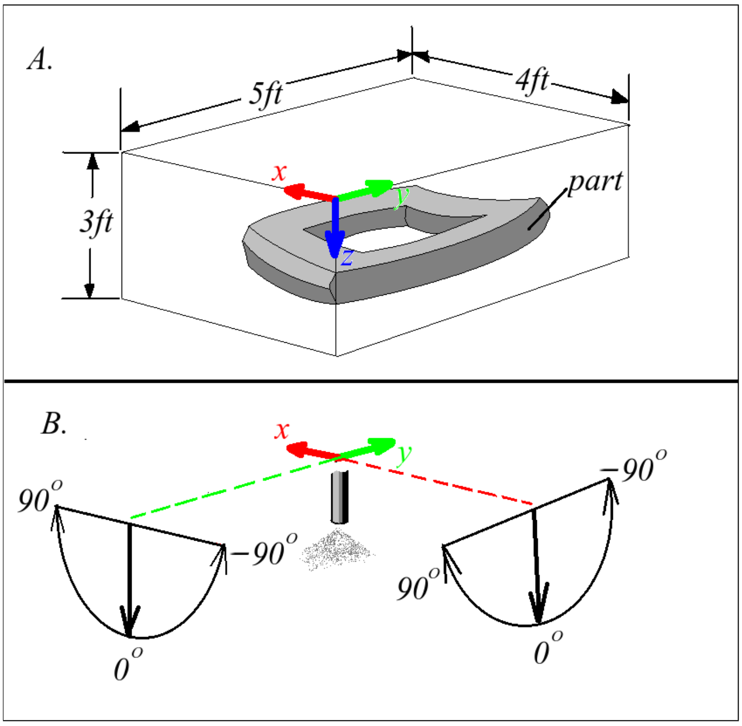

Figure 5: A. Specification for End-effector Position Reach B. Specification for End-Effector Orientation Reach

in minimization of this waste. The precision of control or repeatability offered by other robot manufacturers (such as Motoman[4], KUKA[5] and Staubli[6]) ranges from $\pm 0.02mm$ to $\pm 0.5mm$. So, the precision of the designed robot should at least be better than $\pm 0.5mm$.

3.5 Spraying Gun

The spray gun has three adjustible parameters: *Volume*, *speed* and *spread*. Increasing the *volume* will increase the quantity of the spray coming out of the gun. Increasing the *speed* will increase the speed with which the paint comes out of the gun. And increasing the *spread* will increase the width of the flow coming out of the gun. The path plan being fed to the applicator when it is being programmed to spray a new part should provide the user the ability to program these three parameters along the way. *DevilBiss Compact* spray guns are currently in use. A video showing this gun can be found here[7].

[4] http://www.motoman.com/datasheets/Robot%20Series%20Brochure.pdf

[5] https://www.robots.com/kuka/kr-100-ha

[6] http://www.staubli.com/en/robotics/6-axis-scara-industrial-robot/specialized-robot/painting-robot/rx90-paint/

[7] https://drive.google.com/file/d/0B0hRGVYqXqmJWnU3NXE0R1hPODA/view?usp=sharing

4 Physical Size and Weight

Based on the layout of the plant the footprint of the machine should be limited to 2ft $\times$ 2ft. There is no specific limit on the weight of the machine.

5 Power

The power input to the machine is the standard three phase voltage with 400 / 230V on each phase. Assuming power consumption is the only running cost of the machine, the limit on the wattage of the machine will be determined from the current running cost of human painting. The idea is that the running cost of the machine shouldn't exceed the running cost of human painting. The monthly wages H of the human operator is currently:

$$H = \text{Rs. } 22,000 \text{ per month} \tag{2}$$

In order to find out the hourly expense h of a human operatoror we divide it by the number of work-days in a month and number of work hours every day:

$$\begin{aligned} h &= \frac{\text{Rs. } 22,000/\text{month}}{26\text{workdays/month} \times 8\text{work-hours/day}} \\ &= \text{Rs.}105/\text{hour} \end{aligned} \tag{3}$$

The current electicity charges are Rs. 18 per kiloWatt-hour, so we conclude that the upper-limit P_{max} of the power consumption is:

$$\begin{aligned} P_{max} &= \frac{\text{Rs. } 105/h}{\text{Rs. } 18/kWh} \\ &= 5.83kW \end{aligned} \tag{4}$$

Such a power consumption will result in the same operation cost as a human operator. Of course, the actual consumption should be much lower than this to financially justify replacement of a human operator with a machine and to recover the purchase cost of the machine well before its life ends.

6 Life and Cost Specification

Say, L is the number of months in which we want the investment of the buyer to fully recover. And say P (kW) is the operating power consumed by the machine then the monthly savings S will be:

$$\begin{aligned} S &= \frac{P_{max} - P}{P_{max}} \times H \\ &= \left(1 - \frac{P}{P_{max}}\right) H \end{aligned} \tag{5}$$

Then the price p at which the buyer purchased this machine is:

$$\begin{aligned} p &= SL \\ &= \left(1 - \frac{P}{P_{max}}\right) HL \end{aligned} \tag{6}$$

Working on designing such a machine is financially feasible for the company if the overall revenue generated by the machine as a result of this project exceed the overall costs. If the cost of production of one machine is C_p, the design cost is C_d and the estimated number of pieces we will sell is n then:

$$\begin{aligned} C_p + \frac{C_d}{n} &< p \\ C_p + \frac{C_d}{n} &< \left(1 - \frac{P}{P_{max}}\right) HL \end{aligned} \tag{7}$$

The relationship 7 is the specification for the power consumption, useful life of the machine, production cost of the machine and design cost of the machine. If the inequality is satisfied by a good enough margine, then the project is satisfying our specifications. As an example, if the life of the machine $L = 60$ months, power consumption $P = 1kW$, number of pieces we will put to use or sell are $n = 15$, design cost is $C_d = \text{Rs.}800,0000$ then the production cost should stay well below $\left(1 - \frac{P}{P_{max}}\right) HL - \frac{C_d}{n} = \left(1 - \frac{1kW}{5.83kW}\right) \times \text{Rs.}22,000 \times 60 - \frac{\text{Rs.}800,000}{15}$ $= \text{Rs.}10,40,286$

7 Conclusion

The purpose of this document was to lay out the specifications that need to be satisfied in order for the project to be deemed as satisfactory, successfully meeting the goals we laid out in the *Statement of Need*. We specified in the preceding paragraphs the environment, the requirements on speed, reach, precision, spraying, power, life, cost and size of the machine. This document should serve as the basis on which design decisions for the project are taken.

8 List of Companies who Provide Painting Robots

1. YASKAWA[8]—US
2. Compass Automation[9]—US
3. irbs[10]—US
4. KUKA[11]—Germany
5. SMR[12]—Germany
6. FANUC America[13]—Japan
7. ABB China[14]—China
8. Alibaba Automatic Paint shops[15], Honglichang[16], TradeIndia[17]—China
9. Staubli[18]—Switzerland
10. Epistolio[19]—Italy
11. Surface Finishing Systems[20]—Malaysia
12. -Ecopaint[21]—US
13. -Eisenmann[22]—Germany
14. -Kawasaki[23]—Japan
15. -Doolim[24]—Korea
16. -ABB Australia[25]—Switzerland
17. -Paintbox[26]—UK
18. –INTECH Powercore[27]
19. –Turbo Spray[28]
20. —ISRA Vision[29]
21. —-Benet Automotive[30]

9 Other possible specifications?

Do your research!

1. The Art of Industrial Painting with Robots[31]
2. Applying Robotics to your Paint Line[32]
3. Progress in Robotic Painting Systems[33]
4. A New Generation for Paint Robots[34]
5. Automotive Painting Technology into the 21st Century[35]
6. -Robotics Bible[36]

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[8] http://www.motoman.com/products/robots/painting-robots.php

[9] http://www.compass-automation.com/

[10] http://www.irbs.us/implementacion.php

[11] http://www.kuka-robotics.com/en/solutions/branches/automotive/start.htm

[12] http://www.smr-automotive.com/painting.html

[13] http://robot.fanucamerica.com/Products/Robots/painting-robots.aspx

[14] http://www.abb.com/References/Default.aspx?db=db/db0003/db001466.nsf&c=388F798560C0E2AAC1257559003B752B

[15] http://www.alibaba.com/product-detail/Robot-Paint-Shop-for-Automotive-Parts_557884730.html

[16] http://www.honglichang.co.in/robotic-painting-line-for-automobile-parts-2539502.html

[17] http://www.tradeindia.com/selloffer/4518892/Robot-Paint-Shop-For-Automotive-Parts.html

[18] http://www.staubli.com/en/robotics/robot-solution-application/painting-robot/

[19] http://www.epistoliorobot.com/en/

[20] http://gse-m.com/products/sfs/

[21] http://www.durr.com/fileadmin/user_upload/Erlebniswelt/Innovations/DURR_EcopaintRobot_EN.pdf

[22] http://www.eisenmann.com/en/products-and-services/general-finishing/paint-shops-for-plastic-parts/paint-systems.html

[23] https://robotics.kawasaki.com/en/applications/robotic-painting/

[24] http://www.doolim-robotics.com/source/images/img/media/Doolim_cat2015_Coating_e.pdf?ckattempt=1

[25] http://www.abbaustralia.com.au/cawp/seitp202/c821f1979f2a2ba3c1257ecd001ca713.aspx

[26] http://paintboxuk.com/paint-application

[27] http://www.intechpower.com/products/cast-parts-for-electrically-insulated-robotic-arm

[28] http://www.turbospray.com/finishing-systems-2/

[29] http://www.isravision.com/AUTOMOTIVE------_site.site..html_dir._nav.193_likecms.html

[30] http://www.benet-automotive.cz/en/production/paint-shop

[31] http://www.robotics.org/content-detail.cfm/Industrial-Robotics-Industry-Insights/The-Art-of-Industrial-Painting-with-Robots/content_id/4447

[32] http://www.pfonline.com/articles/applying-robotics-to-your-paint-line

[33] www.ifr.org/index.php?id=59&df=Progress_in_robotic_painting_systems.doc

[34] http://www.automotivemanufacturingsolutions.com/process-materials/a-new-generation-for-paint-robots

[35] http://issinstitute.org.au/wp-content/media/2011/04/ISS-FEL-REPORT-C-KELLY-low-res.pdf

[36] http://www.roboticsbible.com/spray-painting-robot.html