ROBOTHINK SUMMER CAMP ‘21

RACHSAW

REPORT FILE

A Smart Car Washing Robot

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Problem Statement :

Automated Car washing Robot/system:
Go through the various aspects of Car washing, cleaning. Develop a Car washing system with robotic hands , brushes, water sprinklers etc and the system should be automatic, which performs primary washing and under secondary washing it should detect any stains and clean it. Go through all the possible Car washing systems and explore every pin-point area and come up with a report for good Automated Car washing system (It may be a Mobile robot or a System)

There are more than 30 million cars running in India and the number is expected to double in a couple of years. Car Washing is an important task that needs to be performed to maintain the car in a good condition. The existing solutions to this task take up a lot of resources and time. Hence there is a strong need for an Automated and Efficient Car washing Robot. The problems we address here are :

1. Waterwash all sides of the car primarily.
2. Clean the stains on the car if any.

3. Minimize the amount of resources being used.
4. Reduce the time taken to clean the car.
5. Minimize the complexity of design.
6. Obtain an Economically Feasible and Viable solution.

Impact of Solution :

Solving Water Crisis :

Regular car-wash service stations consume more than 120 to 150 litres of water for a single wash. This is a huge number considering the number of cars that are being washed daily. And most of the existing car-washing solutions spend the same amount of water for both heavily-stained and a relatively cleaner car. On the other hand, our smart bot is aware of the stains in the car and spends water accordingly. This would bring down the amount of water being used per wash greatly.

Mobility and Complexity :

The existing solutions are heavy, complex (in design) and are stationary. Our bot takes up less space than the usual ones and is mobile as well. We have kept the design of the bot simple and user-friendly.

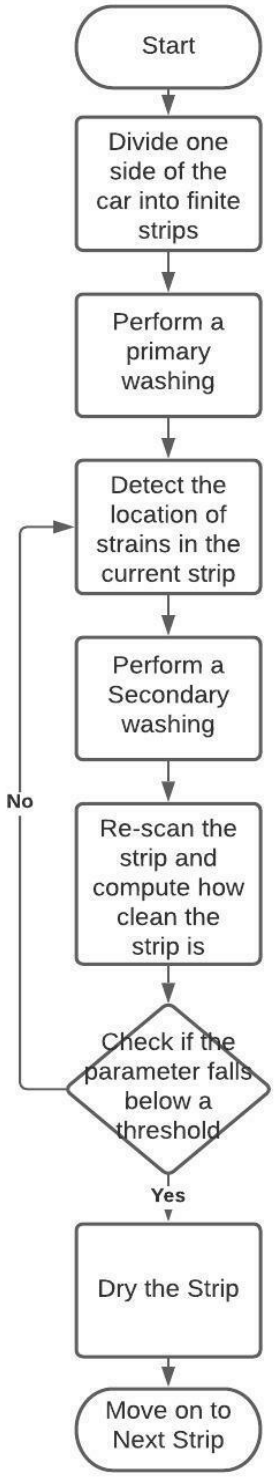
Cost :

Most of the existing car washing services are costly. The average price of a car washing system ranges from Rs. 8 Lakhs to Rs. 30 Lakhs. Our bot is way cheaper than most of the existing solutions. If the cost could be further reduced, we could make this a personal household bot.

Beyond Automation :

There are a lot of health hazards in working on areas of water and detergents for a long time. The bot not only cuts down the man-force used in the car washing, It also goes beyond mere automation. Our bot is smart in the sense that It is integrated with a mobile app, thus giving the user a seamless experience.

Mechanism of Bot :



Strip method cleaning

When the Ultrasonic sensor detects presence of the, It measures length of the car, and divides the car into four strips. Each strip is cleaned separately one after the other. Command to move to the other strip is given only after the respective top, left, right parts of the strips are cleaned.

Primary washing

In the primary washing, the nozzles cover from top to bottom to clean the car. While the nozzle is in motion, pressure changes with height and the velocity of the ejected water is adjusted according to height. Parallelly, cameras are attached to the nozzle to detect the stains and their coordinates. Brushes at the bottom are used to clean wheels, in the primary washing.

Secondary washing

In the secondary washing, The stains are detected and the brushes are moved to the location of stains. A small nozzle is attached inside the brush which has a fixed amount of shampoo stored in it. The small nozzle (embedded in the brush) will move towards the coordinate and spray **3 ml** of shampoo and go inside.

Brush drills **360 degrees** with the speed of **1600rpm** and it cleans the rectangular area of stains for the required amount of time. Water is spared to check the stains percentage, If the stain is less than the threshold value, meanwhile brush rests /delays till the other side brush finishes cleaning else it will go for another wash. When all the sides of the first strip are cleaned , the bot moves to the other strip with the help of a motor (the wheels are adjusted to move).

The process repeats till it cleans four strips.

The structure of the bot is symmetrical and heavy enough. Hence, It is quite structurally stable, even under the reaction force caused due to the water leaving out of the nozzles.

Link for Animation :

https://drive.google.com/file/d/1zdn4qhqnn7fKnDonbEJkUWXi0OftcJGs/view?usp=sharing

Design of Chassis :

Nozzle Design :

Washjet nozzles are being used where 25° spray angle nozzles are used for pre rinse (**primary washing**) as well as for washing the soap after the application of brushes (**secondary washing**).

Nozzles are installed on a manifold. Distance between the car surface and nozzle is detected by the ultrasonic sensor and the links attached to the rectangular component are adjusted to maintain a **40 cm gap**.

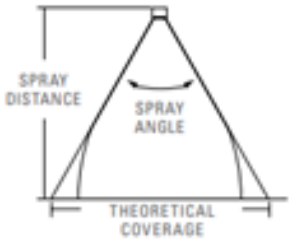
Nozzles with pressure **1000 psi** and flow rate of **1 GPM** with diameter 1mm are selected from the table-1.

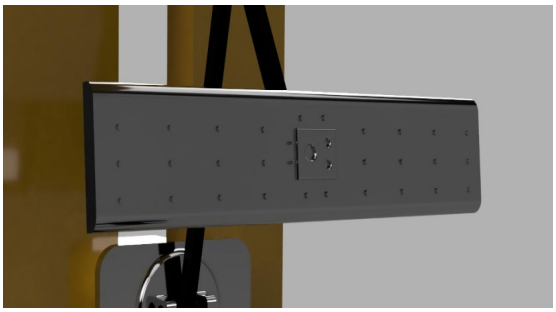
PERFORMANCE DATA:
STANDARD ANGLE SPRAY

Inlet conn. (in.)	Nozzle Type	Spray Angle			Capacity Size	Flow Rate Capacity (gallons per minute)							
	CERMEG	15°	25°	40°		300 psi	500 psi	750 psi	1000 psi	1500 psi	2000 psi	2500 psi	3000 psi
1/4	•	•	•	•	02	.55	.71	.87	1.0	1.2	1.4	1.6	1.7
	•	•	•	•	025	.68	.88	1.1	1.3	1.5	1.8	2.0	2.2
	•	•	•	•	03	.82	1.1	1.3	1.5	1.8	2.1	2.4	2.6
	•	•	•	•	04	1.1	1.4	1.7	2.0	2.4	2.8	3.2	3.5
	•	•	•	•	05	1.4	1.8	2.2	2.5	3.1	3.5	4.0	4.3
	•	•	•	•	06	1.6	2.1	2.6	3.0	3.7	4.2	4.7	5.2

Table-1

Nozzle with **25** ° spray angle and at a spray distance of 40cm has theoretical coverage of **17.7cm**. Here for the calculations, car measurements used are:



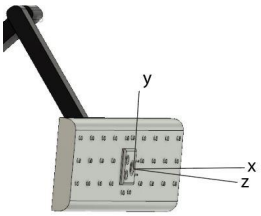


- **Length**: 3.0-5.0 m
- **Width**: 1.7-2.0 m
- **Height**: 1.6-2.0 m

The maximum area of 1 strip is 1.25*2 m^2. Maximum length of 1 strip is 1.25 m. Thus in order to cover the entire strip, around 8 nozzles are needed along the length. Total of ***28 nozzles*** are installed on the manifold with 8 nozzles in 1 row and 3 columns. 2 nozzles are attached on both sides of the cameras. The length and breadth of the manifold are around 1.2m and 0.4m respectively.

On the roof/top of the bot, the nozzles have to be installed such that it covers the width of the car. The maximum width of the car is 2m. So around 12 nozzles are required. Total of ***40 nozzles*** are installed on the manifold with 12 nozzles in 1 row and 3 columns. 2 nozzles are attached on both sides of the cameras. The length and breadth of the manifold are around 2m and 0.4m respectively.

To get pressurized water, the **pump** and **motor** need to be connected from the water source to the nozzle manifold which is connected by a high pressure flexible hose. In our case, around 96 nozzles each with 1 GPM. So the total flow rate is 96 GPM i.e. 363 LPM. Thus we use a pump with around **400 LPM** maximum flow rate. Also a **back pressure regulator** is used to control the flow of the pump. It maintains a defined pressure upstream of itself, at its own inlet. When fluid pressure at the inlet exceeds the setpoint, the valve opens to relieve the excess pressure.



To slide the nozzle assembly, an **electromechanical linear actuator** is used to travel in y- direction. It moves with a speed of around 0.25m/sec.

A **solenoid valve** is an electromechanically operated valve. A solenoid valve has two main parts: the solenoid and the valve. The solenoid converts electrical energy into mechanical energy which, in turn, opens or closes the valve mechanically. Solenoid Valve is used to turn the water supply on or off.

Brush Design

Brush is at rest for the first half of the cleaning (primary cleaning).

Brush Mechanism

Coordinates of stains are given by the sensors, brush require to reach the points on the car and this can be done by the following mechanism
The brush has **3** degrees of freedom with a slider to actuate in the x-direction, the remaining links are joined through the **revolute joint** with angle constraints to reach every point on the car surface

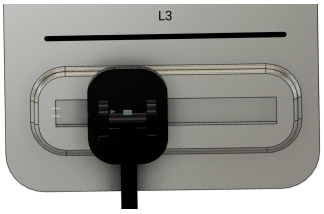
The computer controls the arms by rotating individual **servo motors** connected to each joint. Unlike ordinary motors, servo motors are much lighter and readily available.
The potentiometer constantly monitors the position of the output spline.When the output spline reaches the desired position, the power to the motor is cut and the servo will hold that position until it receives a signal not to. While stopped in a given position, a servo motor will actively try to hold that position.
This allows the computer to move the arm very precisely. The robot uses motion sensors to make sure it moves just the right amount.

Standard **40g to 79g 20mm 38mm**
High precision and high repetition**(ac)**
brushless is less noisy
Brush hands have built-in **force sensors** that tell the computer how hard the arm is thrusting the brush placed on the car. This keeps the robot from breaking the car surface. To apply optimum pressure on the car surface while washing, the distance between the car surface and the bot should be less than the sum of the length of the two links

l1+l2> distance b/w car surface and bot
average car size: 1693mm-1895mm
2*Gap b/w car and bot: 2238-2400mm
let's consider l1+l2=1250mm to reach all the points on the car
l3 is the length of the slider: 1250mm(one strip length)
Thickness and width of the link=100mm

Side brush mechanism :

When the slider is adjusted to the corresponding x from given coordinates side links in the mechanism follows two degrees of freedom
Relation between the angle made with both links with horizontal is given by:
Θ1 = angle between the link1 and horizontal
Θ2 = angle between the link2 and horizontal
y, z coordinates to be aligned



$l_1 cos(\theta_1) + l_2 cos(\theta_2) = z$

$l_1 sin(\theta_1) + l_2 sin(\theta_2) = y$

$Let\ A = y,\ B = z, C = ((z^2 + y^2 + l_1^2) - l_2^2)/(2 * l_1)$

$Asin(\theta_1) + Bcos(\theta_1) = c$; solve for θ_1

$tan(\theta_2)$=(y-$l_1 sin(\theta_1)$)/(z-$l_1 cos(\theta_1)$) ;solve for θ_2

The angle between the links is controlled by the microprocessor.

A small nozzle is used inside the brush to spray the shampoo

- 1.45mm nozzle size
- 65° spray angle
- 1/4" MNPT threaded connection
- Gray Polyvinylidene Fluoride (PVDF) polymer body
- Chemical resistant

- Maximum flow: 1.77 GPM
- Maximum pressure: 500 PSI
- Distortion-resistant body shape
- Weight: 0.01 lbs.

The brush is controlled by the battery inside the connecting link which turns on after shampoo is spared. The brush is rotated at a speed of 1600 rpm and cleans the stains for 10 seconds.

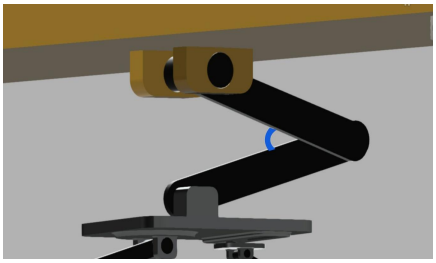
There are two **12v three 18650 cell pack lithium-ion batteries** provided with a charger Brushes rub the surface for two minutes on the detected rectangle. Battery Weight and dimensions:135 Grams (LxWxH)6.8 x 5.5 x 2 Cm.

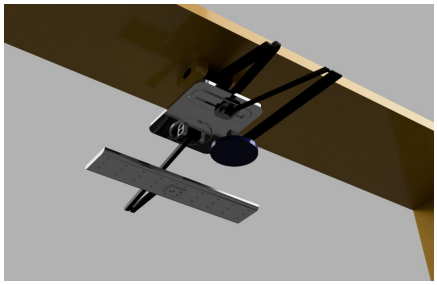
The brush goes back and rests on the bot to avoid the disturbance with the nozzle mechanism, the nozzle will rinse the strip to clean the foam, cameras take photos after the rising is done and detect the stains.
If the stains are less than the threshold value it delays till the other parts complete the cleaning else bot is moved to the other strips.

Top Brush :

The Ultrasonic Sensor is placed in top part of the bot which can detect the distance between car and surface and fixed support if it exceeds/reduces the value of 0.4 meters the rod extends (the motor rotates such that it will maintain constant distance)

Length of the two rigid links is 780mm
Angle they are making in rest position: 22 degrees
Angle between the link of arm in rest position =10 degrees

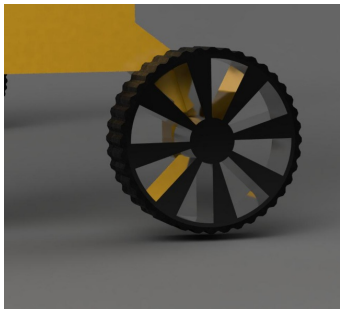




Wheel Design

Mechanism of wheel

The IR sensor detects the car, when the car is detected, wheels start moving towards the car, and stops when the object is not detected, from here we can calculate the length of the car.After reaching the end of the car, wheels move to the opposite direction by L/8(L=length of the car).Speed of the wheels which they rotate while calculating the length of car = 0.4m/sec (2 radians/sec)
The radius of the wheel=0.2meters ; Width of the tyre is 200mm
When the strip is cleaned the wheels move towards the second strip by L/4 distance

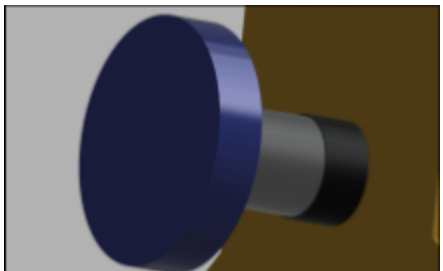


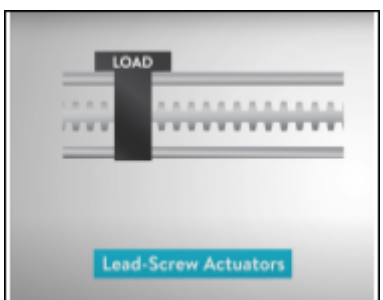
Working principle

The wheel has motion only in one dimension so positive velocity is given to move front and negative velocity is given to move backward using four Omron Servo Motor(Peak torque 300% of continuous torque,sizes from 50 W to 1.5 kW, rated speed 3,000 rpm)connected to the wheels operated by the accelerometer.

Brushes for car wheels

In the primary washing parallel to the nozzle, brushes are placed at the bottom with the stroke length of 1.25 meter towards the car to clean the wheels of the car, a **lead screw actuators** are placed inside the brushes to control linear motion and motor is used to control the rotation of the brush.
Material used for brushes are Synthetic Wool because it is incredibly soft, doesn't flick dirty water back and is chemical free.





Material used :

To make the chassis of the bot, Aluminum is used because:

1) Aluminum is lighter than iron and stronger enough. Aluminum strengthens the robot and makes it light weighted.

2) As the robot will always be in contact with water and hence the metal should not rust. Aluminum does not rust easily and hence it increases the life of the robot and minimizes the cost of maintenance.

3) Aluminum is cheaper than steel and hence it reduces the manufacturing cost.

The special type of aluminum known as ‘Clear Satin Anodized Aluminum’ is used. Its properties are so great that it is used in various fields, projects and many more.

Aluminum (Satin) is used in making the chassis of the robot. The same metal is used in arms of brushes and nozzle plates. Black Oxide is used as coating for these arms. Metal Flake (Yellow) colour is used to paint the body of the robot. The paint/coating used not only makes the robot glow but also protects its parts from corrosion.

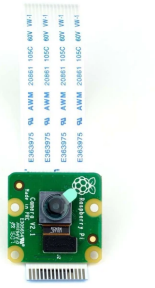
For the wheels, steel is used. Galvanization is done to protect it from rusting. The rubber is used in order to increase the friction between wheel and ground. This avoids sliding of the wheels.

Sensors:

Camera

Purpose: To take pictures of strips which will then be fed into the algorithm for stain detection. this will be connected to raspberry pi

Model: Raspberry Camera VW-1Raspberry Pi Camera Module V2 8 Megapixel 1080P
Number needed: 3
Position: In all the nozzles
Size: 25 mm x 23 mm x 9 mm
Price: 180 $ approx for 3 camera



Connecting the camera and code to use it:

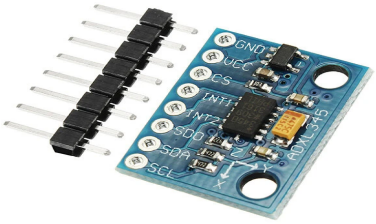
Sample Code to use :

```
from picamera import PiCamera
from time import sleep
import cv2

camera = PiCamera()

for image in camera.capture_continuous(rawCapture, format="bgr", use_video_port=True):

    frame = image.array
    frame = cv2.flip(frame,1)
    loct,area = DetectStains(frame)
```

Reference : https://projects.raspberrypi.org/en/projects/getting-started-with-picamera

Accelerator Sensor

Purpose: To measure acceleration of the bot.
Working: With the output given by the accelerometer, we will control the motion of the bot
Model: Raspberry Pi **ADXL345** Accelerometer
Number :1
Size:1.3 x 2.3 cm
Price : 7$
Reference :
Connecting the accelerometer:



Hardware requirements :

1. I2C adapter
2. ADXL345
3. Lan cable

4. Micro usb cable

Python code to be run: https://github.com/ControlEverythingCommunity/ADXL345

Force Sensor

Purpose : To measure the force applied by the brush of the bot.
Number :5
Price per piece : $6
Position : on the brushes
Size:
Overall length: 2.375"
Overall width: 0.75"

Sensing diameter: 0.5"

How it works:
Model: SPRK-SEN-09375

Reference :
https://learn.adafruit.com/force-sensitive-resistor-fsr/using-an-fsr

Ultrasonic sensors

Purpose : To measure the distance between surface of car and nozzle/brush
How it works: Ultrasonic sensors work by emitting sound waves at a frequency too high for humans to hear. They then wait for the sound to be reflected back, calculating distance based on the time required.
Position : all nozzles and brushes
Price : $4
Number :8
Model :HC-SR04
Reference :

How to use and code to run:

https://tutorials-raspberrypi.com/raspberry-pi-ultrasonic-sensor-hc-sr04/

Pressure sensor

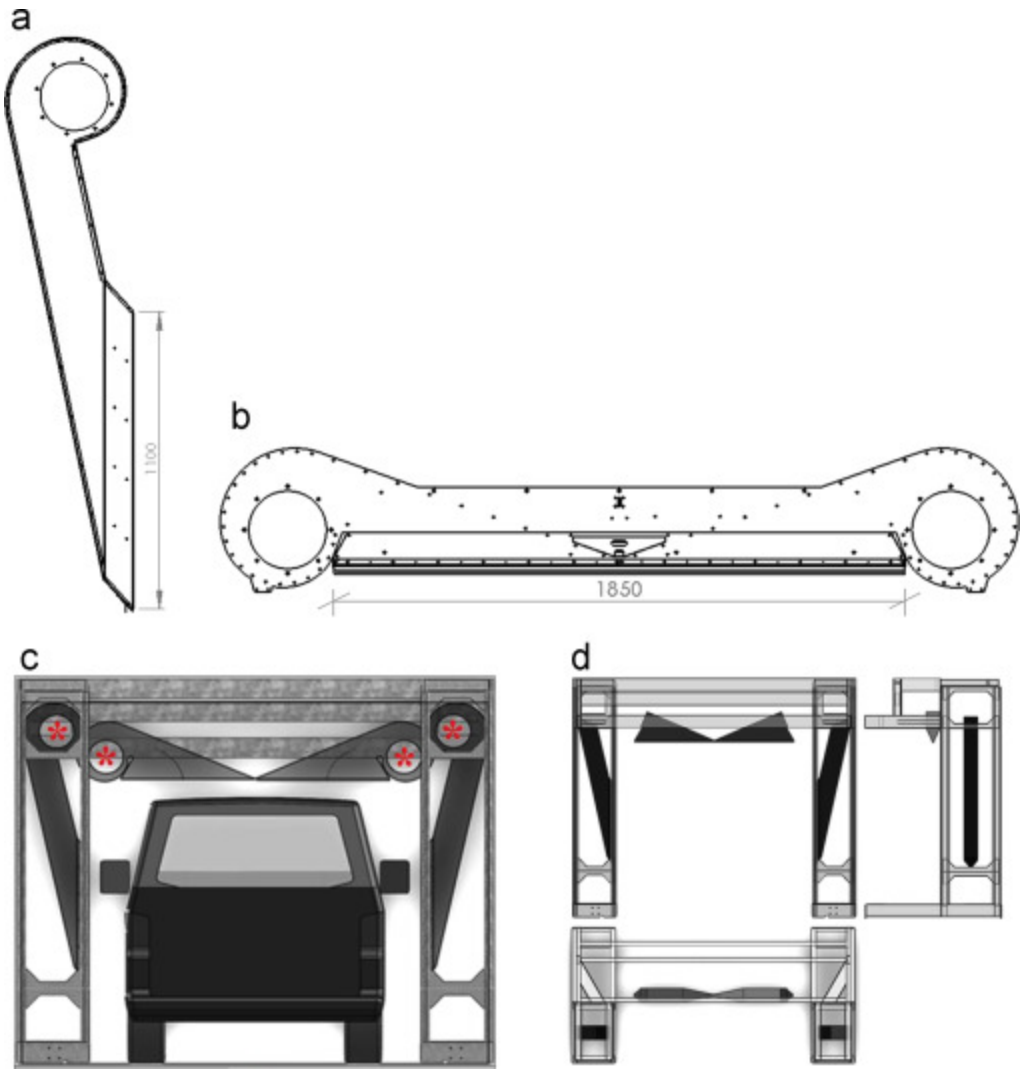
Purpose: To detect the pressure at which the water enters the bot from external source
Position : in the pipes
How it works: These mechanical water flow meters work by measuring the speed of flowing water running through the pipe that causes a turbine or piston to rotate. The volumetric flow rate of the water is proportional to the rotational speed of the blades.
Model: DIGITEN G1/2" Water Flow Hall Sensor Switch Flow Meter 1-30L/min

Dryer :

This Dryer is designed as an add-on to our Car washing bot.

Design :

The architecture of the drying system of the present car washing machine is composed of two fixed vertical dryers on the sides, a horizontal dryer which is movable.



a. Represents one of the two vertical dryers.
b. Represents the horizontal dryer.
c. Represents the position of the entire drying system relative to the vehicle.
d. Represents the standard view of the drying system.

Working :

The vertical dryers are fixed on the sides which are accommodated in the columns and are fed by two centrifugal fans.The horizontal dryer is movable with two centrifugal fans mounted at each end.The horizontal dryer is controlled to move vertically with the help of an ultrasonic sensor which detects the presence of the vehicle in the drying area and enables the dryer to follow its contour and precisely position relative to the surface.(The distance between the tip of the dryer and the car surface is usually maintained between 10 to 20 cm for effective drying).

The ideal drying system forces the water droplets downwards away from the roof and sides of the vehicle. Both the dryers are equipped with 3KW fans.The horizontal dryer's outlet has an area of 1850×18mm^2, while that of the vertical one is 1100×18mm^2.(based on an average car).

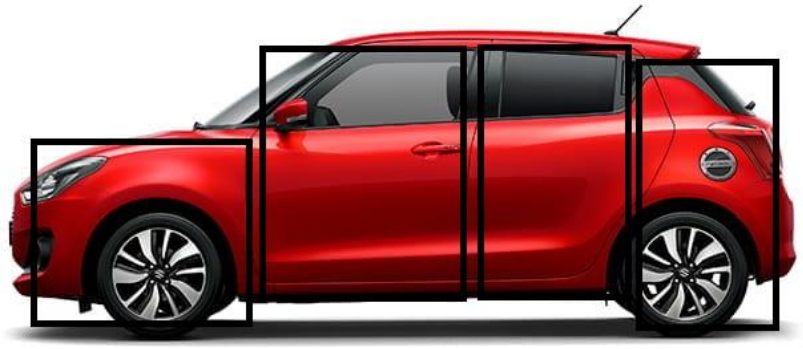
Details of Fan :

It's a centrifugal single-inlet medium pressure fan. The technical specification are:

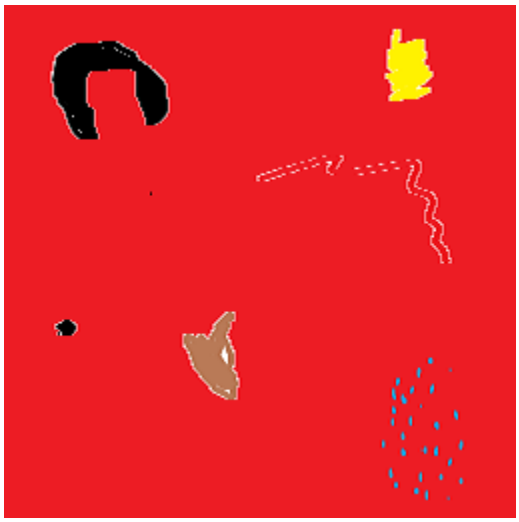
Model	Velocity (r/min)	Maximum current permissible (A)	Installed power (kW)	Maximum flow (m3/h)	Sound pressure (dB)	Weight (kg)
CMP-1025-2T-4	2895	10.57	3	2830	77	37.6

Stain Detection :

In this section, let me explain about the algorithm employed by the bot to detect the stains on the surface of the car. As explained in the Mechanism Section, the side of the car is first divided into 4 vertical strips and each of them is cleaned one after the other. The below pictures describe this strip division mechanism for the side surface of a typical car.



Now further in a single strip, say the second one, the camera takes multiple images(for better quality) and flattens them out into a single image which is further used for processing. A sample of such an image(with stains) is shown below.



The above image is a representation of a single patch in a strip with stains on it. The above image is drawn such that all kinds of stains are taken into consideration. Like :

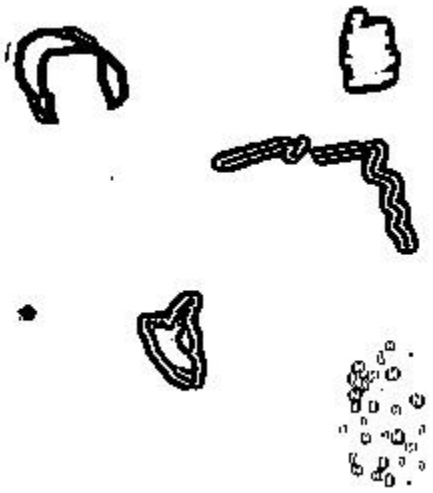
1. Convex polygons
2. Concave polygons
3. Small stains
4. Stains of various colors

5. Stains which are of the same colour of car body
6. Group of smaller stains representing mud splashes

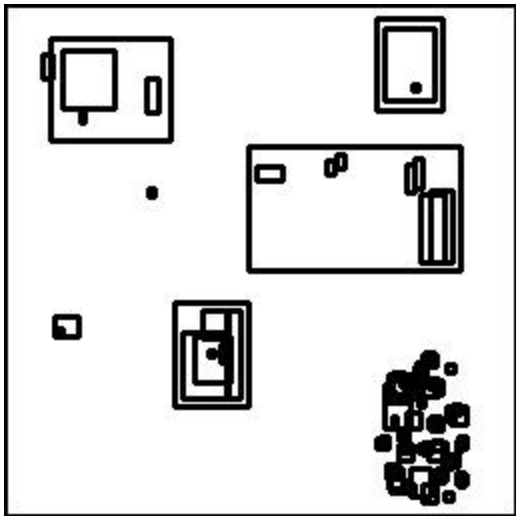
Now our Stain detection algorithm must be powerful enough to detect them and output of the coordinates of each of the stains.

STEP 1 : So we first read the image and convert it into grayscale for easier processing.

STEP 2 : Then we perform adaptive gaussian thresholding to remove the background and get accurate pictures of stains.

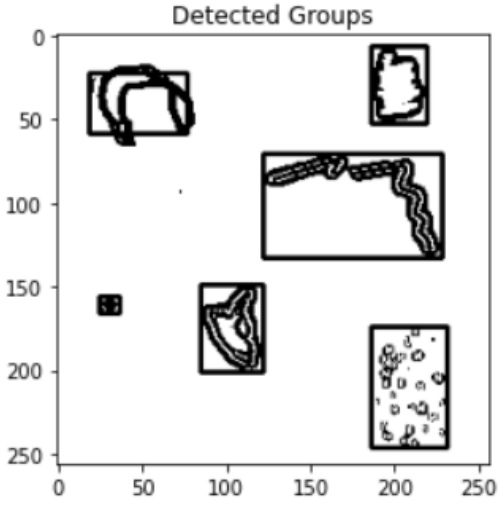


STEP 3: Next we detect the contour lines in the picture and approximate them using rectangles. But the problem here is this would consider each of the small stains as individual stains, even if some of them are very close to each other.



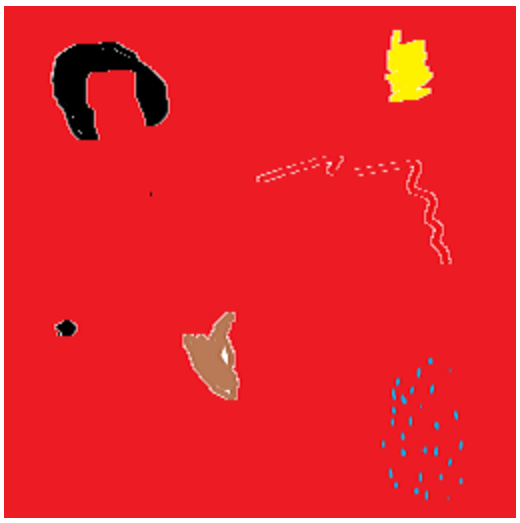
STEP 4: To avoid the above mentioned problem, we group the stains together as clusters by fixing a maximum threshold distance. This would result in the patches of small strains to be considered as one. One such cluster is shown below.

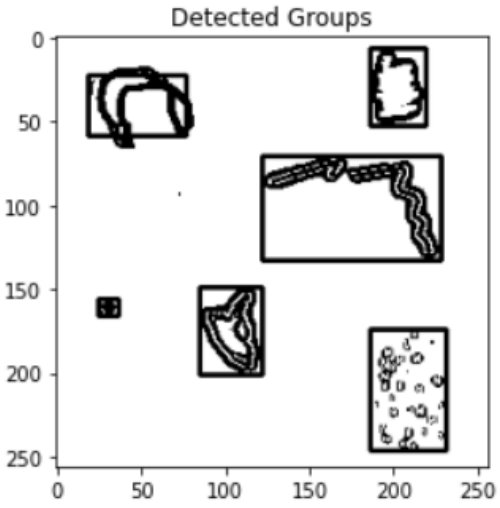
STEP 5 : Now the output that needs to be sent to the nozzles is the location and area of this stain. Hence we bound this stain by a rectangle and also remove the redundant rectangles formed if any. The final detected stain groups are given in the below picture.



Feeding in different hand-drawn images of car surfaces with stains to this algorithm yielded in the below results.

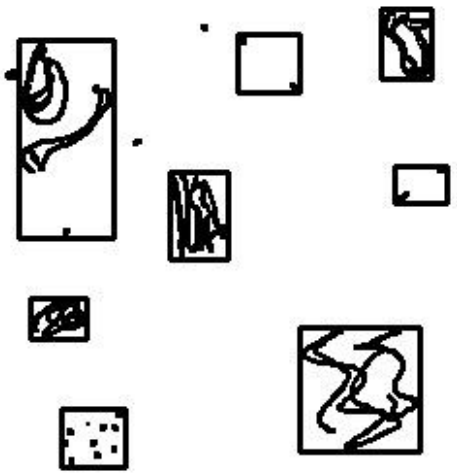
SAMPLE 1 RESULT 1





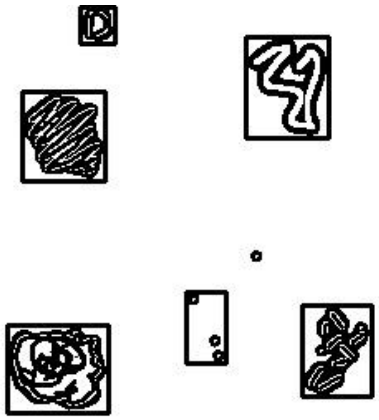
SAMPLE 2

RESULT 2



SAMPLE 3

RESULT 3



It is evident from the above results that our algorithm is performing quite a good job in detecting stains. The source code we wrote for the above mentioned algorithm can be found in the link given below.

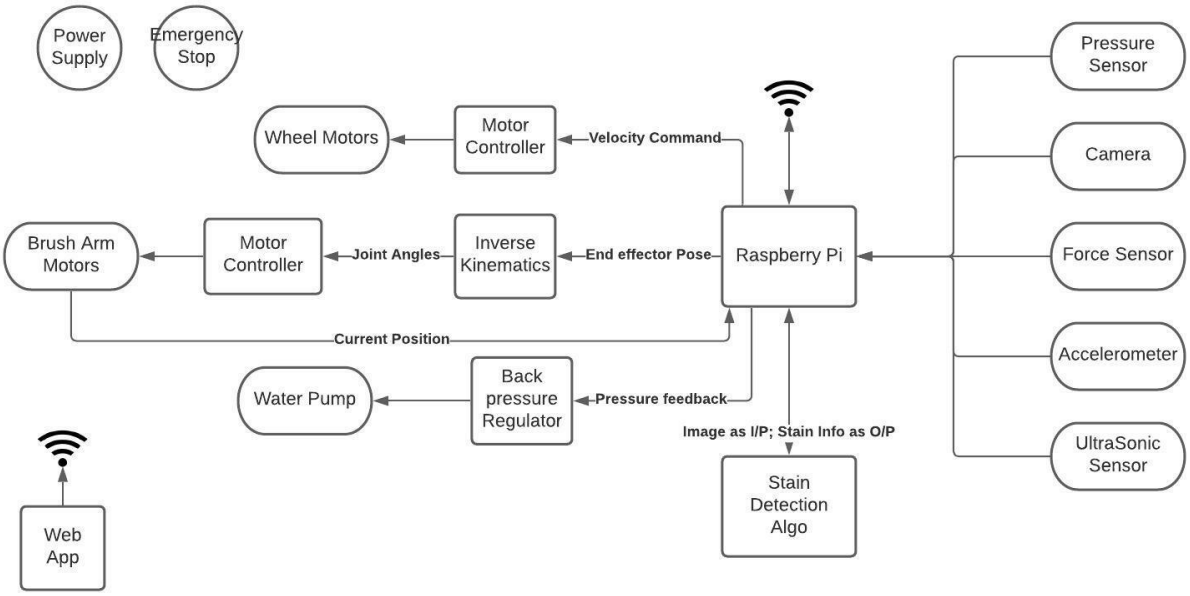
LINK : https://github.com/HR-1-1/Rachsaw.git

Programming and Communication :

We use the ROS platform to program our bot to perform the needed tasks and achieve integration between various components. We use the Raspberry Pi, a Single - board computer, as our computing platform, which is ROS compatible.

The integration of sensors,nozzles,brushes and motors is achieved using a Raspberry Pi. The board takes in inputs from cameras and sensors. And processes it to get the location of stains and their area. Next it gives the required instructions to motors present in links to guide the nozzle and brushes to the desired location. Also once a single strip is cleaned, The instruction is sent to the motors attached to the wheels to take the bot to the next strip. Meanwhile, a feedback loop is established between the back pressure regulator and the pressure sensor in the nozzle, through which the pressure is regulated.

The below picture shows the ROS Block diagram of the communication that takes place between various components of the bot.



Smart-Bot :

The Rachsaw bot is integrated with a mobile application, through which the user can select the type of wash he wants - the primary wash OR primary + secondary wash.This option is introduced because some cars may not need a secondary wash if it is relatively clean. If the owner feels so, then he could opt for a primary wash via the mobile app, thus saving water and time. Also, the bot sends a message to the user once the car wash is finished. This further reduces human intervention. Also the database of cars washed everyday with their details is stored in the cloud.

Power :

In order to ensure the normal operation of the control system in the case of power failure, the double power supply circuit shown in Figure is designed.

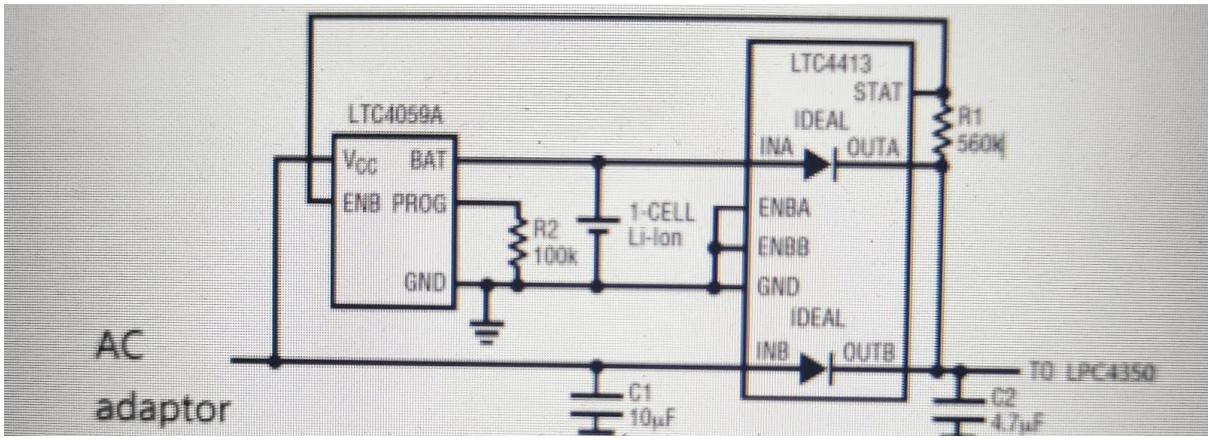


Fig : Dual power supply circuit

The function of the circuit in Figure is to automatically switch the power supply of the control system (or load) from the battery to the AC adapter and control an LTC4059A battery charger. When the AC adapter is not connected, LTC4413 connects the load to the lithium-ion battery, the stat pin is at high level, and the battery charger fails. If the AC adapter is connected, the load voltage will rise as the ideal diode is connected between the inb and outb pins. When the load voltage exceeds the battery voltage, the battery will be disconnected from the load immediately, and the voltage of the stat pin will drop, so as to turn on the LTC4059A battery charger and start a charging cycle. When the AC adapter is removed, the load voltage will drop sharply. When the voltage drops below the battery voltage, the battery will resume to supply power to the load, and the voltage of the stat pin will drop, resulting in the failure of the battery charger.

The switching time of the circuit is less than 0.1ms. It also has the function of limited current and thermal protection and slow shutdown to protect the device from voltage spikes. When the AC power supply to the load, the battery can be replaced without disturbing the power output. Therefore, the circuit realizes the uninterrupted power supply of the control system and greatly improves the reliability of the control system.

Cost and Feasibility :

Cost of nozzles and nozzle links : 42000 Rs
Cost of Arm brushes : 14600 Rs
Cost of wheel brushes(links + brushes) : 40000 Rs
Cost of sensors : 6500 Rs
Cost of servo motor : 13520*4 Rs

Cost of Back Pressure Regulator : Rs 6500
Cost of Batteries: 3000Rs

Height Width Thickness = 2.7 * 0.78 * 0.12 m^3
Density of Al = 2.7g/cm^3
Cost per kg = 140 Rs
Cost each 2 side + top panel in the frame : 1.5 lakhs

Additional cost : 5000 Rs

Total cost : 3.15 lakhs

Link for CAD files :

1. Entire Bot - https://a360.co/3zRIpj3
2. Brush - https://a360.co/3ye92hV