Design and Development of Low Cost Automatic Parking Assistance System

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ABSTRACT
Parking cars is quite a challenge in congested parking bays and for inexperienced drivers. Automatic parking assistance systems (APAS) are limited to high-end cars in India. This paper discusses the design of APAS for Hyundai Santro and development of an automatic parking assistant system for a scaled down prototype model using a stepper motor mounted ultrasonic sensor to scan the obstacles. 3-point unequal rotating radius algorithm is used to identify parking path shifting points and parking trajectory. Path shifting control algorithm based on timing and distance traversed is developed using MPLAB IDE.

A prototype is developed on a scaled down model of a vehicle and performance of the APAS system is verified. Accuracy of the system is ±10% which is acceptable for low cost solution developed. Repeatability of APAS is tested, which is ±15%. This can be improved with closed loop control in parking process. Cost of the developed system is reduced by more than 50% of the commercially available APAS systems. From the results, APAS system can be used in any small segment cars with little changes in logic. Path traversed can be used as feedback to further improve the accuracy of APAS system.

Keywords
Parking Assistance, Automatic, Intelligent, ECU, Three-point Unequal Rotating Radius

1. INTRODUCTION
In present day situation exploring the empty parking slot and getting best maneuver while parking has become tedious because of congested parking lots. Expert driver's parking skill is transferred to an intelligent system which can alleviate the driving burden and enhance safety in the next generation passenger vehicles [1]. Automatic Parking Assistance System (APAS) comes to the rescue of inexperienced drivers to avoid collision while reverse parking. An APAS is an emerging standard safety feature in modern vehicles. The significance of this system is to assist the driver to take 'parking slot fitment decision' and also in 'parking the vehicle' once the slot is confirmed. This system has the advantage of safety, while parking in reverse direction by taking care of the blind spots.

In APAS the parking slot availability is explored by the system and then the parking is done on its own, thus minimizing driver involvement. APAS operates in two phases namely exploration and parking. In exploration phase, the system evaluates the length and width of parking slot for parking and confirms. In the parking phase the system guides the vehicle to along a suitable trajectory and park in the identified slot without collision. Various sensors like infrared sensors, camera, ultrasonic sensors, RADAR etc are used to observe the obstacles during parking.

In automatic parking systems radar, sonar, vision and ultrasonic sensor are used in combination for obstacle avoidance in parking trajectory. APAS systems are available in various models from Toyota (Advanced Guided Parking System), Lexus (Intuitive Parking Assist), and Volkswagen (Park Assist) among others [2, 3]. The parking assist modules in these cars cost in the range of 500$ to five thousand dollars as per the data available in the open source websites. This clearly indicates the expensive nature of the sensors and algorithms built into the system and hence make it unaffordable by the small segment Indian car owners. In the Indian context no entry level cars like Maruti 800, Tata Nano, and Hyundai Santro have APAS. Among various sensors used for parking assistance, ultrasonic sensors are used as low cost alternative for parking assistance [4]. Multiple ultrasound sensors at fixed locations on the car are used for obstacle detection purpose[5-6]. In this paper it is proposed to use a stepper motor mounted single ultrasonic sensor for scanning the obstacles for automatic parking assistant system and develop a prototype of a scaled down model.

2. DESIGN OF APAS
Figure 1 shows the parallel parking slot in which each vehicle parks behind another vehicle which is assumed for the design. Assumptions based on the minimum turning angle and steering capabilities are made to choose the parking slot size. Minimum margin while parking the vehicle from parking slot corner points are made. These values are for actual vehicle chosen (Hyundai Santro). For designing the parking path knowledge of parking trajectory, final and corner points is required. Pf (xf, yf) is the final point where the parking process finishes, P1(x1, y1) is the starting point of parking process and P0 (x0, y0) is corner point of the parking slot. Parking slot dimensions are assumed to (6000, 3000), which is average and sufficient parking space for most of the Indian cars [2].

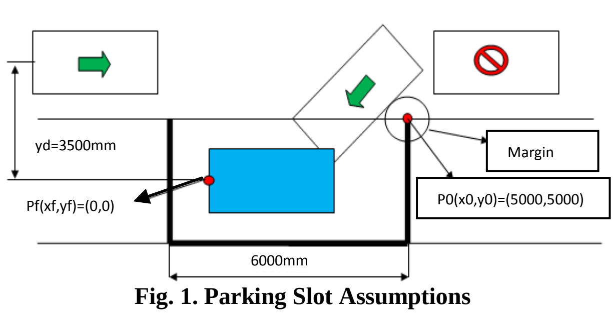

Fig. 1. Parking Slot Assumptions

APAS has sub-functions like gathering the driver inputs from switches, reading the sensor data, checking the necessary conditions, actuating the motors etc. The functional block diagram of the system is developed and is shown in Figure 2.

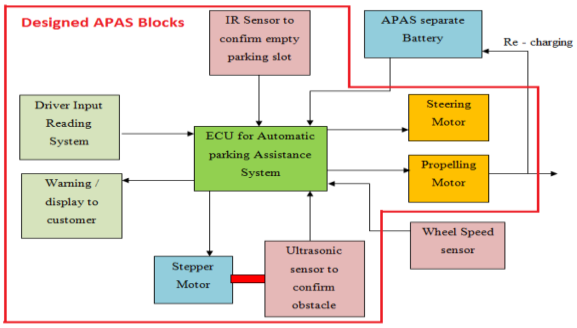

Fig. 2. Functional Block Diagram of APAS

Driver warning block gives instructions and commands to the driver, to take necessary actions, to make parking process safer. LEDs, buzzers are to indicate the process status to the driver. Sensor blocks are the major functional areas, which helps the system to detect or sense the change in electrical or physical parameters of that system. Sensor blocks collect the sensor data and produce them in the readable format for microcontroller. This makes the system to work as closed loop and to add correction factors if there is an error inside the system. Actuators like motors, electrical coils etc. are present in this block. In micro controller block, the compatibility of the controller the code required to run the application is developed [3].

Parking paths are specific to vehicles and are designed based on the vehicle dimensions, handling parameters and parking limitations. In this work *3-point unequal rotating radius* method is used for generating the parking path for row parking. Once the parking path is designed for that specific vehicle, parking path shifting points are identified. This helps the controller to take decision while parking the vehicle.

2.1 Propelling Motor Power Calculation

Sum of all the individual powers required to overcome the dynamic specifications like rolling resistance, acceleration and aerodynamic resistances gives the total power required to run the vehicle. Rolling resistance and aerodynamic resistances are less or negligible compared with power required to accelerate. Power required to propel the vehicle is proportional to the maximum acceleration designed for that vehicle. Different resistances offered to propel the vehicle are shown in motor power calculation equation [7, 8].

$$P_t = \frac{\delta M}{2t_a}\left({V_f}^2 + {V_b}^2\right) + \frac{2}{3}\left(Mgf_rV_f\right) + \frac{1}{5}\left(\rho_a C_D A\right)$$

2.1.1 *Known Parameters:*

Mass of the vehicle, $M = 900kg$
Air density, $\rho_a = 1.15\ kg/m^3$
Gravity, $g = 9.81\ m/s^2$

2.1.2 *Required Parameters:*

Acceleration time, $t_a = 2\ s$ [Assumption]
Final Velocity, $V_f = 2.7\ m/s$
Motor basic Velocity, $V_b = 1.85\ m/s$

2.1.3 *Calculated Parameters:*

Aerodynamic Drag,
$C_D = 0.32$ [Assumed from frontal area shape]
Mass factor, $\delta = 1.05$ [Calculated for unknown δ]
Rolling Resistance, $f_r = 0.011$
Frontal area, $A_f = 2.424\ m^2$
$P_t = 2.691\ kW$

2.2 Calculation of Turning Radii (R1 & R2)

Based on the algorithm chosen, for 'Hyundai Santro' specifications parking path is generated. The specifications are listed below and based on these values Final Turing Radius (R1) while parking and First turning radius (R2) while parking are calculated based on the algorithmic equations[9] as shown in Figure 3.

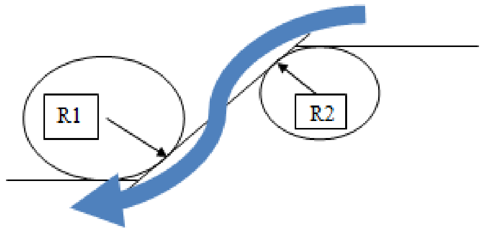

Fig 3: Turning Radius R1 and R2

2.2.1 *Parameters Required,*

Wheel Base $L_1 = 2380mm$
Overall Width $l = 1525mm$
Overall Length $L = 3565mm$
Maximum Steering Angle, $\emptyset_{max} = 44.91°$

Minimum Rotating Radius,
$R_1 = L_1/tan\,\emptyset_{max}$
$R_1 = 2387mm\ (For\ circle\ O1)$

Parking Corner Safety Radius, $R_2 = l/2 + d$
$R_2 = 1262.5mm\ (Safety\ margin, 500mm)$

Based on the R1 and R2 values draw two circles on the graph sheet to understand the 'Parking Path'. 'R1' can be taken as minimum turning radius of that vehicle, which gives the shortest parking path. Minimum turning radius for Hyundai Santro is 4.7m.

2.3 Specifications of Hyundai Santro

To design path for the chosen vehicle the specifications are collected from the manufacturer of that vehicle. Dimensions of the vehicle, steering data for that vehicle and tire type, specifications are collected and analyzed before starting the design process. Those specifications are listed below.

2.3.1 *Dimensions:*

Wheel Base $L_1 = 2380mm$
Overall Width $l = 1525mm$
Overall Length $L = 3565mm$
Overall Height $= 1590mm$
Front Track $= 1315mm$
Rear Track $= 1300mm$

2.3.2 *Steering Data:*

Minimum Turning Radius = 4.7m
Steering Wheel Rotation (Lock to Lock) = 4.3 rotations

2.3.3 *Tire Type and Specifications:*

Tyre Type is P 155/70 R13"
Tyre Width $= 163mm$
Outer Diameter $= 556mm$
Rolling Circumference (P) $= 1617mm$
Rear Track $= 1300mm$
Effective Rolling Radius, $R_d = 266mm$

Using 'Pythagoras Theorem', the shorter distance between two points on the same circles are found. 'AC' is the shortest distance and the angle is found out using the relation of sine function.

$R = AB = BC = 4.7m$
$AC^2 = AB^2 + BC^2$
$AC = 6.66mm$
Using definition, $\sin\theta = Opposite\ Side/Hypotenius$,
$\theta = \sin^{-1}(0.706)\theta = 44.91°$
(Max. turning angle at min. turning radius, $\emptyset_{max}$)

2.4 Calculation of Steering Angle at Initial Position

Calculations for steering angle at point P1 is shown here,

$\theta_{t1} = \cos^{-1}\{0.8101\}$
$\theta_{t1} = 35.855°$

Turning Angle of the vehicle at corner Point $P0: (x_0, y_{01})$ is found here. Using this value 'Parking path shifting points' are calculated (like Point1, Point 2 etc.). To find path points, the geometric values of a, b and α values have to be calculated first. For calculation purpose P_0 (Corner point) values are assumed. That is, $P_0 = (1500, 5000)$

$$\theta_{t1} = \cos^{-1}\{\frac{1}{(R_1 - y_0)^2 + {x_0}^2}[(R_1 + R_2)(R_1 - y_0) + \sqrt{(R_1 + R_2)^2\,(R_1 - y_0)^2} - \alpha]\}$$

$\alpha, a\ and\ b$, are the design constants required to find out the shifting points, the calculation as follows,

$\alpha = \{(R_1 - y_0)^2 + {x_0}^2\}\{(R_1 + R_2)^2 - {x_0}^2\}$
$\alpha = \{(2387 - 1500)^2 + 5000^2\}\{(2387 + 1262.5)^2 - 5000^2\}$
$\alpha = -30121910257657.75$
Using the constant value, 'a' and 'b' values are calculated.

$a = (\tan\theta_1)\alpha = 0.723$,
$b = y_0 + \frac{R_2}{\cos\theta_0} = -557$

2.5 Finding the Parking Path Points

Initial point is the one from where the reverse parking process is started. 'P1' describes the parking space required for that system or vehicle.

$P1: (x_1, y_1)$
$P1 = (\frac{R_1\sqrt{(a^2 + 1)} + y_3 - b}{a}, y_d)$
$P1: (6900, 3500)$
Here, $P2\ or\ P3: (x_2, y_2)$

$P2 = (R_1 \sin\theta_{t1}, R_1(1 - \cos\theta_{t1}))$
$P2\ or\ P3: (1399.13, 454)$
These calculated values can be compared with the values after the parking path graph is developed. If both calculated and the graph values are within the design tolerance then these values can be used as final points in parking process.

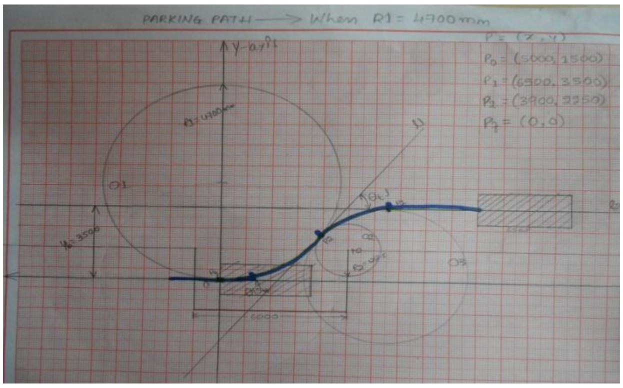

Fig 4: Parking Path Shifting Points in Graph

Parking path shifting points are identified from Figure 4. These values are compared with calculated path shifting points to verify the values in Table 1.

Table 1: Comparison of Desired And Actual Values

Calculated Shift Point Values	Graph Shift Point Values	Difference
P1: (6900, 3500)	P1: (7000, 3500)	(0100, 00)
P3: (1399.1, 454)	P3: (1400, 500)	(0001,-0046)

The values are compared and found within the prototype tolerance range [8].

3. DEVELOPMENT OF PROTOTYPE

Low-cost APAS system functionality is verified by developing a prototype of the system. Design and dimension of the prototype is shown in Figure 5. Actual prototype developed is shown in Figure 6.

Based on prototype dimensions, parking path is generated again. Parking path shifting points are found to implement in to the logic. Path generated is shown in Figure 7.

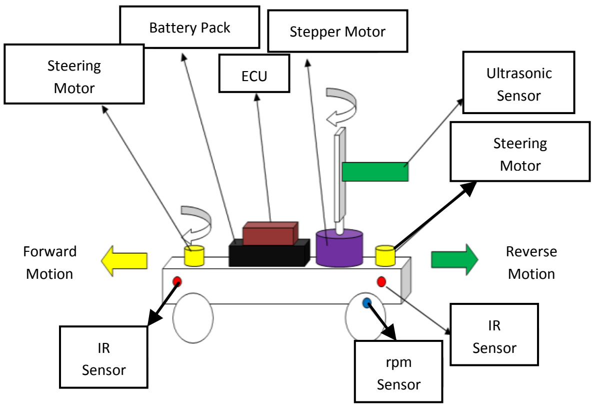

Fig. 5. Prototype Design

Fig 6: Prototype Developed

Table 2: Specifications of Prototype

Specifications	Dimensions
Over all weight	~10kg
Overall Length	900mm
Overall width	570mm
Minimum Turning Radius	3.0m (Approx.)
Maximum steering angle	~25 degree (Approx.)
Assumed P0(x0, x0)	(3000,1000) Parking slot
Margin (d)	200mm
Wheel radius (Rd)	105mm

Overall travelled distance (space searching function) is, Distance = 4750mm, Rotations = 6.5, Time taken =12 to 14 sec, detailed breakup is shown in Table 3.

Table 3: Details of Distance Travelled

From – To Shift Point	Distance	Rotations	Time
P1 to P2	1750mm	2.5	5 sec
P2 to P3	1750mm	2.5	5 sec
P3 to Pf	1250mm	1.5	3 sec

Control logic is developed based on the parking pattern and algorithm chosen. Parking path shifting points found from the graph are coded to control the Parking process. Flow chart of the control logic is shown in Figure 7.

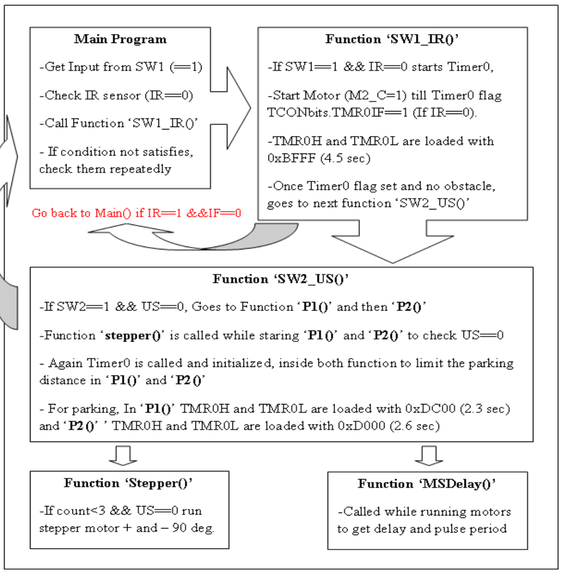

Fig 7: Flow Diagram of APAS

Hardware is developed for APAS, Figure 8 shows hardware schematic diagram. Figure 9 shows the prototype developed for Low Cost APAS, with all the components assembled.

Ultrasonic sensor mounted on stepper motor to replace the RADAR and IR sensor to confirm the parking space is shown in Figure 9 and Figure 10.

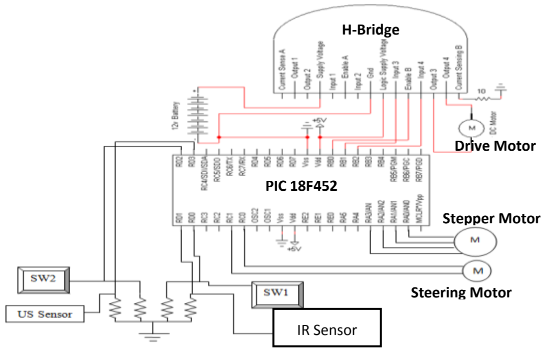

Fig 8: PIC18F Interfacing with Peripherals

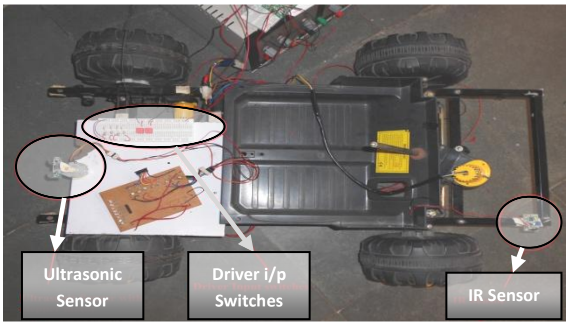

Fig 9: Low Cost APAS Prototype

4. RESULTS AND DISCUSSIONS

Low-cost APAS system functionality is verified, with different tests. Time taken to travel from one point to another and distance traversed from one point to another are listed in Table 4. Rotating radius of the prototype is deviating from the desired values and making the system unstable. To achieve better performance and high accuracy closed loop system can be adopted in the same system. Table 3 shows the comparison of desired values and actual values of APAS shift points.

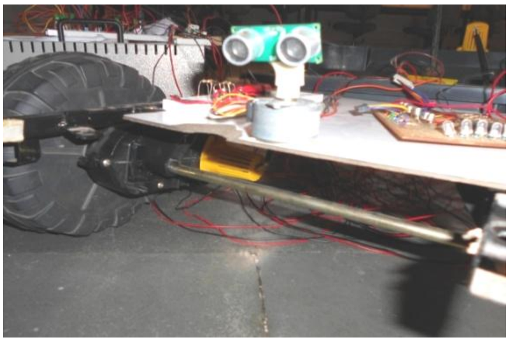

Fig 10: Ultrasonic Sensor on Stepper Motor

The developed low-cost APAS is run on the floor to compare the design specifications and actual parking path specifications. Based on the demo vehicle specifications, the code is developed and the specifications like parking path shifting time, distances etc. are collected to compare with given value. While implementing the ECU on vehicle the parameters like approximate steering angle, distance to be travelled while searching the parking slot are given. Before testing the vehicle, fine tuning to match the actual path is made. Correction values are noted and then the testing is carried out. Figure 11 shows a test case for parking [10].

Table 4: Comparison of Desired and Actual Value

Parameters	Desired value	Actual value
Time to reach P1	10 to 12 sec	13 sec
Time P1 to P2	5.5 sec	6.0 sec
Time P2 to Pf	6.5 sec	7.0 sec
Min. Rotating Radius	3000mm	4000mm
Steering Angle	25` Approx.	< 25` Approx
Distance P1	4250mm	4500mm
Distance P1 to P2	2000mm	2250mm
Distance P1 to Pf	2250mm	2250mm
Repeatability	+/- 5%	+/- 15%

4.1 Test Case when P0 (3000, 500) as Corner Point

- Overall travelled distance (space searching function) is, Distance = 4750mm, Rotations = 6.5, Time taken =12 to 14 sec
- P1 to P2: Distance = 1950mm, Time taken = 5 s
- P2 to P3: Distance = 2550 mm, Time taken = 5 s
- Based on these values the correction is made in timings and the tests are repeated again. The test results are shown in Table 5.

Table 4: Demo Vehicle Accuracy Test

Parameters	Desired Value	Actual Value
Point P1 Values	(4750, 1500)	(4700, 1500)
Point P2 Values	(2800, 950)	(2900, 1000)
Point Pf values	(0, 0)	(150, 40)
Time 1st Phase	10 to 12 s	10 to 11 s
Time 2nd Phase	10 to 12 s	12 to 14 s

4.2 Accuracy Test for APAS

Accuracy test is conducted for the developed demo vehicle for APAS. This based on the actual vehicle distance travelled and the time taken for the vehicle to travel is compared with designed values. The position of the vehicle after the test is shown in Fig. 11.

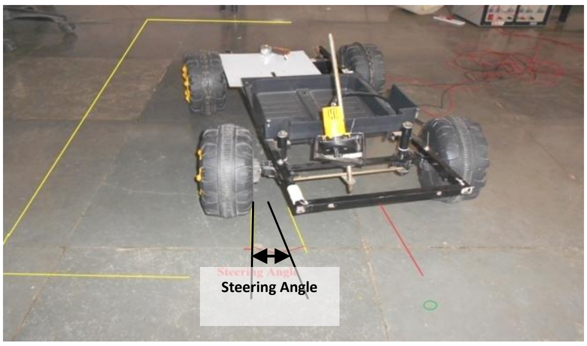

Fig 11: Test Case

4.3 Repeatability Test

Repeatability test is conducted to compare both accuracy and reproducible capability of the system and ECU. In Tables 6-7 distance travelled values are listed. Around three cycles are tested while running. Finally the average of the value is taken to find the compatibility of the system.

Based on these two tests, the vehicle accuracy and repeatability are tested. The test result is the accuracy of the vehicle is well within 50-130mm of the designated parking place after travelling a distance of 4750-5000mm. But there is difference in repeatability, which is basically due to demo vehicle doesn't have accurate steering capability. Finally with these results it is clear that the developed system is suitable for small segment cars.

4.4 Cost Analysis

In this work, ultrasonic sensor, microcontroller and other discrete components are used for prototype development. The cost of these components is very nominal compared to the motor. Assuming similar motor is used in commercial APAS which range in the order of $500-$5000, the cost of the APAS can be reduced substantially to suit small segment Indian cars.

Table 6: Phase -1 Distance Travelled Values – Repeatability Test

Desired / given Value mm	**Actual Value** mm	**Difference** mm
4750	4720	-30
4750	4700	-50
4750	4730	-20

Table 7: Phase -2 Distance Travelled Values – Repeatability Test

Desired / given Value mm	**Actual Value** mm	**Difference** mm
5000	4890	-110
5000	4920	-80
5000	4870	-130

5. CONCLUSIONS

A low-cost APAS is designed and a prototype of scaled down model of Santro is developed. Instead of using sensors in fixed locations, a stepper motor mounted single ultrasonic sensor is used to scan the surroundings thus reducing the cost. The prototype vehicle parks itself within 50mm of the designated parking place which is good enough for the vehicle with poor steering capability and after a travel of 4750mm. The accuracy of the system is limited due to use of DC motors instead of dedicated brake systems and vehicle dynamics calibration. The cost of the designed APAS is reduced by around 50% when compared to the existing commercially available systems. So it is advantageous for small segment cars. As single ultrasonic sensor is used to scan the region, relatively more parking time would be required. For demo purpose fixed-time based path shifting logic is developed, which needs to be updated to more accurate algorithm depending on the speed of the vehicle and the distance travelled and tested on an actual car.

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