Design of Working Model of Steering, Accelerating and Braking Control for Autonomous Parking Vehicle

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Abstract: Now a days, the number of vehicles especially cars are increased day by day and the people expect sophistication with safety and they wish automation for the perfection by reducing their effort and to prevent damage from collision of the vehicle. Parking the vehicle has always been a big task for the drivers that lead to problems such as traffic, congestion, accident, pollution etc. In order to overcome the parking problem, an automatic steering, braking and accelerating system is proposed to park a vehicle in a stipulated area and also to enhance the parking in a safety and secured way. This paper is part of our research in designing a pallet over the automated vehicle. In this paper, an automatic parking system over the existing vehicles is proposed. The vehicle to be parked will be carried by the pallet over the proposed autonomous vehicle. A detailed design of automatic car parking system has been proposed with a working model. The proposed model is equipped with sensors and the controls such as steering, acceleration and braking are achieved with the major objectives such as safety and accuracy. The proposed autonomous parking vehicle is modeled. The micro controllers in the control systems are programmed. The working model was rigorously tested with all the possibilities including collision, speed, trajectory and efficient placement on the stipulated parking slot. The system has been analyzed against various parameters and found that more durable. The performance analysis has been made on the proposed model and shaft analysis is made with Ansys. The proposed geometric modeling ensures precision with safety.

Keywords: Vehicles, parking, automatic, steering, braking, acceleration.

1 Introduction

Automatic car parking has been one of the sophistication and feature which the drivers looking for a long time. It has been seen that many people who drives their own car comfortably in highways and roads but they struggle to park their vehicle in a parking slot. Hence, Automatic car parking will be a solution for the people who struggle to park their vehicle. The past research has seen developments in the field of automation and it will not be too long before the roads are filled with automatic vehicles. Driving always needs a safety and comfort. Car parking is always been a tedious task for common drivers/peoples in metro cities and in apartments. Automatic car parking features are available in very few high end

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car models however it costs more and make many assumptions which are not much feasible in real time. Hence, in this paper, an autonomous portable car parking system is proposed. The proposed parking system component will be deployed in a vehicle to park the vehicle without the assistance of driver. It may help the aged, women and other novice who feel difficult to park. Though the proposed system initially designed to park the vehicle in a predefined parking slot, identification of the slot has also been integrated.

In this paper, parking a vehicle has been focused with the microcontrollers, programmed with set of pic programs. Minimal electronic components were used with the precise mathematical model. In this paper, a working model of the car has been designed, fabricated and experimented for real time testing. In order to prove the effectiveness of the system, a mathematical model has been presented. The performance analysis of the proposed system has been made and the working model is found to be more feasible in real time with precision and minimal movement of components which makes more effective than the manual and other autonomous parking systems. The rest of the paper is organized in to six sections. The model of the proposed system is presented in Section 2. The geometrical model is presented in Section 3. Section 4 discussed about the fabrication and assembly of the working model while the Section 5 presented the parking scenarios. Section 6 analyzed the performance. The related works were discussed in Section 7and Section 8 concludes the paper with future scope of the work.

2 Model of autonomous portable parking system

The main objective of this paper is to design a portable driverless parking system. In other words, the proposed system will park the vehicle in the designated slot by considering all the factors without a driver or his/her assistance. The proposed driver less parking system consists of three major automation modules, Steering control, Speed control and Collision detection & braking automation. In all these automations, the associated electronic components are programmed with pic programs. The overview of the autonomous parking system is shown in Fig. 1. The process involved in fabrication and working are discussed below in detail.

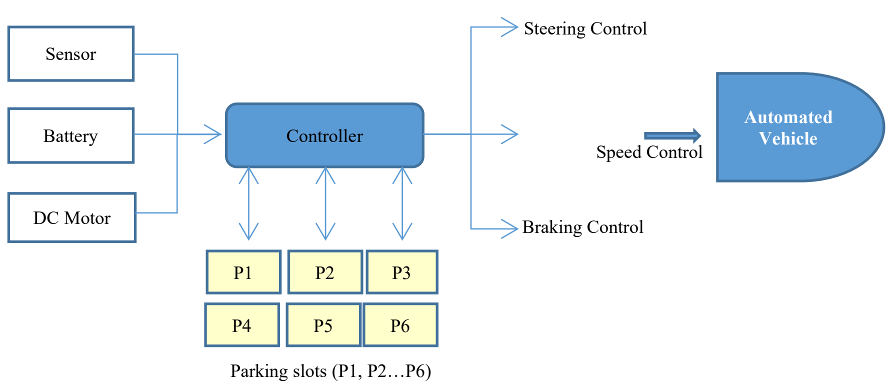

Figure 1: Overview of autonomous portable parking system

2.1 Steering control and automation

In order to automate steering control, an arrangement for converting the conventional steering system into an automatic steering system is carried out using microcontroller, ultrasonic sensor, DC motor and a helical gear arrangement. A DC motor is connected to helical gear setup which is fixed in the steering arm. The DC motor is actuated by a microcontroller when it receives signal from the ultrasonic sensor. The conceptual block diagram as shown in Fig. 2 gives the working principle of the steering system.

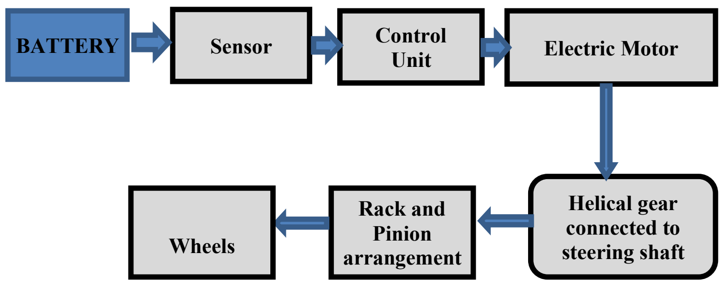

Figure 2: Working principle of steering control system

2.1.1 Design of helical gear

The design of component is the preliminary step for any manufacturing process. The key component in automatic steering mechanism is the Helical Gear which will be fixed in the steering arm which is further used to turn the steering automatically using motor and microcontroller. The parameters such as power, volt, Pinion speed, Wheel speed, Speed ratio, Number of tooth on pinion, Pressure angle, Helix angle (β) were calculated and the values are shown in Tab. 1.

Table 1: Parameters of Helical gear design

Parameter	Obtained value
Power	50 w
Volt	12 v
Pinion Speed	45 rpm
Wheel speed	14 rpm
Number of tooth on pinion	27
Pressure angle	20˚
Helix angle	15˚

In order to make the steering automation, various design factors required to design and manufacture basic dimensions, right from material selection, calculation of tangential load on teeth, beam strength, dynamic load, etc., to wearing load were meticulously calculated and tabulated as in Tab. 2. The basic dimensions required to manufacture a helical gear for the steering arm were obtained by mechanical design procedures [Design Data Book].

Table 2: Parameters obtained based on design calculation

Parameter	Formula used	Calculated value
Tangential load	F_t=P/V*Kθ	1138 N
Initial Dynamic load, Fs	Fs=Ft/Cv	3036 N
Module	From design data book	2
Face width	b=module*10	20 mm
Pitch circle diameter	PCD (d1)=mn/cos β *Z1	56 mm
Pitch line velocity	(v)=πd_1N_1/60	13 m/s
Accuarate dynamic load, Fd	$F_d=F_t+\frac{21v(b*C+Ft)}{21v+\sqrt{(b*C+Ft)}}$	75.66 N
Centre distance	mn/cosβ $[\frac{Z1+Z2}{2}]$	118 mm
Height factor	1 mm	1 mm
Bottom clearance	0.25×module	4.5 mm
Tooth depth	2.25×module	4.5 mm

Since Fs>Fd, the design is safe. And hence the basic dimensions required to manufacture a helical gear are obtained by mechanical design procedures.

2.1.2 Cad modeling

The CAD Modeling of for automatic steering mechanism has been made using Creo parametric 2.0 software to have virtual design of the system. The helical gear arrangement to be fixed on the steering and place where it has to be fixed were virtually designed and visualized. The Creo modelling is shown in Fig. 3.

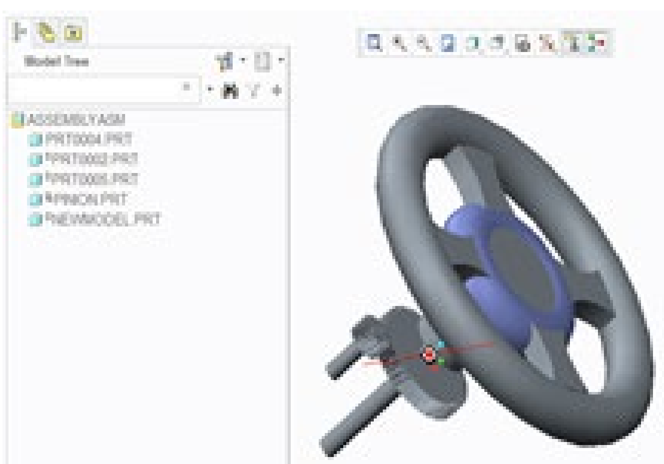

Figure 3: CAD modeling of steering system

2.1.3 Manufacturing and assembly of automatic steering system

Based on the design calculation, helical gear was manufactured and fixed in the steering arm along with the motor. The motor is connected to a battery which is actuated by the micro controller. The components fixed in the steering arm are shown in Fig. 4.

Figure 4: Automatic steering system unit

2.2 Automatic acceleration system

Upon different approach for to achieve automation of acceleration system for four wheelers, we have implemented the simple and effective working of automation of acceleration system of the vehicle.

The block diagram automatic acceleration system for four wheelers is shown in Fig. 5.

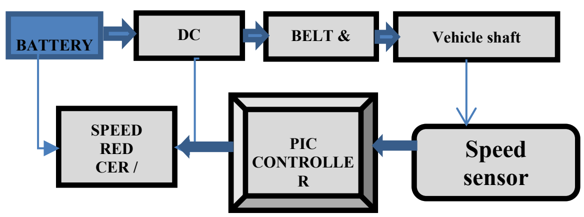

Figure 5: Conceptual block diagram of automatic speed control system

2.2.1 Design of components for speed control system

For automatic speed control system, a DC motor driven shaft is used to rotate the vehicle wheels. The power from the DC motor is transmitted to shaft using belt and pulley. Hence the specifications of the shaft, belt and pulley are arrived based on the design calculations put up below in Tab. 3.

Table 3: Values assumed for the design of hollow shaft

Parameter	Obtained value
Hollow Shaft	
Type of shaft	Hollow shaft
Outer diameter, d_o	27mm
Inner diameter, d_i	22 mm
Length of shaft, l	1090 mm

Weight of shaft, w	14.72 N
Belt and Pulley	
Speed of driving Wheel, N_1	750 rpm
Speed of driving Wheel, N_2	250 rpm
Diameter of the driving wheel d	95 mm
Centre distance b/w pulley & wheel, C	670 mm
Current, I	70 A
Voltage, V	12 V

The basic dimensions required to manufacture a Hollow shaft, Belt and Pulley for the controlling the speed were obtained by mechanical design procedures [Design Data Book]. The formulas used are given in the Tab. 4.

Table 4: Parameters obtained based on design calculation

Parameter	Formula used	Calculated value
	Hollow Shaft	
Maximum bending moment, M_b	$M_b = \frac{wl^2}{8}$	2.18 N-m
Equivalent twisting moment for a hollow shaft	$M_{te} = \sqrt{(k_b * M_b + \frac{\alpha F d_o * (1+k^2)}{8} + (k_t + M_t)^2)}$	25.536 N-m
Shear stress, τ	$M_{te} = \frac{\pi}{16} * \tau * d^3 (1-k)^4$	10 Mpa
Angular twist between the bearings	$\frac{M_{te}}{J} = \frac{G * \theta}{L}$	$\theta = 0.599^{\circ}$
	Belt and Pulley	
Centre distance, C	[From Design data book]	700 mm
Nominal pitch length, l	$2C + \frac{\pi}{2}(D+d) + \frac{(D-d)^2}{4C}$	2068 mm
Arc of Contact	$180° - (\frac{D-d}{c}) \times 60°$	161°
Maximum power capacity, Kw	$(0.453 - 0.09 - (\frac{19.62}{d_e}) - 0.765 \times 10^{-4} s^2)\ s$	0.832 w
No. of belts, n	$n_b = \frac{p \times F_a}{kw \times F_c \times F_d}$	1
Actual centre distance	$A + \sqrt{A^2 - B^2}$ $A = \frac{L}{4} - \pi(\frac{D+d}{8})$ $B = \frac{(D-d)^2}{8}$	904 mm

Hence, from the design calculations, $C_{actual}>C$, and therefore the various dimensions assumed were found to be safe and the other dimension required have also been obtained.

2.2.2 Manufacturing and assembly of automatic speed control system

The automatic steering system consists of Battery, DC motor, microcontroller and sensor. The DC motor is connected to the propeller shaft using belt and pulley arrangement. The dimensions of the shaft, belt and pulley were arrived based on design calculations and have been selected based on the design. The motor can be actuated by the controller unit using battery. The speed control is carried out based on the pulse variation and signal control from the ultrasonic sensor. The system is used for parking the vehicle and hence constant acceleration about 10 km/hr is preferred based on the literature survey. The assembled view of the system is shown in Fig. 6.

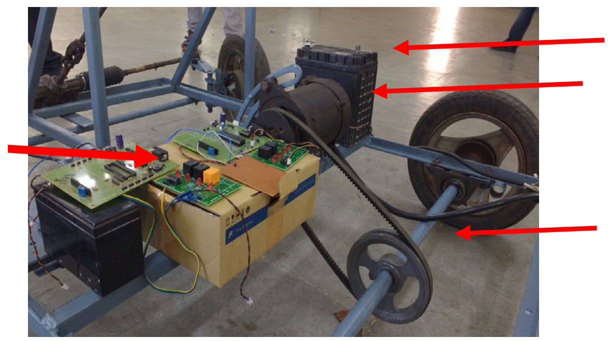

Figure 6: Automatic acceleration system

2.3 Automatic braking system

The design of automatic braking system provides a system to stop the vehicle and acts as an additional braking system. This can be done by using Ultrasonic sensor works by transmitting an ultrasonic burst and providing an output pulse which corresponds to time required for the burst echo to return to sensor. By measuring the echo pulse width, the distance of target can be easily calculated. The sensor provides an output pulse to the microcontroller which compiles the output pulse with the corresponding coded pic program. Digital signal from microcontroller is given to head lamp relay which alternates the output voltage hence the ON time pulse width is varied and the speed of the vehicle is controlled. When our vehicle exits the minimum inter gap distance output from the microcontroller is given to the solenoid switch works on electromagnetic principle and brake is applied. The working principle is shown in Fig. 7.

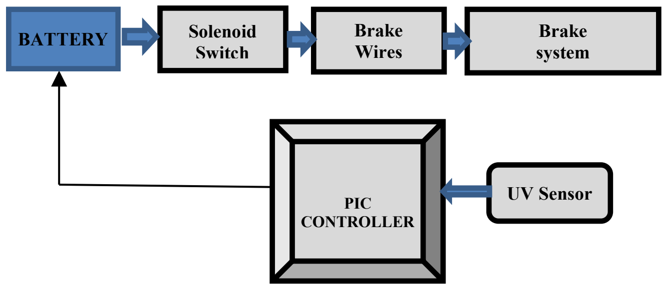

Figure 7: Conceptual block diagram of Automatic braking system

2.3.1 Design calculations for brake force

In order to stop the moving vehicle, the required force is to be computed. Precisely, the pulling force has to be obtained by selecting the solenoid component. Here, the brake force is calculated based on the design procedure with some basic assumptions. The assumptions and the values obtained by design calculations are shown as below in Tabs. 5 and 6.

Table 5: Parameters measured for Automatic braking from the model

Parameter	Obtained value
Brake drum diameter, d	110 mm
Brake lining, l	15 00
Distance of force F1 from fulcrum O_1, l_1	100 mm
Normal pressure	210 N/m^2
Coefficient of friction, μ	0.4

Table 6: Parameters calculated for automaticbraking for design

Parameter	Formula used	Calculated value
Braking Torque or Braking capacity. T_B	$T_B = \mu.\ P_1.b.r^2(\cos\theta_1 - \cos\theta_2)$	939 N-mm
Moment of frictional force about fulcrum, M_F	$M_F=\mu P_1.b.r[r(\cos\theta_1 - \cos\theta_2]+a(\cos 2\theta_2 - \cos 2\theta_1)/4$	1540 N-m
Moment of normal force about fulcrum, M_N	$M_N=1/2P_1.b.r.OO1[(\theta_2-\theta_1)+(\sin 2\theta_1 - \sin 2\theta_2)/2)]$	2260 N-mm
Force required for primary moments about fulcrum, F_1	$F_1 \times l = M_N - M_F$	7.20 N
Force required for secondary moments fulcrum, F_2	$F_2 \times l = M_N + M_F$	38.00N

2.3.2 Manufacturing and assembly of automatic braking system

The automatic braking system consists of ultrasonic sensor, battery, solenoid switch, brake wires, brake drum and a microcontroller. When the ultrasonic sensor senses any obstacle at a distance of 5 mts, the signal is sent to the microcontroller. The microcontroller actuates the solenoid switch which pulls the brake wire and thereby stops the vehicle. The assembled view of braking system is shown in Fig. 8.

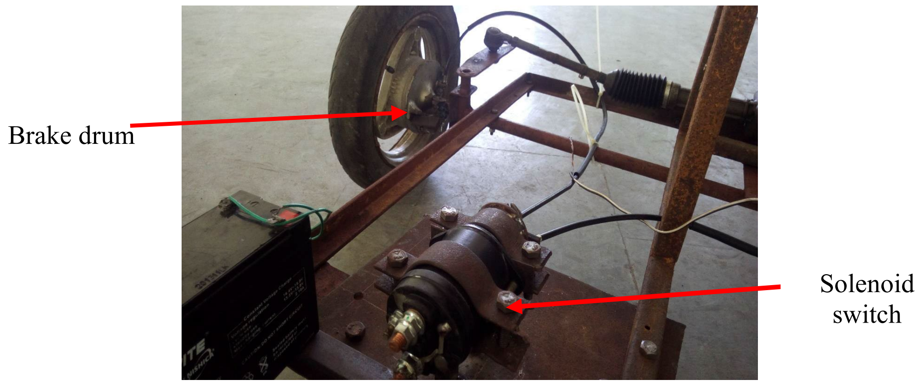

Figure 8: Automatic braking system

3 Mathematical track modeling

Geometric path trackers are the popular path tracking methods which is commonly found in robotics. These methods used geometric relationships between the vehicle and the path resulting in control law solutions to the path tracking problem. They are also used to measure error ahead of the vehicle and can easily be extended to more complicated calculations which we applied in our project to calculate the arc movable by the car. A common simplification of an Ackerman steered vehicle used for geometric path tracking is the bicycle model. For the purpose of geometric path tracking, it is necessary to state that the bicycle model simplifies the four-wheel car by combining the two front wheels together and the two rear wheels together to form a two wheeled model, like a bicycle. The second simplification is that the vehicle can only move on a plane. These simplifications result in a simple geometric relationship between the front wheel steering angle and the curvature that the rear axle will follow.

As shown in Fig. 9, this geometric relationship can be written as

$$\tan(\delta) = \frac{L}{R}$$

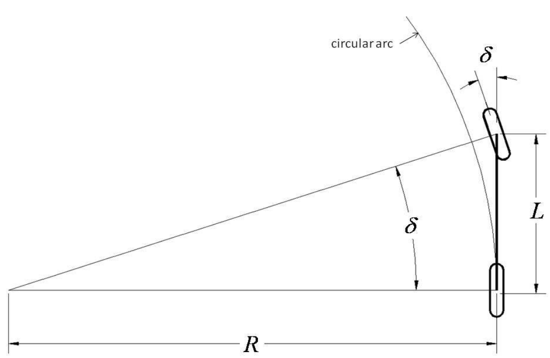

Figure 9: Geometric trajectory modelling of wheel

The steering control was done by the microcontroller using programming techniques. The helical gear has to be rotated only for certain angle using stepper motor based on the instruction from microcontroller through the sensor. The various sensor position used for the control of the steering wheel and the time taken for each angle of rotation is shown in the Tab. 7.

Table 7: Sensor position for steering control

S.NO	Sensor position A	Sensor position B	Sensor position C	Gear Rpm	Angle of rotation of wheel	Time taken (seconds)
1	ON	ON	OFF	18	Left side 32˚	5
2	ON	OFF	ON	18	Straight 0˚	5
3	OFF	ON	ON	19	Right side 32˚	5
4	ON	OFF	OFF	18	Straight 0˚	5
5	OFF	ON	OFF	18	Left side 32˚	5
6	OFF	OFF	ON	18	Right side 32˚	10

4 Assembly of automatic steering, acceleration and braking system

The various components of the automatic acceleration system are Hollow shaft, Belt & Pulley, D.C Motor, Bearings. The design specifications are arrived based on the design calculations and to the nearest standard market specifications. The design calculations have been made for the components and the dimensions are arrived based on the design procedure. The components were manufactured by using basic mechanical techniques like welding, lathe working, grinding, milling, hobbing etc. The length of the vehicle is 1. The assembled view of the project is shown in Figs. 10 & 11.

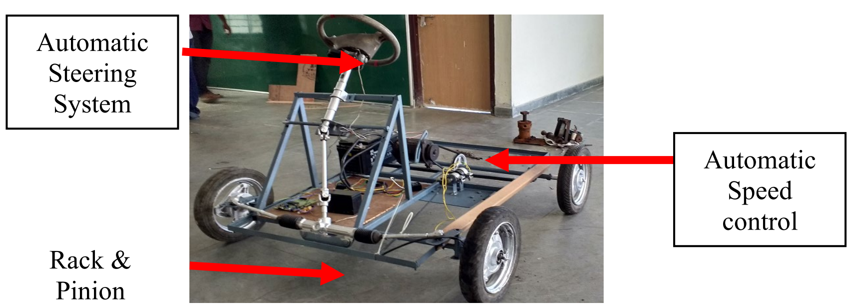

Figure 10: Front view of assembled vehicle

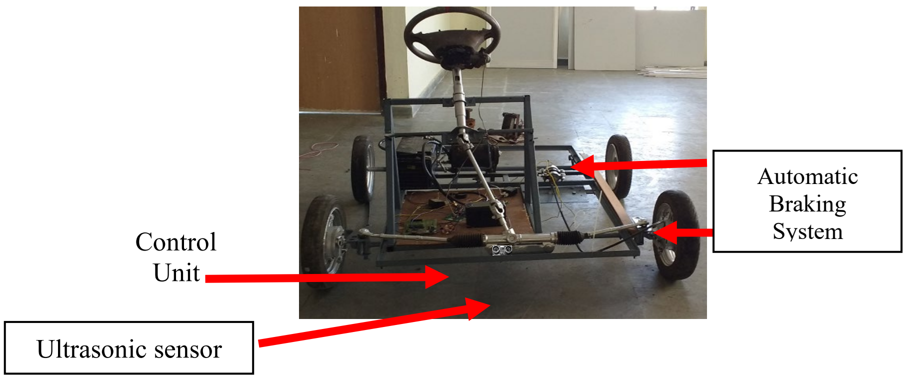

Figure 11: Vehicle with automatic parking system

5 Experimental parking

The working model of a car with its important components was successfully designed and fabricated. An experiment was conducted to verify the working of the automatic parking system as shown in the Fig. 12. In the experiment, a parking area of required length was marked on a road. The modeled car of dimension 2.1×1.4 m was initially held in front of the parking area. The vehicle moves to the predefined parking slot based on the inputs given to the microcontroller.

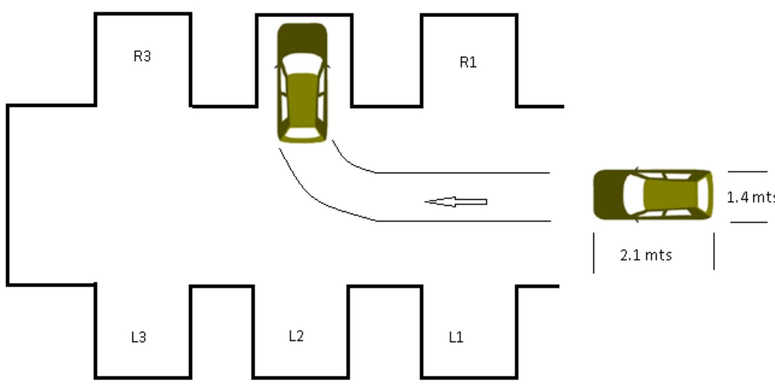

Figure 12: Experimented car parking slot

6 Analysis of components

The durability of the component used in the proposed model is analyzed in this section, which is used to assess the stress analysis of shaft. In the virtual model of the project, the components were designed using Cre-O software and the stress analysis were carried out using the Ansys work bench software. Since, the shaft is one of the main component in our design, the stress analysis of the shaft for a load of 60 kgs were determined using ANSYS software. The results are shown in Fig. 13 and tabulated in the Tab. 8.

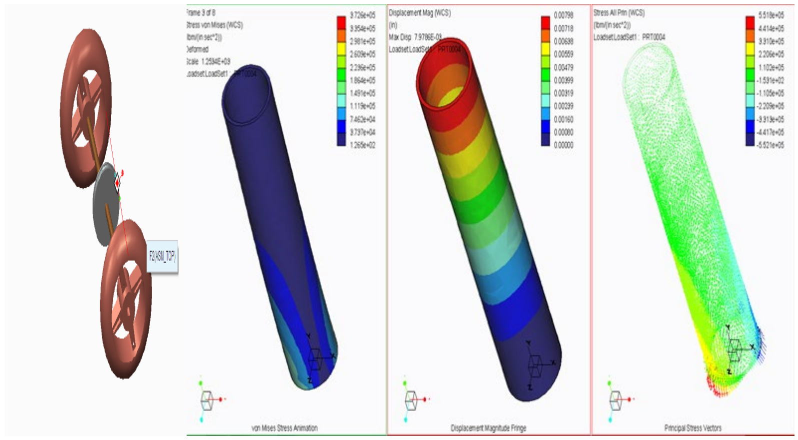

Figure 13: Design and analysis of shaft

Table 8: Analysis results from ANSYS

Parameter	Maximum Value	Minimum Value
Total Deformation	7.9786×10^{-3} m	0 m
Von Mises Stress	1.2534×10^{3} pa	1.265×10^{2} pa
Von Mises Strain	4.044×10^{-5}	4.005×10^{-14}

From the above results, it is observed that the shaft design is safe for up to 60 kgs.

7 Related works

Due to the rapid development in the field of e automobiles, electronics and information technology, plethora of research works [Thaina, Nakorn and Rojviboonchai (2011); Guo, Luo and Li (2015); Shahzad, Choi, Xiong et al. (2018)] have been made on autonomous vehicles in the recent past. The exponential growth of automobiles leads to the major problem of parking.

Many research works were reported on automatic steering and automatic braking of vehicles [Chen, Yang, Wang et al. (2018)]. Motion control for robots using basic mechanical links and joints has been utilized for designing robots that can be used for rescue operations [Edlinger, Polzleithner and Zauner (2010)]. In Yaacob et al. [Yaacob and Azize (2016)], integration of GnSoYagerFNN with a car driving simulator has been performed to demonstrate self-trained control system resulting in intelligent automated driving. In Thomton et al. [Thomton, Redmill and Coifman (2014)], investigation on the possibility of automating the data gathering and information extraction using two-dimensional scanning light detection, and ranging (LIDAR) sensor mounted on a vehicle was carried out. The study was helpful in knowing the algorithm for parallel parking. Most of the proposed models and parking solutions [Mohanapriya, Hema, Yadav et al. (2014); Ghosh, Prusty and Natarajan (2018)] available are limited to the certain assumptions like, equipped vehicle, heavy sensor dependent, indoor and outdoor restrictions and code dependents like bar/rfid. Hence, in this paper, an automatic parking solution is provided with pallet to be built over the proposed car like mobile robot with steering, acceleration and braking.

8 Conclusion

In this paper, an autonomous parking vehicle is modeled with the control of steering, acceleration and braking to park the vehicle automatically. The sensors are equipped in the model to identify the slot and obstacle before parking. The trajectory of the vehicle is modeled based geometric model and the acceleration and braking controls are achieved with the feedings from sensors. All the mechanical designs are calculated meticulously and tabulated. The required torque was generated from a battery for the wholesome weight of 60kg and to achieve constant acceleration at a rated speed which can be used as the improved technology based system for effecting parking, running the vehicle in insufficient fuel condition and made auto pilot mode by moving the vehicle with constant speed safely by relaxing driver's stress. Also for steering control, a separate gear attachment with inbuilt motor was designed and fabricated which is actuated by a sensor that is controlled by a microcontroller. Finally, an additional braking system that stops the vehicle when receives signal from the sensor by using microcontroller actuated by solenoid switch using battery. The project has been successfully completed and the test drive on the model has also been carried out successfully. Designing of shaft, belt, pulley and bearings have been designed and fabricated. Manufacturing and Assembly process like welding, lathe working, soldering, drilling and grooving process have also been made. Mechanical software like Pro-E, Ansys are used for virtual analysis. Though the main focus of this paper is design control of the vehicle, the proposed model is to be deployed with pallet for parking. The design details of pallet are not in the scope of this paper, but part of our main project work.

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