Design and fabrication of a Self-Balanced Narrow Track Vehicle

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ABSTRACT

The use of an electrical narrow tilting car instead of large gasoline cars should drastically decrease traffic, pollution, and parking related issues. It is the main objective most of the car manufacturers are producing narrow track based electrical cars prototypes. The narrow track cars had the tendency of rolling during the curved motions in this work, an attempt made to develop a tilting mechanism for a narrow tracked car to give it the flexibility of a motorcycle during the curved movement. A new model is proposed for a tandem two seats narrow tracked tilting car it reduces lanes thereby increasing the effective capacity of highways. The proposed model facilitates to enable the car to tilt into the curved motion; this analysis shows that the proposed model provides increased the stability during the curved motion more than 50% of stability of the previous models. The method we have used is a simple mechanical tilting system controlled with the help of simple electronically controlled DC stepper motor. The proposed tilting mechanism works successfully at the maximum speed during the curved motions and which provides the passenger comfort handling.

Keywords: Self-balancing, Narrow track, Tilting car, Stepper motor, Auto balancing.

1. Introduction

Narrow track cars are without the doubt the future of urban mobility. These cars have a very short wheel track in comparison to normal cars. Most of the international car companies have production models and prototype of narrow track cars. Some examples are Nissan Land Glider, Nissan Pivo, Honda 3R-C, etc. Such cars are mostly single seated or double seated with back-to-back seating configuration. These cars have several advantages:

- Half the width means half the weight, more rigidity, more access to narrow roads, easier parking and much quicker transit times.
- In an electric vehicle, the lighter weight of this much smaller vehicle will help to enhance the torque power characteristics of an electric motor to achieve “linear acceleration”.
- At highway cruising speeds, such cars will be using half the frontal area and half the drag coefficient, plus reduced running losses make for a very energy efficient vehicle.

All these advantages make the narrow track vehicle as appealing as an alternative to the car. Such cars combine the comfort of a car with the functionality of a motorbike. But these cars have a very important and dangerous drawback. With a very comparatively narrow track and heights almost equal to normal cars, these cars are very susceptible to rolling. As of now all such narrow track cars are electrically driven and have a limited top speed and hence this drawback is comparatively negligible. However, later these cars will have to get highway cruising speeds. Then this drawback will be of grave importance. Our project took shape as an attempt to face this drawback. We thought so if the car has the functionality of a motorcycle why not gives it the flexibility of a motorcycle. This gave use to the idea of an auto-tilting car. There have been many tilting body designs in rail but what we have done is not just a body tilting, in it, the car tilts as a whole. Recently there had been some development in making three-wheeled tilting cars like the carver, but only prototypes or concepts exist in the field of four-wheeled tilters.

2. Literature Survey

In the past couple of decades, there were many kinds of literature were presented in the study of inverted pendulum (Kee, & Tan, 2002; Casavola, Mosca, & Papini, 2004, 2006; Lin & Mon, 2005; Hawwary et al., 2006; Takimoto et. al. (2008); Tao et al 2008, Lin and Tsai (2009), Chiu et al. (2011), Dai F et al (2015)). For meeting present industrial and social requirement and consideration of the suitability such as zero radius turning ability, agility in narrow spaces and crowded conditions and left a small footprint etc. the two-wheeled inverted pendulum has become a research hotspot recently. In the case of growing more and more congestion due to serious city traffic, the Inverted pendulum robot is the best choice for a city commuting or a patrol transporter. The two-wheeled, inverted pendulum can also be chosen for the service robot platform because of its menu variability and consuming less space while operation [Tsui (2011)]. The two-wheeled, inverted pendulum type robot is an under-actuated Non-linear system, for teaching or a research platform for investigating advanced control methods [Ravichandran and Mahindrakar (2011), Chun & chith (2009), lee et al., (2012)].

Mr. Grasser (2001) developed a prototype of a revolutionary two-wheeled, inverted pendulum vehicle with the configuration of two coaxial wheels. Each wheel was coupled to Direct Current motor, and the pendulum vehicle is facilitated to make stationary or U-turns. The system kept equilibrium by pilot motors and two decoupled state-space controllers. Grasser et al., (2002), imagine a form of human transport whereby the driver balanced on two coaxial wheels, however, they decided to begin with a scaled down prototype with a fixed weight replacing the human driver. This led to “reduced costs and removed the risk to test pilots” whilst the simplified model eliminated many variables in terms of modeling and controller design. The prototype, named “Joe” by its creators, was modeled using modern state space theory instead of the more common classical control, as this allowed for better control of the linear speed and turning rate of the device. However, nowadays, there are many investigations on controlling extensions of the one-dimensional inverted pendulum. In which the most challenging problems, investigates the control of a mobile wheeled inverted pendulum system. The different control methods were proposed to regulate the two-wheeled, inverted pendulum typed robot due to its challenging nature.

In general, PID employed for that and there is no need to create mathematical models, but only the choice of the parameters by trial and error method or by experience [Nakagawaet al. (2009) and Solis et al (2009)]. Dai F et al (2015) studied friction compensation in the two-wheeled inverted pendulum. However, this research focused on the design and simulation of a two-wheeled, inverted pendulum based a balanced, easy moving vehicle for the material handling purpose in the congested industrial environments. A radio-control system implemented to give the team control over “Joe” during testing. The mathematical model simplified significantly by using a fixed weight to simulate the human driver, eliminating many variables.

Saravanan. R et.al. (2016), design and simulate a two-wheeled inverted pendulum for material handling vehicle which balanced automatically and with the help of a stepper motor. The narrow track cars are not newer there are several production models exist and several prototypes were being tried out by major automobile companies. Some production models are Nissan Pivo, Honda 3R-C etc. Several automobile majors like Toyota, Mercedes, Nissan, Kia, Suzuki etc have prototypes for narrow track cars.

Fig.1 Various narrow track vehicles

A very successful product is a narrow car of the name NARRO, this car is expensive at $48000. However, has managed to find customers, which stresses the acceptability of narrow cars for the public. Two motors each power this car driving one rear wheel; it has a maximum speed of 120 kmph. But narrow is a tall car, too tall for its track. It rolls tremendously on curves, the manufacturer has compensated for this by providing it a very stiff suspension. Since the car is only meant for urban road use the compromise made in suspension does minimum damage, but even with stiff suspension, the threshold velocity of this car in a curve is very low in comparison to a full track width car.

2.1. Tilting Train

Tilting trains are today common in Europe and Japan. These trains are rail running; they have very high curve velocities. In order to enable trains, to negotiate curves at high speeds, tracks are slightly banked (up to 11 degrees). However, these trains are too fast, and it is not possible to tilt track beyond a limit because trains also pass along these curves slowly at times. Tilting trains are an optimum solution for this problem. These types of train tilt the body on the curve, this is a sort enables faster curve threshold speed and increased passenger comfort. The figure below shows two tilting mechanisms used in trains.

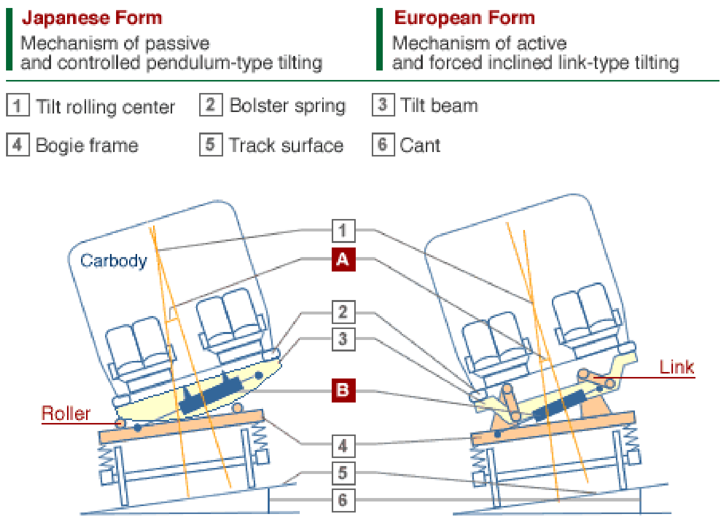

Fig.2 Self balanced Train

2.2. Three Wheeled Tilting Cars

These types of cars are a new species, but their number is fast increasing. These cars tilt about their rear wheels. Either there can be two wheels at the rear like the carver. Which has two wheels at the rear and the car body tilts about the rear wheels. Steering is done using the front single wheel or these can be one wheel at the rear about which the body tilts. Like the GTR (Grand Tilting Racer).

Fig.3 Three wheeled tilting cars

3. Methodology

The objective of this project work is successfully developing a design of a tilting mechanism for a narrow tilting car. The mechanism is to be reliable, simple, cost-effective and practically feasible. The aim of this tilting mechanism is to provide banking to the car on unbanked curves, to enable added threshold speed on curves in comparison to a narrow non-tilting car. This system is also supposed to enhance passenger comfort, as the side force felt by passengers in a car taking a turn is comparatively less in a tilting car. Also in our purpose is the fabrication of a mini-prototype a remote-controlled toy car-to demonstrate the tilting in the real world.

The methodology adopted to use standard and presently used components in design rather than to design all components from the ground up. The advantage of this method is that you do not have to spend a ridiculous amount and time in testing the integrity of each part as they have already proved their worth in real-world applications. Initially, the frame design was adopted from an already existing narrow car and minor changes were made to suit our purpose, the tilting mechanism first devised was based on using power screw driven by stepper motor lifting and lowering each wheel of the car. This mechanism later dropped in testing phase due to following disadvantages.

- It had a very large response time; this was not suitable for a car-approaching curve at a very high speed.
- Wear and tear of screw and contact nut bearing is too high to be satisfactorily used in a car.
- The system used four high torque steppers; this along with controls could shoot up the cost of production.

Due to these disadvantages, the power screw design dropped and a fully new design proposed. The prototype car also uses the same tilting mechanism setup. The software to be used in the design and testing of design is pro-engineer version 4.

3.1 Manufacturing

By using the fundamental abilities of the software about the single data source principle, it provides a rich set of tools in the manufacturing environment in the form of tooling design and simulated CNC machining and output. Tooling options cover specialty tools for molding, die-casting and progressive tooling design.

4. Fabrication and Design Procedure

The mini-prototype fabricated on a toy car, which is a 1:18 scale model of a hummer SUV. The entire plastic base of the toy car replaced with sheet metal parts. All parts used in the same design in mild steel sheet metal. For control of the car, the same PCB as used in the toy car used. Its connections were re-laid. Small D.C motors with no speed or motion control were used. These motors were but reversible in direction of operation. The tilting mechanism was power driven only on rear just like our actual design.

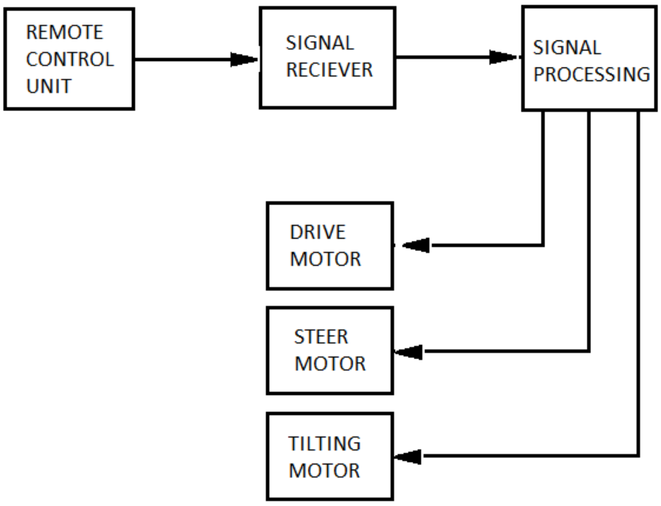

Fig. 4 Layout of fabrication and design procedure

4.1. Frame Design

The frame has been designed with parameters taken from an already existing and successful narrow track car. The entire suspension system has been redesigned and an additional tilting tyre holder was welded on the frame both at the front and at the rear. The adoption of an already existing frame for our design ruled out the requirement of stress analysis. The frame is sure to hold on, even in case of most hostile conditions, as it is a tried and tested design.

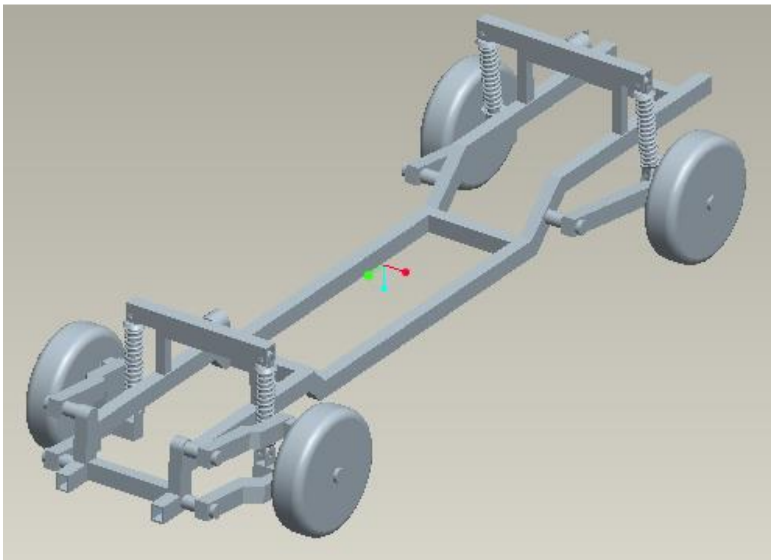

Fig. 5 Shock Absorbers system of the model

4.2. Design of Drive Motor

In the design of the car, we have followed a “no risk policy”, instead of designing all the parts. The parts are already used and tested in others cars. This is advocated as we needn’t have to test these already tested parts unnecessarily. Also, these parts are already in use and are satisfactory in their operation. The only new design is actually the suspension and the tilting mechanism. We have discussed in detailed all the design details in the coming pages. In design we have decided to stick to an electrical drive system for the vehicle, though it is going to be more expensive than oil, it is certainly futuristic and eco-friendly. Besides, the electrical drive system can be mounted lower and can help to lower the center of gravity and thus increase the threshold speed at curves.

4.3. Design of Power Plant

The propulsive power for the vehicle has been decided based on the top speed needed. It was decided that the vehicle should be able to attain a highway cruising speed of 120 Kmph. So the vehicle must be good for a top speed of at least 150 Kmph. Hence the power of propulsion is to be decided in terms of the maximum speed required.

Estimated weight of the car = 650*9.8 = 6370N
$P_V = (R_a + R_r)*V$
P_v is power for propulsion.
R_a =aerodynamic resistance.
R_r =rolling resistance.
V = Speed in kmph.
$R_r = (a+bV)*W = 6370*(0.015+0.00016*150) = 238.875N$
$R_a = K_a*A*V^2$
K_a is aerodynamic co-efficient =.027
A is frontal area = $0.98m^2$
$R_a = 0.027*0.98*150^2 = 595.35N$
$P_v = (595.35 + 91.875)*150/3600 = 34.76hp.$
Power required = P_v/efficiency= 34.76/.97 = 35.83hp.

Hence, it decided to use two 20 hp motors of DC brushless type. The motor in question has a torque of around 800 Nm. These hub motors are already used in some electric vehicles. The battery that would power the system is of the lithium-ion type with specifications as below. Voltage- 144V, Capacity- 10KWh, Weight- 80kg. The battery under full charge can provide the vehicle a range of around 100 km/s.

4.4. Design of the Tilting Mechanism

The tilting mechanism design was a complex question. Initially, it was decided to use a power screw driven screw driven screw holders for each individual wheel controlled by a stepper motor. The design almost completed. It had several advantages:

1) Each wheel could be moved independently of the other.
2) More precise control was possible with power screw lifters.
3) It could be modified to incorporate other systems like body level control, ground clearance adjustment system etc.

But analysis showed some critical disadvantages of screw lifters. They were

- Their response was slow at very high speed and repeated steering and control steering.
- The wear and tear in screw parts were more than desirable. This would only aggravate in a real-life situation where dust and sand particles can accelerate the wear of the screw and lifters.

Hence the design was discarded and we were on the lookout for a new and simple tilting mechanism. It was at this point, it decided to use the present design of a tilting mechanical tyre, controlled by a stepper motor. The ends of the tyre were linked to each rear wheel through struts as used in bikes rear shocks but with universal joints on both sides. The tyre is moved about a central pivot mount on the frame, this motion in result lift the wheel on one side, while lowering the other, and this in result tilts the vehicle to one side. The reverse motion of the tyre tilts the vehicle in opposite direction. After much thought and consultation, it was decided to power only the rear-rotating tyre, the front was free and was supposed to follow the rear. This adopted not to reduce the cost but it had the following advantages:

- It provided more freedom of movement to the front wheels, which ensured better comfort.
- The freedoms of movement of front wheels also give the vehicle added steerability and mean variability.
- It also reduced the overall weight of the vehicle.

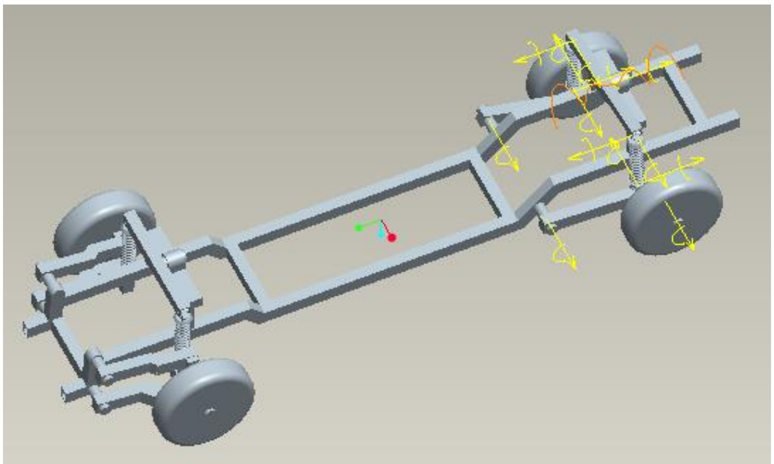

Fig. 6 Chassis of proposed design

5. Construction

5.1 Electrochemistry

The three participants in the electrochemical reactions in a lithium-ion battery are the anode, cathode, and electrolyte. Both the anode and cathode are materials into which, and from which, lithium can migrate. During insertion (or intercalation) lithium moves into the electrode. During the reverse process, extraction (or deintercalation), lithium moves back out. When a lithium-based cell is discharging, the lithium is extracted from the anode and inserted into the cathode. When the cell is charging, the reverse occurs. Useful work can only be extracted if electrons flow through a closed external circuit. The following equations are in units of moles, making it possible to use the coefficient *x*.

The positive electrode half-reaction (with charging being forwards) is:

$$\mathrm{LiCoO_2} \leftrightarrows \mathrm{Li_{1-x}CoO_2} + x\mathrm{Li^+} + xe^-$$

The negative electrode half-reaction is:

$$x\mathrm{Li^+} + xe^- + 6\mathrm{C} \leftrightarrows \mathrm{Li_xC_6}$$

The overall reaction has its limits. Over-discharge supersaturates lithium cobalt oxide, leading to the production of lithium oxide. Possibly by the following irreversible reaction:

$$\mathrm{Li^+} + \mathrm{LiCoO_2} \rightarrow \mathrm{Li_2O} + \mathrm{CoO}$$

Overcharge up to 5.2 Volts leads to the synthesis of cobalt (IV) oxide, as evidenced by x-ray diffraction

$$\mathrm{LiCoO_2} \rightarrow \mathrm{Li^+} + \mathrm{CoO_2}$$

In a lithium-ion battery, the lithium ions are transported to and from the cathode or anode, with the transition metal, cobalt (Co), in $\mathrm{Li}_x\mathrm{CoO_2}$ being oxidized from $\mathrm{Co^{3+}}$ to $\mathrm{Co^{4+}}$ during charging, and reduced from $\mathrm{Co^{4+}}$ to $\mathrm{Co^{3+}}$ during discharge.

5.2 Electrolytes

The cell voltages given in the Electrochemistry section are larger than the potential at which aqueous solutions can electrolyze, in addition, lithium is highly reactive to water, therefore, nonaqueous or aprotic solutions are used. Liquid electrolytes in lithium-ion batteries consist of lithium salts, such as $\mathrm{LiPF_6}$, $\mathrm{LiBF_4}$ or $\mathrm{LiClO_4}$ in an organic solvent, such as ethylene carbonate, dimethyl carbonate, and diethyl carbonate. A good solution for the interface instability is the application of a new class of composite electrolytes based on POE (poly (oxyethylene)) developed by Syzdek et al. It can be either solid (high molecular weight) and be applied in dry Li-polymer cells, or liquid (low molecular weight) and be applied in regular Li-ion cells. Another issue that Li-ion technology is facing is safety. Large-scale application of Li cells in Electric Vehicles needs a dramatic decrease in the failure rate. One of the solutions is the novel technology based on reversed-phase composite electrolytes, employing porous ceramic material filled with electrolyte.

5.3 Specifications and design

- Specific energy density: 150 to 250 W·h/kg (540 to 900 kJ/kg)
- Volumetric energy density: 250 to 620 W·h/l (900 to 1900 J/cm^3)
- Specific power density: 300 to 1500 W/kg (@ 20 seconds and 285 W·h/l)

Because lithium-ion batteries can have a variety of cathode and anode materials, the energy density and voltage vary accordingly.

Lithium-ion batteries with a lithium iron phosphate cathode and graphite anode have a nominal open-circuit voltage of 3.2 V and a typical charging voltage of 3.6 V. Lithium nickel manganese cobalt (NMC) oxide cathode with graphite anodes have a 3.7 V nominal voltage with a 4.2 V max charge. The charging procedure performed at constant voltage with current-limiting circuitry (i.e., charging with constant current until a voltage of 4.2 V reached in the cell and continuing with a constant voltage applied until the current drops close to zero). Typically, the charge terminated at 3% of the initial charge current. In the past, lithium-ion batteries could not be fast-charged and needed at least two hours to fully charge. Current-generation cells can be fully charged in 45 minutes or less. Some lithium-ion varieties can reach 90% in as little as 10 minutes.

5.4 Stepper Motor Design

For tilting the vehicle by 20 degrees each side should be able to move up and down by at least 13 cms.

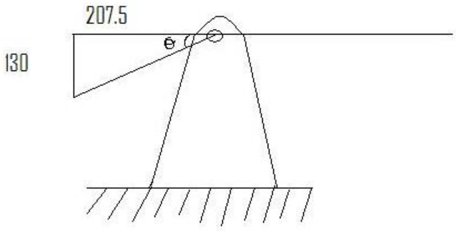

Fig. 7 schematic view of stepper motor design

This gives the total rotational measure for the stepper motor i.e. 64.13 degrees in all. The stepper motor is to be controlled by a microprocessor based on inputs from the following types of sensors.

1) Speed of sensor
2) Steering position sensor
3) Yaw rate sensor
4) Level sensor

The signal to the stepper motor generated in proportion to the speed of the vehicle. The signal is given to the motor based on the steering position. The level position sensor senses if the road already banked, it then adjusts the signal accordingly so that the vehicle does not over tilt at any point.

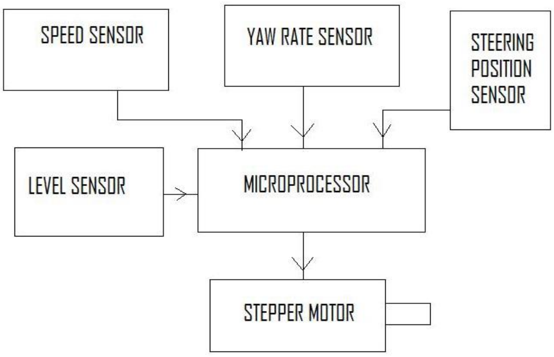

Fig. 8. Block diagram of controlling unit

5.5 Testing of Design

The proposed tilting mechanism model was designed and tested in PRO-E simulation environment. Initially, the tyre resisted movement and after many rounds of fine-tuning the dimensions, the assembly began to show positive results. Only the rear-rotating tyre had to be tested, as the front was not underpowered motion. The front rotating tyre assembly was also dimensionally modified to suite the rear one. A certain range of motion imparted to the rear-rotating tyre and the process captured as a video for presentation. The complete frame design with final dimensions are

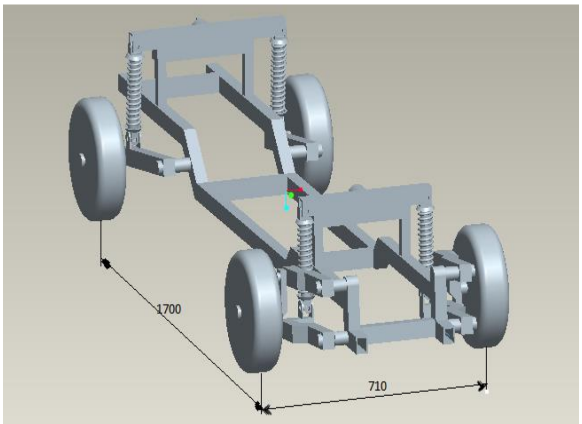

Fig. 9 A three-dimensional view of proposed model

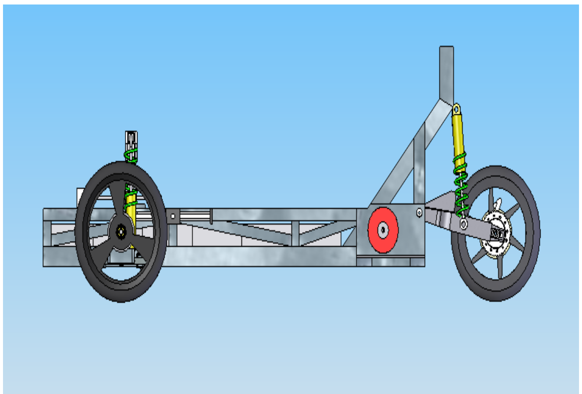

Fig. 11.Front view of a simulated model

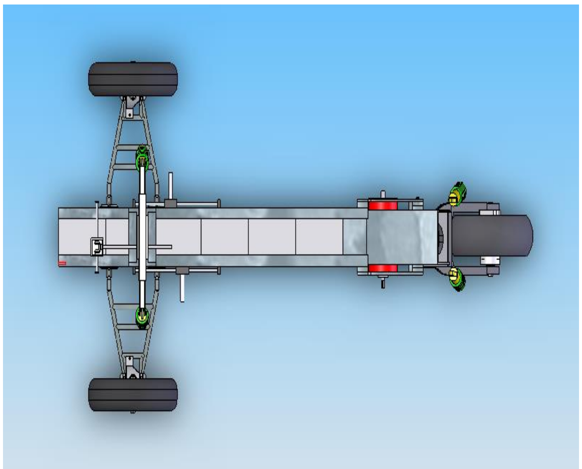

Fig. 12. Top view of a simulated model

5.6 Advantages of Narrow Tilting Car

Several of the advantages of our design over conventional car was discussed are

- This car is much more efficient than a conventional gasoline car due to reduced aerodynamic drag at cruising speed due to reduced frontal area.
- This design combines the utility of a car with the flexibility like motorbikes.
- Narrow track cars are definitely the future of urban mobility, but our tilting car can also handle highway cruising as well.
- Like any other electric car, it is cheap to run and environment-friendly.
- It is also likely to be a solution to real day traffic congestion.

5.7 Comparison of Threshold Velocity on Curves for Tilting and Non-Tilting Cars

From equations of vehicle dynamics, for a vehicle in a curve

Maximum sliding velocity, $Vs^2 = gC(\sin\theta + \mu\cos\theta)/(\cos\theta + \mu\sin\theta)$

Maximum overturning velocity, $V_o^2 = gC(a\cos\theta + 2h\sin\theta)/(2h\cos\theta - a\sin\theta)$

For a non-tilting car under the following parameters

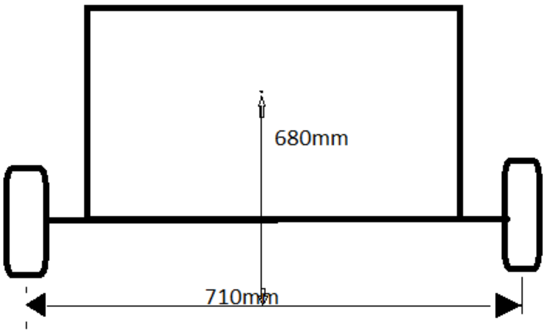

Fig. 10 Basic drawing of the model

5.8 Design Parameters

$\mu=0.6$

$\theta=20^0$

$C=50m$

$g=9.8m/s^2$

$a=0.71m$

$h=0.68m$

Fig. 13. Fabricated Model

Sliding velocity for non-tilting car =17.14m/s =61.7kmph

Overturning velocity for the same =15.99m/s =57.56kmph

Whereas for a tilting car that can tilt 20 degrees into the curve,

Sliding velocity = 24.58m/s =88.48kmph

Overturning velocity = 82.86kmph

Increase in sliding velocity = 43.4%

Increase in overturning velocity =43.9%

The figure shows the fabricated model of the concept car. The concept model was fabricated with four-wheeled tilted cars. This is naro track based car. The naro track car is till in the concept level. Through this concept, the car was fabricated. In a mass production the fabrication cost will come down and it reduce the today's traffic in the cities.

6. Conclusion

The proposed self or auto balanced vehicle design performs very well the model facilitates to enable the car to tilt into the curved motion. The result shows that the objective of this work increases the threshold velocity of a narrow car in a curve has been successful. The design of the car and tilting mechanism worked flawlessly in simulation as well; the mini-prototype to demonstrate the tilting mechanism works successfully in all the aspects facts as decided of the objectives. The analysis shows that the proposed model provides increased the stability during the curved motion more than 50% of stability of the previous models.

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