Stability Enhancement of A Powered Two Wheeler Vehicle Under Curve Negotiation

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Abstract:- During cornering of a two wheeler under dynamic conditions when the vehicle is steered to the left or right, the axis of the wheels and other rotating parts undergoes precession along with spinning which produces a gyroscopic couple. Due to the action of these moments on the vehicles along with the centrifugal forces and gravity acting on it, the vehicle may either skid or overturn depending on the angle of tilt, velocity of the motorcycle, radius of the curve & mass of the vehicle. The main objective of this work is to ensure the safe negotiation of the turn and to prevent accidents by establishing a harmonious relationship between the effecting parameters. A device was developed to act as a feedback control system; taking the inputs from a IMU sensor, predict the equilibrium conditions and thereby control the dynamic parameters of the 2 wheeler in order to enable it negotiate the curve safely.

I. INTRODUCTION

Two wheeler are inherently unstable vehicles. When a two wheeler moves straight on road, vehicle remains stable under the action of various forces like tractive effort, resistance forces, gyroscopic couples etc., For velocities lower than the critical velocity of the vehicle in order to stabilize the vehicle the riders need to turn the handle bar left or right in order to generate the necessary steering torque to balance the vehicle. As the speed of two wheeler increases above its critical velocity, it becomes more stable. In this condition, even if rider leaves the steering handle, the vehicle is under stable condition due to the balanced gyroscopic couple which maintains the front wheel straight on road. But during curve negotiation when the two wheeler vehicle is steered to the left or right, the axis of the wheels and other rotating parts undergoes precession along with spinning, which produces a gyroscopic couple to also act along with other forces like the centrifugal force and gravity force. This causes a state of instability.

A curve is negotiated successfully & safely when there is a dynamic equilibrium between the different forces and couples acting on the two wheeler at that particular stance. In order to negate the instability caused due to the couples, the driver needs to lean inwards or reduces the velocity of the vehicle to generate the necessary steering torque so that he safely negotiates the curve [1]. Present work aims at developing an automated real time control system which involves identifying the state parameters by taking feedback from the vehicle and appropriately controlling system parameters to ensure the safe negotiation of the curve by the vehicle even without human intervention.

II. LITERATURE REVIEW

A number of studies have been reported on the analysis of vehicle roll angle, vehicle dynamics & control and vehicle stability under curve negotiation. Simple models of bicycle dynamics are given by Timoshenko-Young model in which the steer angle and speed completely determine the lateral motion of the base point of an inverted pendulum that represents the vehicle's roll dynamics [1]. K. J. Åstrom, R. E. Klein and A. Lennartsson have observed the bicycles from its control perspective [2]. D. Bortoluzzi, R. Lot & N. Ruffo made a study on motorcycle steady turning & the significance of vehicle geometry and inertia. A rider was assumed to behave like a PID controller by applying a steer torque proportional to bicycle lean to maintain stability [3]. V. Cossalter R. Lot and F. Maggio have presented a study on the braking style and its implication on motorcycle stability [4]. David J. N. Limebeer and Amrit Sharma studied the dynamics of the accelerating bicycle under straight running and cornering conditions [5]. Hac, A., Nichols, D., and Sygnarowicz, D. made studies on Integration of ESC and occupant protection system designed to deploy during rollovers. The algorithms were based on kinematic relationships, thus avoiding dependence on vehicle and tire models, which minimizes tuning efforts and sensitivity to parameter variations [6]. M Ghosh, S Mukhopadhyay observed that roll behavior worsen with the braking force applied during a turn, but the stability of the two-wheeler under hard braking conditions may be better [7]. We propose a method for implementation of these studies on an actual vehicle at a real-time control basis using a feedback controller.

III. RESEARCH MET HODOLOGY

A mathematical model of a standard two wheelers under curve n egotiation was considered [8] with all the forces & torques it encounters. This model was imported in MATLAB and a standard set of vehicle parameters were assumed for analysis of the model. The system was a nalyzed for the dependency and effect of eac h parameter on the stability of the two wheeler during cornering.

Factors and parameters governing the 2 wheeler dynamics during curve negotiation were identifie d. A device was developed which would act as a control mechanism maintaining stability, by dynamically nullifying instaabilities in the vehicular system.

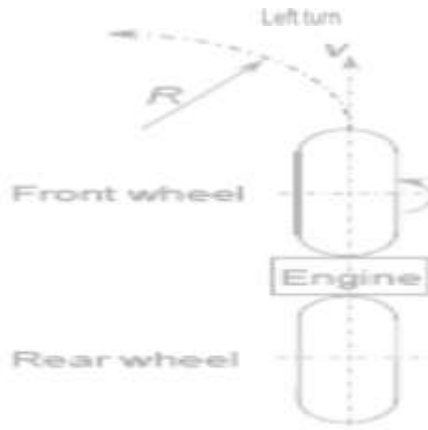## IV. MATHEMATICAL MODELLING OF A VEHICULA R SYSTEM DURING CURVE NEGOTIATION
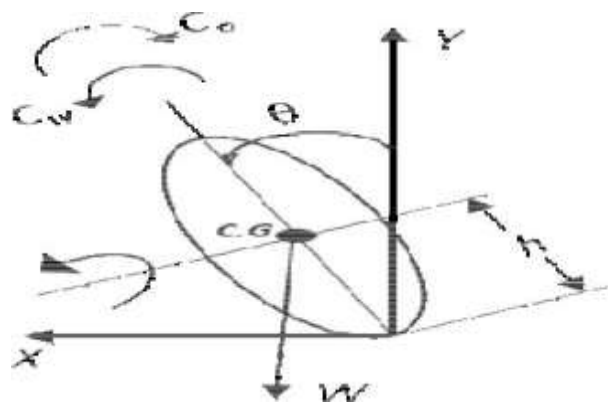
Figure 1 Schematic representation of a two-wheeler vehicle

Figure 2 Couples acting on a two wheeler during curve negotiattion

A. During negotiating a curve as the vehicle takes a turn, it does not remain in the vertical plane but inclinedd to the vertical plane at an angle of heel Θ [8]. The active
gyroscopic couple acting on the system because of the rotating parts, C_{Active} is given by:
(1)

$$c_{Active} = \frac{v^2}{R * r_w} \left[2 * I_W + I_E G \right] \cos\theta$$

B. A centrifugal force acts on the system horizontally through center of gravity along the outward direction. The centrifugal couple C_c is given by:

2   (2)

$$C_C \quad \Box \quad \frac{m\,v_p}{R}\,h\cos\theta$$

C. Since the centrifugal couple has a tendency to overturn the vehicle, therefore, the
Total Overturning Couple (C_o) is given by:
C_o = Active Gyroscopic Couple + Centrifugal Couple = $C_{Active} + C_c$

$$C_O \quad \Box \quad \frac{v^2}{R}\left[\frac{2*I_W \; \Box \; I_E * G}{r_w} \; \Box \; m*h \; \cos\theta\right] \tag{3}$$

D. For equilibrium or stability of the system during turning, we have $C_o = C_w$ at each given instance (4

$$\frac{v^2}{R}\left[\frac{2*I_W \; \Box \; I_E * G}{r_w} \; \Box \; m*h \; \cos\theta\right] \; \Box \; m*g*h*\sin\theta$$

i.e.

If $C_o > C_w$ the vehicle overturns; else if $C_o < C_w$ then the vehicle skids.

From the above equations the velocity ( ) to be maintained for safe negotiation of the curve without overturning or skidding at a particular angle θ is determined. Thus θ is the control parameter for the output , as all other parameters remain constant for a system.

where as
   mass of the system (vehicle + rider)
h height of the CG of system
   mass moment of inertia for the wheel
   mass moment of inertia of rotating parts of the engine

Ɵ   angle of inclination of the vehicle

   velocity of the vehicle
 w   radius of wheels

   radius of road curvature
ω_w angular velocity of wheels (= / w),
ω_E angular velocity of the engine parts,
   Gear/Transmission ratio (= ω_E / ω_w)

V. ANALYSIS

Vehicle parameters (assumed)	Value	Unit
Mass moment of inertia of each wheel ( )	2	kg m^2
Mass moment of inertia of rotating parts of the engine ( )	0.2	kg m^2
Radius of track curvature ( )	100	m
Radius of wheel (w)	0.35	m
Gear/Transmission ratio (G = ω_E/ω_w)	5	
Height of CG of the system (*h*)	0.6	m

Mass of the system (vehicle and rider) ( )	180	kg

A standard set of system parameters were assumed upon to perform the dynamics analysis of the two-wheeler vehicle. Eq. (4) was fed into MATLAB R2013b and various plots were obtained by changing the system parameters to analyze how each parameter affected the angle of heel, to determine how much the rider needs to lean in order to safely negotiate the curve with changing vehicle velocity.
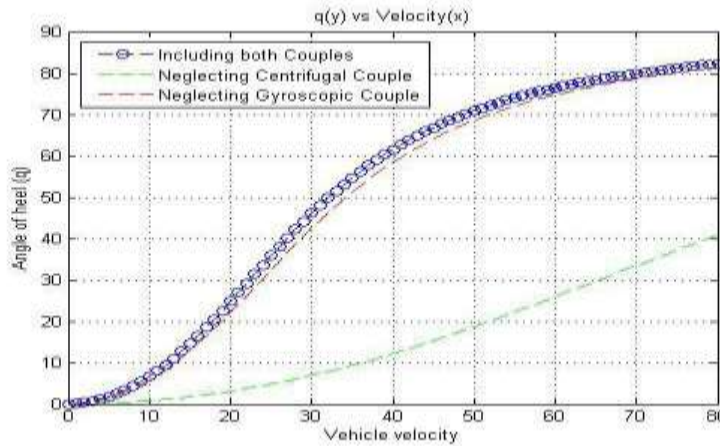
Figure 3 Plot of angle of tilt θ vs velocity

From Fig. 3 we observe that the angle of heel required for the safe negotiation of the curve is affected majorly by the centrifugal force. Higher the vehicular velocity more rapidly the system need to lean in order to safely negotiate the curve. Further analysis was done by assuming a constant velocity of 20ms^{-1} to analyze & validate the effect of other parameters.
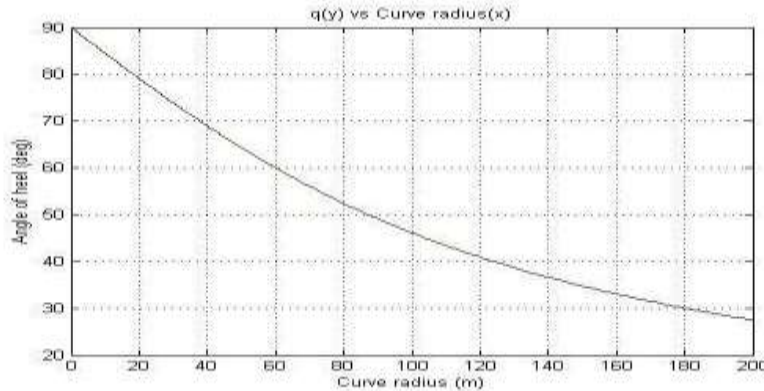
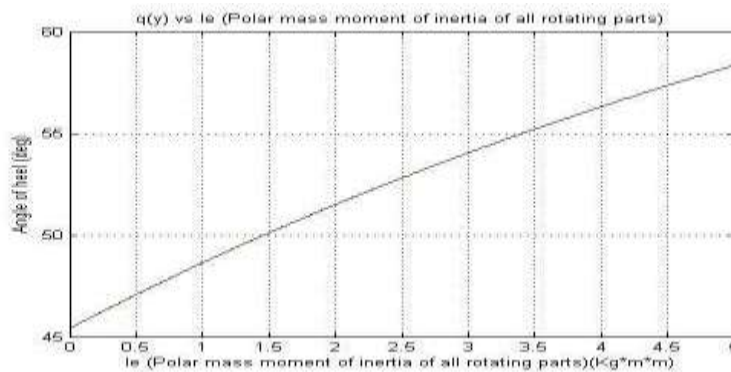**Figure 4** Plot of angle of heel θ vs radius of road curvature R

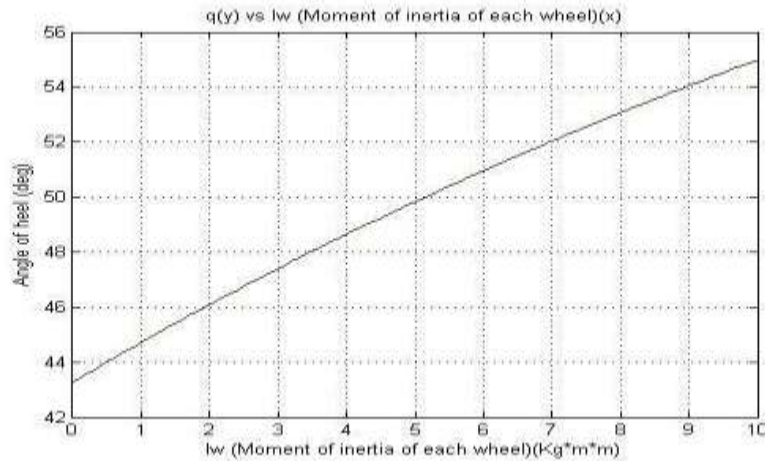**Figure 5** Plot of angle of heel θ vs Moment of inertia of rotating parts in engine

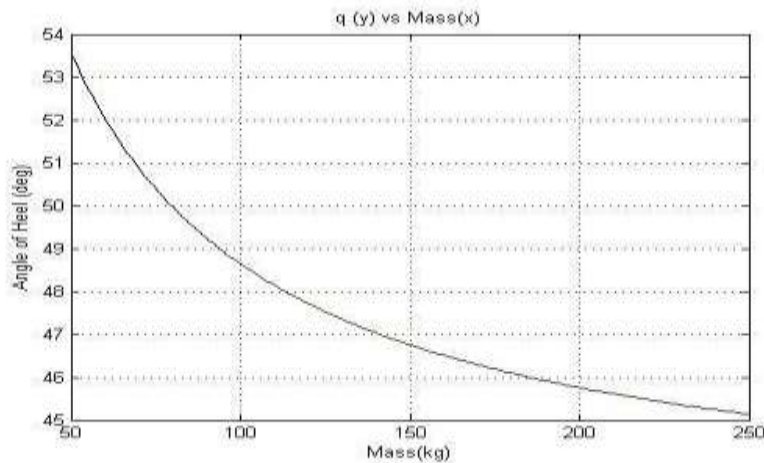**Figure 6** Plot of angle of heel θ vs Polar moment of inertia of wheels

Figure 7 Plot of angle of heel θ vs mass of the system *m*

Above studies were a imed at exploring the effect of each systemm parameter on dynamics of the vehicle during curve negotiation. The findings of the analysis are expected to be of special advantage in building safer vehicles. The following conclusions were drawn based on the discussions in the analysis.

- The influence of gy roscopic forces due to the rotating parts on the angle of heel is very small (almost negligible) when compared to the influence of the centrifugal forces.
- At a constant velocity, angle of heel is inversely proportional to the radius of curvature.
- The effect of momeent of inertia of the engine rotating parts and wheel on angle of heel is directly proportional, but small compared to the effect due to change in curve radius.
- Angle of heel was found to be inversely proportional to the mass of the system. Thus we can conclude that heavier the vehicular system, lower will be the required angle of tilt for a given h and   .

Based on the analyssis, we can predict and set boundary co ndition to the parameters for a stable curve negotiation. We plan in developing a control system which can be used in an y powered two-wheeler to automatically adjjust its velocity ensuring safe negotiation of the curve depending on the angle of heel the user makes during executing the turn.

VI. PROTOTYPE OF THE CONTROL SYSTEM
The control system can be divided into two parts,
- **Sensor:** A unit to monitor & measure the dynamic system parameterrs like velocity & angle of heel of the vehicle undertaking the curve on a real-time basiss.

- **Controller**: A unit to control the system parameters in order to neggate the effect of imbalance on the system due to the changes in parameters like angle of heel for a safe and successful curvee negotiation.

6.1. SENSOR

An Inertial Measurement Unit (IMU) is a device which contains an accelerometer, a gyroscopic sensor and a magnetometer. Using the accelerometer, the acceleration of the IMU w.r.t each axis can be precisely monitored and measured [9]. This can be used to determine the angle of orientation of the system in motion. Deepending on the angle of heel at the particuular instance during the curve negotiation, thee velocity of the system to be maintained for safe negotiation of the curve can be predicted using Eq. (4).
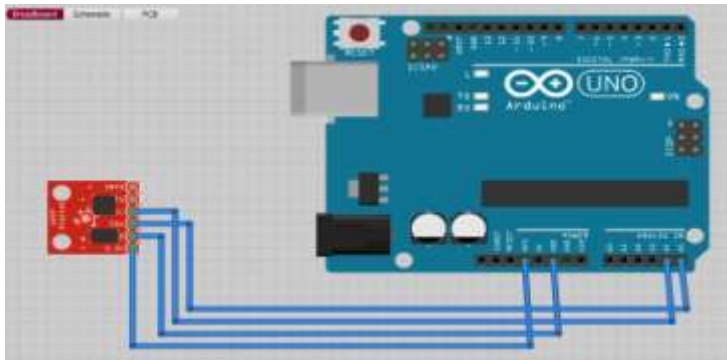
Figure 8 IMU an d Arduino circuit representation using Fritzing software
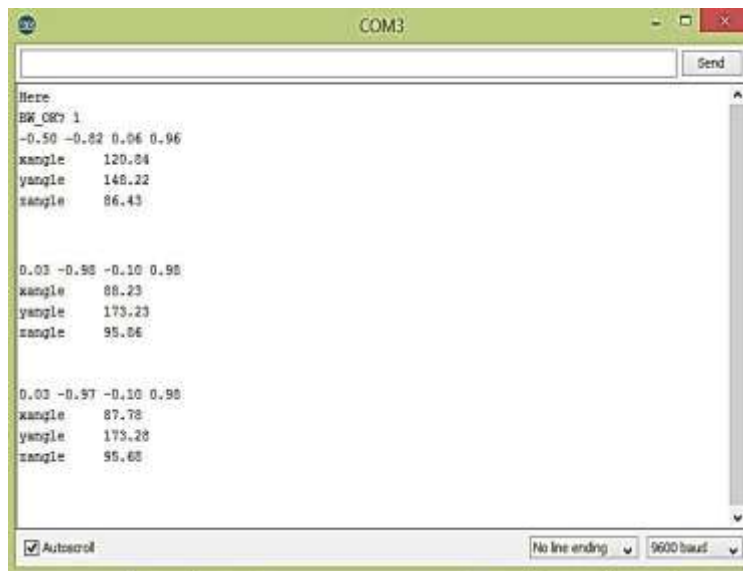
Figure 9 Real-time monitoring of vehicle orientation details on Arduino serial monitor

Two analog ports in the Arduino UNO (microcontroller) were connected to the SDA (serial data) & SCL (serial clock) ports on IMU to get the real-time acceleration readings from it. An in-h ouse program was developed using the Arduino compiler to calculate the orientation of the IMU. The acceleration values w.r.t the principle axes is measured by accelerometeer, thus determining the position vector of the IMU.

The position vector P is the resultant acceleration vector that the accelerometer is measuring on real-time basis and P_x, P_y, P_z are the projections of vector P on the X, Y, Z axes respectively. Resultant position vector P is expressed as:

$$P = \sqrt{P_x^2 + P_y^2 + P_z^2} \qquad (5)$$

Referencing the position vector, the magnitude of angle of P vectorr w.r.t each axis can be determined.

$$\theta_{xr} = \cos^{-1}\frac{P_x}{P}$$

$$\theta_{yr} = \cos^{-1}\frac{P_y}{P}$$

$$\theta_{zr} = \cos^{-1}\frac{P_z}{P} \qquad (6)$$

Even a small changee of orientation of the IMU is precisely measured at a frequency of 1MHz. The angle of heel (θ) to be measured can be referenced to either of these angles depending on the mounting orientation of the IMU on the vehicle.
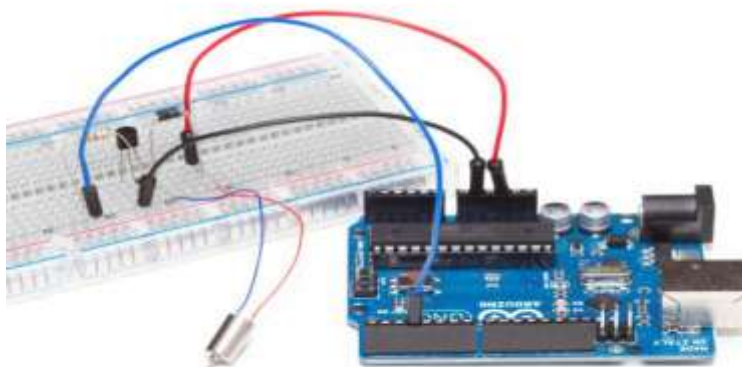
6.2. CONTROLLER
The effect of the Arduin o controller on the vehicle is simulated on a RF-300FA motor.

An assumption is madde that the system continues to move at a coonstant velocity on a straight road. On enccountering a curve as the vehicule is steered, the velocity of the system is to be controllled depending on the measured dynamic parameters like the angle of tilt, radius of thee curve etc from the sensor in order to safelly negotiate the curve. This is analogous to a motor which continues to rotate at a connstant rpm until when there is change in the angle of tilt which will be measured by the IMU and triggered by the sensor unit. This effect of change in angle of tilt will introduce an imbalance in the system equilibrium, which will be negated by a changge in rpm of the motor (triggered by the coontroller based on the sensor input) ensuring that if it were a vehicular system the rider would safely negotiate the curve safely compensating the effect of the dynamics during cornering or curve negotiation.
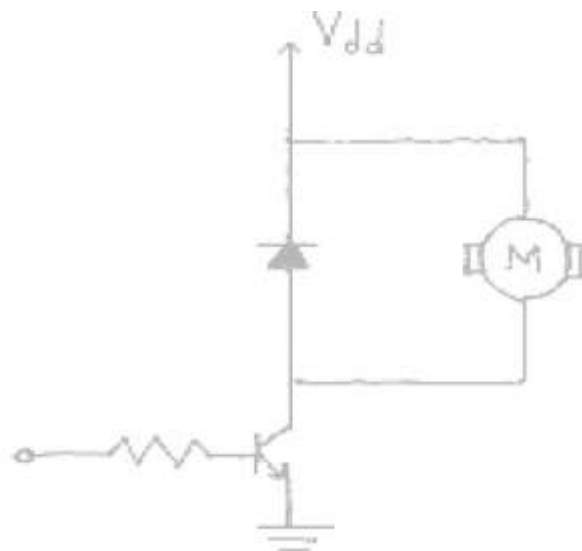
Figure 10 Circuit diagram of the controller unit

Figure 11 A picture showing the controller unit (Arduino & Motor)

6.3. integration of the sensor & controller using matlab

An in-house code was written in MATLAB R2013b integrating both, the Sensor, and the Controller unit. MATLAB first receives the data of angle of heel ( ) from the serial monitor of the Arduino connected to the IMU. The value of   is referenced with value of   in a [vs] matrix which is calculated using Eq. (4) for   in the range 0 to 90^0. MATLAB triggers the Arduino controller which controls the rpm of the motor which corresponds to   of the actual vehicle, for every dynamic value of

VII.   CONCLUSIONS

Depending on the radius of road curvature (R), the [vs] matrix for controlled velocity   of the vehicle required for safe negotiation of the curve at a constant angle of heel ( ) changes according to Eq. (4). Changes in orientation of the system ( ) is captured by the IMU sensor. At a given radius of the curve (R), for every angle of heel ( ) measured by the IMU a corresponding   is mapped and signal is sent to the microcontroller controlling the speed of the vehicle. Thus establishing a real time feedback control for the safe negotiation of the curve.

The above control system has a limitation of assuming a single radius of road curvature R. Further, advances in image processing can be incorporated to obtain the road curvature using an image captured using a camera for a real time updating of [vs] matrix, thus establishing an end-to-end safety system in a 2-wheeler vehicle.

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