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Low Cost Autonomous Navigation and Control of a Mechanically Balanced Bicycle with Dual Locomotion Mode

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Abstract

On the lines of the huge and varied efforts in the field of automation with respect to technology development and innovation of vehicles to make them run on electric power and moreover autonomously, this paper presents a research and innovation applied to a bicycle. A normal daily-use bicycle has been modified at low-cost such that it runs autonomously, while maintaining its original form i.e. the manual drive. Hence, a bicycle which could be normally driven by any human and with a press of switch could run autonomously according to the user's needs has been developed.

Introduction

The complete paper has been divided into three sections broadly, viz. the Mechanical Design, the Control and Planning and finally the actual implementation of the bicycle along with the limitations and applications of the product. The point kept in mind throughout the design process is that the full cost of the modifications made to the bicycle should be low and the electrical and computational complexity as well should be minimized so as to lead to robust product. These requirements have been met to a great extent as shall be shown in the following sections.

Any autonomous vehicle along with all its advantages of reducing human effort and better repeatability etc. carries some disadvantages which are very well known and are majorly the reasons why autonomous vehicles aren't yet on the roads and are far from daily usability. The biggest advantage that this autonomous bicycle, named the i-Bike has, is that it takes the best of both the worlds, the robustness and fail-safe properties of manual vehicles along with the low human effort (& user-friendliness) and advanced-innovative tools available in an autonomous vehicle. The i-bike successfully achieves that.

Added to this, during the design process of the i-Bike it was realized that achieving a full fetched autonomous bicycle is a humongous task (pertaining to its unstable characteristics) and one that requires great efforts to achieve robustly. Hence, the identity of the bicycle wasn't sacrificed by making only as few modifications (reversible ones) as possible at low-cost.

The motivation to build this product comes from the fact that it's always difficult and time consuming to retrieve one's bicycle from the parking stand. It is even worse for someone who has a disability or is a differently-abled person, people who can drive a bicycle but face a lot of difficulty in getting it back from the parking zone, which usually turns into a disorganized area, especially in a country like India. The i-bike solves this problem along with being user friendly as described in the last section and has many other applications as well. It has certain other features as well such as Tracking through GPS, wireless GSM based control and vehicle security applications. In essence, the modifications brought in serve the purpose to a great extent and are quite robust and feasible both in terms of its cost and durability. The initial two sections describe the technical details of the modifications made to the bicycle, mechanically (first section) and in motion control & planning (second section).

Background

The problem of automated stabilization of bicycles has been an area of research for many years and a lot of methods have been proposed. One of the most common methods of balancing a bicycle is the use of inverted pendulum model. In this method the balancer (inverted pendulum) configuration is changed according to the states of motion and position of the bicycle elements. Experimental study of balancing an autonomous bicycle with a balancer has been reported in [2] and [3]. Stabilizing the bicycle with additionally controlling the steering has much better performance and has been reported in [4] and [5]. Further works has been reported which involves acrobatic maneuvers of a bicycle using a new balancer configuration [1]. In all of the reported experimental setup the balancer is controlled by a motor, thus constantly consuming energy and insensitive to abrupt changes in the configuration of the cycle which will require faster motors with higher torques. However, this paper presents a method to attain the same with ease using a mechanically implemented control system which stabilizes the roll of the system. The research focuses on the novel system design to achieve the stability mechanically and to convert the bicycle into a drive by wire system with proper modifications to the braking and driving. The uniqueness of the design is that the bicycle doesn't lose its normal operation and can be operated in a dual locomotion mode.

Mechanical Design

The mechanical design of each and every component is such that it only adds onto the existing structure of the bicycle and any modification does not interfere with riding capabilities of a normal user or rider. The volume a rider may occupy was also kept in mind while designing each and every structure.

Drive Mechanism

Driving Mechanism [6] refers to the complete mechanism designed for the translation of the bicycle. In autonomous mode, the drive mechanism enables it to translate both in forward and backward directions. There are various ways in which driving is achieved in vehicles. Electric motors are the most commonly used actuators due to their easy availability, simple setup and cheap nature. The i-Bike uses electric motors, the details of which are given in the next section. Power transmission can be achieved using various methods like chain drive, shaft drive and wire rope & pulley drive. Hydraulics can also be used for power transmission. But the most economical and viable option is the chain and sprocket mechanism which is used in the current hardware model.

A normal bicycle has a free wheel on the rear hub shell and there is ample space for a motor driven chain-sprocket mechanism to be installed for automation. The motor has been placed on a base supported on the rack of the bicycle (as shown in Figure) because it provides a firm and rigid base reducing the need to make design changes to the bicycle.

The freewheel was modified which works as a sprocket, since sprocket of the required size was not available prefabricated and getting it fabricated would add a lot to the cost to the bicycle. TO provide for both autonomous and manual cycling modes a mechanism has been provided for engaging/disengaging the motor from chain-sprocket assembly by simply sliding and locking it.

Disengaging/engaging mechanism has been chosen such that the cost of manufacturing is low and is easy to use. Proper SolidWorks designs were made and tested for Strains and using the animations, before fabricating on the bicycle. Two shafts were designed based on lock and key mechanism. One of the shaft was attached to the motor's shaft and another part was attached to modified freewheel supported by two self-aligning ball bearings. The use of self-aligning ball bearings reduces high accuracy needs which is otherwise very important during to align the motor's shaft with the modified freewheel’s shaft. The mechanism is engaged when moved towards each other and unlocked when moved away from each other. To allow such movement, motor is provided with a base which slides on the main base. The shaft attached to the motor has a hexagonal shape and the shaft on the sprocket has its counterpart.

The shape of the shaft has to be chosen such that engaging process is easy and there should be less wear of shaft. Hexagonal shape was chosen so that cyclist needs to rotate the shaft by max 30 degree (~15cm forward or backward) for engaging the motor. The material used for the shafts is mild steel and the lock and key part is flame hardened to reduce wear.

Steering Mechanism

Efficient steering mechanism [7] [8] is required to control the bicycle autonomously and its design plays a very major role in position control as it controls the direction in which the bicycle with move.To steer the bicycle the motor should over come torque on the stem due to gravity and centrifugal Torque, gyroscopic effects and momentum induced torque.

Torque=

$$\Delta_{scalar} * [\theta_f * \sin(\phi) + \sigma * \cos(\phi)] * \frac{A}{L} * \mathrm{M} * g$$

Where, $\Delta_{(scalar)}$ is scalar value of trial vector,

Θ_f is the lean axis of frame,

Φ = steering axis angle,

σ = turn angle of handle bar,

L = the distance between the wheel hubs,

A = the horizontal distance rear wheel hub - centre of mass

The required torque comes out to be 2.7 N-m.

A servo motor matching required torque is used for steering the bicycle which is mounted parallel to the head tube. A chain sprocket mechanism is used for power transmission. A sprocket freely moves below the headset and can be tightened using a lever welded to headset. On tightening the sprocket motor is engaged with the stem of the cycle due to high friction and to disengage the motor sprocket is loosened. The motor is mounted using clamp attached to top tube and parallel to the head tube.

Braking Mechanism

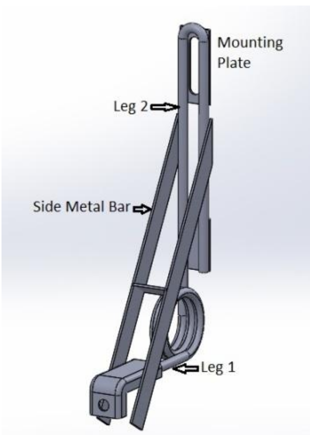
Three mono pivot breaks have been used for braking, two of which are at their normal position which are manually operated and the third is attached on the front wheel opposite to the normal position of manual brake.

Autonomous braking in the bicycle is controlled by a DC motor which rotates a disk on which a wire gets wound up. The motor when switched on pushes the brakes pads towards the wheel, but prolonging the same may lead to damaging of the motor. To avoid this the motor is moved in oscillating function t''o required accuracy.

Balancing Mechanism

Usually bicycles are balanced with electronic feedback control; in this bicycle the aim is to reduce the already complex system by using mechanical feedback control. There can be many such control systems; we chose to use a torsional spring and damper system for the same.

A pair of balancing wheels are used which remain in contact with the ground even when bicycle is moving upright. They are attached on the axle of rear wheel hub. A normal set training wheel would not allow the cycle to lean while taking turns. A balancing wheel includes a torsional spring on which a freely rotating wheel is mounted.



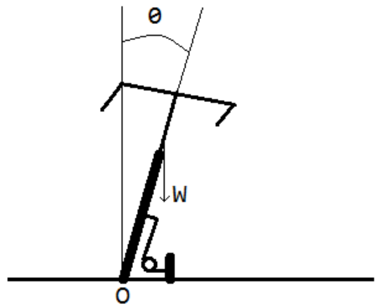
SolidWorks Model for the spring balancer

Spring Design: Both springs are helical torsion spring with right handed helical loop for left spring and left handed helical loop for right spring. If there is no restriction, leg 1 of spring acts as a cantilever beam and vibrates about vertical axis. The two side metal bars restrict the vibration of the spring but allow winding of spring. A plate with slot is welded on other leg of spring. The rear wheel hub bolt come through this slot and whole assembly is tightened by nut. The slot on plate allows adjusting height of balancing wheel.

Calculation of Spring Constant: Considering space constraints the mean coil diameter of spring is kept 5 cm. The radius of rear wheel of bicycle is 30cm and of trainer wheel is 6cm. Therefore, length of leg1 (l_1) is given by:

l_1= 30-6-2.5=21.5cm.

If the bicycle tilts in one direction while turning or due to some obstacle; it should be able to regain vertical position all by itself. Consider a situation where bicycle is tilt and makes an angle θ with vertical. Therefore, spring also winds by angle θ.



Free Body Diagram for Torque Calculation

Torque due to weight of bicycle about point O is given by:

$$T_W = mgh\sin\theta$$

Where, m=mass of bicycle except one balancing wheel (25 kg), g=gravitational constant (9.81 m/s2), h= height of center of mass of bicycle from ground in vertical position (.6 m).

Torque due to spring about point

O= T_S= k*θ*R/l_1

Where, k=spring constant (in N-m/radian), R=radius of rear wheel (0.3 m), l_1= length of leg 1 (0.215 m)

For bicycle to regain vertical position, there must be a net counterclockwise torque about point O for every value of θ greater than 0.

T_S - T_W> 0

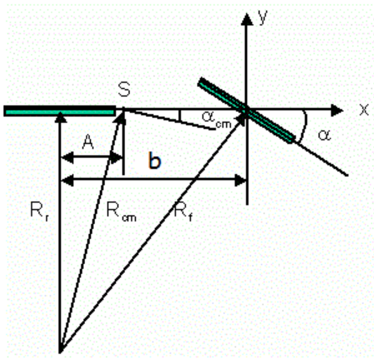
T_S> T_W

k*θ*R/l_1>mgh*sin(θ)

$kR/mghl_1 > \sin(\theta)/\theta$

As $\theta \to 0$, $\sin(\theta)/\theta \to 1$

$kR/mghl_1 > 1$; We get, k > 117.7 N-m/radian = 2.05 N-m/degree



In figure, b=wheel base (1m); A=horizontal distance of center of mass of bicycle from rear wheel axle (.4m); α = steering angle; R_{cm}= Radius of turn of center of mass of bicycle

$$R_{cm} = \sqrt{A^2 + (b/\tan(\alpha))^2}$$

Using the above relation we get that maximum steering angle is kept to be 300. So, smallest possible value of r = 1.78m.

While taking turn, torque of centrifugal force about point O = $T_C = mv^2h*\cos(\theta)/r$

Where, m=mass of bicycle; v=velocity of bicycle; r= radius of turn

Though maximum possible velocity of bicycle is 5m/s, while turning it will be brought down to 2m/s to reduce centrifugal force. For maximum value of T_C, we should put maximum value of v (2m/s) & minimum radius of turn (1.78m).

At this condition bicycle should not tilt by more than 10^0. Therefore, at $\theta=10^0$ net torque about point O should be just zero.

$T_S - T_W - T_C = 0$

$T_S = T_W + T_C$

$k\theta R/l_1 = mgh*\sin(\theta) + mv^2h*\cos(\theta)/r$

Putting values we get k= 4.9 N-m/degree. By formula,

$$k = d^4 E\pi / (64*180 D N_a)$$ (N-mm/degree)

Where, d= diameter of spring wire; E= modulus of rigidity of stainless steel (180GPa); D= mean coil diameter (5cm); N_a = equivalent number of active turns;

$$N_a = N_b + (l_1 + l_2)/3\pi D$$

Where, N_b= body turns (2.25); Putting values & equating to k=4.9 N-m/deg, we get d=1.47cm.

Calculation of Maximum Safe Compression of spring

Minimum Tensile Strength of spring $S_{ut}= A/d^m$. For stainless steel wire, A= 2911 MPa-mm^m& m=.478. Torsional yield strength S_y= .61*S_{ut}=491.4 MPa. Bending stress for round wire torsion spring is given by:

$$\sigma = \frac{32K_i M}{\pi d^3}$$

Where, K_i = Bending stress correction factor; M = moment of force acting on spring

$$K_i = \frac{4c^2 - c - 1}{4c(c-1)}$$

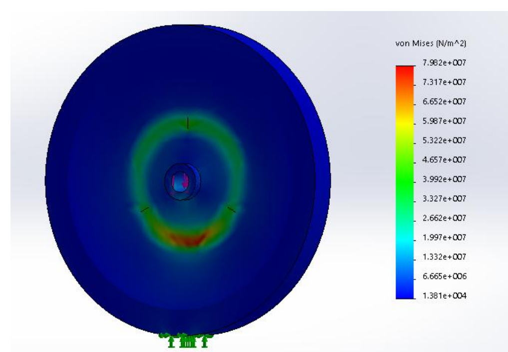
Where c = spring index=D/d; at maximum compression σ = S_y

$$\therefore M = \frac{\pi d^3 S_y}{32K_i} = 119.7 \text{ N-m}$$

Therefore, Maximum safe compression angle

$$\theta = \frac{M}{k} = 24.4^o$$, which is greater than 10^o.

A shorter length of leg2 will increase compressive stress on trainer wheel which is made of plastic but longer length will increase its probability of hitting obstacles. So to optimize the length of leg2, a stress analysis of trainer wheel was performed in SolidWorks.



Stress Analysis Results in SolidWorks

The moment of normal force acted by ground on trainer wheel balances the moment of spring. So, maximum normal force will occur when spring is compressed at maximum angle, which are 10^0.

$$N_{max} = \frac{M_{max}}{l_2}$$

Where, M_{max} = maximum value of moment (641.5 N)

l_2= length of leg2

Trainer wheel was modeled in SolidWorks and High Density Polyethylene (HDPE) material was assigned. Stress analysis was performed at different N_{max} by increasing values of l_2 until sufficient factory of safety was obtained. At l_2 = .11m, Factor of Safety of 2 was obtained hence length of leg2 is kept .11m.

Control and Planning

The mechanical modifications made in the bicycle need to be actuated properly and the required peripherals were added to complete the automation process. The complete process is divided into various parts described in detail as subsections. The Instrumentation and Control System of the bicycle can be further subdivided into the following:

Drive Control System

The translation motion of the i-Bike, both forward and backward, and hence the velocity control is achieved using a feedback control system. The actuators used in the control system are two high torque DC motors [9]. The sensor giving the velocity feedback in the form of counts per revolution is the rotary encoders placed around the motor shaft. The control is achieved using a PID controller algorithm [10] implemented on an electronics chip.

The steer motor was coupled using a sprocket and chain mechanism directly to the main handle of the cycle and the drive motor was coupled using a similar mechanism to an extension to the back wheel of the cycle. As mentioned earlier, the cycle can move using human power and also can be motor driven. So for achieving this, an engaging-disengaging mechanism was added to the drive motor for control method chosen.

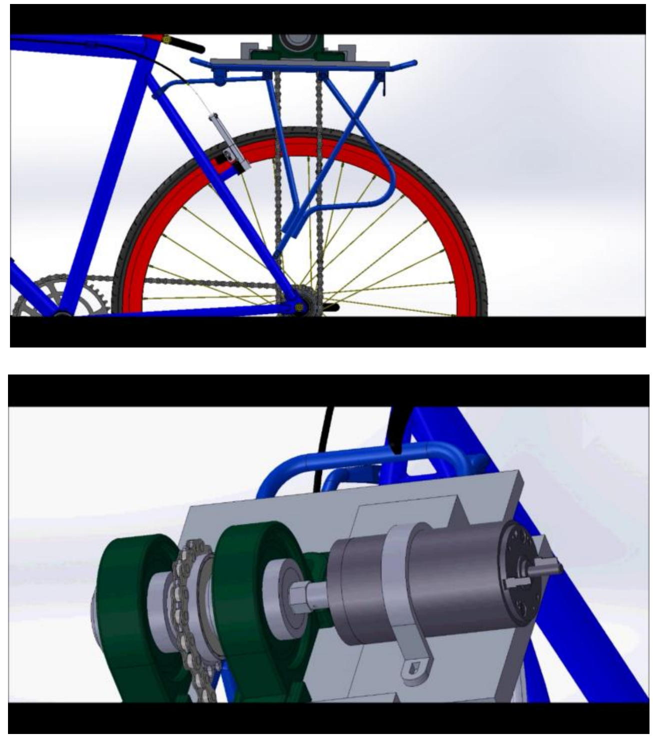


Figure showing drive mechanism, SolidWorks design

The motor is driven using a pulse given by the microcontroller, the Arduino having ATmega 2560 chip on which the control algorithm is implemented. The frequency of the PWM decides the speed to which the motor is sped.

The motor requires quite a high amount of current at full load (7 A) and this was achieved using lightweight but high capacity Lithium Polymer (LiPo) batteries of 2200mAH. The motors were successfully able to do both operations, given their high amount of advertised torque (120 Kg-cm). The battery lasts through about 2 hours on a single charge. This may be improved further by using motors with lower current rating.

Tests were performed on the mechanisms for testing for any kinds of slipping due to mechanical fault and results were satisfactory in case of the drive motor, but the steer motor encountered a lot of slipping in a particular direction, which was corrected by an LED-LDR pair (an Opto-Coupler).

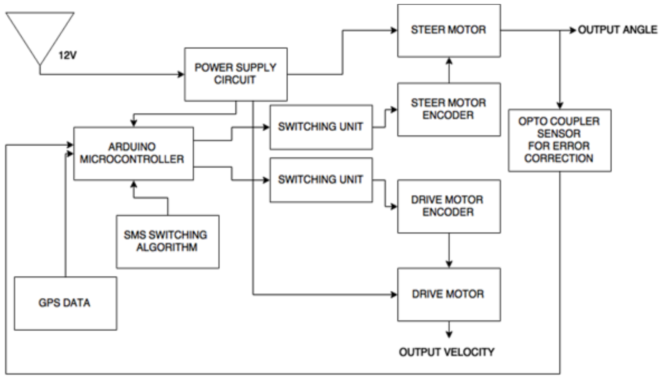


Figure 1: Block Diagram showing the complete control system schematic

For the localization of the bicycle, a basic form of odometry [11], [12] was also implemented using simple geometric formulae and using data of encoders on the motor, which were correct to an error of 5-7% because slipping was negligible during translation. Odometry can be perfected by using encoders on the wheel rim and calculating the distance using real world data, incorporating all kinds of mechanical errors. This would make the path planning code work more accurately. For now, The i-Bike has relied on the motor encoder assuming that the control mechanisms inside work perfectly. In future implementations, external control systems might be used to incorporate errors.

Localization

Magnetometers were used on top of the bicycle for yaw measurement during the motion. Since magnetometer provides the angle with respect to the geometric north, Yaw is measured every time assuming linear variation of magnetometer angle change with the yaw for a very small angle.

But to have a more precise localization of the bicycle [11], along with Yaw measurement for orientation, wheel odometry for the drive motor has been implemented. These calculations lead to the position of the bicycle known to the controller at every instant with a fair deal of accuracy. The counts from the encoders of the drive and steer motor help us to calculate angle and distance travelled by the bicycle in discrete time steps using the model that it rotates in a circle for every small time interval.

Steer Angle Measurement and Control

A dc motor was used to actuate the steering control system in the bicycle. The complete control system for the steering was achieved in a complex way incorporating various innovations. This was needed since the velocity control of the steer drive is not sufficient in itself for the accurate steering control. The main reason for inaccuracies is slippage between the motor axle and sprocket in the mechanical design. Hence, the need for a closed loop control on top of the internal encoder based velocity feedback control was realized using a potentiometer fixed on the drive using an L-clamp [13].

Steering Mechanism SolidWorks Model

During testing, it the control system was further improved upon since the central position of the bicycle was still in doubt and incorrect results were being obtained. Hence, a custom-made encoder was designed and placed on the mudguard of the bicycle. The encoder was realized in the form of an IR sensor, called the MOC sensor. A flap was designed which was placed judiciously such that every time the wheel crossed the central position a signal was received and we could eliminate all the errors accumulated in that run (and hence nullify all such errors). This lead to a very accurate steer angle control mechanism.

The steering microcontroller receives the data from the drive microcontroller which acts as a path planner for the bicycle, giving it the steering angle to rotate, after calculations and estimations suggested by the Obstacle Detection module.

On encountering an obstacle, the obstacle avoidance module is activated instantly (prioritized over others) and its data is overridden on the steering control so that the safety is maintained as a first priority. In future there are scopes to make the algorithm for obstacle avoidance and planning more robust for better practical application.

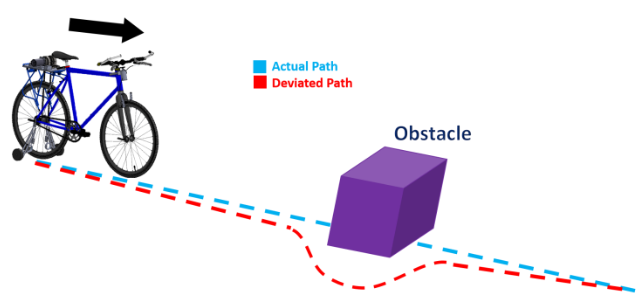


Figure showing Obstacle Avoidance

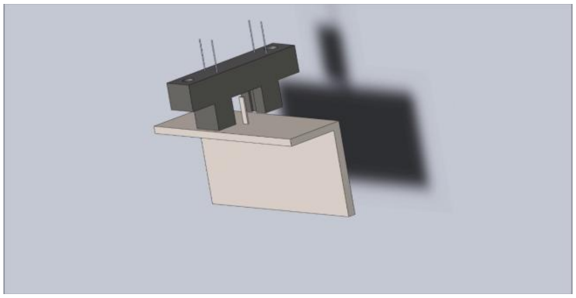


Figure: Feedback Control Mechanism to reduce errors in Steering Control

Obstacle Detection and Avoidance

Two ultrasonic SONARs with a range of 2-400 cm were used for obstacle detection in which time of flight of the ultrasonic wave is determined and hence obstacle distance and angle (measured because of the position of the sensor).

The i-Bike uses 2 SONARs inclined at an angle of 10 degrees with vertical in same horizontal plane. Each SONAR detects obstacles on either side of the bicycle with overlapping cones for also detecting obstacles in front of bicycle, covering a total obstacle detection cone of 45 degrees. In this way, obstacle detection with a considerable field of view was achieved. After the detection of an obstacle, the control was shifted to the obstacle avoidance module which was implemented on the microcontroller driving the bicycle.

Autonomous Braking

A low rpm dc motor with appropriate torque (to pull the brake wire) was used as the braking actuator. The braking wire is attached to the axis of the dc motor and the other end is attached to the bicycle rear wheel braking mechanism used in normal bicycles. A proper motor angle range is chosen to brake the front wheel to make sure that the braking shoes maintain a constant range of braking force required to stop the bicycle. Currently, the system implements braking as an open loop system, improvements could be made upon this design to make the braking closed-loop by detecting and choosing when to brake. Additionally, along with this braking system the drive motor on the back is capable on itself to slow the bicycle down (or even move it backwards!). Though, since currently the bicycle demonstrates very low speeds such as 5m/s or even less, braking is not much of a concern. But, the arrangement in place ensures for the autonomous braking whenever needed.

User-friendly Interface and Features

Autonomous Navigation in the bicycle is achieved by localizing it with respect to its initial position using global positioning system (GPS) and then it is controlled using a SMS (received from the user) which could either contain destination GPS co-ordinates or relative position of the destination with respect to its initial position. This has been discussed in [1]. SMS communication is used to communicate between user and bicycle making it ultimately simple and user friendly. [2] explains more in detail on this fact.

To facilitate this SMS based system in the bicycle, GSM Sim900 module is interfaced with the controller to receive/send messages regarding the target location which bicycle has to achieve or any other control actions. The current location of the bicycle is determined by the GPS module which is interfaced to find the GPS coordinates of bicycle.

Online Tracking of the Bicycle

This significant feature in the bicycle is achieved using GPRS technology available in the GSM SIM 900 module. A GSM modem containing a SIM card of any valid service provider and is used to send the position (Latitude and Longitude) of the vehicle from a remote place over the internet. GPRS is activated on this module using the HTTP protocol which facilitates to send the current GPS coordinates to the web server which is created using a java script. This feature adds to the safety as well as advanced technology implemented on the bicycle.

Data Processing and Acquisition

In this bicycle system the whole data processing is taking place in a distributive manner on two 8 bit 16 MHz Atmega2560 microcontrollers.

The drive microcontroller plans the motion for the bicycle using the algorithm fed to it and executes appropriate commands to the actuators. Along with this, the drive microcontroller is also receiving the GPS coordinates, SMS and Call commands through GSM Modem and controlling the drive motor. The required steer angle for reaching the destination point using the path planning algorithm is sent to the steer microcontroller using UART communication.

Power Distribution and Management

Proper voltage regulator circuits are in place to provide different voltages to different components. The same is clear from the electrical Architecture as shown in the figure.

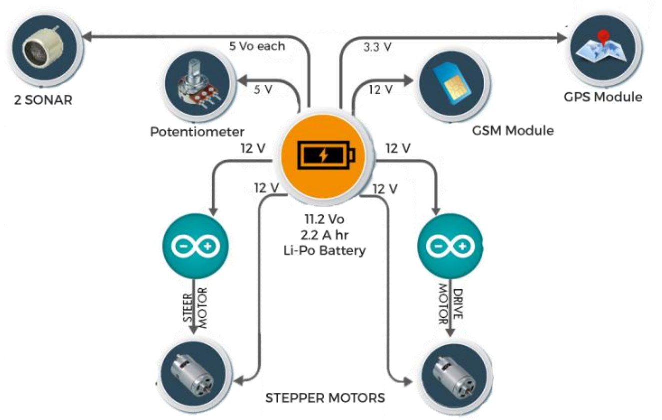


Figure: Electrical Architecture showing Power Distribution

Each of the 12V DC servo motors draw a current of 800mA under no load condition and 7.5A current under the maximum speed condition. i-Bike being autonomous uses various electronic components for its operation. So a proper power distribution system is designed by taking into account the power ratings of all the electronic components used. The whole system of the i-Bike is powered by a single 11.7 V 2.2 AH Li-polymer battery. In order to supply power to all kinds of components which differ in their voltage and power ratings proper voltage regulator circuits are designed. LM7805 Voltage regulator IC which is present in the voltage regulator circuit plays an important role in providing a constant 5 V supply.

The motor used in the model has a voltage input of 12 V and current requirement of about 7.5 Amps. The 11.7 V, 2200 mAH battery [14] is the one easily available in market that is close to its voltage rating and the Discharge Current is 30*2200 mAH = 66 Amp.Li-Po battery is preferred because of its light weight, high discharge rate and relatively good capacity. This battery also supports other components in the bike for power requirements, thus keeping a margin in Amps available and Amps required reduces the stress on the battery and increases its life and capacity. Two or three mid to large capacity lithium batteries could easily fit on one i-bike, giving potential ranges of 100 miles (160 km) or more.

Well designed and soldered PCB were used for all kinds of power distribution and signal conditioning circuits, further adding to the robustness of the vehicle. The table below summarizes the complete requirements.

Table 1. A detailed description of the power ratings of all the components is written below—

Components	Specifications	Description
Arduino Mega[A]	Input Voltage (Recommended) - 7 to 12 V. DC current per I/O pin - 40 mA. DC current for 3.3 V pin - 50 mA	It has a voltage regulator installed on the board. There are 5 V and 3.3 V pin outs on the board that supplies power to other components.
DC Servo Encoder Motors[B]	Input Voltage - 12 V. No load current - 800 mA. Load current - 7.5 A (max). Pulse and Direction pins Input Voltage - 2.5 , 3.3 or 5 V.	The motors are powered separately as they have high power requirement. Arduino controls the speed and direction of motor.
SIM900 GSM Module[C]	Power supply - 5 V. Current consumption (continuous) - 500mA(max) Sleep Mode - 1.5mA.	The module has a DC jack of 12 V with a voltage regulator to take down the voltage to 5 V.
Sonar module HC-SR04[D]	Operating Voltage - 5 V. Operating Current - 15mA.	It is a continuous power consumption source
66 channel GPS module[E]	Operating Voltage – 3.3 V. Power Consumption - 55mA (acquisition), 40mA (tracking).	Data output UART interface 3.3 V

The Actual Implementation and Testing

The figures shown below depict the actual implementation of the bicycle described in detail in the previous sections.

Prototype of the autonomous bicycle

The driving mechanism in the autonomous bicycle

The Steering Column (Modified) in the autonomous bicycle

The balancing mechanism

Applications and Future Prospects

There are many applications of a smart and autonomous bicycle in today's world. It will be a boon for people who are differently-abled, people who are visually impaired or those who have difficulty in localization can use this vehicle to travel across a crowded city. With the autonomous ability of the cycle comes the freedom for multiple people to use the same vehicle for transit. The cycle can to rode to a place and then be called back to be rode to a different place, just by using mobile SMS (while maintain the security all along). The product can also be used to deliver courier or food to customers as it is capable to traversing through narrow and crowded lanes. With the ability to travel through narrow roads, it would be the ideal vehicle for Street view mapping. The painful task of street view mapping can be done by a smart and autonomous bicycle. It could also be used for real-time traffic monitoring as it wouldn't be adding to the traffic. A smart bicycle would also ease the pain of properly and systematically parking a cycle as one wouldn't need to scout manually for an available parking space. As per need, the cycle could be called to one's location instead of manually walking to the parking zone. In this modern era, we have huge factories with complex equipments; an autonomous cycle would be the ideal mode of transport between any two points in the factory as it can then return to its designated space after assisting technicians move.

Future Prospects of technology

The algorithm that is used by the bicycle to achieve its autonomy can be used in ally form of autonomous vehicle especially autonomous Electric scooters. The engaging mechanism used for dual mode can be used in other vehicles where such need might arise. The MOC circuit used to ensure resetting of the steering even in the event of a mechanical offset can be used in other autonomous vehicles to ensure that the vehicle travels rectilinearly.

Conclusion and Limitations

Current experiments with the prototype have shown obstacle avoidance capability with sonar at slow speeds, but further work must be done to avoid obstacles at higher speeds. The design of the spring limits the maximum speed during a turn and the maximum tilt angle which needs further optimizations. The design is also suitable for flat terrain with minor disturbances but some fluctuations still exist. For precise control of the bicycle the backlash error in the steering and rear wheel has to be reduced and along with that the processing power could be increased.

The bicycle achieved what it set-out to, initially. It demonstrated great robustness as any user can sit on it to drive it anywhere and then the tests have shown that one SMS sent to the bicycle activates the autonomous mode and the bicycle avoids all obstacles in its way, giving the user a track of its position online, reaches the final destination.

References

[1] L.Keo, M.Yamakita, "Dynamic Model of a Bicycle with a balancer and its control" Proceedings, Bicycle and Motorcycle Dynamics 2010 Symposium on the Dynamics and Control of Single Track Vehicles, 20–22 October 2010, Delft, The Netherlands

[2] M. Yamakita, A. Utano and K. Sekiguchi, "Experimental Study of Automatic Control of Bicycle with Balancer", IEEE/RSJ Int. Conf. on Intelligent Robots and Systems, Beijing, China, 2006, pp. 5606-5611.

[3]A. Murayama and M. Yamakita, "Development of Autonomous Bike Robot with Balancer", SICE Annual Conference, Kagawa, Japan, 2007, pp. 1048-1052.

[4]L. Keo and M. Yamakita, "Controller Design of an Autonomous Bicycle with Both Steering and Balancer Controls," IEEE Multi-conference on Systems and Control. pp. 1294-1299, 2009.

[5]L. Keo and M. Yamakita, "Controlling Balancer and Steering for Bicycle Stabilization," IEEE/RSJ Int. Conf. on Intelligent Robots and Systems. pp. 4541-4546, 2009.

[6] http://en.wikipedia.org/wiki/Bicycle_drivetrain_systems

[7] http://www.real-world-physics-problems.com/bicycle-physics.html

[8] https://sites.google.com/site/bikephysics/english-version/5-torques-acting-on-the-steering-axis

[9] Elbuluk, M.E.; Kankam, M.D. Aerospace and Electronic Systems Magazine, IEEE 1995. Motor drive technologies for the power-by-wire (PBW) program: options, trends and tradeoffs. I. Motors and controllers

[10] Xiaolong Jin ; Intell. Vehicle Res. Center, Beijing Inst. of Technol., Beijing, China ; Zhibao Su ; Xijun Zhao ; Jianwei Gong 2011Design of a fuzzy-PID longitudinal controller for Autonomous Ground Vehicle

[11] Ji Zhang, Sanjiv Singh, George Kantor, *Carnegie Mellon University* , Robust Monocular Visual Odometry for a Ground Vehicle in Undulating Terrain

[12] Keith W Gray, Obstacle Detection and Avoidance for an autonomous farm tractor

[13] Konyk, S., Jr. ; Dept. of Electr. & Comput. Eng., Villanova Univ., PA, USA, A student personal positioning system approach to the analysis, design and fabrication of actual control systems

[14]] http://www.ebikeschool.com/electric-bicycle-batteries-lithium-vs-lead-acid-batteries/

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