IoT enabled e-Bicycle: An ecofriendly solution to ease Local Mobility

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Abstract. The use of e-bicycles is increasing every day. It is comparable to a traditional bicycle, but with the potential of using electric motors to help or replace pedalling efforts. The main motivations for this endeavour are environmental awareness, health concerns, independent transportation mode, and growing fuel prices. Both urban and rural commuters find it to be a cost-effective mode of transportation. A battery-powered PMDC motor drive-based e-bicycle was investigated in this work. This contains the motor hub, as well as the mid-chain drive that connects to the back wheel. This technology allows the user to either peddle the bicycle or use the 7Ah battery to power the motor. The traction system has a torque constant of 0.588 Nm/A and an emf constant of 0.0763 V/rad/s. This bicycle has been put through rigorous testing in the lab and on the road. The test result shows the vehicle's duty cycle behaviour both loaded and unloaded. During the road trial, its mechanical stability and charging sustainability were assessed. The VI findings point to the solution's efficacy in terms of local mobility.

Keywords: Bicycle, electric, mobility, environmental, trial run, economical, traction.

1 Introduction

Nowadays, rising prices of fuel, as well as automobile vehicles, are the key reasons to find an economical way of mobility for nearby places. Moreover, most countries are looking for such options. Few Indian cities have also adopted this eco-friendly traveling mode. In this initiative, many educational institutes and industries are encouraging the usage of e-bicycle at their campus. Though this is the budding solution among the people but there are several types of researches going across the world.

1.1 Literature Review

Some of the recent studies on ease of mobility have been highlighted as below: Safety measures have been analysed by Ding et al. [1]. In 2021, a group of researchers has studied bicycle commuting dynamics on the wide road to understand its effects on traffic [2]. Thereafter, Zhao and Ong have studied parking allocation and shared cycling usage [3]. In

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continuation with it, Zacharias has studied destination-based dock-free bicycle-sharing [4]. Along with it, the effect of cycling on mental refreshment has been evaluated [5]. An e-bicycle could be the key mobility means for students in both rural as well as urban areas as its viability has been evaluated in Tanzania [6]. In consideration rising significance of electric mobility, its sharing usage amongst commuters will improve resource utilization with comparatively higher speed [7]. Environmental aspects across bicycle routes have been studied in [8]. Health awareness is the key reason behind adopting cycling practices by urban and sub-urban populations [9]. A mobility care possibility for commuters has been evaluated for various city routes [10]. In Agartala, a study was conducted to understand the behavioural attitudes of users while cycling [11]. Sersli et al., have surveyed the role of cycling as a recreational activity among middle-aged people [12]. Thereafter, the possibility of bicycle crashes and accidental impact analysis has been performed [13]. Hereafter, real-world cycling issues at various routes in Brazil's Natal city have been evaluated [14]. Once again, commuters' habitual practices and their attitudes have been analysed [15]. Like one of the previous studies, Chen et al., have evaluated the benefits of bicycle sharing in a free-floating way at the university campus in China [16]. There are also healths benefits of cycling that have been checked in [17]. One more study on bicycle crashes and legal obligations has been evaluated in [18]. A large number of bicycle travelling effects on traffic signal system has been tested in [19]. A hybrid power-based bicycle-sharing scenario has been evaluated in [20]. The paediatric injuries possibility in different demography has been studied while cycling [21]. A case study on sharing of bicycles in urban transit has been performed [22].

E-bicycles are bicycles battery-powered that can be operated via pedaling or a throttle. When we push the pedals on a pedal-assist e-bicycle, a small motor engages and gives a boost, so one can zip up hills called "pedelecs," [13]. Many kinds of e-bicycles are available worldwide, from E-bicycles that only have a small motor to assist the rider's pedal-power to somewhat more powerful e-bicycles which tend closer to moped-style functionality: all, however, retain the ability to be pedaled by the rider and are therefore, not electric-motorcycles. e-bicycles use rechargeable lead-acid batteries and the lighter ones can travel up to 20 to 30 km/h.

1.2 Review of Market Potential for e-Bicycle

India is the second-largest producer of bicycles with 12 million units per year of which 5-7% are premium bicycles and the regular use cycles are growing at the rate of 25% annually [3]. Now, there are plenty of international and domestic brands available in the Indian market. Recently, the e-bicycle is emerging as a new segment across the country and it is having a market potential of 5.3 billion USD. Some companies have started their e-bicycle production like Roulik, Spero, Hulikkal, Being Human, etc. The project explains the concept of using electricity as a linear motive force. We will build an e-bicycle that will not only reduce our effort and make it easy to even go uphill but also help us keep our environment healthy, safe, and most important environment friendly.

Paper Organization: Remaining portions of this study has been illustrated in the following sequence: Section-II: Mathematical Modeling, Section-III: Model Description, Section-IV: Operating Principle, Section-V: Hardware Realization, Section-VI: Trial Run and at the end paper has been concluded in Section-VII.

2 Mathematical Modeling of e-Mobility

While the bicycle is running at a curved surface, it experiences centrifugal force along with frictional forces, which could be represented by (1) [2],

$$\frac{Mv^2}{R} = BMg \tag{1}$$

where, M: bicycle mass, v: speed of the bicycle, R: radius of the road arch, B: co-efficient of friction in the perpendicular direction, g: acceleration due to gravity.

The number of cyclists passing perpendicularly the line segment with respect to the direction of movement could be formulated as in (2) [2],

$$q = \frac{N_c}{[(T - T_i)w]} \tag{2}$$

where, q :flow rate, N_c: cyclists count, w: track width, T: test run duration, and T_i: test run interval timing.

The test run route is having both curved and straight paths, and there are other cyclists who were also travelling on the road, in such circumstances velocity could be given by (3) [2],

$$v(t) = \frac{\sqrt{[x(t+\Delta t) - x(t-\Delta t)]^2 + [y(t+\Delta t) - y(t-\Delta t)]^2}}{2\Delta t} \tag{3}$$

where, $[x(t), y(t)]$ is location of the cyclists, and Δt is the time interval.

In order to understand, the battery traction backup, its internal resistance could be found by (4) [23],

$$R = n_c \times \frac{R_{ic}}{C} \tag{4}$$

where, n_c: battery cell count, R_{ic}: internal resistance per cell and C: charging capacity.

The energy storage to the lead-acid battery is correlated by (5) [23],

$$\text{Energy} = V \times Ah \tag{5}$$

The chopper based motor speed control could be given by (6) [23],

$$\omega_m = \frac{\delta V_a}{k} - \frac{R_a . T}{k^2} \tag{6}$$

where, δ : duty cycle, V_a : armature voltage, R_a : armature resistance, T : motors' torque and k : proportionality constant.

3 Proposed Model Descriptions

An electric bicycle uses rechargeable batteries, electric motors, and some form of control. This control is usually an electronic pulse width modulation control. The e-bicycle is charged with 1-phase AC mains [5]. This is a lead-acid battery that is cost-effective. The PMDC motor has been used as it has low cost as compared to BLDC motors and there is no copper loss since the field winding is absent in PMDC motors, which makes it advantageous to be used [6]. Two-step verification has been included for security purposes. The block diagram of the e-bicycle is presented in Fig. 1, and its major components are given in Table I.

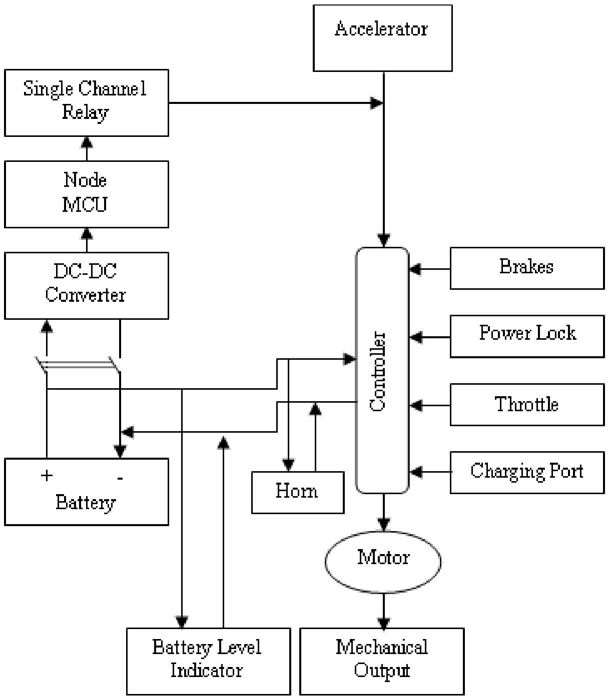

Fig. 1 Block diagram of e-bicycle

To operate the e-bicycle, one needs to unlock it manually as well as through an IoT switch using Blynk App. This system makes our project different from usual e-bicycles. For the IoT switch, NodeMCU with Single Channel Relay is used. It has been programmed with the Arduino IDE platform to have compatible use with the Blynk app. The relay requires 5V voltage to get activated and this voltage is fed by DC to DC step down converter that further, converts 24V to 4.7V. A PWM controller is used to feed the required power to various components such as motor, throttle, lock, brakes, etc. The controller gets power from the 24V lead-acid battery. The integration of NodeMCU to the system is given in Fig. 2.

Table I Integral components of the model

Sl.	Components	Quantity
1	PMDC Motor (350 W, 24 V, 50 Hz)	1
2	Battery (12V, 7Ah, Lead Acid Battery)	2
3	Battery Charger	1
4	Motor Controller	1
5	Throttle	1
6	Brake Lever	1
7	Speedometer	1
8	DC To DC Step Down Converter	1
9	Node MCU	1
10	Single Channel Relay	1
11	Brakes	1
12	Freewheel	1
13	Spokes	1

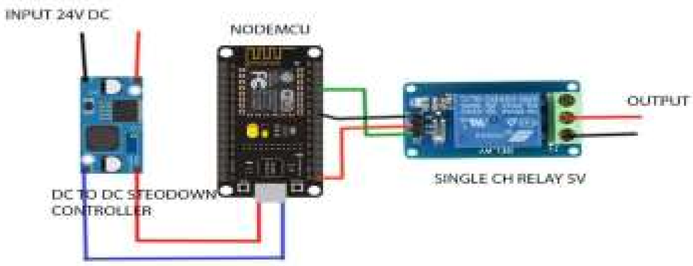

Fig. 2 Connection of Node MCU

A battery level indicator has been installed that will keep a check on the amount of charge left in the battery. This indicator is necessary so, as, to get the battery charged before it gets fully discharged. This will ensure a smooth operation of the e-bicycle. There is three mode of operation of the proposed e-bicycle, as follows:

- Mode-a: *Only Pedal*,
- Mode-b: *Only Traction Motor*,
- Mode-c: *Pedal Assist*.

When the battery is low, the pedal will aid the motor in propelling the e-bicycle. E-bicycles can be an excellent addition to cardiac rehabilitation initiative. Patients may feel comfortable transitioning from manual bicycles to e-bicycles because exercise-based cardiac rehabilitation activities cut fatalities in persons with coronary heart disease.

4 Operating Principle of e-Bicycle

An e-bicycle is having of a PMDC motor and 12 V, 7 Ah rechargeable batteries. The PMDC motor, which works on the principle of rotating magnetic field production, is the main traction component of the e- bicycle. A current carrying conductor will experience a mechanical force when it interacts with a magnetic field, and the direction of this force is determined by Fleming's left-hand rule. These motors are smaller in size, and the permanent magnet reduces the production cost, making it a more cost-effective motor. These motors do not require field

windings; thus there will no copper losses in the field circuit, which enhances overall efficiency.
To begin, the batteries must be charged via a charging port, which takes around four hours to complete. A DPDT switch has been used to turn on the e-bicycle after it has been charged. Electric current is generated and passes from the battery to the controller, where it is sent to various sections such as the accelerator, brake, and motor. An electric bicycle's speed controller is an electronic circuit that controls the speed of an electric motor while simultaneously acting as a dynamic brake. The electric bicycle speed controller gives various voltage signals to the bicycle's motor. The direction of a rotor in relation to the starter coil is detected by these signals. The rotor turns at a set speed as soon as we accelerate the bicycle. It then turns, causing the flywheel to rotate the e-bicycle. Then e-bicycle runs and it goes approximately 25 kms in one full charge. If there is a low charge in the battery then the e-bicycle can be operated via pedals. Here, we have installed one speedometer, which measures the speed of the rotating wheel.

5 Hardware Realization

The IoT elements such as security and anti-theft facilities are integrated into the proposed e-bicycle as portrayed in Fig. 3. The Arduino IDE was used to programme the NodeMCU component. If we don't have a default board, we'll have to manually install the ESP-32 library.

- Installing ESP-32 Library: To program the NodeMCU Devkit, it manually needs to install ESP-32 library.
- Including Blynk Library: Blynk Library from Github must be included. We need to download the latest Blynk library from github in order to add library files.
- Connecting NodeMCU: The voltage has been stepped down using the LM2596 DC to DC step-down converter. The NodeMCU operates at 4 V (3.3 V+0.7 V) to do this.

Fig. 3 2D model of IoT enabled e-bicycle

The input voltage from the battery has been taken here, which is 24V DC. It reduces the output voltage by adjusting the module's potentiometer. Fig. 2 shows the connections between the NodeMCU, single channel relay, and DC to DC step down converter. The LM2596 module's output is connected to the NodeMCU input via a modified micro USB cord. The NodeMCU's connection to the Single Channel Relay Module is now a critical component. However, the female-to-female jumper was used to connect the NodeMCU GND to the relay module GND, the single channel relay module's input V_{cc} was provided by the $3V_3$ port, and digital pin $4D_3$ was connected to the relay module's input. As a result, the relay output is connected in common and has open ports by default. The technique for launching the suggested system is as follows:

Step-1: Install and open Blynk App
Step-2: Register using Google Plus account
Step-3: Login using that email id
Step-4: Check the inbox for authentication token
Step-5: Close the app
Step-6: Restart the app
Step-7: Create a new project
Step-8: Choose hardware as NodeMCU
Step-9: Add a button
Step-10: Configure the button:
Name of the button is Relay 1.
Set Output D3 and Low=1 and High=0
Change it from push to switch
Step-11: Run the project

6 Discussion on Trial Run

It has been observed that the many people are still not familiar with the benefits of electric bicycles. Furthermore, people are dissatisfied with its market pricing, which affects the satisfaction of potential clients. It's also been discovered that once people are aware of the e-bicycle's concept and benefits, they respond with enthusiasm and regard it as a terrific endeavor. In order to understand, the viability of proposed cycle, there are 30 test runs has been performed. The on-road trial was held at Paschim Burdwan (West Bengal) in between Asansol Engineering College and Chittaranjan Indoor Stadium across a 20.9-kilometer circuit. Its root map is presented in Fig. 4.

Fig. 4 Route map for the test run

Many people are cycling to work due to commute difficulties caused by limited public transportation since the lockdown when we were called into work after a partial re-opening. The fact that we no longer have to wait for buses or share taxis has given us a sense of freedom even after that. These considerations prompted us to develop an e-bicycle to aid local mobility. The proposed e-bicycle will serve motor as well as pedalling, thus being found to be more effective for fitness-oriented mobility. Manual cycling burns energy between 450-750 calories per hour for the average person. The number of calories that will be burnt is determined by weight, pace, and amount of time spend on cycling. A comparative review of the battery energy consumption with conventional cycling efforts has been illustrated in Fig. 5.

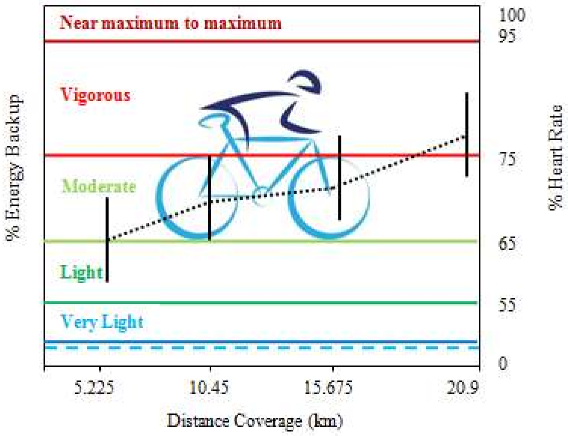

Fig. 5 Comparative characteristics between energy backup and heart rate throughout

The price of the bicycle can be reduced by utilizing advanced technologies and mass production, or some pricing or offer discounts should be incorporated in order to increase the number of customers. Under both loaded and unloaded conditions, the operational viability of the employed PMDC traction motor was tested. The chopper-based speed-controlling strategy was used in this investigation, and the findings (*Case-i: Unloaded Condition* and *Case-ii: Loaded Condition*) are presented in Table II.

Table II Operational results of traction motor

Case-(i): Unloaded Condition				
Sl.	Duty cycle	Armature voltage (V)	Armature current (A)	Speed (rpm)
1	0.38	16	0.33	671
2	0.49	17	0.35	955
3	0.62	18	0.37	1179
4	0.71	20	0.39	1478
5	0.87	22	0.47	1819
Case-(ii): Loaded Condition				
Sl.	Duty cycle	Armature voltage (V)	Armature current (A)	Speed (rpm)
1	0.43	12	0.61	576
2	0.58	13	0.72	870
3	0.70	14	0.81	1025
4	0.81	17	0.83	1281
5	0.98	19	0.94	1472

7 Conclusion

In today's world, it's critical to eliminate negative effects of pollution at the earliest for survival of the civilization. The major emitter of harmful gases is the conventional vehicles which are fuel powered. These fuels are costly and non-renewable. In this paper, an IoT enabled e-bicycle model has been presented which is not only eco-friendly but also good for our health. The developed e-bicycle has been tested for 30 runs on a typical terrain and major findings are as follows:

- It offers a top speed of 25 kmph,
- the distance travelled was 20.9 km on a single full charge using the motor traction and 35 km when aided by a pedal,
- The adopted battery can be charged 700-1000 times during its lifetime.

Further, the problems associated with typical e-bikes, such as their high cost on the market, have been handled by using low-cost components without sacrificing speed.

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