

HEART RATE REGULATION FOR HYBRID HUMAN ELECTRIC BICYCLE RIDER BY TWO CONTROL APPROACHES

A PROJECT REPORT

submitted by

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of

Master of Technology

in

Electrical and Electronics Engineering

with specialisation in

Industrial Instrumentation And Control



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DECLARATION

I undersigned hereby declare that the project report entitled "**Heart Rate Regulation For Hybrid Human Electric Bicycle Rider By Two Control Approaches**", submitted for partial fulfillment of the requirements for the award of degree of Master of Technology in Electrical and Electronics Engineering with specialisation in Industrial Instrumentation and Control, of the APJ Abdul Kalam Technological University, Kerala is a bonafide work done by me under supervision of *Prof. Sumayya Jaleel*, Assistant Professor, Department of Electrical and Electronics Engineering. This submission represents my ideas in my own words and where ideas or words of others have been included. I have adequately and accurately cited and referenced the original sources. I also declare that I have adhered to ethics of academic honesty and integrity and have not misrepresented or fabricated any data or idea or fact or source in my submission. I understand that any violation of the above will be a cause for disciplinary action by the institute and/or the University and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been obtained. This report has not been previously formed the basis for the award of any degree, diploma or similar title of any other University.

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CERTIFICATE

This is to certify that the report entitled " **Heart Rate Regulation For Hybrid Human Electric Bicycle Rider By Two Control Approaches** " submitted by **MEGHA S NAIR** , (Reg. No. **TKM20EEIII13**) of fourth semester to the APJ Abdul Kalam Technological University in partial fulfillment of the requirements for the award of the Degree of Master of Technology in Electrical and Electronics Engineering with specialisation in Industrial Instrumentation and Control, is a bonafide record of the project work done by her under our guidance and supervision. This report in any form has not been submitted to any other University or Institute for any purpose.

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Abstract

The need for healthy lifestyle has now become an important concern among the population. As a part of this the electric bicycle had its significance. The electric bicycle has its advantage to improve the physical health of the rider thereby providing better mental health. It is also a great alternative to fuel vehicle. These electric bicycle are easier to ride and safe to use. Electric bikes are an arising method for transportation for both public as well as private mode. Particularly individuals with actual impediments benefit from the additional engine ability to push the bike. In this work another regulator for electric bikes is proposed to keep an ideal pulse level and further develop the riding experience of cyclists. The control calculation utilizes the ongoing pulse, force and rhythm of the rider as sources of info, and changes the help of the engine adaptable. In this work we compare the proportional integral derivative and sliding mode controller. The controller is implemented with a commercial electric bicycle. The Proportional Integral Derivative controller and Sliding Mode Controller is used here. Simulation and experimental results are tested to find out the validity of the controller. From the results it is clear that the overshoot found during the Proportional Integral Derivative controller output is completely eliminated by using Sliding Mode controller.

Contents

Abstract

List of Tables **i**

List of Figures **ii**

Abbreviations **iii**

Notations **iv**

1 Introduction **1**

1.1 Overview 1

1.2 Objectives 4

1.3 Organisation of Report 4

2 Problem Definition **6**

2.1 Introduction 6

2.2 Summary 8

3 Motivation **9**

3.1 Introduction 9

3.2 Summary 10

4 Literature Review **11**

4.1 Introduction 11

4.2 Literature Survey 11

4.2.1 Controlling technique used 12

4.2.2 Optimization Techniques 16

4.2.3	Strategies For Power Management	21
4.2.4	Adaptive ECMS	21
4.2.5	Model Predictive Control	22
4.3	Research Gap	23
4.4	Summary	23
5	Modelling	24
5.1	Introduction	24
5.2	System model	24
5.3	Cycle model	27
5.4	Summary	28
6	Controller Design	29
6.1	Introduction	29
6.1.1	Proportional Integral Derivative	29
6.1.2	Sliding Mode Control	30
6.1.3	Stability Proof	32
6.2	Summary	32
7	Results and Analysis	33
7.1	Model Validation	33
7.2	Proportional Integral Derivative Controller	34
7.3	Sliding Mode Controller	35
7.4	Comparison of PID and SMC	37
7.5	Summary	37
8	Conclusion And Future Scope	38
8.1	Future Scope	39
	References	40
	List of Publication	42

List of Tables

5.1	Estimated parameter set for the nonlinear model of the human heart rate response	26
5.2	Parameters used for simulating the bicycle longitudinal dynamics	28
6.1	Parameters for PID tuning	29

List of Figures

2.1	Model of Human Electric Hybrid Bicycle	7
4.1	Diagram of Electric Bicycle Model	19
4.2	Block diagram of series hybrid electric battery	20
4.3	Block diagram of real-time route-based power management	22
5.1	Block diagram of control system	24
5.2	Human heart rate response for different activity	25
6.1	Block diagram of sytem with PID	30
6.2	Block diagram of sytem with SMC	31
7.1	Heart rate output for open loop model	33
7.2	Speed rate output for open loop model	34
7.3	Heart rate output for PID Controller	35
7.4	Speed output for PID Controller	35
7.5	Heart rate output for SMC Controller	36
7.6	Speed output for SMC Controller	36

Abbreviations

HEHV	Human Electric Hybrid Vehicle
HR	Heart Rate
PID	Proportional Integral Derivative
PSoC	Programmable System on Chip
SMC	Sliding Mode Control
SOC	State Of Charge
TS	Torque Sensor

Notations

$I_{rw/fw}$	mass moment of inertia of rear/front wheel, Ω
$r_{rw/fw}$	radius of rear/front wheel
v_w	velocity of bicycle
v	acceleration of gravity
f_{sr}	static rolling coefficient
c_w	aerodynamic drag coefficient
ρ_{air}	air density
F_{air}	air resistance force
F_{roll}	rolling resistance force
F_{slope}	slope resistance force
r_w	rider force at rear wheel
f_w	motor force at front wheel
TR, p	rider torque at pedals
TR, rw	rider torque at rear wheel
TR^*	estimated rider torque at pedals
PR	power output of the rider
TM, fw	motor torque at front wheel
TM, fb	control signal of the sliding mode controller
TM, ff	control signal of the feedforward controller
TM^*	desired motor torque
TD	torque generated by disturbances
t	transmission ratio
ω_p	pedaling frequency

Chapter 1

Introduction

1.1 Overview

The consciousness of a sound way of life has significantly developed among the populace. Over this turn of events, electric bikes (E-bicycles) have acquired significance as an elective means of transportation for business as well as confidential versatility, since they offer a sound and natural well-disposed structure of movement at low costs. E bicycles typically have an electric engine incorporated into either the wheels or the base section (mid-mounted), which helps the cyclist during accelerating with a power that is relative to the cyclist's own power yield. Solid impedance or missing appendages can make active work troublesome, and in result, people with such in capacities frequently experience the ill effects of optional medical issue like cardiovascular infections [1].

Electrical help empowers those people to securely participate in physical movement by decreasing the gamble of depletion, overexertion, wounds, or much more serious occasions. Consequently, E-bicycles can be implies for sound and autonomous portability for clients with actual constraints. Regardless of these benefits, two significant factors actually forbid the more extensive utilization of E-bicycles — range uneasiness what's more, an adaptive help. Ordinary help techniques limit the effect on the well being and prosperity of cyclists. They don't offer quite a large number different help levels to decrease the working intricacy by restricting the decisions accessible to the cyclist. Notwithstanding, contrasts in physiological capacities among people and changing cycling protections make it attractive to have a fine tuned help to keep an open to cycling experience furthermore, a reasonable measure of actual effort.

Therefore, E-bikes can be means for healthy and independent mobility for users with physical limitations. Despite these advantages, two important factors still prohibit the wider use of E-bikes—range anxiety and an adaptive assistance. Good models of the heart rate response of the human for different activities and workload intensities are necessary in order to design well performing controllers. In two auto-regressive models with exogenous input (ARX) were used to model the heart rate kinetics during wheelchair ergometry. A Hammerstein model consisting of a nonlinear static element followed by a linear dynamic element was used. The model was chosen to account for the nonlinear relationship between walking speed and heart rate during treadmill exercises. The model parameters were identified using support vector machine algorithms.

Once more, for clients with actual limits, a help that consequently adjusts to their physiological abilities and that directs over the top actual strain can forestall adverse consequences on well being. Subsequently, new help frameworks are important to get to the next level the convenience of E-bicycles. These need to think about trip data to limit the gamble of running out of energy, and consequently change the help level to the individual physiological abilities of the cyclist. To make cycling protected and gainful for clients with actual impediments, the framework needs to follow up on two levels: a physiological level what's more, a bio mechanical level. Changing the electrical help on a physiological level diminishes the gamble of overexertion and depletion and builds the beneficial outcomes on the soundness of the person. Changing the engine help on a bio mechanical level can repay irregular characteristics in force yield between the legs and decrease joint minutes.

We allude to this mix of help on a physiological and bio mechanical level as bio metrical help. In a model reference adaptive control design with an adaptive PID controller was used to follow a desired heart rate profile when using a human hybrid electric vehicle. The controller achieved good performance but there was an overshoot in the velocity output which is eliminated using a sliding mode control. In this work, a sliding mode controller combined with feed forward control is proposed for electric bicycles to regulate the heart rate level and improve the riding experience of the cyclist by automatically adjusting the assistance torque.

In this way, E-bicycles can be implying for solid and autonomous portability for clients with actual impediments. Regardless of these benefits, two significant factors actually deny the more extensive utilization of E-bicycles — range tension and an adaptive help. Great models of the pulse reaction of the human for various exercises and responsibility forces are vital to

configuration well performing regulators. In two auto-backward models with exogenous info (ARX) were utilized to demonstrate the pulse energy during wheelchair ergometry. A Hammerstein model comprising of a nonlinear static component followed by a straight powerful component was utilized. The model was decided to represent the nonlinear connection between strolling velocity and pulse during treadmill works out.

The model boundaries were distinguished utilizing support vector machine calculations. As of late, a nonlinear pulse model was proposed in to display the human pulse reaction during treadmill work out. The model takes prompt as well as graduate reactions of the cardiovascular framework into account and thus can be utilized to portray the pulse reaction during short as well as lengthy activities.

While the contribution to the model is the treadmill speed, the human pulse reaction to the responsibility is the result of the model. This model was utilized for planning regulators for treadmill practices [4] too as to manage the pulse during bike ergometry. This multitude of regulators were created for fixed preparing gear. Great models of the pulse reaction of the human for various exercises also, responsibility powers are vital to configuration well performing regulators. In two auto-backward models with exogenous info (ARX) were utilized to display the pulse energy during wheelchair ergometry.

A Hammerstein model comprising of a nonlinear static component followed by a direct unique component was utilized. The model was decided to represent the nonlinear connection between strolling pace and pulse during treadmill works out. The model boundaries were distinguished utilizing support vector machine calculations. As of late, a nonlinear pulse model was proposed to show the human pulse reaction during treadmill works out. The model takes quick as well as graduate reactions of the cardiovascular framework into account and subsequently can be utilized to depict the pulse reaction during short as well as lengthy activities. Though the contribution to the model is the treadmill speed, the human pulse reaction to the responsibility is the result of the model. This model was utilized for planning regulators for treadmill practices as well as to control the pulse during bike ergometry. All these regulators were produced for fixed preparing gear.

1.2 Objectives

Electric bicycles are becoming a very important way of transportation. This type of bicycles is capable of limiting the perceived exertion for the cyclist and is therefore suitable to automatically follow a given heart rate profile when riding outdoors. However, changing environmental conditions make it more difficult to keep a stable heart rate level compared to riding indoors. Cyclists have to adjust the speed or the assistance level according to changing conditions. Since the heart rate response to changing workload is not immediate, keeping a constant heart rate level is a difficult task, which requires a lot of attention from the cyclist.

To overcome this difficulty automated systems can help to keep the desired heart rate level and therefore reduce the distraction of the cyclist. A continuous variable transmission system combined with a sliding mode controller was used, and it changed the transmission ratio automatically to follow a desired heart rate profile. This directly affects the riding speed and may slow down the cyclist. Electric bicycles are often used for commutes to keep up a high riding velocity despite of changing environmental conditions. Changing the assistance level of the motor can regulate the heart rate without affecting the current speed.

In this work, a sliding mode controller combined with feed forward control is proposed for electric bicycles to regulate the heart rate level and improve the riding experience of the cyclist by automatically adjusting the assistance torque. A sliding mode controller is designed to keep the human heart rate at a predefined level. Furthermore, a feed forward controller is introduced into the system to improve both the tracking performance and riding experience. The feed forward controller consists of an inverse human heart rate response model, which estimates the necessary rider torque for a desired heart rate level. The controller is implemented with a commercial electric bicycle. Simulation and experimental results are presented to assess the validity of the controller. Whereas the sliding mode controller itself achieves good tracking performance, the sliding mode control combined with the feed forward control additionally reduces the maximal exerted rider torque and improves the riding experience.

1.3 Organisation of Report

The project work is organized in 8 chapters. Chapter 1 titled by Introduction includes overview and objectives. Chapter 2 problem is identified. Chapter 3, the motivation in doing the work is identified. Chapter 4, the literature review done on the work. Chapter 5 the modelling of the

overall system is done. Chapter 6, the system design and methodology is explained. Chapter 7 the results are explained and finally in Chapter 8 conclusion and future scope is discussed .

Chapter 2

Problem Definition

2.1 Introduction

Riding an electrically helped bike diminishes the actual effort fundamentally, working with the physical action for individuals of each and every age and wellness level. Admittance to an electrically helped bike appears to expand the recurrence of purpose and the distance covered with the bike, and accordingly assists with advancing the bike as an elective means of transportation and for active work. People with actual impediments like the older, stationary endlessly individuals with persistent illnesses or in-capacities especially benefit from the electrical help. They are urged to be genuinely dynamic however frequently manage decreased practice limits [10], and hence, need to observe cautiously their activity power [11].

Electric bikes are turning into a vital way of transportation. This sort of bikes is equipped for restricting the apparent effort for the cyclist [10] and is in this manner reasonable to consequently follow a given pulse profile while riding outside. Notwithstanding, changing natural circumstances make it more challenging to keep a steady pulse level contrasted with riding inside. Cyclists need to change the speed or the help level as per evolving conditions. Since the pulse reaction to changing responsibility isn't quick, keeping a steady pulse level is a troublesome errand, which requires a great deal of consideration from the cyclist.

To defeat this trouble robotized frameworks can serve to keep the ideal pulse level and consequently lessen the interruption of the cyclist. A nonstop factor transmission framework joined with a sliding mode regulator was utilized [11], and it changed the transmission proportion naturally to follow an ideal pulse profile. This straightforwardly influences the riding speed and may dial back the cyclist. Electric bikes are frequently utilized for drives to keep up a high

riding speed notwithstanding of changing ecological circumstances. Changing the help level of the engine can control the pulse without influencing the ongoing speed. Conventional help procedures limit the effect on the well being and prosperity of cyclists. They don't offer quite a large number different help levels to diminish the working intricacy by restricting the decisions accessible to the cyclist.



Figure 2.1: Model of Human Electric Hybrid Bicycle

Notwithstanding the great following execution, Fig.2.1[2] shows high pinnacle rider force values in situations where the cyclist speeds up the bike. The regulator doesn't make up for these high qualities due to the low pulse. Be that as it may, these force tops outcome in unfortunate riding experience, in light of the fact that the emotionally seen effort is high during these periods. Consequently the feed forward control (FF) is added to the control framework. The following presentation and the applied engine force of the consolidated control framework for a long test ride. The consolidated regulator accomplishes great following execution as long as the natural aggravations are inside the constraints of the engine. Moreover, as should be visible in Fig. 6b, the pinnacle rider force values are essentially decreased and the general force yield is more predictable. The apparent effort is hence diminished and more steady all through the ride which prompts a superior riding experience.

E-bicycles normally have an electric engine incorporated into either the wheels or the base section (mid-mounted), which helps the cyclist during accelerating with a power that is

corresponding to the cyclist's own power yield. Riding an electrically helped bike decreases the actual effort essentially, working with the physical action for individuals of each and every age and wellness level [3] and [7]. Admittance to an electrically helped bike appears to expand the recurrence of purpose and the distance covered with the bike, and thusly assists with advancing the bike as an elective means of transportation and for actual work [8].

2.2 Summary

In this work, design a Sliding Mode Controller and Proportional Integral Derivative controller is designed to keep the human heart rate at a predefined level. Furthermore, a controller is introduced into the system to improve both the tracking performance and riding experience. controller consists of an inverse human heart rate response model, which estimates the necessary rider torque for a desired heart rate level. The controller is implemented with a commercial electric bicycle.

Chapter 3

Motivation

3.1 Introduction

This work has been moved as electric bicycles are an emerging technique for transportation. Especially people with genuine cutoff points benefit from the extra motor capacity to drive the bicycle. Standard motor assist procedures with introducing limits on the usability of these bicycles they miss the mark on versatility to conform to the individual physiological constitution of cyclists and don't true to form manage the assist with controlling over an entire journey.

Another nonlinear control methodology for electric bikes that changes the engine help naturally to keep an ideal pulse level of the cyclist. The control calculation utilizes the ongoing pulse, force and rhythm of the rider as data sources, and changes the help of the engine adaptive. The regulator comprises of feed forward as well as criticism parts: Whereas the pulse is the criticism part, the framework's feed forward part is the rider's assessed force yield at the ideal pulse level. Natural changes like slant or headwind are displayed as aggravations that the regulator needs to dismiss.

We lead test rides with one subject at various force levels to create and approve a nonlinear pulse reaction model of the bike rider. The model purposes the power result of the cyclist as an information and takes quick also, slow reactions of the pulse into account. We utilize a business electric bike with a front wheel center point engine to test the regulator plan. The bike is altered to gauge force yield and accelerating recurrence of the rider and to control the engine force.

3.2 Summary

Ordinary actual work forestalls various physical furthermore, mental illnesses like strokes, diabetes and dementia [1]. To accomplish a high effectiveness of the action and forestall overexercising, it is critical to pick the activity powers suitably for instructional courses. The pulse is a decent mark of activity force and is fairly simple to quantify contrasted with other crucial boundaries (like oxygen utilization) connected with work out force [2]. Along these lines fixed preparing gear frequently incorporates highlights to follow a client determined pulse profile by changing the responsibility.

Chapter 4

Literature Review

4.1 Introduction

This chapter presents the foundation overview of the current writing on Sliding Mode Control for Heart Rate Regulation of Electric Bicycle Riders. In the writing many articles assess the capability of electric bicycles as a viable dynamic portability instrument that can help numerous to meet their active work rules. Bourneet al. [6] thought about a few investigations showing the e-bicycle well being potential by breaking down actual work results between ordinary bicycles and strolling. Also, made a few near exertion tests utilizing no electric help, low and high help, and voyaging on various kinds of streets (e.g., level, bumpy courses). Subsequently, despite the fact that how much practice performed was more modest than sums performed on a standard bicycle, it is as yet a superior option in contrast to vehicles and public transportation; the lower discernment exertion could boost more individuals to utilize e-bicycles as their day to day method for transportation

4.2 Literature Survey

Of late, electric bikes are turning into a vital method of transportation. This sort of bikes is fit for restricting the apparent effort for the cyclist [2] and is consequently reasonable to naturally follow a given pulse profile while riding outside. Nonetheless, changing ecological circumstances make it more hard to keep a steady pulse level contrasted with riding inside. Cyclists need to change the speed or the help level as indicated by evolving conditions. Since the pulse reaction to changing responsibility isn't quick, keeping a steady pulse level is a troublesome undertak-

ing, which requires a ton of consideration from the cyclist. To defeat this trouble mechanized frameworks can serve to keep the ideal pulse level and consequently decrease the interruption of the cyclist. A constant variable transmission framework joined with a sliding mode regulator was utilized [3], and it changed the transmission proportion consequently to follow an ideal pulse profile. This straightforwardly influences the riding speed and may dial back the cyclist.

4.2.1 Controlling technique used

Presence of an elective energy source alongside the Internal Combustion Engine (ICE) in Hybrid Electric Vehicles (HEVs) allures for ideal power split between them for least fuel utilization and greatest power use. Consequently, HEVs give better mileage contrasted with ICE based vehicles/traditional vehicle. This work depicts different energy the board techniques accessible in the writing. A ton of examination work has been led for energy enhancement and the equivalent is stretched out for Hybrid Electric Vehicles (HEVs). This work focuses on the battery-controlled half and half vehicles. To maintain the heart rate at desired level many controllers are used. Various techniques are presented in the writing and in view of these, a few control methodologies are proposed. These control techniques are summed up here in a cognizant system.

Environment-adaptive Control Algorithm

The control calculation of the power helped cycle which is an electrical cycle driven by a human's accelerating power and an actuator's main thrust. In this calculation, an actuator's driving power is created dependent on the accelerating force of the rider and natural conditions, with the goal that the rider could cycle on any street as though he/she rides on a flat street. Furthermore, this control calculation could change clear opposition powers for riding the cycling contingent upon the rider's actual strength. The proposed control calculation is tentatively applied to an electrical tricycle and the test results represent the legitimacy of the proposed calculation.

Another control calculation of force helped cycles which are acknowledged with a customize natural drag power. When the proposed framework repays the entire natural drag power, a rider could drive the tricycle on an inclined street as though he/she drive on a level street. The proposed framework could likewise change a natural drag power contingent upon a rider's

actual strength. This framework is helpful to use for recovery and preparing. The proposed framework was tentatively applied to the tricycle. The test results are outlined.

Applying Fuzzy Logic Control

Bikes are utilized all over and for numerous applications; transportation, diversion, and work-out. Their dynamic conduct is statically temperamental like the rearranged pendulum. In this paper, we created a canny electric bike based on fluffy rationale and a single chip approach. We picked the PSoC (Programmable System-on-Chips) as the microchip. The central issue is to change the PWM (Pulse Width Tweak) sign to control the speed of the bike, naturally.

With this strategy, trust one can ride the bike easily. Instructions to lessen the creation cost are a significant issue for an article of trade. Soc contradicting message exhibits are programmable Frameworks on-Chips (SOCs) that incorporate the micro controller and the simple and advanced parts that commonly encompass it in an installed framework. The benefits of utilizing the Soc are configuration time and diminished circuit board space necessity.

Moreover, the PSoC is programmable utilizing C language which is a lot simpler than programming Fluffy regulator utilizing low-level computing construct. Assuming a control hypothesis cannot be applied to a commonsense application, the hypothesis isn't of extraordinary worth. In this work, fostered a canny electric bike based on fluffy rationale and a single chip approach.

The bike has three freeing modes, which can be changed by a slide switch. With the Soc, can utilize the C language to develop our fluffy regulator and save gadgets. The PCB, planned in this work, is little and stable. The three modes can work appropriately. Later on, might want to foster a regulator with a boundary-setting capacity. Then, at that point, it will be an agreeable electric bike and fit everybody.

Torque Senseless Control

Bike is one of the well-known human impelled carriers for over 100 years. The verifiable improvement of bike in control perspective can be found [1]. As of late the use of electric bike is expanded because of a few benefits for example, power help drive and enormous driving distance. The principal idea in electric help bike is to help the cyclist in light of his/her requests to build the driving distance.

This kind of electric help bike is named as human electric cross breed bike [2] or "Ped-elec". Some variants of these bikes are called E-bicycle, in which the electric bike can be changed over into human fueled (typical cycle) or human help or on the other hand total run by engines. The complete review and portrayal of electric help bike are introduced in [3]. Different sorts of electric drives utilized for E-bicycles are considered furthermore, the exhibitions are assessed [4].

A support-based calculation is proposed by gaining the progressions from the riding climate to further develop the ride quality which incorporate security and solace [5]. Different recovery techniques are likewise concentrated on in electric bikes in the writing. A powerful unsettling influence spectator is intended to assess the power because of slant [8].

Optimal Control Approach

Electric bikes are an arising method for transportation. Particularly individuals with actual constraints benefit from the additional engine ability to impel the bike. Customary engine help techniques present cutoff points on the convenience of these bikes: they come up short on adaptability to adjust to the individual physiological constitution of cyclists and don't as expected deal with the help control over a whole excursion. This work, present a book energy the executives framework for human-electric half and half vehicles that:

- 1) utilizes an ideal control way to deal with direct the heart pace of the cyclist and
- 2) consolidates trip data to make due the engine help.

The framework comprises of a control stage and a arranging stage. In the control stage, a model prescient regulator manages the pulse by changing the engine power and gear proportion to keep a client characterized effort while considering requirements.

The arranging stage processes deduced data about the client and the course to assess the power interest during various areas of the excursion and to ascertain the ideal engine power for each part. Engine power limitations for each segment are then figured out to restrict the energy utilization what's more, to save energy for those areas when engine power is generally required. We present reenactment results to illustrate that:

- 1) the joined control of engine power and transmission proportion is better than utilizing each control variable independently.
- 2) including an outing data assists with dealing with the energy utilization over the whole outing to diminish the gamble of running out of energy.

This framework can assist individuals with restricted physical capacities to participate in actual work securely. An original energy management framework comprising of an arranging stage as well as a control stage that follows up on a physiological level. In the arranging stage, data about the client and the course is utilized to advance the energy utilization during the excursion by figuring out engine power requirements. In the control stage, a model prescient regulator controls both the engine power and transmission proportion to manage the pulse of riders of HEHVs while considering the engine power limitations. Utilizing reproductions (S1), we showed that the new framework performs better contrasted and utilizing just engine power or transmission proportion. By consolidating two control factors, the framework defeats limits of past control draw near and can keep up with the heart pace of the cyclist at the ideal level all the more successfully. In a different arrangement of recreations (S2), we showed that deduced realized data can be utilized to deal with the accessible energy in the battery.

As far as possible the engine power and in result the energy utilization and on second thought utilizes the transmission proportion to manage the pulse to save energy for areas with high energy interest. In this manner, it is feasible to keep up with the pulse at the ideal level in situations with low SOC of the battery. The framework shapes the premise of an original energy management framework that consolidates trip data and a modified engine help on a physiological and bio mechanical level (which we call bio metrical help).

Regardless of the way that there are still constraints, we accept that this framework can be utilized to support actual work, forestall overexertion, and get to the next level cycling solace for individuals with actual limits. These people benefit from our framework since they depend on the extra help of the engine to lessen their physical exertion and move the vehicle. Different applications could be for recovery purposes or as an activity machine for heart rate-based preparing. At last, in view of the superior energy utilization, HEHVs utilizing the framework could be outfitted with more modest batteries to decrease its weight.

Sliding Mode Control

Another regulator for electric bikes is proposed to keep an ideal pulse level and work on the riding experience of cyclists. The regulator accomplishes this by satisfactorily changing the engine help without influencing the cycling speed. Initial, a human pulse model is fitted to trial information to demonstrate the pulse reaction of cyclists during various activities. Then, at that point, a sliding mode regulator is planned to keep the human pulse at a predefined level.

Moreover, a feedforward regulator is acquainted into the framework with get to the next level both the following execution and riding experience. The feedforward regulator comprises of a reverse human pulse reaction model, which gauges the essential rider force for a wanted pulse level. The regulator is carried out with a business electric bike. Recreation and test results are introduced to survey the legitimacy of the regulator. Though the sliding mode regulator itself accomplishes great following execution, the sliding mode control joined with the feedforward control also lessens the maximal applied rider force also, further develops the riding experience.

Proportional Integral Derivative

The planned regulator depends on the ongoing pulse of the cyclist as well as the ongoing force of the rider. The PID controller is used to find the regulated heart rate and velocity of the HEHV. A sliding mode controller (SMC) is utilized to make up for deviations from the ideal pulse level and diminishes the most extreme rider force to further develop the riding experience. The controllers empower the rider to keep an ideal pulse level and great client experience. The functioning rule behind a PID regulator is that the corresponding, fundamental and subsidiary terms should be separately changed or "tuned."

Based on the contrast between these qualities a revision factor is determined and applied to the information. For instance, assuming a broiler is cooler than required, the intensity will be expanded. Here are the three stages: Proportional tuning: Relative tuning includes rectifying an objective corresponding to the distinction. Hence, the objective worth is never accomplished on the grounds that as the distinction approaches zero, so too does the applied revision. Derivative tuning: endeavors to limit this overshoot by easing back the revision factor applied as the objective is drawn closer.

The PID regulator is utilized to find the controlled pulse and speed of the HEHV. A PID is used to compensate for deviations from the ideal heartbeat level and lessens the most outrageous rider power to additionally foster the riding experience. The regulators enable the rider to keep an ideal heartbeat level and incredible client experience.

4.2.2 Optimization Techniques

Because of the intricate construction of HEVs/PHEVs, the plan of control methodologies is a difficult assignment. The primer objective of the control methodology is to fulfill the driver's

power request with least fuel utilization and poisonous emanations also with ideal vehicle execution. Additionally, fuel economy and discharges minimization are clashing targets; a brilliant control system ought to fulfill a compromise between them. Different control methodologies are proposed for ideal execution of HEVs/PHEVs.

Control Based On Optimization

In these control systems, the ideal reference forces for power converters and ideal stuff proportions are determined by minimization of an expensive work by and large addressing the fuel utilization or outflows. If this advancement is performed over a proper driving cycle, a worldwide ideal arrangement can be found. Truth be told, the worldwide ideal arrangement is non-causal in that it observes the base fuel utilization utilizing information on future also past power requests.

This methodology can't be utilized straightforwardly for ongoing energy the executives; nonetheless, it may be a premise of planning rules for online execution or then again correlation for assessing the nature of other control systems. Then again, by the meaning of an immediate expense work, an ongoing streamlining-based control methodology can be found. Such a capacity needs to rely just on the framework factors at the current time. The momentary expense works ought to incorporate a comparable fuel utilization to ensure the self-manageability of the electrical way. The arrangement of such an issue isn't internationally ideal, however, it very well may be utilized for ongoing execution.

As of late, accomplishing smooth stuff moving and limiting inordinate driveling vibrations, known as disability, are incorporated into constant minimization-based control methodologies. Advancement of control techniques in HEVs from off-the-rack indoor regulator control to a high-level prescient versatile fluffy rationale-based energy the board framework, or insightful ideal decoupling control, has been concentrated. The proposed strategies are ordered into two general patterns: rule-based and advancement-based (worldwide and continuous). Each approach is clarified, and its attributes are assessed subjectively. Worldwide advancement approaches are valuable for plan and examination purposes, notwithstanding rousing the standard-based methodologies.

Energy Based On Optimization

Light electric vehicles are a suitable approach to lessening metropolitan clog and neighborhood poison emanations. Electric bikes join electrical and human power, subsequently they address an engaging class of half and half vehicle in such a specific circumstance. Uniquely in contrast to other crossover vehicles, the energy the executives of mixture bikes are pretty much nothing examined in the writing.

In this work, we concentrate on the issue for a series electric-human-fueled mixture engineering, in which there is no immediate mechanical connection between the pedals and the wheel. We tackle the issue utilizing ideal control standards, meaning to limit the apparent actual effort while ensuring a foreordained electric reach.

We expand on an approximated arrangement of the issue what's more, propose a control framework that adapts to inadequate outing data. In a progression of recreation and exploratory tests, the proposed system approaches the causal ideal and altogether gets to the next level execution whenever contrasted with a benchmark causal strategy; the conversation likewise incorporates the responsiveness of the outcomes to the mentioned data.

This work manages continuous energy the executives of a series HEB. The fundamental objectives of the boss are to limit the effort seen by the cyclist and to ensure that the battery SoC toward the finish of an excursion moves toward an objective characterized by the cyclist. An approximated answer for the causal OCP is utilized to create a continuous calculation. The utilization of course data is found to be very vital to guarantee that the battery SoC toward the finish of the excursion is near the objective set by the client; this thusly influences the worldwide exhibition with regards to apparent effort.

Results from reenactments and tests are examined to assess the execution of the proposed ongoing system, likewise within the sight of unsure course data. Conceivable future work incorporates the augmentation of the way to deal with equal HEBs.

Optimal Power Management for Multi-Information Integrated.

Module crossbreeds' electric vehicles are generally got as a promising method for green versatility by using more battery power. As of late, we have proposed a plan of two-scale spatial-area dynamic programming (DP) as an almost worldwide streamlining way to deal with a trip-based

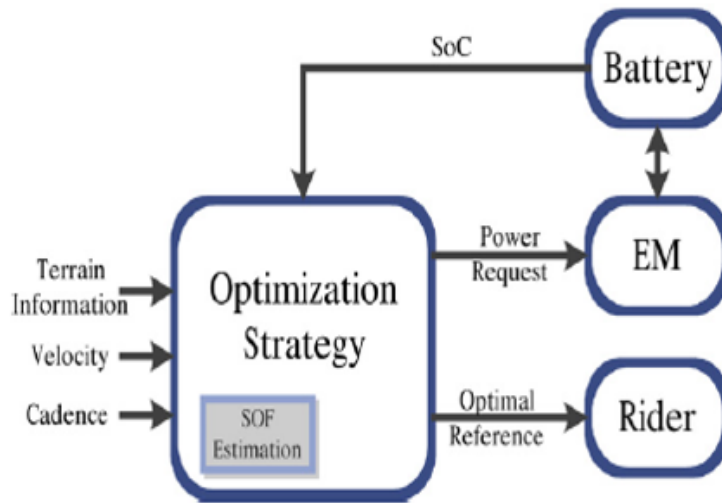


Figure 4.1: Diagram of Electric Bicycle Model

ideal power the executives for PHEV through the mix with traffic information and excursion demonstrating. Already the fragment shrewd power interest and SOC change was determined through mathematical combination dependent overall speed and speed increase of the section, and query tables were gotten.

At the point when more boundaries are involved into power the board, for example, street level and burden change, such process turns out to be exceptionally drawn-out. In this paper, the spatial-area DP is improved by ascertaining the power request and SOC change in a scientific way. The power request is first determined dependent on length, beginning rate, speed increase, street level, payload, and wind of a street section. The SOC change is then determined for various PSRs.

A customize portion conspires utilized of insightful capacity is created to further develop the calculation proficiency of the ideal power the executives without losing a lot of fuel economy. Reproduction concentrates on shows that consolidating extra excursion data, for example, street level and unsurprising payload change into the advancement can altogether further develop the efficiency. The computational proficiency is too assessed. The proposed technique can significantly work with the advancement of ideal power the executive's procedure for HEV with various data inputs.

The control calculation of the power helped cycle which is an electrical cycle driven by a human's accelerating power and an actuator's main thrust. In this calculation, an actuator's driving power is created dependent on the accelerating force of the rider and natural conditions,

with the goal that the rider could cycle on any street as though he/she rides on a flat street. Furthermore, this control calculation could change clear opposition powers for riding the cycling contingent upon the rider's actual strength. The proposed control calculation is tentatively applied to an electrical tricycle and the test results represent the legitimacy of the proposed calculation.

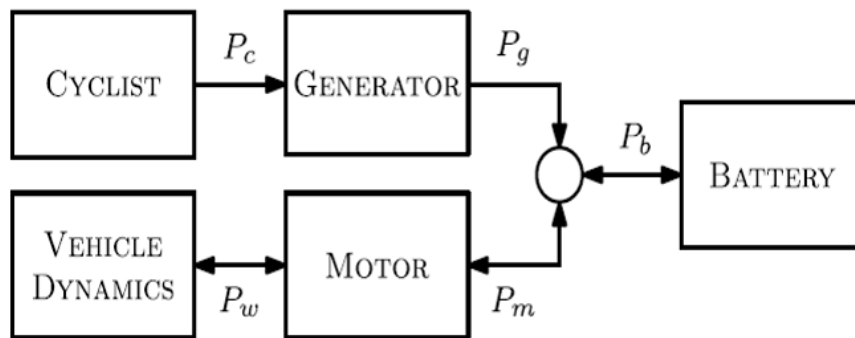


Figure 4.2: Block diagram of series hybrid electric battery

Another control calculation of force helped cycles which are acknowledged with a customize natural drag power. When the proposed framework repays the entire natural drag power, a rider could drive the tricycle on an inclined street as though he/she drive on a level street. The proposed framework could likewise change a natural drag power contingent upon a rider's actual strength. This framework is helpful to use for recovery and preparing. The proposed framework was tentatively applied to the tricycle.

The test results are outlined. data melded system is proposed for the excursion-based ideal power the board for HEV. The possibility of spatial space DP is held, while the section insightful calculation of energy utilization is not set in stone in a scientific rather than mathematical way. Re-enactment results have upheld the validness of the proposed strategy. Improvement will enormously help the advancement of spatial area DP for the excursion-based PHEV power the board, particularly when more outing data is engaged with the enhancement cycle, for example, street-level what's more payload variety.

4.2.3 Strategies For Power Management

Module cross breed electric vehicles (PHEVs) are promising options for feasible transportation. Since of their installed battery pack, they can altogether improve the mileage contrasted with regular vehicle. Moving along the power the executives methodology can take advantage of the maximum capacity of a PHEV powertrain and lessen the fuel utilization extensively.

We think about two remarkable ideal course-based control draws near: model prescient control (MPC) and versatile identical utilization minimization system (AECMS), for various degrees of excursion data. To assess the planned control frameworks, the standard based regulator of Autonomous is considered as a benchmark power the executives framework. The consequence of reproductions shows that MPC and A-ECMS lead to an around equivalent mileage, and they can further develop the fuel utilization of this PHEV.

4.2.4 Adaptive ECMS

ECMS technique was initially proposed for the power the executives of HEVs. HEVs have one outer energy source (fuel), and the electrical energy of the battery is created by consuming fuel energy. In this manner, the same fuel utilization of both fuel and electrical energy decides the energy utilization. Then again, the PHEV can store the lattice electrical energy in the battery, so the principal piece of the battery energy isn't created in the vehicle power-train.

Therefore, the complete expense of the electrical energy and fuel is considered as a basis for assessing vehicle execution, which is figured out. The target of the ECMS power the executive's methodology is to limit absolute energy cost considering the imperatives on the battery SOC, the motor, and battery power. The equivalency factor is characterized as a plan boundary to direct the electrical expense and make a harmony between the market interest of electrical energy during an outing. The ideal worth of the equivalency factor relies upon the future driving condition.

To make the power the board framework free representing things to come driving condition, the versatile ECMS (A-ECMS) is created. In this procedure, the reference SOC is utilized to find the equivalency factor.

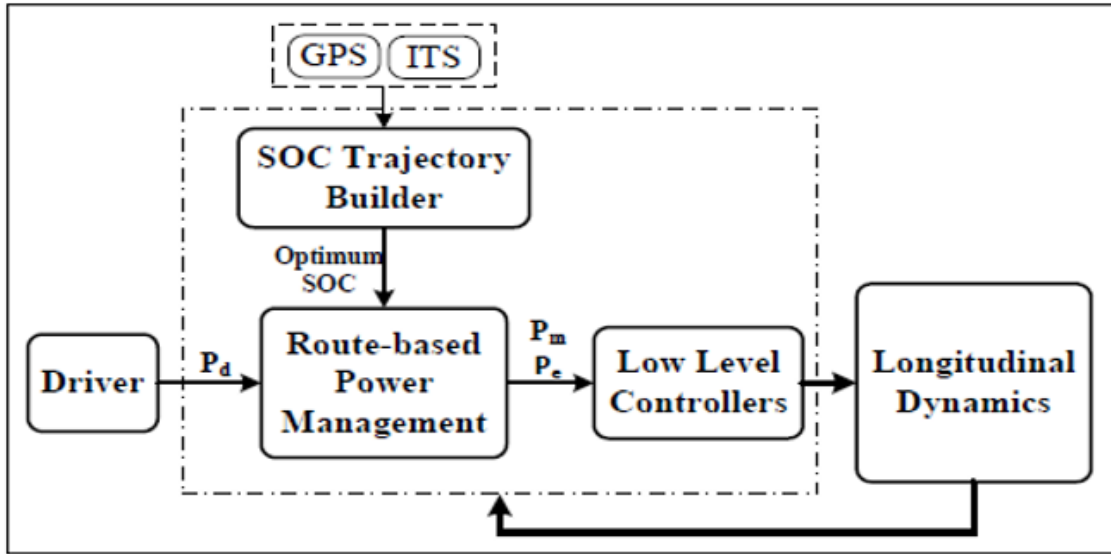


Figure 4.3: Block diagram of real-time route-based power management

In view of the level of the excursion data, the reference SOC can be a direct profile as opposed to voyaging distance or the ideal SOC profile that is recently created by SOC direction developer.

4.2.5 Model Predictive Control

The target of model prescient control is to advance the future way of behaving of the plant yield by registering a direction of a future info. The enhancement is performed inside a period window in light of the ongoing data accessible from the framework toward the beginning of the time window. In MPC, an adequately exact model, the evaluation of current status of the framework, and the instrument of executing the arranged exercises are required. The forecast skyline decides how far we wish to anticipate what's to come. Here, we need to take care of a MPC issue to find a vector that contains the variety of contributions to arrange to arrive at the ideal direction of results.

The length of this vector is known as the control skyline. In the event that the genuine control contribution to the plant just takes the main example of the control signal, while ignoring the remainder of the direction, we call this standard a subsiding skyline control [8]. In the arranging system, we want the state factors at each time step to anticipate the future, which is either straightforwardly estimated or assessed. A decent unique model will give an exact

and steady expectation of the future. In the interim, an integrator is implanted into the plan, prompting the prescient control framework following consistent references what's more, dismissing consistent aggravations without steady state mistakes. One more critical benefit of this approach is at execution stage, where it neither requires the steady state data about the control nor the data about the consistent condition of the state variable.

4.3 Research Gap

For this project, the aim is to model a sliding mode controller and Proportional Integral derivative Controller to keep the human heart rate at a predefined level and the controller is introduced into the system to improve both the tracking performance and riding experience. The controller consists of an inverse human heart rate response model, which estimates the necessary rider torque for a desired heart rate level. The controller is implemented with a commercial electric bicycle.

4.4 Summary

In this section, the literature review related to the work is conducted and different approaches are referred. Different techniques are analysed for references. Strategies For Power Management which include Adaptive ECMS, Model Predictive Control and Optimal Power Management for Multi-Information Integrated are analysed in this section.

Chapter 5

Modelling

5.1 Introduction

The control system of the overall model of the cyclist (Cyclist), the bicycle, the feed, controller (PID and SMC) and the human heart rate response to workload (Human). The heart rate (HR) of the cyclist is measured with a heart rate sensor (HRS) and the rider's torque output at the cranks is measured by a torque sensor (TS).

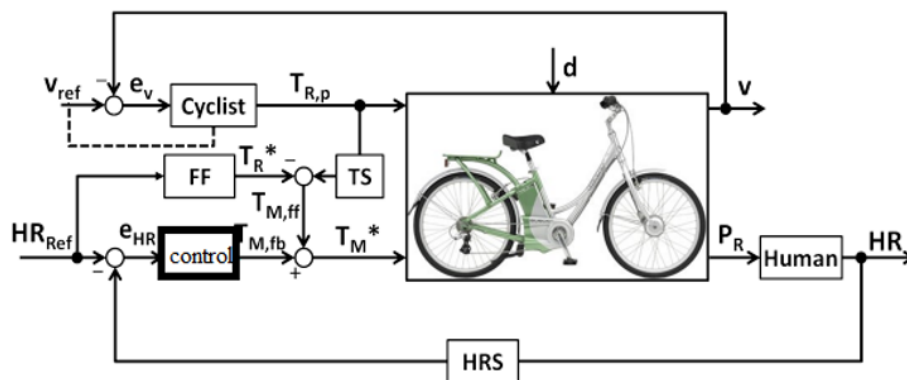


Figure 5.1: Block diagram of control system

5.2 System model

The connection between the power given by the cyclist also, the related heart rate can be expected straight for short activities [15]. For long activities a nonlinear expansion in heart rate

can be seen because of the cardiovascular float [16] brought about by factors like lack of hydration and intensity stress [2]. Thus a nonlinear model was proposed in [5] to portray the human heart rate reaction for strolling on a treadmill. The model considers reactions of the cardiovascular framework to short and long term works out. This model is adjusted and changed in this paper to mirror the human heart rate reaction during cycling works out. In the strolling speed was the contribution to the model, furthermore, a quadratic connection between strolling speed and heart rate reaction was expected. Due to the direct relationship between cycling power and heart rate, this quadratic info was changed to a straight info. The model of the heart rate reaction is consequently given by:

$$\dot{x}_1 = -a_1 x_1 + a_2 x_2 + \frac{a_6 \cdot v}{P_{max}} \left(\frac{T_D}{r_{rw}} - \frac{T_{m,fw}}{r_{fw}} \right) \quad (5.1)$$

$$\dot{x}_2 = \frac{a_4 \cdot x_1}{1 + \exp(-(x_1 - a_5))} - a_3 \cdot x_2 \quad (5.2)$$

$$y = x_1 \quad (5.3)$$

Trial results of the human heart rate response of the ergo-meter experiments furthermore, simulated response using the proposed model with fitted parameters is given by Figure 5.2 [1]. From

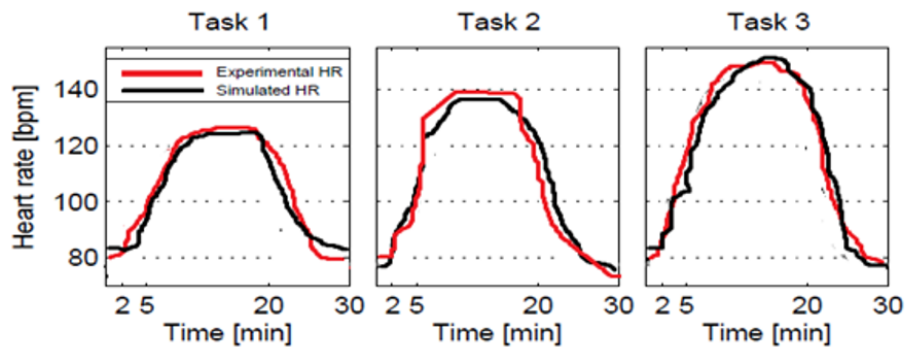


Figure 5.2: Human heart rate response for different activity

this x_1 depicts the quick reaction of the cardiovascular framework to responsibility, and is characterized as the contrast between the current heart rate and the heart rate very still, standardized by the cyclist's assessed most extreme heart rate is by :

$$x_1 = \frac{HR - HR_{rest}}{HR_{max}} \quad (5.4)$$

x2 depicts the slower reaction of the heart rate for delayed practice because of the cardiovascular float. The information u to the model is the power (PR) standardized by the assessed most extreme power result of the cyclist and is in this manner given by:

$$u = \frac{P_R}{P_{\max}} \quad (5.5)$$

The boundaries a1 to a6 in the model were assessed utilizing ergometer trials of one guinea pig. The subject led a sum of four trials on a cycling ergometer (Life Fitness, Brunswick Cooperation, USA). Each trial comprised of three errands where each undertaking was partitioned into four stages - a resting stage, a warm-up stage, an activity stage and a recuperation stage - with various responsibility settings.

Table 5.1: Estimated parameter set for the nonlinear model of the human heart rate response

a1	a2	a3	a4	a5	a6
0.0113	0.0072	0.0049	0.0041	19.8002	0.0072

During the resting stage the subject didn't pedal and no responsibility was applied while in the warm-up stage a little responsibility was applied. In the activity stage an alternate responsibility was set for each errand (100, 125 and 150 Watts). During the recuperation stage again, no responsibility was set. The consequences of the investigations were then used to make a nonlinear dim box model and the boundaries were assessed utilizing a Trust-Region-Reflective calculation given by MATLAB. The last boundaries utilized in the model are given. As can be found in Fig 5.2[1] the model and the recognized boundaries accomplish a solid match and are in this way utilized for the regulator plan.

The cyclist's heart rate answers changes in the power result of the cyclist. Rather than exercise electric bicycle the responsibility can't be adjusted straightforwardly while riding outside. For electric bicycle the engine help can be gotten to impact the power result of the rider. Subsequently the way of behaving of the cyclist to changing engine power should be expected. For this reason, it is expected that the cyclist wishes to keep a consistent riding speed. At the point when changes of speed happen, the rider responds by changing the pedal power to return to his ideal riding speed.

To display this, conduct a straightforward direct regulator was planned. The boundaries of the regulator were decided to fit exploratory information. During these trials the cyclist began

from a still position and advanced to a speed of 20 km/h which he kept up with for a few seconds while the pedal force was estimated. Joined Model. Accepting that the cyclist plans to keep the riding speed consistent, the rider force result can be gotten from Eqn. (5.6) by setting the speed increase equivalent to nothing. The rider's force is consequently given by:

$$T_{M,ff} = \frac{(T_{R,p} - T_{R*}) \cdot r_{fw}}{\tau \cdot r_{rw}} \quad (5.6)$$

$$P_R = \frac{\bar{v}}{r_{rw}} \cdot T_D - \frac{\bar{v}}{r_{fw}} \cdot T_{M,ff} \quad (5.7)$$

with v being the ongoing consistent speed of the bike. The general framework is then depicted by the accompanying state space portrayal:

$$\begin{aligned} \dot{x}_1 &= -a_1 x_1 + a_2 x_2 + \frac{a_6 \cdot \bar{v}}{P_{max}} \left(\frac{T_D}{r_{rw}} - \frac{T_{M,ff}}{r_{fw}} \right) \\ \dot{x}_2 &= -a_3 x_2 + \frac{a_4 x_1}{(1 + \exp(-(x_1 - a_5)))} \\ y &= x_1 \end{aligned} \quad (5.8)$$

The above equations show the final modelling of the system with all the parameters

5.3 Cycle model

The bicycle framework is made out of three sources of info and two results. The sources of info are the force of the rider applied on the pedals, natural unsettling influences (d), and the ideal engine force yield on the front wheel (T_{M*}). The results are the speed of the by cycle (v) and the applied force of the rider (PR). The speed of the bike can be determined by the bikes longitudinal elements [12] given by::

$$M \cdot \frac{dv}{dt} = -F_{bump} - F_{roll} - F_{air} - F_{slope} + F_{R,rw} + F_{M,fw} \quad (5.9)$$

where $M = (m_t + I_{rw}=r_2 \text{ } rw + I_{fw}=r_2 \text{ } fw)$ is the total mass of the bicycle-cyclist system, and $dv=dt$ is the acceleration of the bicycle. $F_{R,rw}$ and $F_{M,fw}$ in Eqn. (5.9) are the force produced by the rider at the rear wheel and the motor force at the front wheel, respectively. The negative forces F_{bump} , F_{air} , F_{roll} and F_{slope} are the average bump resistance, the air resistance, the rolling resistance and the slope resistance, respectively. The average bump resistance can be neglected, because it is much smaller than the other resistance forces on most roads [12].

The remaining resistance forces are considered in the environmental disturbances d acting on the system and are given by [12, 13]:

$$F_{air} = 0.5.C_w.\rho_{air}.A.(v + v_w)^2 \quad (5.10)$$

$$F_{roll} = f_{sr}.m_t.g.cos(\alpha) + f_{dr}.v \quad (5.11)$$

$$F_{slop} = m_t.g.sin(\alpha) \quad (5.12)$$

The parameters used for the bicycle model are given by Tab. 1, where A and c_w were taken from [12] and m_t was measured. Additional parameters were taken from [14]. The power output of the rider is given by the product of the rider torque at the pedals and the pedaling frequency:

$$P_R = T_{RP}.\omega_p = T_{RP}.\frac{v}{\gamma_{rw}.\tau} \quad (5.13)$$

Table 5.2: Parameters used for simulating the bicycle longitudinal dynamics

$c_w[-]$	$\rho_{air}[kg/m^3]$	$A[m^2]$	$m_t[kg]$
1.2	1.25	0.5	107.0

with the transmission ratio:

$$t = \frac{\omega_{rw}}{\omega_p} \quad (5.14)$$

The input TM^* to the bicycle model in Fig. 1 is the desired motor torque. For the simulation, motor dynamics can be neglected, given a good low level controller[18]. Consequently, the desired motor torque TM^* and the actual motor torque at the front wheel TM_{fw} were assumed to be equal.

5.4 Summary

In this section the modelling is done. Here modelling of the system and cyclist are done.

Chapter 6

Controller Design

6.1 Introduction

The planned regulator depends on the ongoing heart rate of the cyclist as well as the ongoing force of the rider. The PID controller is used to find the regulated heart rate and velocity of the HEHV. A sliding mode controller (SMC) is utilized to make up for deviations from the ideal heart rate level and diminishes the most extreme rider force to further develop the riding experience. The controllers empower the rider to keep an ideal heart rate level and great client experience.

6.1.1 Proportional Integral Derivative

The functioning rule behind a PID regulator is that the corresponding, fundamental and subsidiary terms should be separately changed or "tuned." Based on the contrast between these qualities a revision factor is determined and applied to the information. The PID controller is tuned as follows to obtain the desired output:

Table 6.1: Parameters for PID tuning

Proportional (P)	Integral (I)	Derivative (D)
1.5	0.02	1

For instance, assuming a broiler is cooler than required, the intensity will be expanded. Here are the three stages: Proportional tuning: Relative tuning includes rectifying an objec-

tive corresponding to the distinction. Hence, the objective worth is never accomplished on the grounds that as the distinction approaches zero, so too does the applied revision. Derivative tuning: endeavors to limit this overshoot by easing back the revision factor applied as the objective is drawn closer. The block diagram of the system with PID controller is given below:

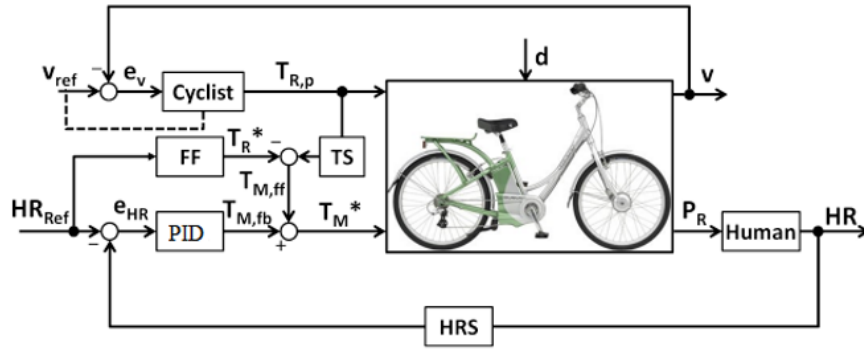


Figure 6.1: Block diagram of system with PID

The PID regulator is utilized to find the controlled heart rate and speed of the HEHV. A PID is used to compensate for deviations from the ideal heartbeat level and lessens the most outrageous rider power to additionally foster the riding experience. The regulators enable the rider to keep an ideal heartbeat level and incredible client experience.

6.1.2 Sliding Mode Control

Sliding Mode Controller is a nonlinear control procedure highlighting exceptional properties of precision, heartiness, and simple tuning and execution. The two primary benefits of sliding mode control:

- 1) the powerful way of behaving of the framework might be custom fitted by the specific decision of the sliding capability.
- 2) the shut circle reaction turns out to be absolutely cold hearted toward a few specific vulnerabilities.

The sliding capability s is characterized as the mistake sign of the heart rate:

$$s = e_{HR} = x_{1,ref} - x_1 \quad (6.1)$$

is bothersome for an electric bike since it causes the rider to feel awkward. The control sign can be smoothed by presenting persistent control regulations into the framework, and various methodologies have been proposed. To diminish the chatting and smooth the control signal, the signum capability is supplanted with an immersion capability. The new control regulation is then given by

$$T_{M,fb} = -\frac{r_{fw} \cdot P_{\max}}{a_6 \cdot \bar{v}} \cdot (\eta \operatorname{sgn}(s) + \dot{x}_{1,\text{ref}} + a_1 x_1 - a_2 x_2) \quad (6.4)$$

where e is a little certain steady and h is picked as in Eqn. (6.3). x_1 in Eqn. (6.4) is the deliberate heart rate standardized as in Eqn. (6.5) and x_2 is assessed by coordinating \dot{x}_2 in Eqn. (6.6).

6.1.3 Stability Proof

Based on the system model (5.8) and the sliding function, the following Lyapunov function is chosen:

$$V = s^2 \quad (6.5)$$

and it follows that:

$$\dot{V} = 2s\dot{s} \quad (6.6)$$

Plugging in the sliding mode control input (14) into (13) yields:

$$\dot{V} = -2s \cdot \left[\eta \operatorname{sgn}(s) + \frac{a_6 \bar{v} T_D}{P_{\max} r_{rw}} \right] < 0, \forall s \neq 0 \quad (6.7)$$

since $\eta \operatorname{sgn}(s)$ dominates. Similarly, if (16) is employed, applying the same Lyapunov function, one can derive:

$$\dot{V} = -2s \left(\frac{\eta s}{|s| + \varepsilon} + \frac{a_6 \bar{v} T_D}{P_{\max} r_{rw}} \right) < 0, \forall |s| > \frac{\varepsilon |T_D|}{|T_{D,\max}| - |T_D|} \quad (6.8)$$

Based on Eqn. (6.8), the asymptotic closed-loop stability is guaranteed with sliding mode control law (6.7). If the sliding mode control law (6.8) is applied, the closed-loop system can achieve bounded tracking errors, as is shown in Eqn. (6.8). This completes the proof.

6.2 Summary

In this section, the methodology is discussed. Here the the PID controller and SMC controller is designed.

Chapter 7

Results and Analysis

In this section experimental results of the control system using two controllers are presented. The simulation uses the system dynamics described before and the results verify the effectiveness of the Sliding Mode Control (SMC) as well as the Proportional Integral Derivative controller (PID). Both controllers are then used to obtain the result using Simulink and the comparison is done between them.

7.1 Model Validation

The open loop response for the model is given below.

The heart rate output for the open loop model is given as shown in figure:

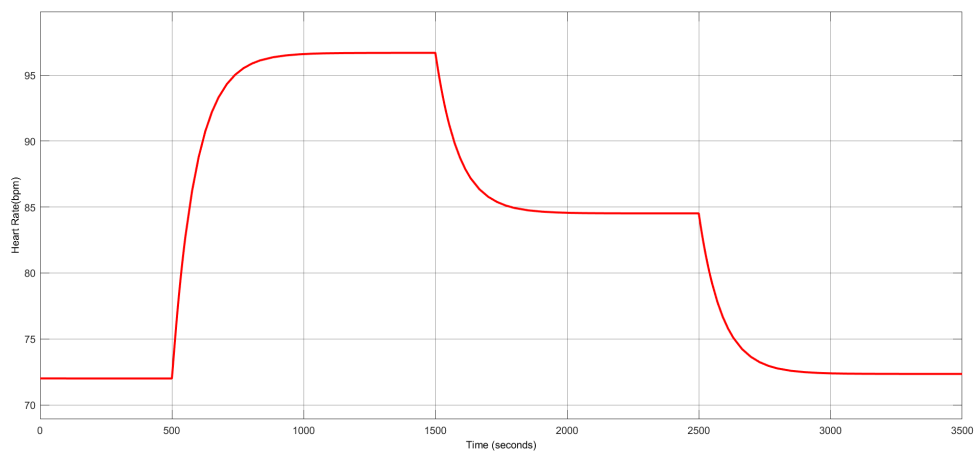


Figure 7.1: Heart rate output for open loop model

From the graph it is shown that initially the heart rate is as desired and when a change in slope or elevation in the road happens the rider has to provide more peddling frequency which results in the rise in the heart rate of the rider and reaches a maximum value. As a result the motor starts and the rise in heart rate is controlled and bring back to the desired level.

The speed rate output for the open loop model is given as shown in figure:

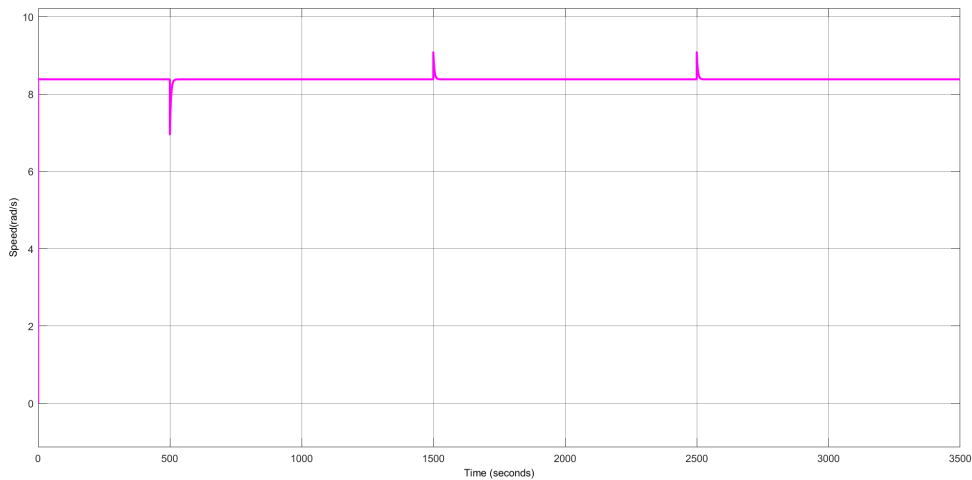


Figure 7.2: Speed rate output for open loop model

The graph shows the speed rate of the electric bicycle. It is maintained at a required input speed of 8.38 rad/sec. Even though it is maintained at required rate the speed response shows overshoot which is eliminated by using controllers.

7.2 Proportional Integral Derivative Controller

In PID controller, the output is obtained by tuning the Proportional (P), Integral (I) and Derivative (D) values.

The speed of the bicycle changes as the road type or elevation occurs. Also, there will be a change in the velocity when the heart rate of the rider changes due to over pedaling during the elevations. The output obtained while using a PID controller is shown in Figure 7.3.

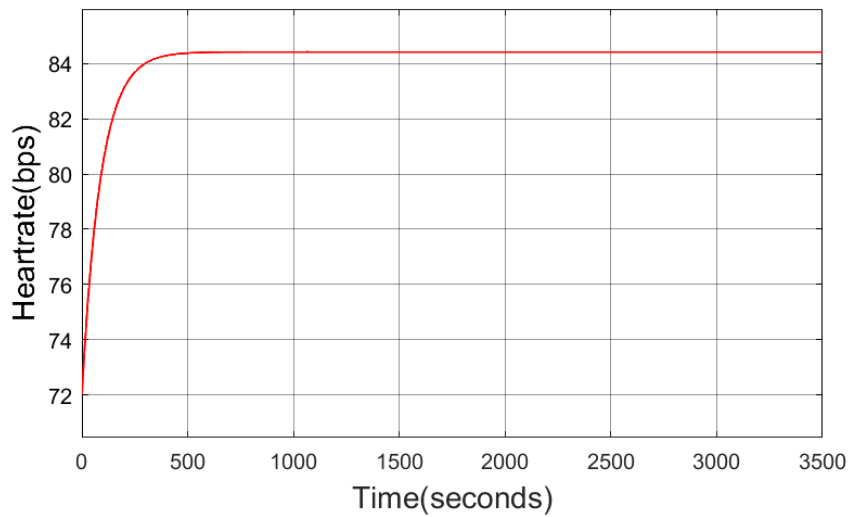


Figure 7.3: Heart rate output for PID Controller

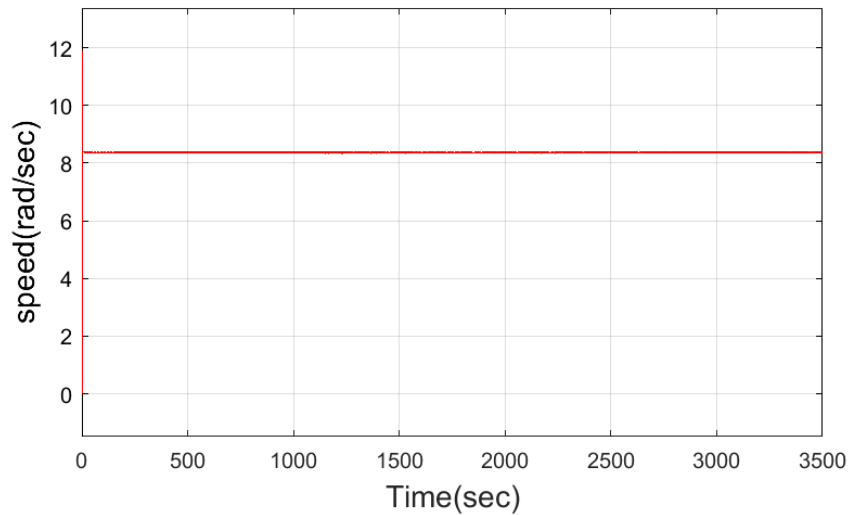


Figure 7.4: Speed output for PID Controller

7.3 Sliding Mode Controller

A fixed-step solver gave by Simulink a stage size of one second was picked Fig 7.3 shows the heart rate along with the applied engine force for a stretch kind reference heart rate profile. The desired heart rate profile is obtained.

In Figure the tracking performance of the SMC is shown. Here from the output, we can clearly say that the tracking performance for heart rate regulation is achieved. As mentioned before, environmental disturbances sometimes force the rider to slow down or stop the bicycle. As a result, the rider has to apply high peak torque values in order to regain the desired velocity, which makes the rider uncomfortable. experience.

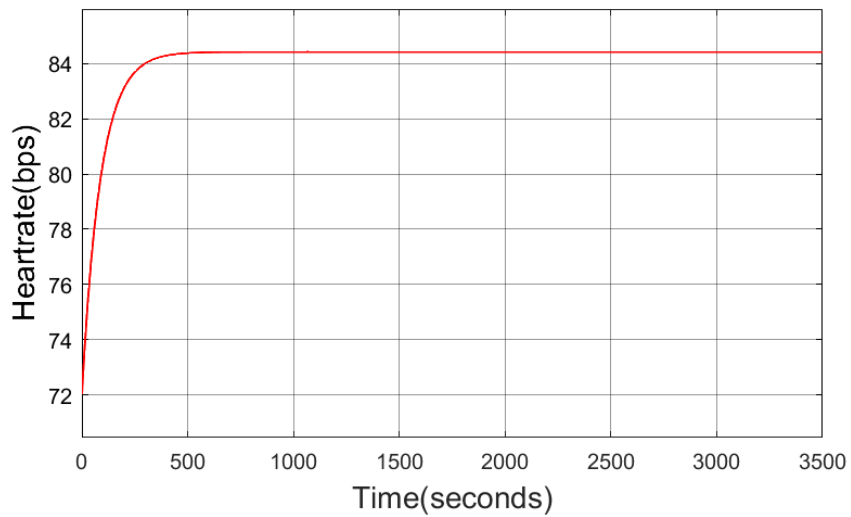


Figure 7.5: Heart rate output for SMC Controller

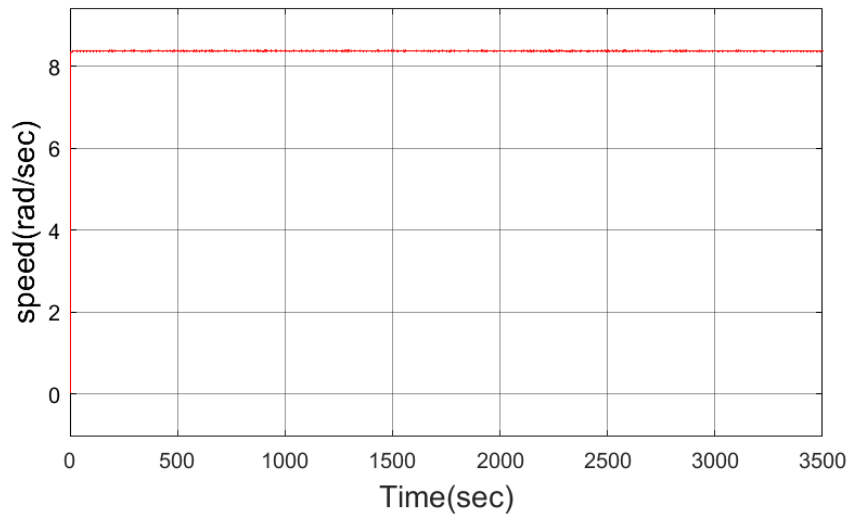


Figure 7.6: Speed output for SMC Controller

Which results in lowering the desired heart rate, to compensate for the high torques and improve the performance of the control system the velocity tracking is also done. The new control improves the tracking performance when decreasing the reference heart rate level and reaches a stable heart rate level. Additionally, it smooths the applied motor torque leading to a better riding

7.4 Comparison of PID and SMC

From the results obtained it is found that the overshoot occurred in the speed output while using a PID controller is eliminated by replacing PID with a SMC controller. From this the conclusion is obtained that the SMC controller gives the better output than PID controller.

7.5 Summary

The results for the PID controller and SMC controller is stimulated and compared for validation.

Chapter 8

Conclusion And Future Scope

In this paper, a numerous outing data melded structure is proposed for the outing based ideal power the executives for PHEV In this work a sliding mode regulator (SMC) and Proportional Integral Derivative (PID) regulator is utilized to manage the heart rate of electric bicycle riders. The SMC changed the engine help level to keep an ideal heart rate level. The regulator was planned by examining the framework elements including models of the human heart rate reaction to responsibility, the bike, and the rider.

The signum capability of the SMC was supplanted by an immersion capability to smooth the control signal. The PID regulator was additionally used to follow the ideal heart rate level and to make the rider more agreeable. The SMC decreased the rider's greatest force yield at the pedals while accelerating or going uphill, and it smoothed the control yield which came about in better riding experience.

The introduced reproduction as well as trial results checked the planned control framework. Continuous work incorporates leading further examinations to check the control plan for various subjects. Likewise, the regulator is restricted by the abilities of the engine. Utilizing extra frameworks to control the transmission proportion when ecological aggravations surpass the restrictions of the engine could build the scope of potential utilization of the control plan.

From the results obtained it is clear that the overshoot in the output obtained when a PID controller is used can be eliminated by using a SMC controller.

8.1 Future Scope

Traditional engine help systems present cutoff points on the convenience of these bikes: they miss the mark on adaptability to adjust to the individual physiological constitution of cyclists and don't as expected deal with the help control over an whole excursion. In this paper, we present an original energy the board framework for human-electric crossover vehicles that:

- 1) utilizes an ideal control way to deal with control the pulse of the cyclist and
- 2) consolidates trip data to deal with the engine help. The framework comprises of a control stage and a arranging stage.

In the control stage, a model prescient regulator manages the heart rate by changing the engine power and stuff proportion to keep a client characterized effort while thinking about requirements. The arranging stage processes deduced data about the client and the course to gauge the power interest during various areas of the outing and to compute the ideal engine power for each area. Engine power requirements for each segment are then formed to restrict the energy utilization and to save energy for those areas when engine power is generally required.

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