ROBUST YAW STABILITY CONTROL OF HYBRID ELECTRIC VEHICLES

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To my parents, my family, wife and children

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ABSTRACT

Yaw stability of an automotive vehicle in a various maneuvers is critical to the overall safety of the vehicle. Robust yaw stability control for a Through-the-Road Hybrid Electric Vehicle (TtR-HEV) with two in–wheel–motors in rear wheels is proposed using a Model Predictive control (MPC) controller. The propose technique aimed to enhance the yaw stability of TtR-HEV, especially on slippery roads to prevent vehicle from spinning out and provide safety driving under wide range of driving. This technique based on developed mathematical models of vehicle and tires. A Model Predictive control (MPC) controller applied to make vehicle yaw rate to track its reference. The control performance of the proposed yaw stability control system verified through computer simulation using MATLAB/SIMULINK. The yaw stability enhanced against uncertainties model, disturbances, and parameter variations. In addition, better performance achieved by applying the robust control that is satisfied high effectiveness and robustness.

ABSTRAK

Kestabilan Yaw untuk kenderaan automotif dalam pelbagai jenis manuver adalah penting untuk keselamatan keseluruhan kenderaan. Kawalan kestabilan Yaw mantap untuk Through-the-Road Kenderaan Hibrid Elektrik (TtR-HEV) dengan dua dalam roda motor dalam roda belakang adalah dicadangkan menggunakan Kawalan Ramalan Model (MPC). Teknik yang dicadangkan adalah bertujuan untuk meningkatkan kestabilan Yaw untuk TtR-HEV, terutamanya di jalan raya yang licin untuk mengelakkan kenderaan daripada berpusing keluar dan menyediakan keselamatan pemandu. Teknik ini adalah berdasarkan model matematik yang didapatkan daripada kenderaan dan tayar. Kawalan Ramalan Model (MPC) digunakan untuk membuatkan kadar kenderaan Yaw untuk menjejak isyarat rujukan kenderaan tersebut. Prestasi sistem kawalan kestabilan Yaw yang dicadangkan disahkan melalui simulasi komputer menggunakan MATLAB/SIMULINK. Kestabilan Yaw dapat dipertingkatkan daripada ketidaktentuan model, gangguan, dan variasi parameter. Di samping itu, prestasi yang lebih baik dicapaikan dengan menggunakan kawalan yang teguh yang berpuas hati keberkesanan yang tinggi dan kekukuhan.

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LIST OF SYMBOLS

δ	-	Wheel steering angle (in degree)
T_{bi}	-	Braking torque at i^{th} wheel (in newton meters)
v	-	Vehicle velocity at centre of gravity (in kilometers per hour)
β	-	Vehicle side slip angle (in degree)
β_d	-	Desired vehicle side slip angle (in degree)
A_s	-	Steering stability factor
$\dot{\Psi}$ (γ)	-	Vehicle yaw rate (in degree per second)
$\dot{\Psi}_d$ (γ_d)	-	Desired vehicle yaw rate (in degree per second)
α_i	-	Sideslip angle at i^{th} wheel (in degree)
ω_i	-	Tyre rotational speed at i^{th} wheel (in revolutions per minute)
F_{xi}	-	Longitudinal tyre force at i^{th} wheel (in newtons)
F_{yi}	-	Lateral tyre force at i^{th} Wheel (in newtons)
M_z	-	Yaw moment (in newton meters)
C_f	-	Nominal tyre cornering stiffness at front wheel (in newtons per radian)
C_r	-	Nominal tyre cornering stiffness at front wheel (in newtons per radian)
l_f	-	Distance from the vehicle center of gravity to the front axle (in meters)
l_r	-	Distance from the vehicle center of gravity to the rear axle (in meters)
I_z	-	Moment of inertia of vehicle body (in kilogram square meters)
g	-	Gravitational acceleration = 9.81 (in meters per second squared)
M_z	-	Yaw moment (in newton meters)
m	-	Total mass of the vehicle (in kilograms)

μ	-	Tire–road friction coefficient
P	-	Predication horizon (intervals)
M	-	Control horizon (intervals)
$u(k)$	-	Input vector
Δu	-	Predicted change in control value
$r(k)$	-	Setpoint
$y(k)$	-	Predicted output
$x(k)$	-	Vector of state variable
$Q(i)$	-	Output error weight matrix
$R(i)$	-	Control weight matrix

LIST OF ABBREAVIATIONS

ABS	-	Anti-Lock Braking System
ASC	-	Active Steering Control
CG	-	Center of Gravity
DOF	-	Degree of Freedom
DYC	-	Direct Yaw Moment Control
ESP	-	Electronic Stability Program
FWS	-	Front Wheels Steering
HEV	-	Hybrid Electric Vehicle
ICE	-	Internal Combustion Engine
ISM	-	Integral Sliding Mode
IWM	-	In-Wheel-Motor
LPV	-	Linear Parameter Varying
LQR	-	Linear Quadratic Regulator
MIMO	-	Multi Input Multi Output
MPC	-	Model Predictive Control
PID	-	Proportional Integration Derivative
SA-DOB	-	Steering angle-disturbance Observer
SISO	-	Single Input Single Output
SMC	-	Sliding Mode Control
TCS	-	Traction Control System
TtR	-	Through-the-Road
VSC	-	Vehicle Stability Control
VTD	-	Variable Torque Distribution
YMO	-	Yaw Moment Observer

CHAPTER 1

INTRODUCTION

1.1 Types of Hybrid Electric Vehicle

A hybrid electric vehicle is one that has two or main sources of propulsion power. They have both internal combustion engine and one or more electric motors and can be driven by either powertrain or together sources simultaneously.

Recently, hybrid electric vehicle (HEV) have been developed very rapidly as a solution of energy problems, as well as environmental global warming issues. Compared to an internal combustion engine vehicles, a hybrid electric vehicle (HEV) can help reduce polluting emissions and can also offer highly reduced fuel consumption [1]. Thus, it has become the most available in technology and a great concern of researchers in this field.

HEV have evident advantages over conventional internal combustion engine vehicles. Firstly, a quick, accurate and comprehensible torque response. Secondly, output torque can be easily measured from motor current. Thirdly electric motors which are fixed in each wheel can be independently controlled.

HEV can be classified according to hybrid architectures. The most common architectures are parallel, series, and combination parallel-series hybrid electric vehicles. The resulting configurations can be treated under the following general categories:

1.1.1 The Series Hybrid Electric Vehicle

In the series hybrid electric vehicle, where uses the electric motor to drive the vehicle and this provides all the propulsion power. The internal combustion engine (ICE) directly connected to an electric generator or alternator. The principal advantage of this configuration is that series hybrid vehicle typically used in heavy-duty vehicles such as trucks, buses and other urban vehicles involved in a lot of stop-and-go driving. The system also reduces the need for conventional transmissions and clutches. This architecture has high efficiency and has very low emissions. The inefficiency associated with series hybrid, it is much low efficiency during high speed driving, due to losses in converting the mechanical power from the ICE to electricity and in charging and discharging of the battery as well as it also requires a large and heavy battery pack, which lead to increases cost and reduces vehicle performance from the weight of the batteries. The series hybrid architecture is depicted in Figure 1.1.

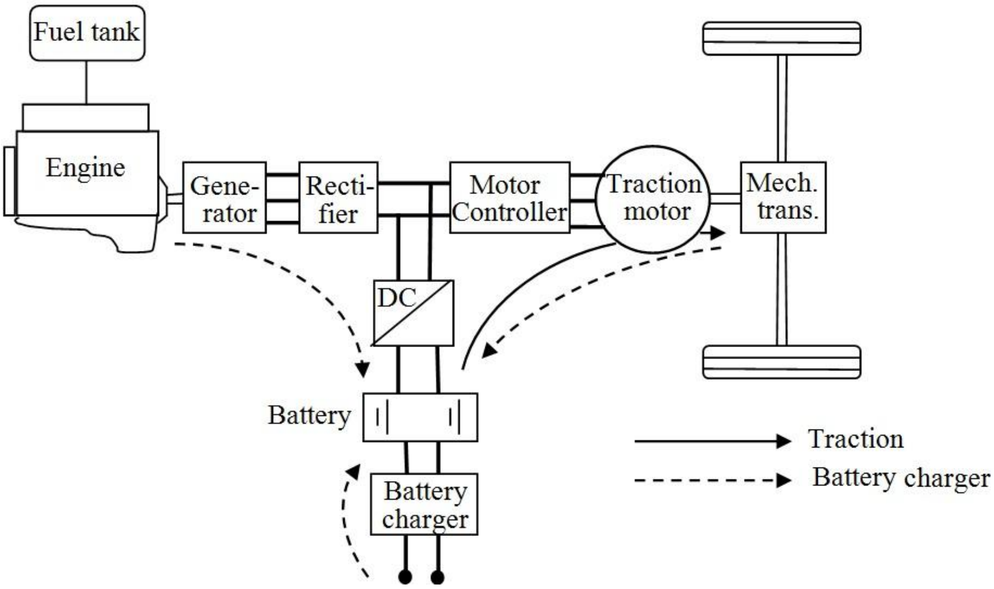

Figure 1.1 Configuration of a series hybrid electric vehicle [2].

1.1.2 The Parallel Hybrid Electric Vehicle

The parallel hybrid uses a motor or more and an engine to powered the wheels of the hybrid electric vehicle together. The engine and motors are both connected directly to the drive train (see Figure 1.2). The main advantages of parallel architecture over a series architecture are generator is not required as well as the traction motor is smaller and light battery. Thus, this can minimizes the additional cost of the motor and battery pack. But the control of the parallel hybrid drive train is more complicated than a series, due to the mechanical coupling between the engine and the driven wheels.

Parallel-hybrid vehicles can be further divided into two categories according to the location of the electric motors. First category, the engine-assist systems, secondly, known as a through-the-road hybrid. In this research will be design robust yaw stability control of through-the-road hybrid electric vehicle (TtR-HEV).

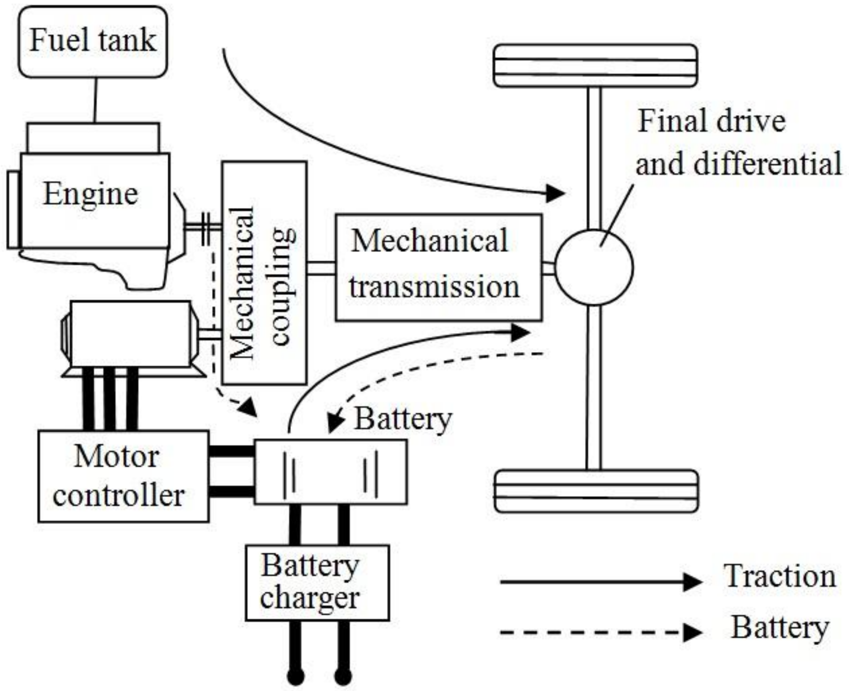

Figure 1.2 Configuration of a parallel hybrid electric vehicle [2].

1.1.2.1 Through-the-Road Hybrid Electric Vehicle

In the Through-the-Road (TtR) configuration of parallel hybrid electric vehicle (HEV), electric motors are coupled on one axle and the internal combustion engine (ICE) is coupled on the other axle. Therefore, the power from the ICE to the electric motors can be transmitted via the road and wheels when the vehicle is moving. In other word, when both ICE and electric motors are operating together, a "TtR-HEV" mode is obtained. An example TtR-HEV architecture is depicted in Figure 1.3.

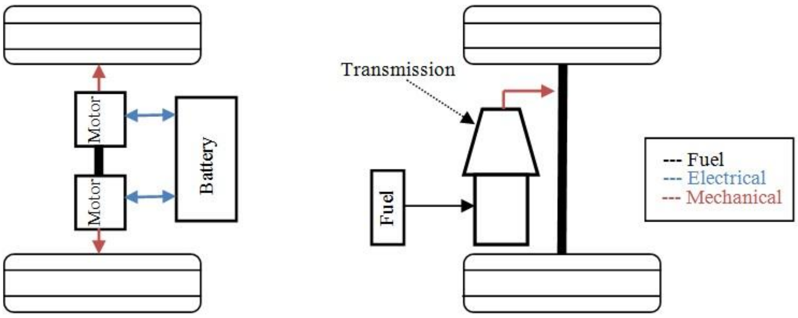

Figure 1.3 Configuration of a powertrain for a TtR-HEV.

1.1.3 Series-Parallel or Power-Split Hybrid

The series-parallel hybrid included usefulness and the construction of the series and parallel drive trains. By consolidating the two configurations, the ICE can be used to propulsion specifically wheels (as in the parallel drive train) and likewise be enough discontinued from the wheels so that only the electric motor propels the wheels (as in the series drive train). As a result of this new design, the ICE works at near optimum efficiency frequently. This framework is more costly because of the more complex hardware. In any case, the series-parallel hybrid has the possibility to fulfill better than either of the series or parallel hybrid systems alone. The configuration of a series-parallel hybrid drivetrain is shown in Figure 1.4.

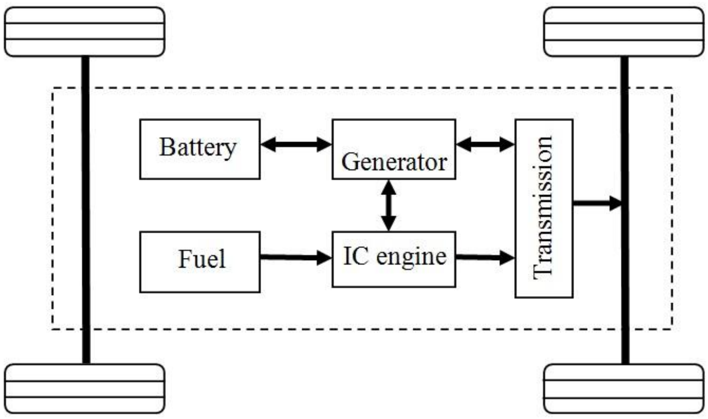

Figure 1.4 Configuration of a series-parallel hybrid or a power-split drivetrain [2].

1.2 Yaw Stability

Stability control systems that prevent automotive vehicle from skidding and spinning out are often referred to as yaw stability control systems [2]. Yaw stability of hybrid electric vehicle in a cornering situation is critical to vehicle stability and handling performance. Yaw stability aims to improve safety by keeping the vehicle yaw rate following its target commanded by the driver and keeping the vehicle slip angle in a small range (see Figure 1.5). In other words, yaw stability ensures a vehicle does not spin uncontrollably during emergency maneuvers and in critical driving conditions.

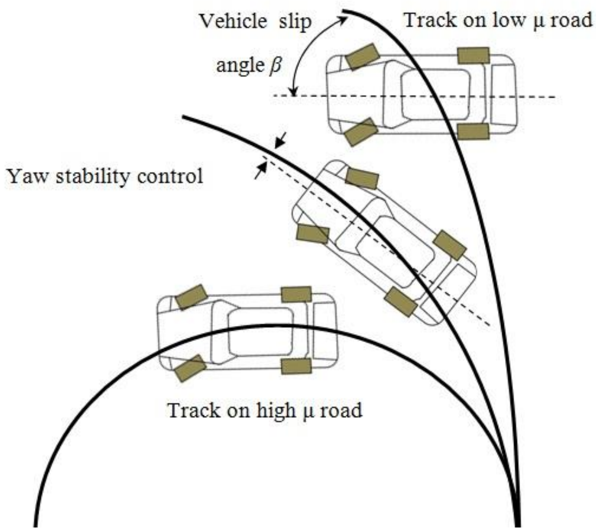

Figure 1.5 The functioning of a yaw stability control system [2].

1.3 Problem Statement

A study done by Ackermann (1997) found that the yaw rate of the automotive vehicle is not only stirred by lateral acceleration in a way that the driver is used to, but also by disturbance torques resulting for example when a car encounters unexpected road conditions, such as a split-μ road, the tire slip angles. So, the vehicle slip angle may suddenly increase, which causes the vehicle to reach its physical limit of adhesion between the tires and the road. The driver has to compensate this disturbance torque by opposing at the steering wheel in order to provide disturbance reduction. This is the more hard task for the driver because the disturbance input comes as an abruptness to him; since most drivers have less experience operating a vehicle under this situation, they might at last lose control of the vehicle [30].

Accordingly vehicle yaw stability ensures a car does not spin uncontrollably during emergency maneuvers and in critical driving conditions. This capability is especially needed when a car makes a sharp or high speed turn along a slippery road. Useful articles, researches and studies have been written about robust yaw stability control of hybrid electric vehicles, but there is little research has been done of TtR-HEV. With the above problem statement established, it is obvious to state that it is highly significant to design a robust yaw stability control of Through-the-Road Hybrid Electric Vehicle (TtR-HEV).

1.4 Objective of Study

The objective of this research are as follows:

(a.) To develop a single-track TtR-HEV model

(b.) To design a controller that is satisfy the robust yaw stability of a TtR-HEV.

(c.) To simulate and evaluate the performance of the system with a proposed controller.

1.5 Scope of the Project

This study focuses on the system that is Through-the-Road Hybrid Electric Vehicle (TtR-HEV), which contains the internal combustion engine (ICE) mounted on the front axle and two in-wheel-motors for rear traction. The work undertaken in this project are limited to the following aspects:

(a.) Mathematical model of the TtR-HEV is developed of a single track car model.

(b.) A controller will be designed to maintain the yaw stability of TtR-HEV based on mathematical models of vehicle and tires using MPC control technique.

(c.) Perform a simulation works by using MATLAB/SIMULINK to observe effectiveness and robustness of the controller.

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