

**YAW CONTROL OF A 3-AXLE SINGLE TRAILER TRUCK USING
STEERABLE WHEEL OPTIMISED WITH GRAVITATIONAL SEARCH
ALGORITHM**

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ABSTRACT

A single-trailer truck plays an important roles of transportation in the economics of modern societies. Despite several advantages in transportation, this vehicle is often involved in a road accident such as skidding, jack-knifing, trailer oscillation, and others led by the unwanted yaw rate on this vehicle while manoeuvring. The stability of the vehicle has been the most concern as it can provide unwanted response properties while traveling at high speeds. This study proposed the development of the yaw rejection control for single-trailer truck using a steerable wheel located at the middle axles. This controller is implemented in order to reduce yaw disturbance which is lateral stability on single-trailer truck vehicles while manoeuvring. The yaw rejection control system was proposed using a PID controller and the controller parameters were optimized using Gravitational Search Algorithm (GSA) to obtain the optimal responses. Then, the result of the active model responses is compared with the result of the passive model response in terms of magnitude and percentage of difference using the RMS method. The proposed yaw rejection controller shows the highest reduction of 34.66% RMS reduction for lateral acceleration response and 22.92% RMS reduction for yaw rate response. Lastly, the yaw rejection controller was validated on a small scale of single-trailer truck vehicle model and steerable wheel actuator through the Hardware-in-the-loop simulation. The results showed that the yaw rejection controller successfully generated realistic steering wheel actions for the steerable wheel in stabilising yaw moment of the truck vehicle while manoeuvring.

ABSTRAK

Lori treler tunggal memainkan peranan penting dalam pengangkutan yang penting dalam sector ekonomi masyarakat moden. Walaupun terdapat banyak kelebihan dalam pengangkutan, kenderaan ini sering kali terlibat dalam kemalangan jalan raya seperti tergelincir, “*jack-knifing*”, treler berayun, dan lain-lain disebabkan oleh kadar pusingan yang berlebihan pada kenderaan ketika melakukan manuver. Kestabilan kenderaan menjadi perhatian utama kerana ia dapat memberikan kesan yang tidak diinginkan ketika memandu dengan kelajuan tinggi. Kajian ini mencadangkan pembinaan kawalan penolakan pusingan untuk sebuah trak treler tunggal menggunakan roda boleh dikendalikan yang diletakkan di gandar tengah. Pengawal ini dilaksanakan untuk mengurangkan gangguan pusingan untuk kestabilan sisi pada kenderaan trak treler tunggal semasa pemanduan. Sistem kawalan penolakan pusingan dikendalikan menggunakan pengawal PID dan parameter pengawal dioptimumkan menggunakan Gravitational Search Algorithm (GSA) untuk mendapatkan tindakbalas yang optimum. Kemudian, hasil tindakbalas model aktif dibandingkan dengan hasil tindakbalas model pasif dari segi magnitud dan peratusan perbezaan menggunakan kaedah RMS. Hasil prestasi pengawal penolakan pusingan tertinggi adalah pengurangan RMS 34.66% tindakbalas pecutan lateral dan pengurangan RMS 22.92% tindak balas kadar yaw. Terakhir, pengawal penolakan pusingan disahkan pada skala kecil model kenderaan trak tunggal melalui simulasi Hardware-in-the-loop. Hasil kajian menunjukkan bahawa pengawal penolakan yaw berjaya menghasilkan signal roda kemudi yang realistik oleh penggerak pada kenderaan semasa manuver.

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LIST OF ABBREVIATIONS

4WS	-	Four-wheel-steering
ABS	-	Antilock Bracking System
AHV	-	Articulated Heavy Vehicle
DLC	-	Double Lane Change
DOF	-	Degree Of Freedom
DYC	-	Direct Yaw Control
ESC	-	Electronic Stability Control
GSA	-	Gravitational Search Algorithm
HIL simulation	-	Hardware In the Loop simulation
ICR	-	Instantaneous Centre of Rotation
ODE	-	Ordinary Difference Equation
RMS	-	Root Mean Square
RSC	-	Roll Stability Control
SISO	-	Single Input Single Output
SLC	-	Single Lane Change
SUVs	-	Sport Utility Vehicle
TV	-	Torque Vectoring
COG	-	Centre of Gravity

CHAPTER 1

INTRODUCTION

1.1 Research Overview

This research focuses on developing yaw rejection control to minimise the unwanted yaw motion of the single-trailer truck while cornering condition. The yaw rejection controller is an active system that controls steerable wheel at the middle axle of the single-trailer truck to minimise unwanted yaw motion during manoeuvring. This chapter will describe the background of this research.

1.1.1 Background on Heavy Vehicle

The single-trailer truck vehicle which also known as lorry, is described as any motor vehicle that is designed to carry freight or goods or to perform special services. A semi-trailer truck is the combination of truck and semi-trailer unit. There are several types of commercial combination vehicle such as single-trailer truck, truck trailer and double-trailer truck. Figure 1.1 shows the types of commercial combination vehicle.

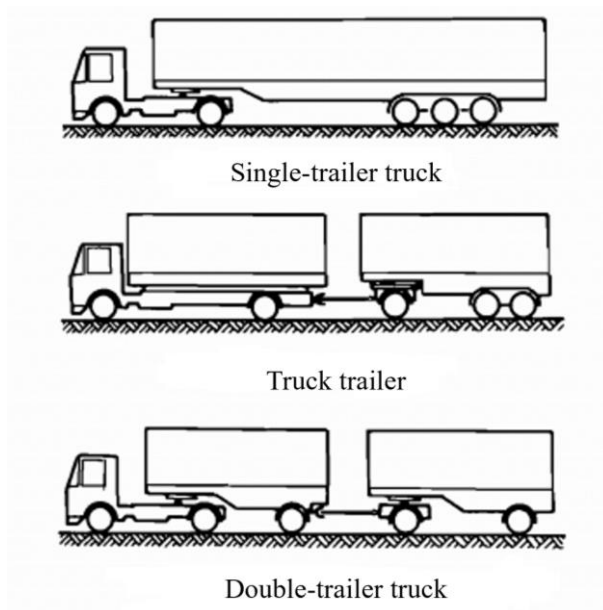


Figure 1.1 Type of commercial combination vehicle [1]

In general, the single trailer truck vehicle is always loaded for long distance transport. This heavy vehicle has the ability to transport an extensive and heavy load with flexible delivery cost. An easy loading and unloading process caused this heavy vehicle to be the best choice of trade transportation. Nowadays, the heavy truck commercial has been used as one of the major cargo transportation systems worldwide [2]. This vehicle can be attached with specialised equipment such as fire trucks, refuse trucks, suction excavators and concrete mixer.

In this study, the stability of a single-trailer truck with three axles in high speed manoeuvring is analysed. In this vehicle, the steering system at the front wheel is being controlled by the driver to provide the overall direction of the vehicle. Therefore, steering system plays an important part in vehicle handling characteristics. A steering arm is attached at one side to the steering box via the sector shaft at the bottom of the steering wheel which converts the angular motion of the sector shaft into linear motion to steer the wheel. The most common steering arm used in heavy vehicle is the Pitman

arm steering system. It is a part of an older recirculating ball steering system that is still used primarily in some trucks and SUVs [3]. Figure 1.2 shows the Pitman arm steering system that is commonly used in a heavy vehicle.

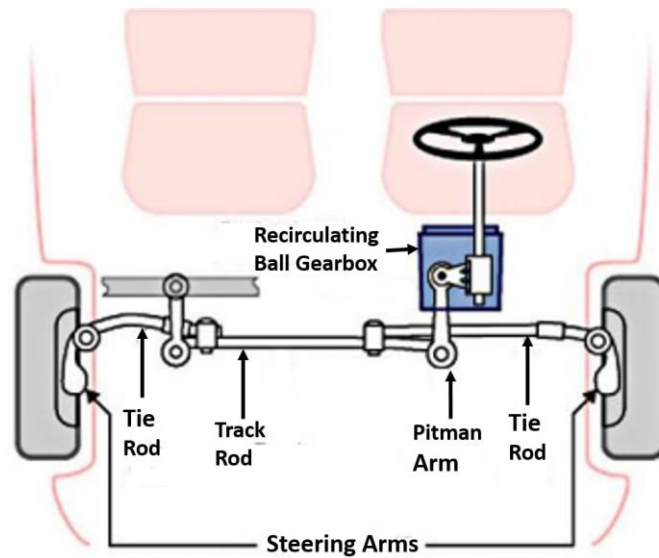


Figure 1.2 Pitman arm steering system [3]

1.1.2 Background on Yaw Rejection Controller Development for Single-trailer truck Vehicles

The single-trailer truck model has three degrees of freedom which are pitch, roll and yaw direction as illustrated in Figure 1.3. In this study, yaw motion is concerned for maintaining the stability of single-trailer truck while manoeuvring. Yaw motion of the vehicle can be described as the rotation of the vehicle body about the z-axis usually caused by yaw moment. Rotational angle about z-axis caused by this motion is known as yaw angle. Yaw motion usually occurred due to yaw moments

caused by steering manoeuvrings as well as external yaw moments caused by any external lateral force that acts away from the centre of rotation (COG).

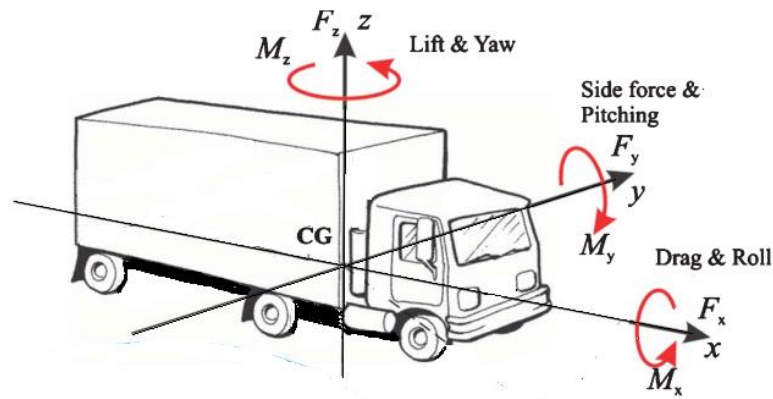


Figure 1.3 Single-trailer truck classification direction [4]

However, many single-trailer truck vehicles were involved in tragic accidents and most cases were implicating the truck driver's safety. Unfortunately, this type of heavy vehicle is exposed to risks that can lead to blind spot crashes, loss of control accidents, and fatigue on longer trips [4,5]. Based on previous studies, accidents involving heavy vehicle in Malaysia were reported as much as 30.3% [6]. Unlike passenger car crashes, single-trailer truck have high fatality and injury rates, that lead to excess property damage and traffic congestion [7]. Manoeuvring a single-trailer truck is much harder compared to a single-unit vehicle as the truck's driver has an additional work on coping with trailer oscillation, path following to the vehicle and possible instability. Also, poor lateral stability of single-trailer truck at high speed can be attributed to unstable motions during changing lanes, such as trailer swing, jack-knifing and rollover causing more traffic accidents [8,9].