ROLLOVER PREVENTION SYSTEM OF TRUCK-TRAILER VEHICLE USING STEERABLE-WHEEL FOR MIDDLE AXLE

MUHAMMAD NADWI HAKIMI BIN ADNAN

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ABSTRACT

It is well-known that single-trailer trucks are one of the common vehicles in transporting goods. Normally, single-trailer truck will lose its manoeuvrability when driving at a high speed during cornering or sudden lane changing manoeuvers due to excessive yaw and roll moments at the body center of gravity. In order to enhance the manoeuvrability as well as to avoid rollover accident in high speed manoeuverings, this study proposes an active roll control using steerable-wheel system middle axle of single-trailer truck. The steerable-wheel system is developed mainly focused to maintain the directional manoeuvrability and stability of the single-trailer truck by providing an electronically controlled wheel angle of middle axle mechanism. The system is designed to reject the unwanted lateral, yaw and roll motions based on trailer responses. Firstly, the control structure of the active roll control system is developed on a verified 18 degree-of-freedoms of single-trailer truck model. The control structure consists of trailer's roll angle feedback control using PID controller and additional roll moment cancellation control using Skyhook controller. The controller is then enhanced by optimising the controller's parameters using Particle Swarm Optimisation. From the simulation results, it can be seen that the proposed control structure is able to reject the unwanted motions in single-lane and double-lane change manoevers as compared to passive system. The benefits of PID-Skyhook controller are also discussed in this study by comparing the performances against the PID controller. Finally, active roll control with PID-Skyhook controller is then tested experimentally through hardware-in-the-loop simulation approach using a small-sized of single-trailer truck with steerable-wheel test rig. From the experimental results, a significantly good agreement between experiment and simulation is observed for lateral acceleration, yaw rate and roll angle responses. It also shows that the proposed steerable-wheel system was proven managed to reduce the unwanted lateral, yaw and roll motions by producing the appropriate wheel steer angle for middle axle to maintain the manoeuvrability and stability of the single-trailer truck from rollover accident.

ABSTRAK

Diketahui bahawa trak treler tunggal adalah salah satu kenderaan yang digunakan dalam pengangkutan barang. Pada kebiasaannya, trak treler tunggal akan kehilangan kemampuan bergerak ketika memandu dengan kelajuan tinggi menukar lorong secara tiba-tiba kerana momen rewang dan gulung pada pusat graviti badan. Untuk meningkatkan kemampuan pengendalian dan juga untuk mengelakkan kemalangan pada kelajuan yang tinggi, kajian ini mencadangkan kawalan gulungan aktif menggunakan sistem roda boleh dikendalikan pada gandar tengah untuk trak treler tunggal. Sistem roda stereng ini memfokuskan bagi mengekalkan kemampuan bergerak dan kestabilan trak tunggal treler dengan menyediakan sudut roda pada mekanisme gandar tengah yang boleh dikawal secara elektronik. Sistem ini direka untuk menolak pergerakan sisi, rewang dan gulung yang tidak diingini berdasarkan tindak balas treler. Pertama sekali, struktur kawalan sistem kawalan gulung aktif dibangunkan berdasarkan pada model 18-darjah kebebasan trak treler tunggal yang telah disahkan. Struktur kawalan terdiri daripada kawalan maklum balas sudut gulungan treler menggunakan pengawal *PID* dan kawalan pembatalan momen gulungan tambahan menggunakan pengawal *Skyhook* serta dioptimumkan menggunakan *Particle Swarm Optimisation*. Hasil simulasi mendapati bahawa struktur kawalan yang dicadangkan mampu menolak gerakan yang tidak diingini dalam pengendalian perubahan lorong tunggal dan jalur dua berbanding sistem pasif. Kelebihan pengawal *PID-Skyhook* juga dibincangkan dalam kajian ini dengan membandingkan prestasinya dengan pengawal *PID*. Akhir sekali, kawalan gulungan aktif dengan pengawal *PID-Skyhook* diuji secara ujikaji melalui pendekatan simulasi dengan menggunakan trak treler tunggal bersaiz kecil dengan rig ujian roda. Dari hasil ujikaji, persamaan yang sangat baik antara ujikaji dan simulasi dapat diperhatikan untuk pecutan sisi, kadar rewang dan gerakan gulungan. Ini juga menunjukkan bahawa sistem roda kemudi yang dicadangkan terbukti berjaya mengurangkan gerakan pecutan sisi, rewang dan gulungan yang tidak diingini dengan menghasilkan sudut roda kemudi yang sesuai untuk gandar tengah bagi mengekalkan kemampuan pengendalian dan kestabilan trak tunggal daripada berlaku kemalangan.

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APPROVAL

The Examination Committee has met on **28 October 2021** to conduct the final examination of **Muhammad Nadwi Hakimi bin Adnan** on his degree thesis entitled **'Rollover Prevention System of Truck-Trailer Vehicle using Steerable-Wheel for Middle Axle'.**

The committee recommends that the student be awarded the of Master of Science (Mechanical Engineering).

Members of the Examination Committee were as follows.

Prof. Dr. Abdul Ghapor bin Hussin
Fakulti Sains dan Teknologi Pertahanan
Universiti Pertahanan Nasional Malaysia
(Chairman)

Prof. Madya Ir. Dr. Saiddi Ali Firdaus bin Mohamed Ishak
Fakulti Kejuruteraan
Universiti Pertahanan Nasional Malaysia
(Internal Examiner)

Prof. Madya Ir. Dr. Mohd Azman bin Abdullah
Fakulti Kejuruteraan Mekanikal
Universiti Teknikal Malaysia Melaka
(External Examiner)

APPROVAL

This thesis was submitted to the Senate of Universiti Pertahanan Nasional Malaysia and has been accepted as fulfilment of the requirements for the degree of **Master of Science (Mechanical Engineering)**. The members of the Supervisory Committee were as follows.

Dr. Zulkiffli bin Abd Kadir
Fakulti Kejuruteraan
Universiti Pertahanan Nasional Malaysia
(Main Supervisor)

Prof. Madya Dr. Khisbullah Hudha
Fakulti Kejuruteraan
Universiti Pertahanan Nasional Malaysia
(Co-Supervisor)

Dr. Noor Hafizah binti Amer
Fakulti Kejuruteraan
Universiti Pertahanan Nasional Malaysia
(Co-Supervisor)

UNIVERSITI PERTAHANAN NASIONAL MALAYSIA

DECLARATION OF THESIS

Student's full name : Muhammad Nadwi Hakimi bin Adnan

Date of birth : 12th September 1996

Title : Rollover Prevention System of Truck-Trailer Vehicle using Steerable-Wheel for Middle Axle

Academic session : September 2019 – August 2021

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LIST OF ABBREVIATIONS

ABS	-	Antilock Braking System
ESC	-	Electronic Stability Control
RSC	-	Roll Stability Control
HiLS	-	Hardware-in-the-Loop Simulation
PSO	-	Particle Swarm Optimisation
GA	-	Genetic Algorithm
RGA	-	Real-Coded Genetic Algorithm
GSA	-	Gravitational Search Algorithm
EP	-	Evoloutionary Programming
DOF	-	Degree-of-Freedom
ECU	-	Electric Control Unit
ARB	-	Anti-roll Bar
AARB	-	Active Anti-roll Bar
LQR	-	Linear Quadratic Regulator
STF	-	Self-Tuning Fuzzy
LTR	-	Load Transfer Ratio
SLC	-	Single Lane Change
DLC	-	Double Lane Change
RMS	-	Root Mean Square
ARC	-	Active Roll Control
SW	-	Steerable-wheel
CG	-	Center of Gravity

LIST OF SYMBOLS

r	-	yaw
θ	-	pitch
ϕ	-	roll
δ	-	steering angle
β	-	hitch angle
m_{truck}	-	mass of the truck
$m_{trailer}$	-	mass of the trailer
m_{ufl}	-	unsprung mass at front-left wheel
m_{ufr}	-	unsprung mass at front-right wheel
m_{uml}	-	unsprung mass at middle-left wheel
m_{umr}	-	unsprung mass at middle-right wheel
I_{roll1}	-	roll inertia of the truck
I_{roll2}	-	roll inertia of the trailer
I_{pitch1}	-	pitch inertia of the truck
I_{pitch2}	-	pitch inertia of the trailer
I_{ztruck}	-	yaw inertia of the truck
$I_{ztrailer}$	-	yaw inertia of the trailer
K_p	-	proportional constant
K_i	-	integral constant
K_d	-	derivative constant
Δe	-	roll angle error rate
$u(t)$	-	control signal
a	-	distance from truck CG to the front wheels

b	-	distance from truck CG to the rear wheels
c	-	distance from truck CG to the hitch
d	-	distance from trailer CG to the hitch
e	-	distance from trailer CG to the trailer wheels
w	-	width of the truck
w_t	-	width of the trailer
S	-	longitudinal slip
R	-	wheel radius
ω	-	angular velocity
u	-	axle speed
α_f	-	slip angle for the front tyres
α_r	-	slip angle for the rear tyres
v_{tf}	-	speed of the front tyre
v_{tr}	-	speed of the rear tyre
$f(\sigma)$	-	saturation function
a_p	-	tyre contact patch lengths
K_s	-	longitudinal stiffness coefficient
K_c	-	lateral stiffness coefficient
σ	-	composite slip
μ_o	-	nominal coefficient of friction dependent on the road conditon
γ	-	camber angle
F_{sfl}	-	spring force in the front left
F_{sfr}	-	spring force in the front right
F_{sml}	-	spring force in the middle left

F_{smr}	-	spring force in the middle right
F_{srl}	-	spring force in the rear left
F_{srr}	-	spring force in the rear right
F_{dfl}	-	damping force in the front left
F_{dfr}	-	damping force in the front right
F_{dml}	-	damping force in the middle left
F_{dmr}	-	damping force in the middle right
F_{drl}	-	damping force in the rear left
F_{drr}	-	damping force in the rear right
K_{sfl}	-	spring constant in the front left
K_{sfr}	-	spring constant in the front right
K_{sml}	-	spring constant in the middle left
K_{smr}	-	spring constant in the middle right
K_{srl}	-	spring constant in the rear left
K_{srr}	-	spring constant in the rear right
C_{sfl}	-	damping constant in the front left
C_{sfr}	-	damping constant in the front right
C_{sml}	-	damping constant in the middle left
C_{smr}	-	damping constant in the middle right
C_{srl}	-	damping constant in the rear left
C_{srr}	-	damping constant in the rear right
F_{tfl}	-	tyre force in the front left
F_{tfr}	-	tyre force in the front right
F_{tml}	-	tyre force in the middle left
F_{tmr}	-	tyre force in the middle right

F_{trl}	-	tyre force in the rear left
F_{trr}	-	tyre force in the rear right
K_{tfl}	-	tyre constant in the front left
K_{tfr}	-	tyre constant in the front right
K_{tml}	-	tyre constant in the middle left
K_{tmr}	-	tyre constant in the middle right
K_{trl}	-	tyre constant in the rear left
$_{trr}$	-	tyre constant in the rear right
$\ddot{Z}_{s1}$	-	acceleration of the truck sprung mass at CG
$\ddot{Z}_{s1}$	-	acceleration of the truck sprung mass at CG
$\ddot{\theta}_{pitch1}$	-	pitch acceleration for the truck at the CG
$\ddot{\theta}_{pitch2}$	-	pitch acceleration for the trailer at the CG
$\ddot{\phi}_{roll1}$	-	roll acceleration for the truck at the CG
$\ddot{\phi}_{roll2}$	-	roll acceleration for the trailer at the CG
$\ddot{x}$	-	longitudinal acceleration
v_x	-	longitudinal velocity
x	-	displacement in longitudinal direction
$\ddot{y}$	-	lateral acceleration
v_y	-	lateral velocity
y	-	displacement in lateral direction
$\ddot{\delta}$	-	steering angular acceleration
$\dot{\delta}$	-	steering angular velocity
F_{xh}	-	longitudinal force acting on hitch
F_{yh}	-	lateral force acting on hitch
$\mathcal{E}_o$	-	magnitude of the output response