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CENTER OF GRAVITY POSITION ESTIMATION OF COUNTERBALANCED FORKLIFT TRUCK BASED ON MULTI MODEL DATA FUSION

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ABSTRACT–The center of gravity of a forklift truck, a crucial parameter for vehicle stability, changes with different loads during operation. We propose an estimation algorithm for the center of gravity position suitable for a counterbalanced forklift truck. By installing sensors on the fork, we use an inclinable platform and propose a static joint center of gravity measurement method. For straight-line driving, we establish a longitudinal dynamics model and propose a nonlinear H_∞ estimation algorithm. For steering conditions, we establish a roll dynamics model and propose a forgetting factor recursive least square estimation algorithm. A data fusion algorithm for the forklift truck's center of gravity position under various working conditions is proposed. The fusion of these estimation results yields the best estimated center of gravity height. We validate the algorithm's effectiveness using a hardware-in-the-loop simulation platform under different working conditions. The experiments demonstrate the algorithm's fast parameter fitting, wide applicability, and accurate position control within a 5 % error range.

KEY WORDS : Counterbalanced forklift truck, Center of gravity, Parameter estimation, Multi model data fusion

1. INTRODUCTION

1.1. Background

Counterbalanced forklift trucks, as a type of engineering machinery used in logistics assembly, are widely utilized in various sectors of the national economy, including ports, stations, airports, freight yards, factory workshops, warehouses, transportation centers, and distribution centers. They play a crucial role in key logistics distribution areas worldwide. With the development of the global economy, the demand for forklift trucks is gradually increasing, which in turn boosts the sales of forklift trucks. According to data, from 2011 to 2021, the global forklift sales continued to increase. In 2020, amidst the serious impact of the global epidemic on the world logistics industry, forklift truck sales continued to increase by 5.98 % year on year, reaching 1.58 million. In 2021, as the global epidemic was brought under control, the demand for forklift trucks was stimulated by the large-scale resumption of work and infrastructure projects. The total sales reached 1.97 million, showing a year-on-year increase of 24.93 % (Jie, 2022). While the functionality of forklift trucks draws people's attention, the safety requirements for forklift trucks are also increasing.

With the development of automobile electronics, an increasing number of active safety systems are being applied to counterbalanced forklift trucks to prevent accidents. However, the stability and reliability of the active safety systems of forklift trucks are not only determined by the robustness of the control algorithm, but also by the accurate acquisition of parameters. Vehicle parameters determine the intervention time and control input of the active safety control system, which are of great importance for ensuring safety without the driver's intervention (Piyabongkarn *et al*., 2008). Unlike traditional vehicles and other engineering machines, a forklift truck operates in a complex working environment where the position of its center of gravity can vary significantly. It is prone to losing vertical and horizontal stability and even rolling over, especially when performing high-speed steering maneuvers and lifting loads aloft. Therefore, research on the active safety control system of forklift trucks primarily focuses on anti-rollover control measures worldwide. The position of the center of gravity is an important parameter in the current major indexes of estimating the danger of rollover, such as lateral load transfer rate (LTR) (Stone and Cebon, 2010; Larish *et al*., 2013) and rollover index (RI) (Yoon *et al*., 2007; Phanomchoeng and Rajamani, 2012). Inaccurate

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