UNIVERSITI TEKNOLOGI MARA

RADAR - ACOUSTIC VEHICLE CLASSIFICATION SYSTEM BASED ON SHALLOW CONVOLUTIONAL NEURAL NETWORK

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ABSTRACT

Rapid urbanisation and growing traffic volumes have intensified the demand for efficient vehicle classification (VC) systems in Intelligent Transportation Systems (ITS). Traditional unimodal approaches, such as loop detectors or cameras, often fail under adverse conditions, limiting accuracy. Previous works relied mostly on single-modality sensors, which required complex algorithms to mitigate noise and cluttered environments. Many also adopted standard machine learning with hand-crafted features, which are difficult to design and sub-optimal. Moreover, limited research has validated multimodal frameworks such as dual-channel CNNs with real-world data.

This study addresses these challenges by developing a multimodal shallow Convolutional Neural Network (SCNN) that integrates radar and acoustic sensors, exploiting their complementary strengths. Radar offers robustness in varying weather and lighting conditions, while acoustic sensors capture distinctive vehicle sound signatures from any angle. The objectives of this research are threefold: (i) to develop a dual-channel VC framework using radar and acoustic modalities, (ii) to design a dual-channel shallow CNN for efficient vehicle classification, and (iii) to validate the model using real-world traffic data. Experimental evaluation explored variations in time window lengths, spectrogram sizes, fusion stages, and operators. The proposed multimodal SCNN achieved a maximum classification accuracy of 96.7% with a 1-second time window, 128x 128 spectrogram, and late-fusion concatenation. In contrast, unimodal models achieved 89.4% (radar-only) and 91.2% (acoustic-only), confirming the benefit of multimodal fusion. Decision-level fusion consistently outperformed pixel-level fusion, with concatenation superior to summation. Compared with prior studies, which typically reported accuracies of 90-94% using unimodal sensors and conventional ML or deeper CNNs, the proposed approach not only achieved higher accuracy but also reduced computational complexity due to its shallow design. This shows that lightweight multimodal fusion networks can match or surpass state-of-the-art methods without the heavy resource demands of deeper models. The key contributions of this research are: (i) the design of a novel dual-channel shallow CNN for radar-acoustic vehicle classification, (ii) empirical validation of multimodal fusion for improved robustness and accuracy, and (iii) demonstration of superior performance relative to existing works using real-world data. Overall, this study delivers a reliable, precise, and efficient framework for next-generation ITS, enabling cost-effective, real-time vehicle classification for smarter urban traffic management.

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TABLE OF CONTENTS

CHAPTER 1
INTRODUCTION

1.1 Research Background

Rapid urbanisation in Malaysia has led to a significant increase in the number of vehicles, surpassing roadway capacities and causing severe traffic congestion [1]. The consequences of congestion include longer travel times, higher fuel consumption, increased carbon emissions, and reduced productivity. Traditional solutions, such as widening roads or constructing new infrastructure, are often expensive, disruptive, and limited by available space, making them unsustainable in the long term. Intelligent Transportation Systems (ITS) offer a more feasible and sustainable solution by integrating advanced technologies, including communication networks, information systems, and satellite positioning, to optimise traffic flow, enhance safety, and support environmental sustainability [2]. Real-time data and automated systems allow ITS to manage traffic more effectively, reduce congestion, and improve response to incidents. By lowering vehicle idle times and improving overall traffic efficiency, ITS also contributes to reduced fuel consumption and emissions, aligning with global sustainability goals [3]. As urban populations grow, ITS becomes increasingly essential for creating efficient, safe, and adaptable transportation systems.

A critical component of ITS is an effective traffic monitoring system, in which vehicle classification (VC) plays a central role. VC collects vital traffic data, including vehicle count, type, and speed, and supports applications such as congestion prediction, infrastructure planning, and traffic management optimization [8]. Despite its importance, existing VC technologies face significant limitations. Loop detectors rely on magnetic signals that fluctuate with vehicle type and speed, often resulting in misclassifications, especially for small vehicles and motorcycles [11]. Radar sensors alone, while effective in detecting vehicle speed and distance. It face challenges in accurately classifying vehicle types due to their limited ability to differentiate between vehicles of similar sizes and speeds, , especially in complicated traffic settings or when the vehicles occlude with other vehicles [8]. These constraints make it challenging to achieve accurate, real-time vehicle classification in complex traffic conditions, limiting