


Interuniversity Department of Regional and Urban Studies and Planning

Doctoral Dissertation Abstract
Doctoral Program in Urban and Regional Development (36th Cycle)

ICT in Public Transport: Exploring the Potential of IoT and Machine Learning in the context of Automatic Passenger Counting Systems.

Investigating the implementation hurdles and exploring the potential of ICT-driven APC systems for low-cost demand estimation in the transport sector.

By
Deepan Anbarasan

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Supervisor:
Prof. Cristina Pronello

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ABSTRACT

The Fourth Industrial Revolution (4IR) has catalysed transformative changes across multiple sectors, with the transport industry being significantly affected through advances in digitalisation and automation. This era, characterised by robust Machine-to-Machine (M2M) and Internet-of-Things (IoT) integration, presents novel opportunities and challenges, particularly in the realm of public transport. Despite the rapid advancements in this field, the full spectrum of its impacts, especially in the transport sector, remains partly unexplored (Liao et al., 2018). This thesis aims to evaluate the impact of these technological advancements, specifically through the lens of Automatic Passenger Counting (APC) systems in public transport.

The objective of this study is to investigate the integration and efficacy of Information and Communication Technology (ICT) in enhancing APC systems within public transport service. Emphasis is placed on using Wi-Fi probe requests as a cost-effective method for counting passengers, a key metric for optimising service delivery. The potential of modern data processing and analysis techniques in improving the accuracy of passenger counting of such a system is also investigated. Additionally, the thesis examines the challenges and obstacles hindering the widespread adoption of Wi-Fi probe request-based passenger counting systems.

The methodology employed is comprehensive and multidimensional, integrating both qualitative and quantitative research techniques. It starts with an extensive literature review of existing and past APC technologies, examining their evolution, effectiveness, and areas needing enhancement. Field studies and surveys are conducted in various urban environments including aboard buses in a small city and a larger city and at a bus stop in a large city to collect real-world data on the performance of Wi-Fi-based APC systems. High quality ground truth data along with qualitative data about surroundings are also collected during these exercises to validate the tested system. Additionally, complementary datasets are collected to examine the influence of Points of Interest (POI) density, categorized by type, on passenger count. Statistical tools are employed to evaluate factors affecting APC system performance, identifying patterns and error rates to enhance understanding of the technical and environmental influences on system accuracy and reliability. Advanced data analytics, including machine learning (ML) and deep learning (DL), are applied to process the collected data and improve the accuracy of the APC system. Further analysis identifies the factors influencing the selection of filters that enhance accuracy and determines derived variables that could facilitate the dynamic adjustment of these filters.

The findings demonstrate that Wi-Fi-based Automatic Passenger Counting (APC) systems offer a cost-effective alternative, particularly when compared to the high expenses of traditional methods as discussed in the paper on benchmarking APC systems (Pronello et al., 2024). The study also finds that there are also challenges that need to be overcome to make the system commercially viable, especially in the context of MAC address randomisation. The research identifies several factors influencing the accuracy of these systems, including the number of passengers aboard – high passenger count can lead to body-blockage – and the application of effective RSSI filters to mitigate external signal interference. Notably, the research challenges the assumption that external factors such as pedestrian traffic significantly impact counting accuracy. Furthermore, some new derived factors that could assist in setting effective RSSI filters for different crowding levels were identified. Moreover, the deployment of ML and DL algorithms has shown potential in enhancing system performance, increasing accuracy from 69.33% to 78.28% in a survey involving data collected in the field for more than 40 days. The improvement in accuracy was also observed in correlation with pearson correlation increasing from 0.27 to 0.73 after using a ML model.

This thesis highlights the practicality of Wi-Fi-based Automatic Passenger Counting (APC) systems in public transport, showing that they can achieve reasonable accuracy in real-world scenarios, not merely under ideal laboratory conditions. Nonetheless, the research identifies crucial areas for further

investigation, particularly the challenges introduced by MAC address randomisation and the physical obstruction of Wi-Fi signals by human bodies. It suggests pathways for future enhancements, including the use of derived variables for dynamic RSSI filter adjustments, recommendations for the optimal number of sensors in a standard-sized bus, and potential improvements in accuracy through specific algorithmic and architectural configurations in data analysis methods.

Future studies should aim to refine data collection techniques, extend the duration of data collection, and explore the integration of machine learning and deep learning models that are specifically tailored to the unique characteristics of both the raw dataset and its derived features. The insights from this study lay a solid foundation for future research and development that guide the design and implementation of more accurate and reliable automatic passenger counting systems, setting the base for the development of more reliable and efficient public transport systems.