FRAMEWORK FOR PEDESTRIAN WALKING BEHAVIOUR RECOGNITION TO MINIMIZE ROAD ACCIDENT

ZAHRAA HASHIM KAREEM

UNIVERSITI TUN HUSSEIN ONN MALAYSIA

UNIVERSITI TUN HUSSEIN ONN MALAYSIA

STATUS CONFIRMATION FOR THESIS
DOCTOR OF PHILOSOPHY

FRAMEWORK FOR PEDESTRIAN WALKING BEHAVIOUR RECOGNITION TO MINIMIZE ROAD ACCIDENT

ACADEMIC SESSION: 2020/2021

I, **ZAHRAA HASHIM KAREEM**, agree to allow this Thesis to be kept at the Library under the following terms:

1. This Thesis is the property of the Universiti Tun Hussein Onn Malaysia.
2. The library has the right to make copies for educational purposes only.
3. The library is allowed to make copies of this Thesis for educational exchange between higher educational institutions.
4. The library is allowed to make available full text access of the digital copy via the internet by Universiti Tun Hussein Onn Malaysia in downloadable format provided that the Thesis is not subject to an embargo. Should an embargo be in place, the digital copy will only be made available as set out above once the embargo has expired.
5. ** Please Mark (√)

☐ CONFIDENTIAL (Contains information of high security or of great importance to Malaysia as STIPULATED under the OFFICIAL SECRET ACT 1972) *Title and Abstract only*

☐ RESTRICTED (Contains restricted information as determined by the Organization/institution where research was conducted) *Title, Abstract and Introduction only*

☐ EMBARGO _____ (date) until _____ (date)

☑ FREE ACCESS

Approved by,

(WRITER'S SIGNATURE)
ZAHRAA HASHIM KAREEM

(SUPERVISOR'S SIGNATURE)
ASSOC. PROF. DR. KHAIRUN NIDZAM BIN RAMLI

Permanent Address:

BABYLON RESORT STREET,
HILLAH, BABIL, IRAQ

Date : 20/2/2021 Date: 20/2/2021

NOTE:

** If this Thesis is classified as CONFIDENTIAL or RESTRICTED, please attach the letter from the relevant authority/organization stating reasons and duration for such classifications.

This thesis has been examined on date 11 February 2021
and is sufficient in fulfilling the scope and quality for the purpose of awarding the Degree of Doctor of Philosophy in Electrical Engineering.

Chairperson:

ASSOC. PROF. DR. NOORSALIZA BINTI ABDULLAH
Faculty of Electrical and Electronic Engineering
Universiti Tun Hussein Onn Malaysia

Assistant Chairperson:

DR. YEE SEE KHEE
Faculty of Electrical and Electronic Engineering
Universiti Tun Hussein Onn Malaysia

Examiners:

PROF. DR. AISHA HASSAN ABDALLA HASHIM
Department of Electrical and Computer Engineering
Kulliyyah of Engineering
International Islamic University Malaysia

PROF. DR. JIWA BIN ABDULLAH
Department of Electronic Engineering
Faculty of Electrical and Electronic Engineering
Universiti Tun Hussein Onn Malaysia

FRAMEWORK FOR PEDESTRIAN WALKING BEHAVIOUR RECOGNITION TO MINIMIZE ROAD ACCIDENT

ZAHRAA HASHIM KAREEM

A thesis submitted in
fulfilment of the requirement for the award of the
Doctor of Philosophy in Electrical Engineering

Faculty of Electrical and Electronic Engineering
Universiti Tun Hussein Onn Malaysia

MARCH 2021

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged

Student : .....
ZAHRAA HASHIM KAREEM

Date : .....20/2/2021.....

Supervisor : .....
ASSOC. PROF. DR. KHAIRUN NIDZAM BIN RAMLI

I dedicate this PhD thesis to my beloved mother Mrs. NAAHIDA whose dreams for me have resulted in this achievement and without her loving upbringing and nurturing. I would not have been where I am today and what I am today. This one is for you mum.

ACKNOWLEDGEMENT

First and foremost, I would like to thank God Almighty for giving me the strength, knowledge, ability and opportunity to undertake this research study and to complete it satisfactorily. My gratitude goes to my supervisor in person of **ASSOC. PROF. DR. KHAIRUN NIDZAM BIN RAMLI**, for his patience, kindness, guidance and advice throughout the research. In my journey towards this degree, I have found a teacher, a friend, an inspiration, a role model and a pillar of support in my guide, **DR. BILAL BAHA ZAIDAN**. He has been there providing his heartfelt support and guidance at all times and has given me invaluable guidance, inspiration and suggestions in my quest for knowledge. Without his able guidance, this thesis would not have been possible and I shall eternally be grateful to him for his assistance. I would also like to express my gratitude to my wonderful friends. Without their contribution, this work would have taken much longer time to be accomplished. My warmest appreciation to my beloved parents who support me with their love. My heart overflows with gratitude for my parents My father **HASHIM**, my brothers **ALAA, NOORALDEEN**, and, **ZAINALABDEEN** my sisters **BARAA** and **EILAFF.** A special appreciation goes to my beloved husband **RAMI** and our son **ARAM** for being in my life and standing with me through this journey. Your matchless love, encouragement, and support had impressively contributed towards the realisation of this achievement.

ABSTRACT

Pedestrian walking misbehaviour represents a severe problem to road safety. Therefore, pedestrian behaviour classification is a perfect solution in providing safety for both pedestrians and vehicles by exchanging movement information among entities via wireless communication. However, wireless communication has critical issues with network failure, and these issues significantly affect the communication system. Thus, the framework involved two modules for pedestrian walking behaviour classification in a vehicle-to-pedestrian (V2P) context is proposed. In the methodology, this study discloses five useful stages. Firstly, mobile phone users' irregular walking behaviour is investigated using a questionnaire to determine their options on mobile usage in the street. Secondly, four different testing scenarios are chosen to acquire pedestrian walking data using the gyroscope sensor, where the essential features were extracted and selected. Thirdly, the pedestrian's behaviour is recognized using grid optimizer in machine learning. Fourthly, four standard vectors for pedestrian walking behaviour are developed. Fifthly, the performance of the proposed classification methods is validated and evaluated against multiple scenarios and features. Two sets of real-time data are presented in this work. The first one is related to the questionnaire data, consisting of 262 respondent samples, while the second set has 263 samples of pedestrian walking signals. The results indicate the following: (1) From 262 samples, 66.80% and 48.10% of respondents use mobile phones for calling and chatting, respectively. (2) 263 samples of participants are obtained and analysed, and 90 features are extracted from each sample. (3) 100% classification accuracy are obtained for each class (normal walking, calling, chatting, and running) using the grid optimiser method in machine learning. (4) The precision of classification using Euclidean algorithm for normal walking and calling is 70%. In contrast, for chatting and running behaviour, the accuracy is 100% and 80%, respectively. This study's implication serves the safety system in the V2P context by programming the proposed framework as an application in smartphones for exchanging pedestrian information to the vehicles for avoiding accidents.

ABSTRAK

Salah laku berjalan bagi pejalan kaki merupakan masalah serius terhadap keselamatan jalan raya. Oleh itu, klasifikasi tingkah laku pejalan kaki adalah penyelesaian yang sempurna untuk memberikan keselamatan bagi pejalan kaki dan kenderaan dengan bertukar maklumat pergerakan di antara entiti melalui komunikasi wayarles. Walau bagaimanapun, komunikasi wayarles mempunyai masalah kritikal yang berkaitan dengan kegagalan rangkaian dan masalah ini memberi kesan yang besar pada sistem komunikasi. Oleh itu, dua model untuk pengkelasan tingkah laku berjalan bagi pejalan kaki dalam konteks Kenderaan-ke-Pejalan kaki (V2P) dicadangkan. Dalam metodologi, kajian ini mendedahkan lima peringkat. Pertama, tingkah laku berjalan yang tidak teratur bagi pengguna telefon bimbit disiasat melalui borang soal selidik untuk mengetahui pilihan mereka mengenai penggunaan telefon bimbit di jalan. Kedua, empat senario ujian yang berbeza dipilih untuk memperoleh data berjalan bagi pejalan kaki menggunakan penderia giroskop. Ketiga, tingkah laku berjalan bagi pejalan kaki diiktiraf menggunakan pengoptimum grid dalam pembelajaran mesin. Keempat, empat vektor piawai untuk tingkah laku berjalan bagi pejalan kaki dikembangkan. Kelima, prestasi kaedah klasifikasi yang dicadangkan dinilai dan diuji terhadap pelbagai senario dan ciri. Dua set data masa nyata disertakan dalam kajian ini. Kumpulan pertama berkaitan dengan data soal selidik mempunyai 262 sampel responden dan kumpulan kedua adalah 263 sampel isyarat berjalan bagi pejalan kaki. Hasil menunjukkan perkara berikut: (1) Dari 262 sampel, 66.80% dan 48.10% responden menggunakan telefon bimbit masing-masing untuk memanggil dan berbual. (2) 263 sampel untuk peserta diperoleh dan dianalisis, dan 90 ciri telah diekstrak dari setiap sampel. (3) 100% dikelaskan dengan betul untuk setiap kelas (berjalan normal, memanggil, berbual, dan berlari) menggunakan kaedah pengoptimum grid dalam pembelajaran mesin. (4) Ketepatan klasifikasi menggunakan algoritma Euclidean bagi berjalan biasa dan memanggil adalah 70%. Sebaliknya, bagi tingkah laku berbual dan berlari, ketepatannya adalah masing-masing 100% dan 80%. Implikasi kajian ini menyumbang kepada sistem keselamatan dalam konteks V2P dengan memprogram

kerangka yang dicadangkan sebagai aplikasi di telefon pintar bagi pertukaran maklumat pejalan kaki kepada kenderaan untuk mengelakkan kemalangan.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ADAS	–	Advanced Driver Assistance Systems
ADCs	–	Application-Level Dissemination Channels
AGVs	–	Automated Guided Vehicles
ATM	–	Active Transportation Management
BS	–	Base Station
CS-MAS	–	Cooperative Surveillance Multi-Agent System
DSRC	–	Dedicated Short-Range Communication
DTN	–	Delay Tolerant Network
D2D	–	Device-to-Device
GIS	–	Geographic Information System
ICN	–	Information-Centric Network
ITS	–	Intelligent Transportation System
ITSp	–	Intelligent Transportation Space
JPDA	–	Joint Probabilistic Data Association
LAN	–	Local Area Network
MTT	–	Multiple Target Tracking
OGC	–	Open Geospatial Consortium
PDR	–	Pedestrian Dead Reckoning
RSU	–	Road Side Unit
RTD	–	Road Traffic Domain
SAMCO	–	Service-Actuated Multi-Channel Operation
SFSO	–	Social Force Swarm Optimisation
SNN	–	Spiking Neural Network
UWB	–	Ultra-Wideband
VANETs	–	Vehicular Ad-Hoc Networks
V2P	–	Vehicle-to-Pedestrian
VRUs	–	Vulnerable Road Users

V2X – Vehicle-to-Anything

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background of the study

This chapter introduces the research topic, a brief background about the research, the problem statement, research questions, research objectives, and this research's scope. In section 1.1, a brief background of the research components is presented, while in section 1.2, the problem statement of the research's direction has been identified and introduced. In section 1.3, the research objectives. Whilst in section 1.4, the connections among research objectives, questions, and problems. The study's scope are reported in section 1.5. Finally, the thesis outline is briefly documented in section 1.6.

The increasing number of vehicles has led to a considerable increase in traffic accidents and health damage [1]. The management of road traffic accidents is a highly complex and sensitive issue. At present, the lack of technological solutions to reduce the number of accidents of this collective is clear, and those available are expensive, intrusive, complex, and require external power sources, devices, computers, or interfaces [2]. Given the issues raised by the impact of road traffic on climate, urban traffic management systems must evolve towards an improved consideration of non-pollutant modes of transport driver, passenger, and pedestrian safety. This is a significant challenge in the automotive industry and the governments in many countries. The increasing number of accidents on the road is a primary reason for taking safety very seriously. Vehicle-to-anything (V2X) communication refers to the information exchange between a vehicle and various elements of an intelligent transportation system, including other vehicles, pedestrians, internet gateways, and transport infrastructure (e.g., traffic lights and signs). This technology has considerable

potential in enabling various novel applications for road safety, passenger infotainment, car manufacturing services, and vehicle traffic optimisation [1] (see Figure 1.1).

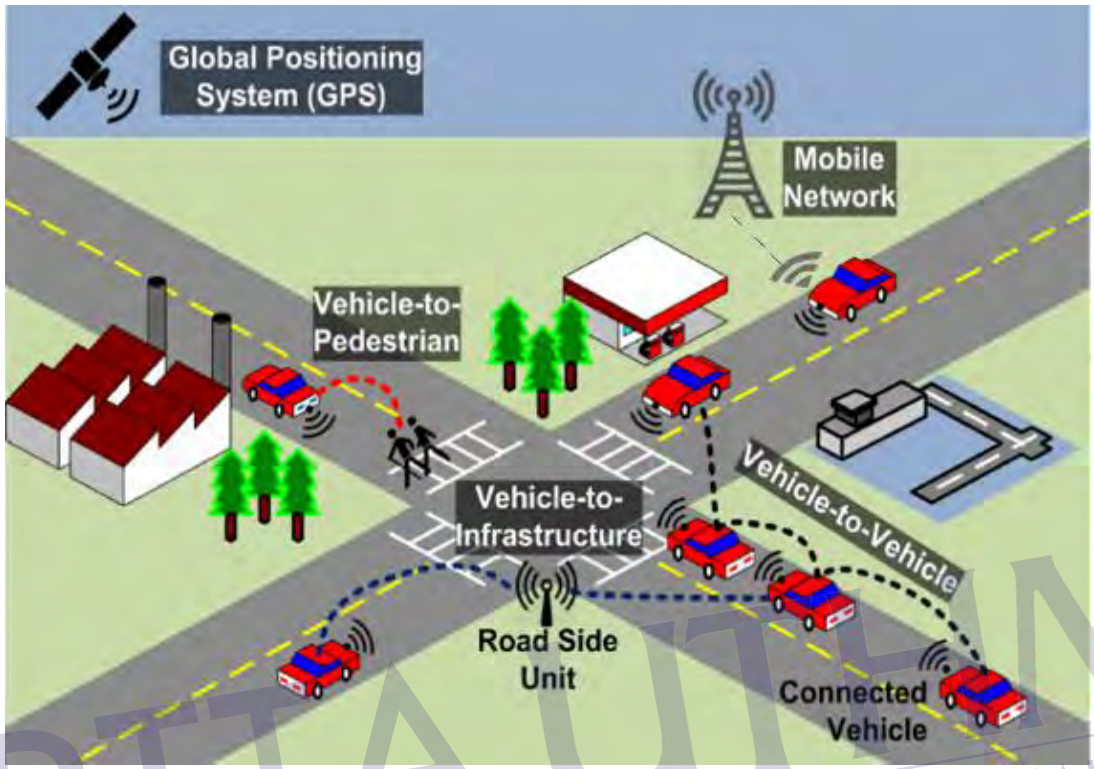

Figure 1.1: V2X communication types

In urban areas of evolving countries, such as India, the range of pedestrian fatalities is between 40% and 60% of the total road traffic fatalities [3, 4]. Also, in Russia, about 170,000 road traffic accidents occurred, according to the statistics of road traffic accidents in 2017 [5]. This is three to four times more than in Europe. For the annual period, pedestrians contributed to 53,000 road traffic accidents, and misbehaviour was reported in about 20,000 cases were found. One in three pedestrians gets injured, while one in six dies hit by a car on pedestrian crossings [5]. Recently, vehicle-to-pedestrian safety applications using wireless communication to exchanging data amongst vehicle and pedestrian was introduced, such as the developed application V2ProVu [6]. It is used for vehicle on-board to suppress Wi-Fi communication, hazard alarm, and risk calculation. The vehicle-to-pedestrian application directly communicates without using infrastructures or vehicular ad-hoc networks (VANETs) [3]. Pedestrians use a smartphone to establish communication either by Wi-Fi network or communicate to the cloud via cellular network (e.g., 3G, LTE). On the other hand,

vehicles utilise either a cellular module (with a dedicated SIM-card) or the driver's smartphone.

The benefits of the vehicular communication system can fall in the domain of vehicular ad-hoc networks (VANETs) and intelligent transport systems (ITS) to improve road safety through real-time communication between vehicles with each other and between pedestrians and vehicles [7]. This is accomplished by periodic exchange of information between the vehicles, known as beaconing. Here, information from the vehicle, such as position, speed, and acceleration, is exchanged so that the cars can create a map of the surrounding vehicles [8]. Safety information in VANETs is precisely associated with time and the geographical area where the information transfer occurs [1]. Car technology has clearly improved since cars were first produced, where safety and accident avoidance is the primary trend of future vehicle development. Pedestrian safety is a severe problem in transportation systems because pedestrian and vehicle crashes often, resulting in fatalities amongst vulnerable road users. A vehicle-to-pedestrian (V2P) communication system allows data exchange between pedestrians and vehicles to prevent or minimise the potential dangers of accidents from happening. The human error in recognition and judgment or the inability of road users to detect and perceive oncoming threats and pedestrians' misbehaviour in the street represents the main reason for accidents [2]**.** Information transfer between pedestrians and vehicles to detect pedestrians and predict the possibility of collisions is a challenging task since pedestrian tracking and detection are more complicated than that for moving rigid bodies [8].

Therefore, the effective measure to prevent accidents is by making each driver notice risky pedestrian behaviour and correctly recognise the related risks. This is done by informing the driver about the pedestrian's existence in the street and warning him of the pedestrian's behaviour. In the future, safety distance measurement and alarm systems will be the basic equipment in vehicles, although only some vehicles are equipped with this system. Warning systems are exclusively provided in modern luxury cars because such systems are too expensive. However, most of these approaches are intended to develop and represent pedestrian safety, traffic accident avoidance, and a warning system. Therefore, vehicle-to-pedestrian (V2P) communication is needed to enable wireless exchanges of various safety and operational messages through a combination of cellular infrastructure and direct Wi-

Fi communication between vehicles and pedestrians. Vehicles can receive real-time alerts from pedestrians regarding the risky situation.

1.2 Problem statement

An accident is an unexpected event. As the number of vehicles increases, the number of accidents on the road increases, which increases pedestrians' fatality number. The popular reasons for these accidents are dangerous driving, inattention, wrong behaviour, and human error of pedestrians and vehicles that can negatively impact their safety. Therefore, pedestrian fatality is the primary safety concern worldwide, and it is the primary reason for taking safety very seriously. According to [6, 9], the leading cause of accidents is pedestrian misbehaviour and inattention while walking in the street. Walking is an essential and least protected mode of road transport.

Moreover, some pedestrians use smartphones when they walk, especially after the fast development of smartphone-based applications, such as social media applications that extensively dominate smartphone usage. This is one of the reasons for pedestrian distraction. It was noticed that pedestrians who watch or stare at smartphone screens while walking on the street face more danger than other pedestrians [10]. Besides, some pedestrian movements during specific activities, such as running, are considered a more risky behaviour [11].

Consequently, pedestrians who use a smartphone while walking in the street and pedestrians who are running are called pedestrians with aggressive behaviours. Therefore, it is necessary to study and develop different technologies to fill the missing gap towards analysing pedestrian walking behaviour. This is to recognise the behaviour, whether it is aggressive or non-aggressive, and realise pedestrian safety. This kind of pedestrian behaviour recognition can be converted into a classification problem, which is considered the pedestrian's safety system's main issue. The classification process needs to collect real time data of pedestrian walking and analyse it to extract the important features that through which the behaviour can be distinguished. Also, choosing the optimal classification algorithm to deal with this data represent a difficult task which depends on where the classification will be done. Since the classification process may be done inside the server or using mobile phone, there

are some issues should be taken in to consideration which are related with mobile resources limitations and the network failure, the problem statement configuration is illustrated in Figure 1.2.

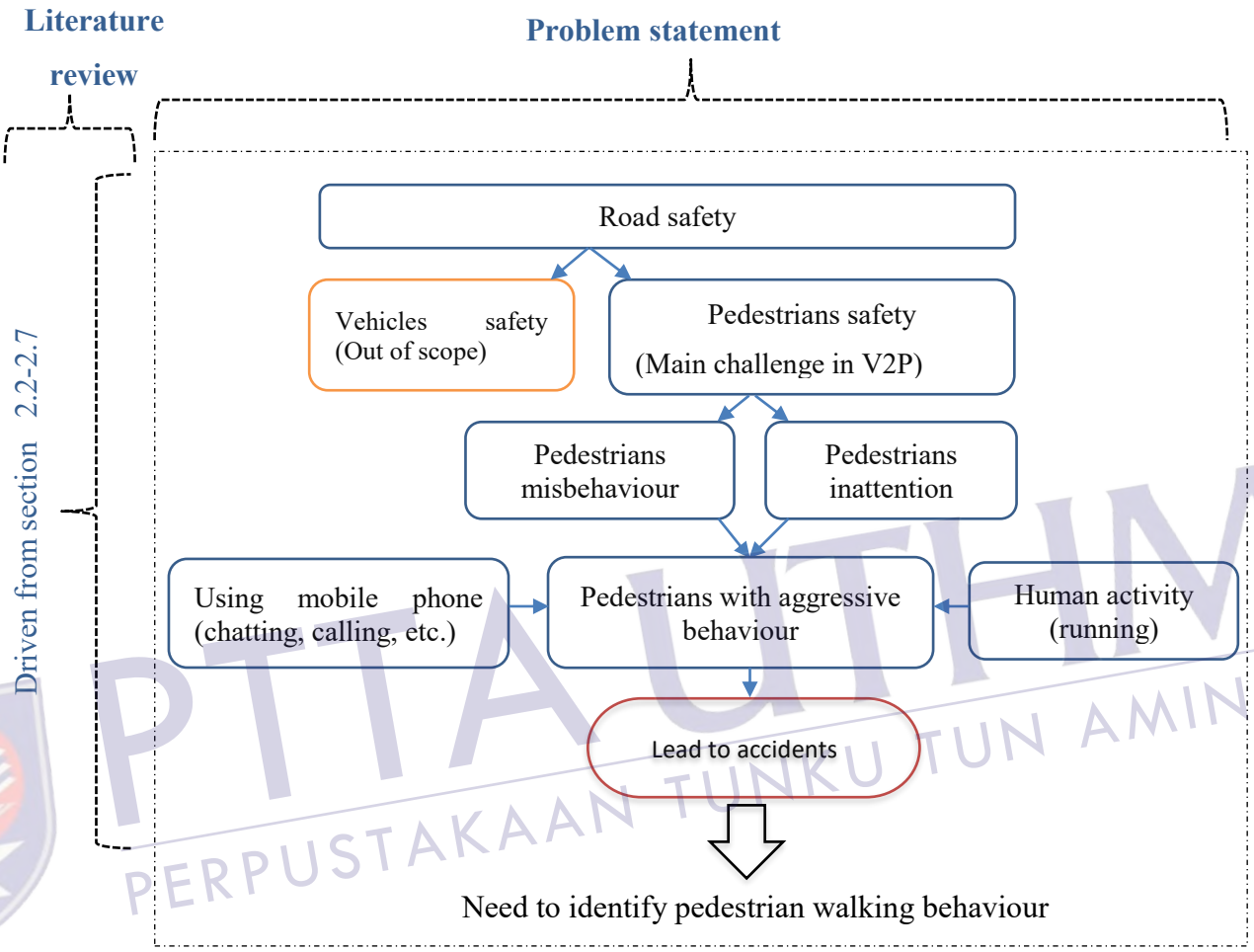

Figure 1.2: Problem statement flow chart

1.3 Objectives

This research aimed to develop a pedestrian walking behaviour classification method using static analysis and multi-classifiers in machine learning. Two main investigations are done, namely on the data exchange in the vehicle-to-pedestrian communication system using systematic review protocol and questionnaire in mobile phone usage. The main research objectives of this research are given as follows:

a) To investigate the existence of technology for pedestrian safety in vehicle-to-pedestrian communication system and identify the irregular pedestrian walking behaviour.
b) To devolve a real time pedestrian walking dataset, feature extraction, and feature selection.
c) To design a classification module for recognising pedestrian walking as aggressive and non-aggressive using machine learning in a client-server architecture.
d) To develop a fault-tolerant pedestrian walking behaviour classification module using the training dataset and Euclidian distance measurement.
e) To evaluate and validate the performance of the classification methods developed in objectives three and four against multiple scenarios and features.

1.4 Connections among research objectives, questions, and problems

In this section, all research questions have been answered by the research objectives. Each objective is linked to one or more questions. Moreover, the specific and general problem is linked to more than one research objectives and questions. Table 1.1 presents the connection between research objectives, research questions, the specific problem, and the general problem.

Table 1.1 : Connections among research objectives, questions and problems

Research objectives	Research questions	Specific problem	General problem
To investigate the existence of technology for pedestrian safety in a vehicle-to-pedestrian communication system and identify irregular pedestrian walking behaviour .	What are trends are covered in the vehicle-to-pedestrian context? What are the challenges identified in the literature with the scope of pedestrian safety? What are the requirements needed to construct PWBR framework? How to prove that mobile phone users are deemed as one of the aggressive pedestrian in the street?	Behaviour identification	The Pedestrian walking behaviour classification problem

To devolve a real-time pedestrian walking dataset, feature extraction, and feature selection.	How to collect a real-time data on pedestrian walking? How to analyse pedestrian walking data in V2P system and extract their features?	Feature extraction and feature selection
To design a classification module for recognising pedestrian walking as aggressive and non-aggressive using machine learning in a client-server architecture.	How to classify the behaviour of pedestrian walking?	Server failure
To develop fault-tolerant pedestrian walking behaviour classification module using the training dataset and Euclidian distance measurement.	How to classify the behaviour of pedestrian walking when server failure occurs?	Reduce the mobile phone overhead, Identify the best machine learning algorithm, Identify the best feature.
To evaluate and validate the performance of the classification methods developed in objective three and four against multiple scenarios and features.	How to evaluate and validate the classification methods?	Optimise parameters for both solutions Result. evaluation and validation

Table 1.1 shows that the first objective answers the first four research questions, while the second objective answers the fifth and sixth research questions. Moreover, the third objective answers the seventh research question, while the fourth objective answers the eighth question. The last objective answers the ninth research question. Moreover, one specific problem in recognising pedestrian walking behaviour when server failure or network congestion is linked to one research objective and research question.

Finally, this research's general problem on pedestrian walking behaviour recognition is linked to four research objectives and research questions. Table 1.2 shows the proportional abbreviations and definitions that is used in the whole thesis.

Table 1.2: Proportional abbreviation and definition

Abbreviation	Description
PWB	Pedestrian walking behaviour
PWBR	Pedestrian walking behaviour recognition
Mobile phone – solution	Using a mobile phone solution for pedestrian walking behaviour recognition when the server is unavailable
Client-server	Using the server for pedestrian walking behaviour recognition

1.5 Scope

This study's scope is as follows:

a) The primary focus on this research is on development of vehicle-to-pedestrian communication system. Therefore, the development of vehicle-to-vehicle communication or vehicle-to-infrastructure is not the main issue.
b) The data extracted were used only four scenarios. Therefore, other scenarios (i.e., video calling, using some new application Like tiktok or snapchat, playing video games, etc.) used are not important.
c) Using RapidMiner software for the validation purposes.
d) Use different a specific range of ages, where the ages below 20 and above 55 years old is out of scope.
e) The selected study case will focus on urban roads with different types of scenarios, including using a different number of pedestrian with different situations.

1.6 Outline of the thesis

This thesis consists of six chapters. Chapter one provided background about the vehicle-to-pedestrian communication system evaluation and problem, research questions, and research objectives. In Chapter two, a depth investigation is conducted

for vehicle-to-pedestrian communication system evaluation approaches. A systematic review protocol is developed for literature review to analyse the challenges and develop a taxonomy for the research articles in the vehicle-to-pedestrian communication system. Benefits and methodologies provided by previous researchers are presented, where critical analysis is conducted and developed. Finally, a brief investigation of machine learning algorithms is presented. The research methodology and the flow of the research are designed and reported in Chapter three. In addition to that, the main features to achieve the research objectives are designed. Meanwhile, Chapter four describes the process of data collection. The main challenges, tools used to collect the data, the experiment scenarios, and the data analysis and findings are discussed. Finally, the main features extracted of the pedestrian walking are presented. In Chapter five, the evaluation and validation methods used are discussed. At last, Chapter six presents the research goals attained, contribution, limitation, and conclusion. The areas to be pursued as future works are also suggested in this chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter introduces the academic literature published with the focus on vehicle-to-pedestrian communication. The main contribution of this chapter can be defined in few points; the first is a coherent taxonomy discussion which shows literature distribution over designated categories for vehicle to pedestrian system identified through the literature analysis to show future researchers in the domain how articles are grouped and classified based on common characteristics. As for the next contribution, a literature discussion which shows literature related to vehicle to pedestrian communication system in forms of challenges and motivations where the first shows what previous researchers have encountered and what sort of academic issues they dealt with or recommended for their future peers, as for motivations, it shows how such topic gain the attention of previous researchers for its significance and its merits. Another significant contribution of this manuscript reside in its deep analysis in parts of the taxonomy where authors have stated various elements like datasets to show future researchers what sorts of methodological elements were defined and used in literature and their analysis.

There are different contributions by different researchers in this area of, however cannot be aware of any attempt to make review of the data exchange on V2P system in such manner. Another contribution is to identify pedestrian behaviour and the evaluation and validation criteria such as pedestrian number and age, scenarios, classification type and accuracy. The final contribution is to investigate the academic

literature on the use of machine learning and Euclidean algorithm in the vehicular network with the focus of V2P applications. In Section 2.1, a brief background about the chapter is presented. In Section 2.2 the systematic review protocol and literature analysis are reported. In Section 2.3, results of literature taxonomy are introduced. In Section 2.4, an overview of the taxonomy. In Section 2.5 the discussion is reported. All benefits, issues, recommendations, and methodological aspects related to vehicle-to-pedestrian system are presented in Section, 2.6, 2.7, 2.8, 2.9, respectively. In Section 2.10 and Section 2.11, the critical analysis and the aggressive and non-aggressive pedestrian behaviour are presented, respectively. Moreover, open issues for PWBR are discussed in Section 2.12. In addition the recommended solutions for this research are explained in Section 2.13. And in Section 2.14 the classification methods are presented. Section 2.15 show the literature summary. Whereas, the literature review structure for this chapter was illustrated in Figure 2.1. The details will be explained throughout this chapter.

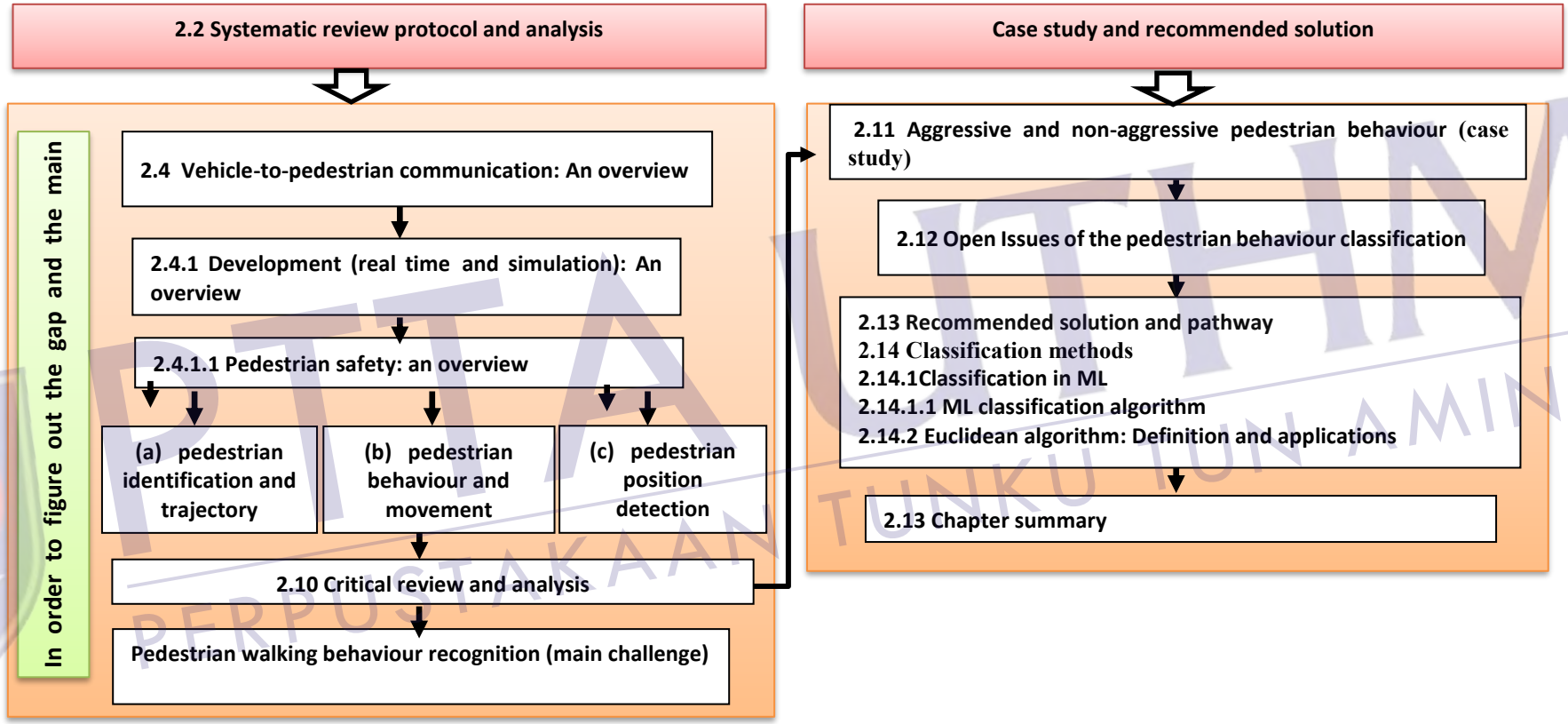

Figure 2.1: Literature review structure

2.2 Systematic review protocol and analysis

Systematic searches for target articles were conducted by subscribing to scholarly research databases: (1) IEEE Explore, (2) Web of Science (WoS) and (3) ScienceDirect. Selection of articles was based on the index that facilitates and formulates a simple and complex search query and specifically tracks journals and conference articles in electronic technologies and electrical engineering. The scope to articles written in English is limited but considered all on data exchange in V2P communication in all scenarios. These three databases sufficiently cover V2P and all communication types in this area and provide a broad view of existing research in a wide and relevant range of disciplines. Study selection involved a search for literature sources and then three iterations of screening and filtering. In the first iteration, all unrelated articles were removed. In the second iteration, duplicates and irrelevant articles were removed by scanning the titles and abstracts. In the last iteration, full-text articles screened from the second iteration were carefully reviewed. All iteration steps applied the same eligibility criteria followed by authors. The search was conducted in January 2020 using the search boxes of ScienceDirect, IEEE Explore and WoS. To identify the studies related to this area query, we used mixed keywords such as 'vehicle-to-pedestrian,' 'V2P,' 'P2V,' 'car to pedestrian' and 'pedestrian' in different variations combined by the operator 'OR,' and 'information exchange,' 'exchanging information,' 'data exchange,' 'exchanging data,' 'data integration' and 'information integration' in different variations combined by the operator 'AND'.

The query text is exactly shown in Figure 2.2. The advanced search options in the search engines were used to exclude book chapters, short communication, correspondence and letters and to gain access to up-to-date scientific works relevant to this survey in this emergent trend of V2P communication. Where the settings used to run the search query was conducted with the last 10 years which include conference, journal and magazine with only English Language Search type. Every article that met the criteria listed in Figure 2.2 was included. an initial target was set for mapping the space of research on data exchange in V2P communication into a general and coarse-grained taxonomy of four categories. These categories were derived from a pre-survey of the literature. After the initial removal of duplicates, the articles were excluded in

two iterations of screening and filtering if they did not fulfil the eligibility criteria. The exclusion criteria included the following: (1) the article was not in English; (2) the article focused on a specific aspect of smart cities and protect the pedestrian from the disaster. The subject that limited to the Vehicles-to-Vehicles (V2V) and Vehicle-to-Infrastructures (V2I).

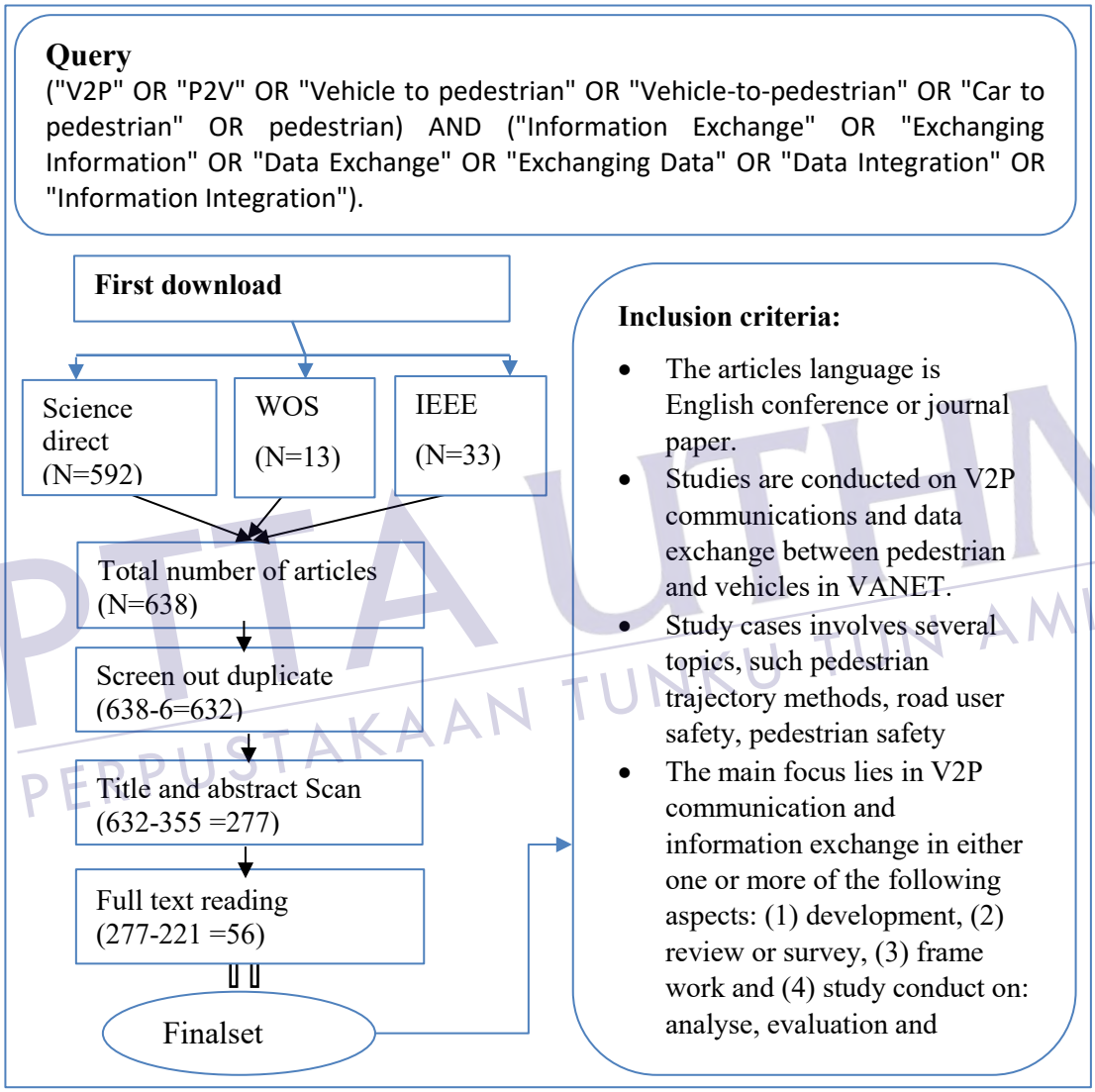

Figure 2.2: Selection of studies, search query and inclusion criteria

The final set of articles is read and analysed. Then, it is classified in detail using the taxonomy and a large collection of highlights and comments. The taxonomy suggested various classes and subclasses, including four main categories: development, survey/review, framework and study conducted on data exchange in V2P communication. Texts were categorised depending on the authors' preferred

style. All the articles from various sources were analysed in depth to provide readers a comprehensive overview of the subject.

2.3 Result of literature taxonomy

The initial query resulted in 638 articles: 13 from the WoS database, 592 from Science Direct, and 33 from IEEE Explore. The filtered articles published from 2008 to 2018 were adopted in the present study and grouped into four categories. In the three databases, 6 out of 638 papers were duplicates. After scanning the titles and abstracts, we excluded 361 papers and obtained a total of 277 papers. The final full-text review excluded 221 papers to obtain a total of 56 papers in the final set, all of which were related to smart-home Internet-of-Things technology through different topics, the effect of natural disasters on pedestrians, V2V and V2I communication. These articles were read methodically to propose a general research map on this emerging area. Based on a series of studies concentrated on the same area, these studies have several specific purposes. Articles were categorised based on the purpose of the study and used to create a taxonomy. Figure 2.3 presents the employed taxonomy to review the research articles that focus on data exchange in V2P communication. This taxonomy shows the comprehensive content of various studies and applications. The classification proposes various classes and subclasses. The first class includes studies with actual attempts to develop V2P communication systems using either real-time or simulation (29/56 papers). The second class includes review and survey articles related to V2P communication (4/56 papers). The third class covers the framework studies (3/56 papers). And the final class included studies conducted on V2P communication systems (20/56 papers). The observed categories are listed in the following sections for statistical analysis.

2.4 V2P communication: An overview

Many studies have focused on the data exchange in V2P communication systems. These articles were read methodically to establish a general research map on this emerging area. On the basis of a series of studies concentrated on the same area, these studies were considered to have specific purposes.

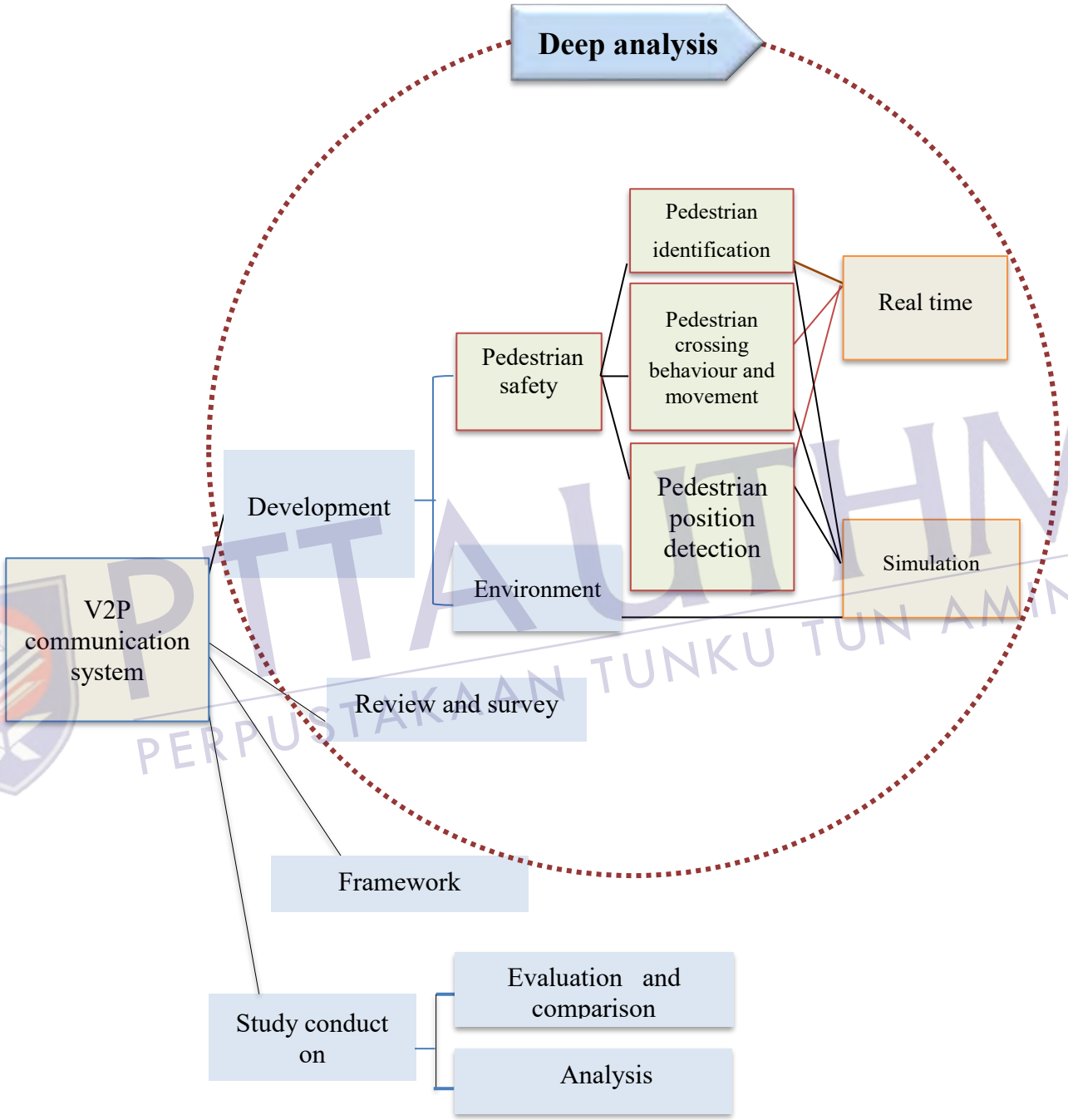

Figure 2.3: Taxonomy of literature research on Vehicle-to-Pedestrian communication

The articles were classified in detail using the taxonomy and a large selection of highlights and comments. All the articles from various sources were analysed in depth to provide readers a comprehensive overview of the subject. The articles were categorised according to the purpose of the study and then used to create a taxonomy. This taxonomy shows the full content of various studies and applications that can be categorised into four groups. The first group includes studies with actual attempts in either real-time or simulation development for data exchange in V2P communication systems. The second group includes review and survey articles related to data exchange in V2P communication. The third group covers the framework studies, and the final group includes studies conducted on V2P communication systems. The observed categories are listed in the following sections for statistical analysis.

2.4.1 Development

This section reviews the development articles that had data exchange on V2P communications as their main contribution. The common context of all works under this group was the development. These articles were classified into two groups (real time and simulation) according to the evaluation method used. The first group of development articles focused on real time development, which applied the proposed approaches in the actual test field with real data. The second group concentrated on simulation development, in which certain types of simulators were used to evaluate the work with or without real data. These articles were categorized according to the purpose of their study in to two classes, pedestrian safety and environment where pedestrian safety class categorized into three subclasses namely, pedestrian crossing behaviour and movement, pedestrian position detection, and pedestrian identification and trajectory, which is belong to real time group. Articles in simulation group consists of four classes, namely pedestrian position detection, pedestrian crossing behaviour and movement, pedestrian identification and trajectory, and environment. The two groups (real time and simulation) have crossovers, as shown in Figure 2.3. Three common classes between real time and simulation development focused on similar topics, such as pedestrian position detection, pedestrian crossing behaviour and movement, pedestrian identification and trajectory.

2.4.1.1 Pedestrian safety

This section present the previous researchers whose study pedestrian safety focusing in three direction which are, pedestrian position detection, pedestrian movement and behaviour, and pedestrian identification and trajectory as shown in the next subsections.

(a) Pedestrian position detection

The first class in real time and simulation group, is pedestrian position detection which is concerned with the estimation, identify, and detection position to the pedestrian. In real time development, the author in [16] introduced an online pedestrian-crossing detection system supplied with traffic-oriented video sensors that provide coarse measurements on areas along a crosswalk. A novel fusion procedure for providing enhanced detection and improved classical Advanced Driving Assistance (ADAS) application was introduced in [17]. An ADAS was described in [2] to prevent accidents involving a VRU detection system based on a standardised V2X communication system. An effective version of an integrated system combining vision-based object detection and VANETs was presented in [18]. A technique for effectively forming and disbanding groups of vehicles and pedestrians was proposed in [19]. The authors in [9] proposed a VRU warning system that aims to provide information exchange amongst road users (e.g. pedestrians, cyclists and vehicles) using commercial devices (i.e. smartphone) about the presence of nearby entities that may cause dangerous situations and send standard compliance messages to the drivers. In addition, the author in [6] proposed a prototype of a P2V communication system using the 3G wireless network and wireless LAN for pedestrian detection. The work in [20] addressed the issue concretely by formulating the requirement of distance support for minimum information exchange via Wi-Fi-based V2P communication. Other articles in simulation development proposed a method for detecting pedestrian positions through the cooperation of multiple cars with directional antennas [21]. The study in [22], proposed a preliminary investigation on the applicability of vehicular communication for protecting VRUs through an intersection collision-avoidance method.

(b) Pedestrian identification and trajectory

This section describe the third group of development. In real time development where in [23], a system was proposed that adapts a powerful data association technique

for multiple target tracking (MTT) and joint probabilistic data association (JPDA). The authors in [24] proposed a UFIR filtering-based pedestrian tracking scheme by combining finite INS and Ultra-Wideband (UWB) data. A novel detector-tracker feedback loop for information exchange based on the spatiotemporal similarity of detections and trackless was proposed in [25]. In the simulation development group, a multi-model agent-based simulation technique based on the incorporation of multiple modules was proposed in [26]. In [24] proposed a new robust method integrating information on spatial position, shape and colour and a set of algorithms on the basis of an SNN model to identify specific persons. Along with agent-based simulation models introduced in [27, 28] for pedestrian dead reckoning (PDR) systems in agent collaborations when two agents are detected close to each other. A multi-agent system architecture of cooperative surveillance extended to incorporate dynamic coalition formation and a simulation-based feasibility study on tight (UWB) and inertial data integration were introduced in [29] and [30], respectively.

(c) Pedestrian behaviour and movement

In the latest years, further researches are focusing on pedestrian behaviour recognition. The purpose of pedestrian safety warning system is protecting not only pedestrians but also drivers and the other road users [31]. In real time development, the author in [32] proposed a GIS-based methodology to collect and process the data required for the analysis of pedestrian crossing behaviour. The proposed model in [33] joins spatial formation to navigation performance, the PIE's ability to represent the walking environment is constant in two different metropolitan areas of different size and with distinct mobility patterns. The effectiveness of a fuzzy logic-based approach in modelling pedestrian steering behaviour by using built environments under normal and non-panic conditions was investigated in [33]. In simulation development, agent-based models and appropriate indicators of behaviour along urban trips were proposed in [34]. In [35], a crowd simulation framework was introduced which incorporated information on the dynamic environment that supports knowledge spreading and allows simulated agents to behave according to their personal needs as influenced by their surroundings to represent the movement of road users and their interaction. There is a specific gap associated with walking path prediction about "how a pedestrian chooses his/her next step position and speed when he/she is exposed to environmental stimuli during a normal and non-panic situation" was solved in [4], where this work focus on analysis the pedestrians' behaviour for selecting the crossing facilities when

on condition that with signalized crosswalks and foot over bridges at the intersections using the field video data to observed the pedestrian crossing behaviour. A new swarm optimisation algorithm and a multilayer approach were introduced in [36, 37] on the basis of the social force model. The authors in [31] proposed a new international standard called 'OGC moving features' for identify the pedestrian using image processing techniques and used multiple-kernel learning to combine information from thermal and visible spectrum images in a pedestrian classification context [38], whilst [25] put forward fused multiple features and classifiers to make decisions for pedestrian tracking. All the three classes are common and labelled similarly in the real time and simulation development groups.

2.4.1.2 Environment class

Environment class is the fourth and last class of development articles for simulation development. It includes the work in [39] which investigated whether dedicated short-range communication (DSRC) performance persists with respect to air density changes in a foggy environment. In [40], credit-based incentive mechanism was proposed for delay-tolerant networks (DTNs) that enable device-to-device data exchange without the support of traditional internet service providers.

2.4.2 Review and survey articles

The survey and review articles condensed the current state of research on V2P communication systems in data exchange, wireless networks, positioning and location systems and information management techniques. The work in [41] summarised communication through the wireless network technique, such as device-to-device (D2D) communication, which is expected to play a significant role in upcoming cellular networks because it promises ultra-low latency for communication amongst users, whilst [12] reviewed potential DSRC and cellular interworking solutions for efficient V2X communication. Furthermore, [42] introduced the current research efforts on information management techniques used for safety-related applications in VANETs, and [43] proposed a unified architecture for location systems using positioning and integration layers as the main building blocks.

2.4.3 Framework

A few articles designed a framework for data exchange in V2P communication. For instance, [44] described the demands on the architectural framework and introduced three new viewpoints that must be considered in future architectural decisions, whilst [45] investigated the performance management system of a national transportation safety agency with qualitative methods. A framework for generating alerts/warnings and control assistance for extreme events and those transmittable by V2V and V2I applications was proposed in [46]. The authors in [47] proposed a set of design changes and enhancements to the 3GPP C-V2X architecture to fully enable Named Data Networking (NDN) amongst the other non-IP networking solutions already supported.

2.4.4 Study conducting on data exchange in V2P communication

This section present the last group in the taxonomy which is classified into evaluation and comparison, and analysis. The first class focuses on the researchers who compared previous works and estimated or evaluated previous results through different validation techniques for data exchange in V2P communication system. In [48], a well-known audit tool was used to evaluate 84 street segments at the urban edge of metropolitan Boston, Massachusetts, through on-site visits and three web-based tools. The assessments were compared to evaluate their relative accuracy and usefulness. In [49], an autonomous driving test on urban roads and freeways open to regular traffic was presented and the milestones, challenges and key results in autonomous driving were compared. A cross-comparison was conducted on various estimation methods to model pedestrian and bicycle crashes in [50]. Meanwhile two classes of forwarding approaches were analysed in [51], namely (i) a minimalist, provider-blind forwarding strategy and (ii) a provider-aware strategy and performance evaluation conducted by ndnSIM. The authors in [52] proposed a set of real-world experiments which were conducted to assess the achievable transmission rates and

transmission ranges and validate the previous analytical results. The approach was also used to assess the performance of floating content in general.

For the analysis class, this section summarised the analytical studies on subjects conducted with network and communication issues on data exchange in the V2P communication system. The study in [53] introduced the concept of intelligent transportation space (ITSp) and analysed possible communication technology candidates for ITSp focusing on the lower layer issues of wireless communication technologies. Another study in [54] presented a platform in which mobile devices can offer network services to other nearby devices and thus act as service endpoints or mobile cloudlets. Researchers in [55] investigated the effect of antenna characteristics on MAC address data in terms of travel-time estimation for pedestrians and cyclists. In [56], ICeDiM, a middleware designed for ICN communication in next-generation scenarios, was presented. In [57], identify the urban Internet infrastructure role in the support of emerging vehicular applications and identify the core internet services matching the services in the vehicle grid. A fundamental concept was presented in [58] and a model of microscopic traffic simulation for vehicles, including a robust protocol for exchanging information, was designed. Another study in [59] focused on building a network-based carpooling scheme by analysing the feasibility and related issues in taxi carpooling on the basis of GPS traces of real taxis. In [60], the use of different computing and wireless techniques and technological systems was investigated for real time navigation support and location-based information delivery for pedestrians. The effects of holding naturalistic voice and text cell phone conversations on the participants' auditory detection for approaching vehicles and crossing thresholds in a nonvisual simulated setting were examined in [61].

Other studies highlighted safety issues, human crowds and walkability on the data exchange in V2P communication systems. For example, [62] proposed a multimodal approach to explore safety at road intersections by simultaneously analysing the safety and flow outcomes of motorised and non-motorised traffic. Furthermore, [63] provided a general description of collective dynamics across species and introduced a classification of these dynamics with respect to not only the way information is transferred amongst individuals but also to knowledge processing at the collective level. The transferability of a composite walkability index (Pedestrian Index of the Environment [PIE]) to the Greater Montréal Area (GMA) was analysed in [64]. The authors in [65] proposed a methodology to quantify the effect of bus stops on the

speed of other motorised vehicles under heterogeneous traffic conditions. Lastly, [66] presented new strategies for New York City which suggest the development of efficient and cost-effective DMS.

2.5 Discussion

This review presented the most relevant studies on data exchange in V2P communication systems. This work aims to highlight the research trends in this area. A taxonomy of the related literature was proposed to provide several benefits. Firstly, it organised various publications. A new researcher in this area may be overwhelmed by the large number of studies available on the subject and the absence of any kind of structure and may thus fail to obtain an overview of the area.

Secondly, the taxonomy could reveal gaps in the research. Mapping the literature on V2P applications into different groups highlighted the weak and strong features in terms of research coverage. For example, the taxonomy in this work showed how groups of individual applications received significant attention in terms of reviews and evaluations at the expense of integrated solutions and framework s as well as development efforts.

The taxonomy also highlighted the lack of studies on the behaviour analysis of pedestrian walking. Similar to taxonomies in other fields, the proposed taxonomy utilised a common language for researchers to communicate and discuss emerging works, such as development papers, comparative studies and reviews. The survey conducted revealed seven aspects of literature content in the description of datasets used in the articles, evaluation techniques adopted, criteria used for the performance evaluation of the methods, motivations behind the development of the V2P system, challenges to the successful utilisation of these technologies, recommendations to alleviate these difficulties and substantial analysis.

2.5.1 Data types and sources

This section presents various sources of data that some researchers have used to collect several types of real time information for V2P communication systems. These sources include location, number and age of vulnerable road users (pedestrians

and cyclists). Other sources are the position and speed of the vehicle. Table 2.1 presents a detailed description of numerous factors involving the real time data type of research experiments designed towards developing hardware and simulation projects in V2P communication.

Table 2.1: Real time dataset type used in the reviewed studies

Reference	Sample type											
	Vulnerable road user											
	Motorcyclist and cyclist position	Pedestrian location	Pedestrian age	Pedestrian number	Pedestrian trajectory	Image of pedestrian	Distance to pedestrian	Speed of motorised	Crash data	Location of bus stops	Vehicle speed and position
[2]	*										
[6]		*									
[32]			*		*						
[17]		*				*					
[23]		*									*
[67]		*									*
[34]			*		*						
[20]		*									*
[68]		*			*		*				
[69]				*		*					
[19]		*		*							
[66]	*	*					*		*		
[33]			*	*	*						
[18]		*				*			*		*
[21]	*							*		*	*
[29]		*					*				
[35]						*					
[16]						*	*				

Other studies used public datasets and ignored real time data, such as data in previous literature or virtual data generated by a simulator.

2.5.2 Performance measurements

In our review, each work in real time and simulation development was measured using specific features. The evaluation criteria represent a practical way of assessing various works. In this survey, it is found that the performance of the

development (real time and simulation) studies was evaluated using three measurement criteria, namely environment, time and data measures. The measurement accuracy of each criterion involved several features or parameters. All these parameters are discussed in this section. Tables 2.2 and 2.3 illustrate the measurement criteria used in the reviewed articles on the development studies of data exchange in V2P communication systems.

.

REFERENCES

[1] M. Yuvaraja, C. Pollachi, S. Poojashree, G. Shaliha, and G. Sureka, "Life Time Enhancement of Wireless Sensor Network for Vanet," EasyChair 2516-2314, 2020.

[2] J. J. Anaya, E. Talavera, D. Gimenez, N. Gomez, F. Jimenez, J. E. Naranjo, "Vulnerable Road Users Detection using V2X Communications," in *2015 IEEE 18th International Conference on Intelligent Transportation Systems*, ed, 2015, pp. 107-112.

[3] P. Sewalkar and J. Seitz, "Vehicle-to-Pedestrian Communication for Vulnerable Road Users: Survey, Design Considerations, and Challenges," *Sensors,* vol. 19, 01/17 2019.

[4] M. Patra, V. Perumal, and K. V. K. Rao, "Modelling the effects of risk factor and time savings on pedestrians' choice of crossing facilities at signalised intersections," *Case Studies on Transport Policy,* 2019/11/02/ 2019.

[5] S. Dorohin, V. Zelikov, and G. Denisov, "Improvement of road traffic safety in the zone of unsignalled pedestrian crossings," *Transportation Research Procedia,* vol. 36, pp. 122-128, 2018/01/01/ 2018.

[6] J. J. Anaya, P. Merdrignac, O. Shagdar, F. Nashashibi, J. E. Naranjo, "Vehicle to Pedestrian Communications for Protection of Vulnerable Road Users," in *2014 IEEE Intelligent Vehicles Symposium Proceedings*, ed, 2014, pp. 1037-1042.

[7] S. J. Ramson, S. Vishnu, and M. Shanmugam, "Applications of Internet of Things (IoT)–An Overview," in *2020 5th International Conference on Devices, Circuits and Systems (ICDCS)*, 2020, pp. 92-95.

[8] H. K. Kim, C. A. Azurdia-Meza, and C. Estévez, "Antenna Array Synthesis Through Genetic Algorithms for Urban V2V Communications: Preliminary Results," in *2020 Congreso Estudiantil de Electrónica y Electricidad (INGELECTRA)*, 2020, pp. 1-5.

[9] A. Napolitano, G. Cecchetti, F. Giannone, A. L. Ruscelli, F. Civerchia, K. Kondepu, "Implementation of a MEC-based Vulnerable Road User Warning System," in *2019 AEIT International Conference of Electrical and Electronic Technologies for Automotive (AEIT AUTOMOTIVE)*, 2019, pp. 1-6.

[10] Y. Li, F. Xue, X. Fan, Z. Qu, and G. Zhou. (2018, Pedestrian walking safety system based on smartphone built-in sensors. *IET Communications 12(6),* 751-758. Available: https://digital-library.theiet.org/content/journals/10.1049/iet-com.2017.0502

[11] D. Mukherjee and S. Mitra, "A comparative study of safe and unsafe signalized intersections from the view point of pedestrian behaviour and perception," *Accident; analysis and prevention,* vol. 132, pp. 105218-105218, 2019.

[12] K. Abboud, H. A. Omar, and W. H. Zhuang, "Interworking of DSRC and Cellular Network Technologies for V2X Communications: A Survey," *IEEE Transactions on Vehicular Technology,* vol. 65, pp. 9457-9470, Dec 2016.

[13] A. Tahmasbi-Sarvestani, H. N. Mahjoub, Y. P. Fallah, E. Moradi-Pari, and O. Abuchaar, "Implementation and Evaluation of a Cooperative Vehicle-to-Pedestrian

Safety Application," *IEEE Intelligent Transportation Systems Magazine,* vol. 9, pp. 62-75, 2017.

[14] O. Diallo, J. Rodrigues, and M. Sene, "Real-time data management on wireless sensor network: A survey, *pervasive and mobile computing,* vol. 35.

[15] P. F. Hu, S. Yang, H.-C. Li, L. G. Stansbury, F. Yang, G. Hagegeorge, "Reliable Collection of Real-Time Patient Physiologic Data from less Reliable Networks: a "Monitor of Monitors" System (MoMs)," *Journal of medical systems,* vol. 41, pp. 3-3, 2017.

[16] L. Boudet and S. Midenet, "Pedestrian crossing detection based on evidential fusion of video-sensors," *Transportation Research Part C: Emerging Technologies,* vol. 17, pp. 484-497, 10// 2009.

[17] F. Garcia, A. Ponz, D. Martin, A. d. l. Escalera, and J. M. Armingol, "Computer vision and laser scanner road environment perception," in *IWSSIP 2014 Proceedings*, 2014, pp. 63-66.

[18] L. Hoehmann and A. Kummert, "Car2X-communication for vision-based object detection," in *SoftCOM 2010, 18th International Conference on Software, Telecommunications and Computer Networks*, 2010, pp. 290-294.

[19] H. Nishiyama, T. Ngo, S. Oiyama, and N. Kato, "Relay by Smart Device: Innovative Communications for Efficient Information Sharing Among Vehicles and Pedestrians," *IEEE Vehicular Technology Magazine,* vol. 10, pp. 54-62, 2015.

[20] C. Sugimoto and Y. Nakamura, "Provision of information support by pedestrian-to-vehicle communication system," in *2008 8th International Conference on ITS Telecommunications*, 2008, pp. 160-163.

[21] Y. Sawa, T. Kitani, N. Shibata, K. Yasumoto, and M. Ito, "A Method for Pedestrian Position Estimation using Inter-Vehicle Communication," in *2008 IEEE Globecom Workshops*, 2008, pp. 1-6.

[22] M. Segata, R. Vijeikis, R. Lo Cigno, "Communication-based Collision Avoidance between Vulnerable Road Users and Cars," in *2017 IEEE Conference on Computer Communications Workshops*, ed, 2017, pp. 565-570.

[23] F. García, A. d. l. Escalera, and J. M. Armingol, "Enhanced obstacle detection based on Data Fusion for ADAS applications," in *16th International IEEE Conference on Intelligent Transportation Systems (ITSC 2013)*, 2013, pp. 1370-1375.

[24] L. Bu, Y. Zhang, Y. Xu, and X. Chen, "Robust tightly-coupled INS/UWB-integrated human localization using UFIR filtering," in *2018 IEEE International Instrumentation and Measurement Technology Conference (I2MTC)*, 2018, pp. 1-5.

[25] M. Dimitrievski, P. Veelaert, and W. Philips, "Information feedback loop for improved pedestrian detection in an autonomous perception system," in *2018 21st International Conference on Intelligent Transportation Systems (ITSC)*, 2018, pp. 3119-3124.

[26] V. Karbovskii, D. Voloshin, A. Karsakov, A. Bezgodov, and C. Gershenson, "Multimodel agent-based simulation environment for mass-gatherings and pedestrian dynamics," *Future Generation Computer Systems,* vol. 79, Part 1, pp. 155-165, 2018.

[27] G. Kampis, J. W. Kantelhardt, K. Kloch, and P. Lukowicz, "Analytical and simulation models for collaborative localization," *Journal of Computational Science,* vol. 6, pp. 1-10, 2015.

[28] G. Kampis and P. Lukowicz, "Collaborative localization as a paradigm for incremental knowledge fusion," in *2014 5th IEEE Conference on Cognitive Infocommunications (CogInfoCom)*, 2014, pp. 327-331.

[29] F. Castanedo, J. García, M. A. Patricio, and J. M. Molina, "Data fusion to improve trajectory tracking in a Cooperative Surveillance Multi-Agent Architecture," *Information Fusion,* vol. 11, pp. 243-255, 2010.

[30] L. Zwirello, C. Ascher, G. F. Trommer, and T. Zwick, "Study on UWB/INS integration techniques," in *2011 8th Workshop on Positioning, Navigation and Communication*, 2011, pp. 13-17.

[31] A. Asahara, H. Hayashi, N. Ishimaru, R. Shibasaki, and H. Kanasugi, *International Standard "OGC((R)) Moving Features" to address "4Vs" on locational BigData*, 2015.

[32] S. Lassarre, E. Bonnet, F. Bodin, E. Papadimitriou, G. Yannis, and J. Golias, "A GIS-based methodology for identifying pedestrians' crossing patterns," *Computers Environment and Urban Systems,* vol. 36, pp. 321-330, Jul 2012.

[33] M. Nasir, C. P. Lim, S. Nahavandi, and D. Creighton, "Inclusion of environmental effects in steering behaviour modelling using fuzzy logic," *Expert Systems with Applications,* vol. 41, pp. 1901-1914, 2014.

[34] P. M. Torrens, A. Nara, X. Li, H. J. Zhu, W. A. Griffin, and S. B. Brown, "An extensible simulation environment and movement metrics for testing walking behaviour in agent-based models," *Computers Environment and Urban Systems,* vol. 36, pp. 1-17, Jan 2012.

[35] K. Jablonski, V. Argyriou, and D. Greenhill, "Crowd Simulation for Dynamic Environments based on Information Spreading and Agents' Personal Interests," *Transportation Research Procedia,* vol. 2, pp. 412-417, 2014.

[36] G. w. Yan, C. q. Li, and M.-c. Lu, "A novel swarm optimization algorithm based on Social Force model for multimodal functions," in *2012 24th Chinese Control and Decision Conference (CCDC)*, 2012, pp. 849-854.

[37] N. Rinke, C. Schiermeyer, F. Pascucci, V. Berkhahn, and B. Friedrich, "A multi-layer social force approach to model interactions in shared spaces using collision prediction," *Transportation Research Procedia,* vol. 25, pp. 1249-1267, 2017.

[38] M. San-Biagio, A. Ulas, M. Crocco, M. Cristani, U. Castellani, V. Murino*, et al.*, "A Multiple Kernel Learning Approach to Multi-Modal Pedestrian Classification," in *2012 21st International Conference on Pattern Recognition*, ed, 2012, pp. 2412-2415.

[39] M. El-Said, V. Bhuse, and A. Arendsen, "An Empirical Study to Investigate the Effect of Air Density Changes on the DSRC Performance," *Procedia Computer Science,* vol. 114, pp. 523-530, 2017.

[40] V. G. Rolla and M. Curado, "Enabling wireless cooperation in delay tolerant networks," *Information Sciences,* vol. 290, pp. 120-133, 1/1/ 2015.

[41] U. N. Kar and D. K. Sanyal, "An overview of device-to-device communication in cellular networks," *ICT Express*.

[42] M. S. Kakkasageri and S. S. Manvi, "Information management in vehicular ad hoc networks: A review," *Journal of Network and Computer Applications,* vol. 39, pp. 334-350.

[43] M. Pelka and H. Hellbrück, "Survey of challenges and towards a unified architecture for location systems," *Journal of Network and Computer Applications,* vol. 67, pp. 75-85, 2016.

[44] P. Pelliccione, E. Knauss, R. Heldal, S. Magnus Ågren, P. Mallozzi, A. Alminger*, et al.*, "Automotive Architecture Framework: The experience of Volvo Cars," *Journal of Systems Architecture,* vol. 77, pp. 83-100, 2017.

[45] P. Mononen and P. Leviäkangas, "Transport safety agency's success indicators – How well does a performance management system perform?," *Transport Policy,* vol. 45, pp. 230-239, 2016.

[46] J. Liu and A. J. Khattak, "Delivering improved alerts, warnings, and control assistance using basic safety messages transmitted between connected vehicles," *Transportation Research Part C: Emerging Technologies,* vol. 68, pp. 83-100, 2016.

[47] M. Amadeo, C. Campolo, A. Molinaro, J. Harri, E. C. Rothenberg, and A. Vinel, "Enhancing the 3GPP V2X Architecture with Information-Centric Networking," *Future Internet,* vol. 11, 2019.

[48] E. Ben-Joseph, J. S. Lee, E. K. Cromley, F. Laden, and P. J. Troped, "Virtual and actual: Relative accuracy of on-site and web-based instruments in auditing the environment for physical activity," *Health & Place,* vol. 19, pp. 138-150, 2013.

[49] A. Broggi, P. Cerri, S. Debattisti, M. C. Laghi, P. Medici, D. Molinari, *et al.*, "PROUD—Public Road Urban Driverless-Car Test," *IEEE Transactions on Intelligent Transportation Systems,* vol. 16, pp. 3508-3519, 2015.

[50] R. Amoh-Gyimah, M. Saberi, and M. Sarvi, "Macroscopic modeling of pedestrian and bicycle crashes: A cross-comparison of estimation methods," *Accident Analysis & Prevention,* vol. 93, pp. 147-159, 2016.

[51] M. Amadeo, C. Campolo, and A. Molinaro, "Forwarding strategies in named data wireless ad hoc networks: Design and evaluation," *Journal of Network and Computer Applications,* vol. 50, pp. 148-158, 2015.

[52] J. Ott, E. Hyytiä, P. Lassila, J. Kangasharju, and S. Santra, "Floating content for probabilistic information sharing," *Pervasive and Mobile Computing,* vol. 7, pp. 671-689, 2011.

[53] F. Qu, F. Y. Wang, and L. Yang, "Intelligent transportation spaces: vehicles, traffic, communications, and beyond," *IEEE Communications Magazine,* vol. 48, pp. 136-142, 2010.

[54] S. Doumiati and H. Artail, "Analytical study of a service discovery system based on an LTE-A D2D implementation," *Physical Communication,* vol. 19, pp. 145-162.

[55] N. Abedi, A. Bhaskar, E. Chung, and M. Miska, "Assessment of antenna characteristic effects on pedestrian and cyclists travel-time estimation based on Bluetooth and WiFi MAC addresses," *Transportation Research Part C: Emerging Technologies,* vol. 60, pp. 124-141, 2015.

[56] A. Morelli, M. Tortonesi, C. Stefanelli, and N. Suri, "Information-Centric Networking in next-generation communications scenarios," *Journal of Network and Computer Applications,* vol. 80, pp. 232-250.

[57] M. Gerla and L. Kleinrock, "Vehicular networks and the future of the mobile internet," *Computer Networks,* vol. 55, pp. 457-469.

[58] P. Gora and I. Rüb, "Traffic Models for Self-driving Connected Cars," *Transportation Research Procedia,* vol. 14, pp. 2207-2216, 2016.

[59] F. Song, R. Li, and H. Zhou, "Feasibility and issues for establishing network-based carpooling scheme," *Pervasive and Mobile Computing,* vol. 24, pp. 4-15, 2015.

[60] G. Saeed, A. Brown, M. Knight, and M. Winchester, "Delivery of pedestrian real-time location and routing information to mobile architectural guide," *Automation in Construction,* vol. 19, pp. 502-517, 2010.

[61] S. J. Davis and B. K. Barton, "Effects of secondary tasks on auditory detection and crossing thresholds in relation to approaching vehicle noises," *Accident Analysis & Prevention,* vol. 98, pp. 287-294, 2017.

[62] J. Strauss, L. F. Miranda-Moreno, and P. Morency, "Multimodal injury risk analysis of road users at signalized and non-signalized intersections," *Accident Analysis & Prevention,* vol. 71, pp. 201-209, 2014.

[63] M. Moussaid, S. Garnier, G. Theraulaz, and D. Helbing, "Collective Information Processing and Pattern Formation in Swarms, Flocks, and Crowds," *Topics in Cognitive Science,* vol. 1, pp. 469-497, Jul 2009.

[64] G. Lefebvre-Ropars, C. Morency, P. A. Singleton, and K. J. Clifton, "Spatial transferability assessment of a composite walkability index: The Pedestrian Index of

the Environment (PIE)," *Transportation Research Part D: Transport and Environment,* vol. 57, pp. 378-391, 2017.

[65] P. Bansal, R. Agrawal, and G. Tiwari, "Impacts of Bus-stops on the Speed of Motorized Vehicles under Heterogeneous Traffic Conditions: A Case-Study of Delhi, India," *International Journal of Transportation Science and Technology,* vol. 3, pp. 167-178, 6/1/ 2014.

[66] H. J. Park, P. H. Kim, M. Marsico, and N. Rasheed, "Data Mining Strategies for Real-time Control in New York City," *Procedia Computer Science,* vol. 32, pp. 109-116, 2014.

[67] T. Dieterle, F. Particke, L. Patino-Studencki, and J. Thielecke, "Sensor data fusion of LIDAR with stereo RGB-D camera for object tracking," in *2017 IEEE SENSORS*, 2017, pp. 1-3.

[68] J. Li, C. Shao, W. Xu, and H. Yue, "Real Time Tracking of Moving Pedestrians," in *2009 International Conference on Measuring Technology and Mechatronics Automation*, 2009, pp. 811-815.

[69] X. Wang, Q. Wu, X. Lin, Z. Zhuo, and L. Huang, "Pedestrian identification based on fusion of multiple features and multiple classifiers," *Neurocomputing,* vol. 188, pp.

[70] Y. Han and H. Liu, "Modified social force model based on information transmission toward crowd evacuation simulation," *Physica A: Statistical Mechanics and its Applications,* vol. 469, pp. 499-509.

[71] J. Albusac, D. Vallejo, J. J. Castro-Schez, and C. Gzlez-Morcillo, "An expert fuzzy system for improving safety on pedestrian crossings by means of visual feedback," *Control Engineering Practice,* vol. 75, pp. 38-54.

[72] D. Mukherjee and S. Mitra, "A comparative study of safe and unsafe signalized intersections from the view point of pedestrian behaviour and perception," *Accident Analysis & Prevention,* vol. 132, p. 105218.

[73] S. Haga, A. Sano, Y. Sekine, H. Sato, S. Yamaguchi, and K. Masuda, "Effects of using a Smart Phone on Pedestrians' Attention and Walking," *Procedia Manufacturing,* vol. 3, pp. 2574-2580.

[74] Q.-H. Nguyen, M. Morold, K. David, and F. Dressler, "Car-to-Pedestrian communication with MEC-support for adaptive safety of Vulnerable Road Users," *Computer Communications,* vol. 150, pp. 83-93.

[75] A. J. Piazza, A. P. Knowlden, E. Hibberd, J. Leeper, A. M. Paschal, and S. Usdan, "Mobile device use while crossing the street: Utilizing the theory of planned behaviour," *Accident Analysis & Prevention,* vol. 127, pp. 9-18.

[76] N. Ahmed, J. I. Rafiq, and M. R. Islam, "Enhanced Human Activity Recognition Based on Smartphone Sensor Data Using Hybrid Feature Selection Model," vol. 20.

[77] R. C. McIlroy, K. L. Plant, U. Jikyong, V. H. Nam, B. Bunyasi, G. O. Kokwaro, "Vulnerable road users in low-, middle-, and high-income countries: Validation of a Pedestrian Behaviour Questionnaire," *Accident Analysis & Prevention,* vol. 131, pp. 80-94.

[78] E. Sahın, M. Aydos, and F. Orhan, "Spam/ham e-mail classification using machine learning methods based on bag of words technique," in *2018 26th Signal Processing and Communications Applications Conference (SIU)*, 2018, pp. 1-4.

[79] R. R. R. Robinson and C. Thomas, "Ranking of machine learning algorithms based on the performance in classifying DDoS attacks," in *2015 IEEE Recent Advances in Intelligent Computational Systems (RAICS)*, 2015, pp. 185-190.

[80] A. Srivastava, H. Eui-Hong Sam, V. Singh, and V. Kumar, "Parallel formulations of decision-tree classification algorithms," in *Proceedings. 1998 International Conference on Parallel Processing (Cat. No.98EX205)*, 1998, pp. 237-244.

[81] M. A. Mangai and N. A. Gounden, "Pedestrian classification using principal eigenspaces," in *2014 Annual IEEE India Conference (INDICON)*, 2014, pp. 1-6.

[82] L. Chia-Chen, W. Pei-Chen, and L. Chang Hong, "Pedestrian detection using heuristic statistics and machine learning," in *2013 9th International Conference on Information, Communications & Signal Processing*, 2013, pp. 1-5.

[83] P. Negri, N. Goussies, and P. Lotito, "Detecting pedestrians on a Movement Feature Space," *Pattern Recognition,* vol. 47, pp. 56-71.

[84] X. He and D. Zeng, "Real-time pedestrian warning system on highway using deep learning methods," in *2017 International Symposium on Intelligent Signal Processing and Communication Systems (ISPACS)*, 2017, pp. 701-706.

[85] E. Irfiani, I. Elyana, F. Indriyani, F. E. Schaduw, and D. D. Harmoko, "Predicting Grade Promotion Using Decision Tree and Naïve Bayes Classification Algorithms," in *2018 Third International Conference on Informatics and Computing (ICIC)*, 2018, pp. 1-4.

[86] I. Chakroun, T. Haber, and T. J. Ashby, "SW-SGD: The Sliding Window Stochastic Gradient Descent Algorithm," *Procedia Computer Science,* vol. 108, pp. 2318-2322,

[87] Okfalisa, I. Gazalba, Mustakim, and N. G. I. Reza, "Comparative analysis of k-nearest neighbor and modified k-nearest neighbor algorithm for data classification," in *2017 2nd International conferences on Information Technology, Information Systems and Electrical Engineering (ICITISEE)*, 2017, pp. 294-298.

[88] A. F. Nugraha and L. Rahman, "Meta-Algorithms for Improving Classification Performance in the Web-phishing Detection Process," in *2019 4th International Conference on Information Technology, Information Systems and Electrical Engineering (ICITISEE)*, 2019, pp. 271-275.

[89] M. Oyedere and K. Gray, "ROP and TOB optimization using machine learning classification algorithms," *Journal of Natural Gas Science and Engineering,* vol. 77, p. 103230, 2020/05/01/ 2020.

[90] B. Şen, M. Peker, A. Çavuşoğlu, and F. V. Çelebi, "A Comparative Study on Classification of Sleep Stage Based on EEG Signals Using Feature Selection and Classification Algorithms," *Journal of Medical Systems,* vol. 38, p. 18, 2014/03/09 2014.

[91] C. Nasa and S. Suman, "Evaluation of Different Classification Techniques for WEB Data," *International Journal of Computer Applications,* vol. 52, pp. 34-40, 08/01 2012.

[92] V. Krishnaveni and G. Arumugam, "Harmony search based wrapper feature selection method for 1-nearest neighbour classifier," in *2013 International Conference on Pattern Recognition, Informatics and Mobile Engineering*, 2013, pp. 24-29.

[93] S. R. Nayak, J. Mishra, and G. Palai, "An extended DBC approach by using maximum Euclidian distance for fractal dimension of color images," *Optik,* vol. 166, pp. 110-115, 2018.

[94] J. Á. Naranjo, J. Lopez-Ramos, and L. G. Casado, "Applications of the Extended Euclidean Algorithm to Privacy and Secure Communications," ed, 2010, p. 702.

[95] J. Shallit, "Origins of the analysis of the Euclidean algorithm," *Historia Mathematica,* vol. 21, pp. 401-419, 1994/11/01/ 1994.

[96] D. Tian, Y. Wang, G. Lu, and G. Yu, "A VANETs routing algorithm based on Euclidean distance clustering," *Proceedings of the 2010 2nd International Conference on Future Computer and Communication, ICFCC 2010,* vol. 1.

[97] L. Wen, L. He, and Z. Gao, "Research on 3D Point Cloud De-Distortion Algorithm and Its Application on Euclidean Clustering," *IEEE Access,* vol. 7, pp. 86041-86053, 2019.

[98] A. Chowdhury and D. De, "MSLG-RGSO: Movement score based limited grid-mobility approach using reverse Glowworm Swarm Optimization algorithm for mobile wireless sensor networks," *Ad Hoc Networks,* vol. 106, p. 102191, 2020/09/01/ 2020.

[99] E. Plesnik, O. Malgina, J. Tasic, and M. Zajc, "Detection of the electrocardiogram fiducial points in the phase space using the Euclidian distance measure," *Medical engineering & physics,* vol. 34, pp. 524-9, 03/12 2012.

[100] P. Praekhaow, "Determination of Trading Points using the Moving Average Methods," GMSTEC 2010: International Conference for a Sustainable Greater Mekong Subregion, 26-27 August 2010, Bangkok, Thailand.

[101] M. M. Salih, B.B. Zaidan, A.A. Zaidan, "Fuzzy decision by opinion score method," *Applied Soft Computing Journal,* vol. 96, pp. 1568-4946 , 4 August 2020.