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INTEGRATED OBD-II AND DIRECT CONTROLLER AREA NETWORK ACCESS FOR VEHICLE MONITORING SYSTEM

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By

KAVIAN KHOSRAVINIA

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Master of Science

October 2018

DEDICATION

To the true teachers of my life:
My beloved mother for endless love and sincere generosity
My dear father for lifelong investigation, pure poetry, and diligent publications.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Master of Science

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October 2018

Chairman : Associate Professor Mohd Khair Hassan, PhD
Faculty : Engineering

The CAN (controller area network) bus is introduced as a multi-master, message broadcast system. The messages sent on the CAN are used to communicate state information, referred as a signal between different ECUs, which provides data consistency in every node of the system. OBD-II Dongles that are based on request and response method is the wide-spread solution for extracting sensor data from cars among researchers. Unfortunately, most of the past researches do not consider resolution and quantity of their input data extracted through OBD-II technology. The maximum feasible scan rate is only 9 queries per second which provide 8 data points per second with using ELM327 as well-known OBD-II dongle. This study aims to develop and design a programmable, and latency-sensitive vehicle data acquisition system that improves the modularity and flexibility to extract exact, trustworthy, and fresh car sensor data with higher frequency rates. Most of OBD-II dongles are based on very low capacity microcontroller hardware which cannot provide in-vehicle data processing, rather they transfer data to an external processing device. Furthermore, the researcher must break apart, thoroughly inspect, and observe the internal network of the vehicle, which may cause severe damages to the expensive ECUs of the vehicle due to intrinsic vulnerabilities of the CAN bus during initial research.

Water coolant temperature, air temperature, and engine speed sensors signal were simulated and generated by using an ATmega8A. Desired sensors data were collected from various vehicles utilizing Raspberry Pi3 as computing and processing unit with using OBD (request–response) and direct CAN method at the same time. Two types of data were collected for this study. The first, CAN bus frame data that illustrates data collected for each line of hex data

sent from an ECU and the second type is the OBD data that represents some limited data that is requested from ECU under standard condition.

On the implementation of the above methods, this dissertation explores the differences between CAN and OBD data by integrating all these methods into one disposable GUI. A comparison has been done between OBD and CAN data to show how the number of data gathering measurement points of desired sensors can be improved to 15 data points per second through applying the proposed approach as compared to the standard OBD (request-response) method. The results have shown by using direct CAN method 25 data points per second for the essential sensors is achieved. The proposed system is reconfigurable, human-readable and multi-task telematics device that can be fitted into any vehicle with minimum effort and minimum time lag in the data extraction process. The standard operational procedure experimental vehicle network test bench is developed and can be used for future vehicle network testing experiment.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

OBD-II BERSEPADU DAN PENGAWAL RANGKAIAN KAWASAN LANGSUNG BAGI SISTEM PEMANTAUAN KENDERAAN

Oleh

KAVIAN KHOSRAVINIA

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Pengerusi : Profesor Madya Mohd Khair Hassan, PhD
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Bas CAN (controller area network) diperkenalkan sebagai multiinduk, iaitu, sistem penyiaran mesej. Mesej yang dihantar pada CAN telah digunakan untuk menyampaikan maklumat negara, yang disebut sebagai isyarat antara ECU yang berbeza, yang menyediakan konsistensi data dalam setiap nod sistem tersebut. Dongel OBD-II yang berdasarkan permintaan dan kaedah tindak balas merupakan penyelesaian sebar luas untuk mengekstrak data sensor daripada kereta dalam kalangan penyelidik. Malangnya, kebanyakan penyelidikan terdahulu tidak menganggap resolusi dan kuantiti data input mereka diekstrak melalui teknologi OBD-II. Kadar imbasan boleh terima maksimum ialah hanya 9 pertanyaan per saat yang memberikan 8 titik data sesaat dengan menggunakan ELM327 yang dikenali umum sebagai dongel OBD-II. Kajian ini bertujuan untuk membangun dan mereka bentuk suatu sistem pemerolehan data kenderaan sensitif pendam dan boleh atur cara yang dapat meningkatkan modulariti dan fleksibiliti untuk mengekstrak data sensor kereta yang tepat, boleh dipercayai, dan segar dengan kadar frekuensi yang lebih tinggi. Kebanyakan dongel OBD-II berdasarkan perkakasan mikropengawal berkapasiti yang sangat rendah yang tidak dapat menyediakan pemprosesan data dalam kenderaan, sebaliknya mereka memindahkan data ke peranti pemprosesan luaran. Selain itu, penyelidik mesti berehat, memeriksa secara terperinci, dan meneliti rangkaian dalaman kenderaan, yang mungkin menyebabkan kerosakan teruk pada ECU kenderaan yang mahal kerana kerentanan intrinsik bus CAN semasa penyelidikan awal.

Suhu pendingin air, suhu udara, dan isyarat sensor kelajuan enjin telah disimulasikan dan dijana menggunakan ATmega8A. Data sensor yang diingini telah dikumpulkan dari pelbagai kenderaan menggunakan Raspberry Pi3 sebagai pengkomputeran dan unit pemprosesan dengan menggunakan OBD (permintaan-tindak balas) dan kaedah CAN langsung pada masa yang Sama. Dua jenis data telah dikumpulkan untuk kajian ini. Yang pertama, data kerangka bas CAN yang menggambarkan data yang dikumpul untuk setiap baris data heks yang dihantar dari ECU dan jenis kedua ialah data OBD yang mewakili beberapa data terhad yang diminta dari ECU di bawah keadaan standard.

Mengenai pelaksanaan kaedah di atas, disertasi ini mengutarakan perbezaan antara data CAN dan OBD dengan mengintegrasikan semua faktor ini menjadi satu GUI yang boleh guna. Perbandingan telah dilakukan antara data OBD dan CAN untuk menunjukkan bagaimana bilangan titik pengukuran pengumpulan data bagi sensor yang diingini dapat ditingkatkan kepada 15 titik data sesaat menerusi pengaplikasian pendekatan yang dicadangkan berbanding dengan kaedah OBD standard (permintaan dan tindak balas). Dapatan menunjukkan dengan menggunakan kaedah CAN langsung, 25 titik data sesaat untuk sensor perlu telah diperoleh. Sistem yang dicadangkan merupakan peranti telematik yang boleh dibaca semula, boleh dibaca manusia dan multitask yang boleh dipasang ke mana-mana kenderaan dengan usaha yang minimum dan susulan masa yang minimum dalam proses pengekstrakan data. Tanda aras ujian rangkaian eksperimental prosedur standard operasi telah dikembang dan boleh digunakan bagi eksperimen pengujian rangkaian kenderaan masa hadapan.

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This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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This is to confirm that:

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LIST OF ABBREVIATIONS

ACK	Acknowledgment
BCM	Broadcast Manager
CAN	Controller Area Network
CAN FD	Controller Area Network with Flexible Data Rate
CARB	California Air Resource Board
CPS	Crankshaft Position Sensor
CRC	Cyclic Redundancy Check
CSMA/CR	Carrier Sense Multiple Access/Collision Resolution
ECU	Electronic Control Unit
DLC	Data Length Code
EDR	Event Data Logger
EOF	End of Frame
GNSS	Global Navigation Satellite System
GPIO	General Purpose Input-Output
GPRS	General Packet Radio Service
GUI	Graphical User Interface
ICE	Internal Combustion Engine
ID	Identifier
IDE	Identifier Extension
ITS	Intelligent Transportation System
ISO	International Standard Organization
KWP	Keyword Protocol
LIN	Local Interconnect Network
LLC	Logic Link Control

MAC	Media Access Control
MOST	Media Oriented System Transport
NTC	Negative Temperature Coefficient
OBD-II	On-Board Diagnostic-II
OBU	On-Board Unit
OSI	Open System Interconnection
PCI	Protocol Control Information
PDU	Protocol Data Unit
PWM	Plus-Width Modulation
RasPi3	Raspberry Pi3
RPM	Revolutions per Minutes
RTR	Remote Transmission Request
SAE	Society of Automotive Engineer
SID	Service Identifier
SOF	Start of Frame
SOP	Standard Operational Procedure
SPI	Serial Peripheral Interface
SRR	Substitute Remote Request
SSH	Secure Shell
TDC	Top Dead Center
UDS	Unified Diagnostic Protocol
UART	Universal Asynchronous Receiver-Transmitter
V2V	Vehicle to Vehicle
VDS	Vehicle Diagnostic Server
VNC	Virtual Network Computing
VR	Variable Reluctant

VPW	Variable Plus-Width
VW	Volkswagen
WCDMA	Wideband Code Division Multiple Access

CHAPTER 1

INTRODUCTION

1.1 Background

It all began with the creation of a wheel, when the early humans tried to relocate bulky articles with ease. Then when the industrial revolution started, the invention of internal combustion engines (ICE) led to the creation of the early vehicles. Over the years, the use of ICE-equipped vehicles has increased dramatically. However, this rapid growth of vehicle technology has led to concerns on global warming, climate change, and energy saving among others. Hence, automotive manufacturers and engineers tried to develop new vehicle technology to address these concerns, focusing primarily on low fuel consumption and low emissions. To support increasing demands, vehicles were equipped with several electronic control units (ECUs), sensors, and actuators. A modern vehicle system has up to 100 ECUs producing more than 2,500 variables and signals [1]. Having several ECUs makes the system more complex, thus numerous vehicle specific buses and gateways are created to simplify the communication between ECUs [2].It should be noted that the most common scalable communication systems used for exchanging information over the buses are controller area network (CAN), local interconnect network (LIN), and FlexRay [1].

The ECUs produce the bulk of valuable data that can be used to assist a driver. For instance, vehicle monitoring is an attractive sensing application for mobile devices that allows users to monitor the position and condition of the car. This later on affects driving behavior. Various automotive manufacturers and companies have been developing systems to monitor a vehicle and its driver's behavior through smartphones. However, these systems are often expensive, unconfigurable, limited in terms of data collection, and yield inaccurate data. The ubiquity of mobile devices provides the opportunity to implement car monitoring on a larger scale quickly. The easy connectivity of mobile devices allows utilization of data for traffic management, traffic information, accident reporting, and other purposes [2].

Moreover, all these systems are based on data that is accessible from the internal network of the vehicle. To obtain this information quickly, there is a computer system called On-Board Diagnostic-II (OBD-II) that can provide the communication between the vehicles' internal network and outside world. The main advantage of the OBD-II system is that it is a more well-known way of knowing the condition of a car. If there is an error, the user can diagnose using a scan tool and then fix the problem [3]. Figure 1.1 shows the vehicle data extraction structure which includes the methods and the parameters that are significant for this process. It also illustrates different ways for transferring these data to the mobile application and user servers. Various communication protocols have been utilized for OBD-II throughout the years. Due to the fact that most of the manufacturers have recently chosen CAN as the main bus in the internal network of the vehicle, CAN can be set as the primary communication protocol between the vehicles and external OBD interface.

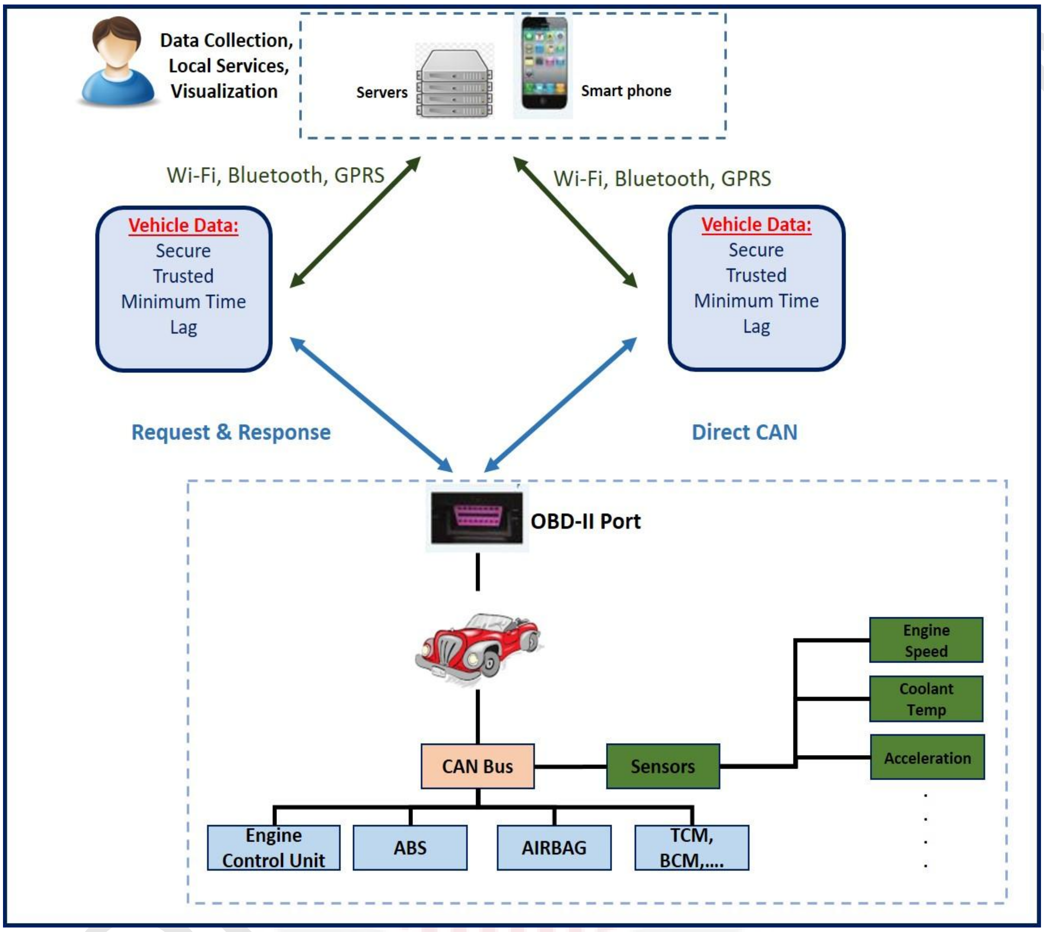

Figure 1.1 : Vehicle Data Extraction Structure

A modern vehicle produces massive amounts of data which corresponds to the continuously changing human requirements. Vehicle owners these days want to know the state of their vehicle, as in fuel consumption, location, and other useful information, remotely. Parallel to this situation is the microprocessor revolution of smartphones, tablets, and other mobile devices. The continuous improvement of space technology and wireless communications created a network chain between the vehicle and mobile phone users. Enterprises are encouraged to use this network chain, to track and monitor the vehicle. Moreover, the researcher and technology experts are trying to utilize this network chain to gather vehicle data for research purposes such as traffic management, traffic information, and driving behavior among others [2].

Most of the current studies rely on OBD-II systems for monitoring the vehicle parameters with common commercial tools. For instance, the vehicle monitoring system provided in [3] and [4]utilizes ELM327 as the OBD-II reader to extract the desired data (e.g., engine speed, vehicle speed, coolant temperature, and pedal acceleration) and transfer it to the user’s smartphone through Bluetooth. Another system that has been presented in [5] is used to analyze the driver behavior. This system based on the Android application and it communicated with an ELM327 interface to extract the vehicle information such as engine speed, vehicle speed, coolant temperature and pedal acceleration. After that, the data was stored in XML format for uploading to the web platform for analysis.

1.2 Problem Statement

Nowadays, OBD-II dongels (in-vehicle) interfaces is a wide-spread solution for extracting sensor information on vehicles (e.g., ELM327 uses as a data gathering device). However, there are some limitations for OBD-II dongels. Most of current data extraction approaches rely on the request-response model for data accessibility [2], [6], [7]. The low scan rate of the traditional request-response method will affect the accuracy of results, leading to extraction of inaccurate values which in turn reduces the performance of many dependent applications in the top layer (e.g., applications including driver behaviour information, automatic accident detection, real-time driving assistance, slippery road detection, safety)[8], [9], [10], [2], [7]. In general, for most of the cases using request-response model, the maximum (i.e., the fastest) feasible scan rate is only 9 queries per second which provide 8 data points per second in [11], [12]. Unfortunately, most of the past researches lack to consider resolution and trustworty of their input data extracted from OBD-II dongels [13], [14]. This may have a significant impact on reliability and trustworthability for the results of such researches. Ideally, it would be desirable to access data on real-time, guaranteeing the resolution and trustworty of input data by minimizing the time lag between each pair of consecutive measurements (i.e., query resolution).

Furthermore, using request-response with OBD-II dongles will force the ECU to enter a diagnostic session, resulting to suspend other ECU’s processes [15], [16]. This might be tolerable for vehicle’s non-safety processes. However, ECU provides priority to the safety-operations and stops OBD’s request-response queries. As the results, the overall query response time will be increased (due to query failures), leading to decrease the scan rate for the data extraction [17].

Most of OBD-II dongles are based on very low capacity microcontroller hardware which cannot provide in-vehicle data processing, rather they transfer data to an external processing device [18], [19], [20], [21], [3]. These systems do not have a high modularity and flexibility, due to their limitations in terms of both hardware and software. In fact, such systems are based on very low capacity microcontroller hardware which can run only a single process for the server-side. This leads to low rate date extraction due to weak hardware and also limits the communication to only one ECU at a time since the server can not serve more than one ECU in parallel.

The researcher must break apart, thoroughly inspect, and observe the internal network of the vehicle, which poses some risks [22]. In addition, purchasing or renting a vehicle for the purposes of this research would entail high costs and would likely cause severe damage to the expensive ECUs [23]. Consistently monitoring the CAN bus in the vehicle drains the battery in just a few hours. Either charging the battery or running the vehicle maintains the state of charge, but does not offer any portability in testing [24].

All of these factors have resulted in the extraction of inaccurate values, which might have affected the results in the analysis, algorithms, and driver application. Therefore, it is necessary to develop a new system to overcome these obstacles in order to create a reconfigurable, and programmable that is capable of multi-tasking. In this research, a system is proposed which is beneficial for research purposes and for the creation of a new platform. Furthermore, this study focuses on two different data collection techniques to gather more trusted and reliable data from the vehicles' internal network. In addition, an experimental vehicle network test bench create a vehicle simulation package that could simulate the ECUs functionality of the modern car while allowing portability.

1.3 Aims and Objectives

The main aim of this research is to develop a system that improves the modularity and flexibility to extract exact, trustworthy, and fresh car sensor data with higher frequency rates. The main objective are as follows:

1. To design and develop a programmable and latency-sensitive in-vehicle data acquisition system for vehicle telemetry applications.
2. To design and develop a multi-functional application, as a client-side, enabling the user to interact with the system efficiently while providing high level of flexibility and ease of use.
3. To design and develop a SOP (standard operational procedure) for vehicle network test bench, enabling to provide a reliable vehicle network, reducing

the risks of performing real tests and could simulate the ECUs functionality of the modern car while allowing portability.

1.4 Research Scopes

The scope of this research is listed below:

- The test bench consists of two ECUs which were physically extracted from the vehicle. The selected engine control unit and instrument cluster both using high-speed (500Kbps) CAN protocol where belongs to Volkswagen Polo (Year: 2013). The sensor simulation for test bench is limited only to water coolant temperature, air temperature, and engine speed sensor.
- A single-board computer, namely Raspberry Pi3 (RasPi3) has been selected as the development board which coordinate processes and stores data.
- Python programming language (version 3.0) has been selected for software application development.
- The Proposed system just provides features of the live data monitoring and data logging. The live data is limited to display an engine speed, a coolant temperature, an air temperature, and a battery voltage.
- The data acquisition process for mentioned sensors use OBD-II technology (request-response) and direct CAN, which cause to have OBD data and normal CAN data frame at the same time.
- This prototype data acquisition system is only can extract sensor data from the cars which have been equipped with high-speed (500Kbps) CAN bus as an internal network. Also, it can collect sensor data from the cars which work with TP2.0 and ISO-TP as a diagnostic communication protocol.
- CAN with flexible data rate (FD) will not cover in this study due to test vehicle is not equipped it.

1.5 Research Contributions

The contributions of this research are:

- Designing and developing a latency-sensitive, and reconfigurable data acquisition system for automotive telemetry applications such as driver behavior characterization, fleet management, and fault detection can be used as a part of Intelligent Transportation Systems (ITS) applications for increasing the effectiveness, safety, and resilience of the vehicle monitoring system. This study explore a new method for the extraction and storage of a selected subset of CAN bus signals, specifically engine speed, water coolant temperature, air temperature, and battery voltage to which use raw CAN bus data. A richer information like the one coming from raw

CAN bus data will provide high precision requirements for many real-time automotive applications such as autonomous driving cars.
- Developing the experimental vehicle network test bench with specific SOP for vehicle network testing is a time-consuming process. This thesis provide the bench and SOP which is not only safe to do experimental testing on a test bench, but also useful for training. A test bench is an affordable solution to safe vehicle network testing for research purposes.

1.6 Thesis Outline

The remainder of the thesis is organized as follows:

- Chapter 2 discusses the technical background information for understanding the underlying technologies and the work done by other researchers. It is divided into three sections:
  - Section 1 explains the CAN bus protocol for the automotive industry.
  - Section 2 describes the OBD-II system, dongles and the various transport protocols that are used for diagnostic purposes.
  - Section 3 reviews the related works that cover the various techniques for vehicle data extraction used for purposes of analysis.
- Chapter 3 illustrates the embedded system needed and utilized for the system to work as specified. The design software applications that are compatible with hardware are in this chapter as well.
- Chapter 4 contains the results of the system development and tests conducted on the prototype and existing alternatives. Furthermore, in this chapter, the prototype is compared with the existing systems in terms of data resolution, efficiency, and performance.
- Chapter 5 outlines the conclusions and recommendations for future work.

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Conference Publication

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K. Khorsravinia, M. K. Hassan, R. Z. A. Rahman and S. A. R. Al-Haddad, Integrated OBD-II and mobile application for electric vehicle (EV) monitoring system, 2017, IEEE 2nd International Conference on Automatic Control and Intelligent Systems (I2CACIS)}, Kota Kinabalu, 2017, pp. 202-206. Doi: 10.1109/I2CACIS.2017.8239058.

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K. Khorsravinia, M. K. Hassan, R. Z. A. Rahman and S. A. R. Al-Haddad, "New Method of Automotive Data Acquisition Efficiency Improvement in Intelligent Transportation System",", 2018 *Smartcity 2018 (The 6th International Conference on Smartcity)*, Malaysia, October 2018.

K. Khorsravinia, M. K. Hassan, R. Z. A. Rahman and S. A. R. Al-Haddad, "Improved Latency of Controller Area Network Vehicle Data Extraction Method",", 2018 *IOV 2018 (The 5th International Conference on Internet of Vehicles)*, Internet of Vehicles 2018, LNCS 11253, France, Paris, October 2018.

Journal Publication

Submitted :

K. Khorsravinia, M. K. Hassan, R. Z. A. Rahman and S. A. R. Al-Haddad, "Latency-Sensitive Enhancement of CAN Bus in Automotive Data Acquisition Platform for Intelligent Transportation Systems", *IEEE Journal (IEEE Transactions on Intelligent Transportation Systems)*, August 2018.(Under review)

K. Khorsravinia, M. K. Hassan, R. Z. A. Rahman and S. A. R. Al-Haddad, " New Method of Automotive Data Acquisition Efficiency Improvement in Intelligent Transportation System ", *Pertanika Journal of Science and Technology (JST) UPM Journal* , September 2018. (Under review)

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