Using Smart Phones to Assessment Road Roughness in the UAE

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Abstract

The pavement structure is a key component of the road network and transportation infrastructure worldwide. Major investments have been made in the United Arab Emirates (UAE) for the building of a wide road network connecting local cities and neighbouring countries. Regular inspection and maintenance in a timely manner are critical to maintain good ride quality and driving safety levels. As a significant component of pavement analysis, longer pavement monitoring is very important for the transportation system. Different sensing technologies have been dedicated to enhancing sensitivity, functionality, and performance since the middle of the 20th century. IRI is a measure of pavement roughness and it is a widely accepted performance index. Transportation agencies expend considerable resources using profiler vans to collect pavement roughness data. The use of existing accelerometers in smartphones as a collection of sensors is a possible alternative to collecting pavement performance equivalent data at a substantially lower cost and a higher degree of temporal resolution. To investigate the feasibility of such an approach, a prototype smartphone application was employed in this paper to collect International Roughness Index (IRI) data. The IRI data was obtained from three routes in the Northern Emirates in the UAE using a prototype program running on an Android smartphone. The analysis of collected data shows that consistent IRI values from various data collection runs can be generated by the proposed smartphone application focusing on other factors such as vehicle speed and vehicle type .Moreover, it is found that the average IRI data sets collected are strongly correlated with the measured IRI data collected by the Federal Road Department of Transportation using profiler vans.

Keywords
International Roughness Index, Smart Phone, Pavement.

1. Introduction

PMS and distress assessments of pavements have been utilized in developed countries for decades as a method to evaluate pavement conditions at network levels and project levels. Pavement condition models are used to predict deterioration of pavements based on historical data and serve as a tool to schedule pavement maintenance and develop future rehabilitation processes. Current practice necessitates qualified rates to conduct pavement distress surveys which cause issues in the process. Although objective data is available through monitoring systems, physical elements also are required to provide efficient maintenance. A more sophisticated tool for assessing the condition of pavements is the use of automated distress vehicles and tools, which is also expensive and not all agencies are able to afford using them.

The schedule for pavement conditioning surveying is usually done yearly or biannually in order to maintain the calibration of pavement condition models. It has been suggested by a few researchers that it should be conducted more frequently in order to detect abnormalities sooner and increase the risk of underestimation of the maintenance cost at a network level (Haider S., 2010). The benefit of frequent pavement condition data collection increases the probability of more accuracy for the developed pavement management programs. The purpose of this study is to address these limitations and problems through the development of a feasible and simple method that will systematically and continuously monitor and quantify pavement conditions of the total road network by making use of technologies that are already available in new cars, smartphones and relevant devices which are used in this study. The ever increasing popularity of big data and crowdsourcing techniques has been the focus of this study where the methodology employed is to use the data collected and integrate it into the pavement management system. The expected outcome is to possibly achieve 100% automation.

Transportation agencies usually minimize the agency and user costs and maximize the pavement condition in the life-cycle cost optimization of the PMS. They are giving little attention to the effect of M/R strategies on the other road users such as residents in close proximity from the road, industrial settlements, trade centres, etc.

Transportation agencies should develop a performance-based PMS which ensures the serviceability, accountability, stewardship, long-term financial plans, transparent investments, and the betterment of the communities. A framework that incorporates the states of land use, regional economies and trade flow, transportation modelling, pavement condition, environmental costs and socio-economic development indicators into the performance-based PMS is required.

Internationally, the practices of PMS are moving from condition-based approaches towards service-based approaches focusing more on customer-driven priorities. A service-based approach that expands traditional condition-based methods has to be balanced against the budget constraint, level of service and risk tolerance. However, transportation agencies have not yet addressed how dynamic traffic loads vary during the life-span of the pavement as a result of the economic evolvement. Currently, capital investments are somehow disconnected from PMS and must be fully incorporated within the decision-making framework. Even though some research has looked into uncertainty, few states of the practice models incorporate it on the performance curves. The economic impact of multiple strategies (i.e., rehabilitation versus capital investments) for condition, congestion, pollution and social cost, has not been addressed. The perception of congestion combined with a condition, highway capacity, and accessibility impact the personal choices of modes, routes and links (Donaghy and Schintler, 1998) and must be included in a wider PMS framework.

In most cases, the PMS is based on the Markov Decision Process (MDP) optimization method that has some limitations. The optimization programming of maintenance and rehabilitation strategies is calculated from the steady-state probabilities. However, in reality, the pavements under a given maintenance policy usually take many years to reach the steady-state and the proportion of the pavements are changing year by year. Therefore, the use of steady-state probabilities in the optimization objective function does not fully reflect reality, especially when this transition period is very long (Li, et al., 2006).

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Transportation agencies should develop a performance-based PMS which ensures the serviceability, accountability, stewardship, long-term financial plans, transparent investments, and the betterment of the communities. A framework that incorporates the states of land use, regional economies and trade flow, transportation modelling, pavement condition, environmental costs and socio-economic development indicators into the performance-based PMS is required.

1.1 Objectives

This paper aims at developing a framework to measure pavement ride quality from real-time data collection using smartphone technology and to investigate possible techniques to integrate the roughness measurements into the PMS at the MOID. Firstly, involves data collection and understanding of smartphone sensing as a potential challenge in data collection and the development of effective processing algorithms for data processing. Specific aspects from this part include the following:

•The development of a model for estimating pavement roughness that may be deployed in smartphone applications to collect the ride quality of pavement surfaces.

•Develop a framework and an experimental plan using a stochastic approach for crowdsourcing data collection that is based on uncertainty evolving from different factors such as vehicle type, vehicle speed, cellular phone mount, cellular device type and etc.

•Compare the roughness data measured by the profilometer and the smartphone application in order to find out the difference between the methodologies and calibrate the smartphone data.

2. Literature Review

A large number of the highway systems was already established in the late 60's and early 70's where there was an increased need for network maintenance and rehabilitation management due to the deterioration of the pavements and lack in available finance and infrastructure. Unfortunately, the practise was such that the roads had to reach a stage of near complete failure before measures were approved to rehabilitate it. Subsequently, this presented a major hazard to road users as their wellbeing was at risk (Mathavan & Rahman, 2014). Crisis management became the operational method and was certainly not ideal as all the roads were not maintained and repaired according to the Needs Analysis Cycle. The problem was that instead of maintaining pavements according to a need's analysis; unfortunately, more expensive rehabilitation needed to be implemented. The army in the United States also discovered that short term fixes like filling potholes and implementing emergency repairs was extremely expensive and there was an urgent need to find a strategy that made provision for continuous monitoring and maintenance of roads and pavements.
The first workshop on pavement management was conducted in two states in the US in 1980, the purpose of this was to establish goals and establishing criteria and priorities for long term and short term pavement management systems to improve, maintain and ensure a safe and efficient network system. This was evidenced as many states adopted this model and Arizona was able to save 14 million dollars during the first year from its plan on the optimization of maintenance on its 7 ,400-mile network with a projected saving of 101 dollars in a period of 4 years (Smith, 2017).

The World Bank was responsible for the development of a PMS software referred to as the Highway Development and management Model (HDM-1V). The main pavement condition indicator used was IRI as an indicator to develop maintenance programs.
The serviceability performance concept of pavements provides invaluable information to assist managers, pavement engineers and administrators. It is regarded as direct measurement of a combination of the comfort and satisfaction level of pavement condition with road users. There are various methods and indices available in order to measure ride quality which has evolved over time. The AASHTO Road test developed a concept which was founded on the user's perception as to the quality of the pavement at any given time.
The smoothness of roads has been established as being one of the main factors in rating the highway network which was determined by surveys that were conducted at a local and national level. The concept of a comfortable ride of Ride comfort came about as an imperative feature for road users more than any other aspect (Simpson, et al., 2013).
The present serviceability rating (PSR) as defined earlier was developed by the Highway Research Board where they used the AASHTO guidelines to determine PSR as being subjective analysis from the panel to establish whether the road has the ability to service the type of traffic it needs to service. Participants were asked to drive on the AASHO test track numerous times in order to rate the ride quality on a scale from 0 to 5 as indicated in Figure 1. The results indicated a relative error in PSR measurements of about 19% and resulted in restrictions of its use.

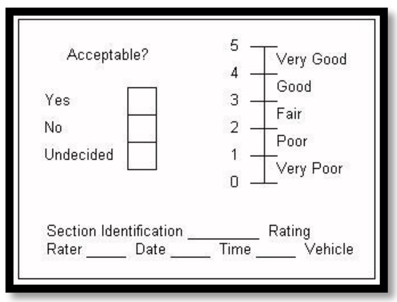
Acceptable?
Yes
No
Undecided
5
4 Very Good
3 Good
2 Fair
1 Poor
0 Very Poor
Section Identification ________ Rating
Rater _____ Date _____ Time _____ Vehicle

Figure 1. Example PSR

Panel ratings are subjective and is dependent on the understanding of the rater regarding the instructions and implicit biases they possess (Fesharaki,&Hamedi, 2016). Consequently, human subjects are partial, and the ratings becomes difficult to correlate to objective data which is why the panel-based rating system was not considered as an ideal method of widespread evaluation. There was therefore an urgent need to establish objective testing which caused agencies to work towards establishing a method for pavement smoothness that resulted with the ride quality index/standardized profile index. The objective was to give a precise value that would connect to the road profile. (Mohammadafzali& Ali, 2017). According to the National Cooperative Highway Research Programme (NCHRP). The profile index (PI) is defined as the root mean square (RMS) profile height of a section of highway after applying a band pass filter (10-50 Hz).
This model is the most popular one used throughout the world and will used for this study as well. There is a general consideration that there is a 10% improvement in IRI with the Half Model Car (see Figure 2), than the IRI quarter model car. Roughness is characterised by distortions in the pavement surface which contributes to an uncomfortable and undesirable ride. IRI is characterized as a scale for roughness that is established on the simulated reaction of a generic motor vehicle to the roughness in a single wheel path of the surface of the road (Baboukani& Sharifi, 2016). The method adopted in the calculation of the IRI, the road elevation profile has to be first filtered by using the 250 mm moving average filter and then the Golden Quarter Car model is used to simulate the vehicle suspension response to the pavement surface at a reference speed of 80km/hr.

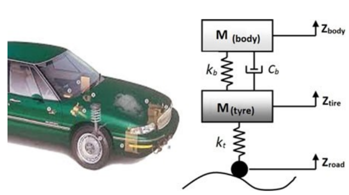

Figure 2. Quarter car model.

In order to maintain quality control for construction, precise measurement of the roughness is required to assist with defining contractor pay factors. There are three components that is needed for the evaluation of pavement roughness which include, first, an accurate measurement of the profile, second, a mathematical model as described above and third, an interpretation of the roughness statistic.

An algorithm used to identify potholes using 3-axis acceleration sensors with a GPS device was developed by Eriksson. They installed the device in seven taxis which was placed in the same location in order to reduce variations in the analysis. Data from the taxi revealed that it received data for 9730 km in total, 14 kilometres of the road was covered ten or more repeated passes and 2492 km of non-repeated road was covered. In order to ensure the accuracy of the pothole detection the method used for filtering data and the algorithms was aligned. The android smart cell for this pothole detection study was implemented. Unlike Eriksson, their method involved using different devices and their algorithm included self-calibration (Mednis, 2011). A completely different approach to detecting the extent and severity of potholes was carried out as recorded in Koch, Christian, Gauri & Brilakis, (2013) and involves video analysis of the texture of the pavement. The algorithm is designed to detect any change in texture and relate it to the pothole.

3. Methods

Methodological field and analytical plan which includes a compilation and evaluation of data gathered from selected road sections in the United Arab Emirates (UAE). This study focuses on the following three areas on which experiments will be conducted.

Data will be obtained from the three federal roads which have been selected (Khalifa Road, Fujairah-Kalba and Fujarah-Khorfakan) in the UAE which span around 71 kilometers. A Preliminary Study will be undertaken using mobile, vehicle-installed sensors and Automatic Road Analyzer (ARAN) networks technologies, with the aim of evaluating the comfort of the ride and to establish if improvements to the present condition should be done or not.

It is possible to map data gathered from smartphones through an application (RoadBump) to have instant feedback from drivers about bumps and vibrations on their journeys. Accelerometers found in smartphones are accurate enough to be used in measuring ride comfort. Also, vehicle-installed sensors - data (from cars built-in sensors) such as accelerometers and wheel speed sensors are processed by a Support Vector Machine (SVM) and are coupled with local and global positioning using GNSS data to identify sections with poor ride quality.

The above technologies will be used to assess the ride quality with reference to IRI, that is used to measure how smooth or rough a pavement surface is. The lower the calculated IRI, the smoother the pavement will ride. The higher the IRI, the rougher the pavement will ride.

4. Data Collection

The method applied for this research includes the use of a smartphone which has 3-axis accelerometers, gyroscope, GPS, and other sensors. The smartphone is positioned on the windshield with a cellphone mount (see Figure 3), and then, a standard smartphone application is utilized to gather the data from the device. The methodology to manage and evaluate the output from the accelerometer measurements will be explained in depth when the actual tests are conducted.

Figure 3. Smartphone setup in a windshield.

There are several android and iOS applications that can be utilized to note this increase in speed. The two applications used for this analysis will be AndroSensor and SensorLog for android and iOS devices respectively. These applications commence recording when the user chooses record and continue until the user pauses or stops the collection. The programs then produce a comma delimited CSV file that can be transferred to Excel. These applications record a timestamp, the geographical position, the 3-axis acceleration, the pitch, roll and yaw. Depending on the capacity of the device, the applications can record vibrations at very high speed, between 10-100 samples per second or even more. In this study, a sampling rate of 10 statistic points per second will be adopted based on the moderate speeds that will be utilized.
A collection of smartphone data introduces a physical component not connected to the vehicle's overall driving quality. In short, the smartphone records the motion of the smartphone itself and not the motion of the sprung and un-sprung mass, by using a smartphone to record motion. The location or orientation of the smartphone is another important consideration and the mobile device must be fixed either on the windshield or on the dashboard. Smartphones have 3-axis accelerometer as well as gyroscope sensors that can record the acceleration in the vertical position, longitudinal and transverse axis as well as the pitch, roll and yaw. With this information, the resultant vertical acceleration can be calculated from the vertical element of each acceleration.
A quarter car based approximation (essentially an assumption that the vehicle is fully symmetric) is first adopted to measure the response of the sprung mass, and then the mount is modeled using a spring and dashpot suspension assumption. In this case, the smartphone roughness measurement model is composed of the un-sprung mass and the sprung mass framework plus the contribution from the movement of the cellphone, similar to the quarter car model.
Surface irregularities in the asphalt (non-planar road profile) create vertical accelerations in vehicles. The magnitude of vertical acceleration, depends on the severity and frequency of pavement distresses and other surface irregularities, vehicle suspension characteristics, and vehicle speed.
A 3-axis accelerometer enabled cellphone can be used to collect vehicle vertical acceleration data, as demonstrated in some studies, such as the one conducted at the Massachusetts Institute of Technology in 2013 to identify localized pavement defects. An android-based cellphone application has been developed in the present study that can capture acceleration for the purpose of characterizing pavement roughness and individual pavement distresses.
Modern smartphones are equipped with a number of sensors including multi-axis accelerometers, temperature probes, gyroscopes, light intensity sensors, magnetic field sensors, etc.
The Roughness Capture application collects acceleration in three orthogonal directions, a timestamp, and GPS coordinates and stores them in an ASCII text file. Data collection rate is specified by the user, generally in the range of 10 – 100 samples per second, but higher sampling rates are possible depending upon smartphone hardware. In general, the higher the data collection rate, the better the accuracy of the estimated pavement profile (with diminishing returns at very high sampling rates).

The first phase involves (i) data collection and understanding of smartphone sensing as a potential challenge in data collection and (ii) the development of effective processing algorithms for data processing. Specific aspects of this phase include the following:

- The development of a model for estimating pavement roughness that may be deployed in smartphone applications to collect the ride quality of pavement surfaces.

- Development a framework and an experimental plan using a stochastic approach for crowdsourcing data collection that is based on uncertainty evolving from different factors such as vehicle type, vehicle speed, cellular phone mount, cellular device type…etc.
- Comparison of the roughness data measured by the profilometer and the smartphone application in order to find out the difference between the methodologies and calibrate the smartphone data.

The scope of the first phase include the collection of IRI measurements considering the following factors:

1. Number of road sections: 3 sections on three different roads
2. Type of smartphone: Only Samsung Galaxy
3. Type of vehicle: 2 vehicles (Sedan and SUV)
4. Type of smartphone mount: 2 (one Windshield and one Magnetic)
5. Vehicle speed: 2 (80 km/h, 100 km/h)
6. Number of passes (Replicate): 3 passes

Table 1 includes the design of experiment for Phase I. The filtering of IRI signals collected by the smartphone to match the standard profilometer IRI values will eventually lead to finding the prominent factors of those measurements and studying each of them separately by repeating the experiment several times with a variety of users.

Table 1: Factor combinations for the 6-factor full factorial design

Type of smartphone mount			Windshield		Magnetic	
Type of Vehicle			Sedan	SUV	Sedan	SUV
No of Roads	Vehicle Speed	Type of Smartphone	Number of IRI Replicates (Passes)			
Road 1	80 km/h	Samsung Galaxy	3	3	3	3
	100 km/h	Samsung Galaxy	3	3	3	3
Road 2	80 km/h	Samsung Galaxy	3	3	3	3
	100 km/h	Samsung Galaxy	3	3	3	3
Road 3	80 km/h	Samsung Galaxy	3	3	3	3
	100 km/h	Samsung Galaxy	3	3	3	3
Total Number of IRI Profiles			24*3 = 72			

The experiment was carried out on several federal roads in the United Arab Emirates, and as shown in (figure 3), the federal highway linking Dubai and Fujairah was used using a smartphone and was compared to Profiler van, with almost identical results, especially in the use of the SUV: Nissan Petrol. On smart phones, when measuring road roughness, and in phase no. 2, data will be filtered and the error rate will be determined in each experiment, allowing us to find the most accurate results.

5. Results and Discussion

This research shows that low-cost pavement roughness measurement technology at the consumer level has the potential to meet user needs in pavement management by returning results comparable to an inertial profiler. Using consumer software packages and industry-specific analysis methods to measure IRI from accelerometer data obtained from consumer smartphone devices, this research used a multi-step methodology. Data were compared with baseline data obtained on a 1 km test section of each of the three roads using an inertial profiler. The results observed support previous research showing that smartphone devices can be used to accurately measure road anomalies and expand information by successfully using a multi-step approach to find an industry standard pavement performance measure (IRI) comparable to an inertial profiler from consumer smartphone devices. The successful findings indicate opportunities for future research to discuss the unexplored components of this report, including:

•A longer test section with horizontal and vehicle curves and several types of surface with various degrees of roughness;
• Additional types of vehicles, including suspension monitoring, tire pressure and engine vibration;
•Paired tests of equipment in the same vehicle;
•Consistent recording frequency among applications with accelerometers;
• Exploration at 100 m and 10 m intervals of all IRI data;
•Effectiveness in meeting ERS for contractor self-evaluation;
•Potential for association with vibration of the entire body.

In order to make the measured IRI values closer to the inertial profiler values, further investigation of these and other factors could lead to the creation of correction factors that could be applied. How to understand the effect of the variability of these variables among the thousands of customer or fleet vehicles that could be potential data collection platforms remains a wider challenge, and whether a central pattern on a large scale will return significant IRI results.

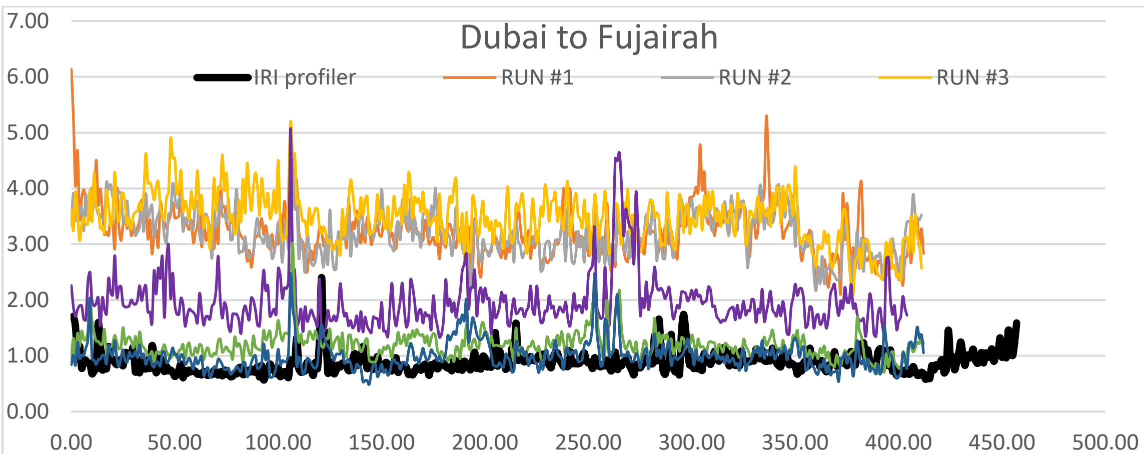

Figure 4. Dubai to Fujairah Individual IRI Measurement

6. Conclusion

All the necessary equipment and devices that have been selected for the study will be set up on the inside of the vehicle. The purpose of this analysis is to gather ride quality statistics by being dependent on the data gathered from motorists. During the study the following questions will be considered.

Does it make a difference when using one automobile?
Does it make a difference when using numerous vehicles?
Does it matter if extreme heavy duty commercial vehicles are used instead of standard sedans?

The objective of the Preliminary Study which will be conducted on Kalifa Road will answer the first question above with aim of highlighting individual random elements that can affect the Ride Quality Index (RQI) measurements. These results will be obtianed from the mounted smartphones on the dash board of the slected vehicle.

The purpose of the Comprehensive Study is to obtain extensive data that will reveal the RQI values by using the ARA, smartphone sensing and several vehicles. It is assumed that in the individual cases a smartphone-mount-speed-vehicle configuration will give a greater or lower RQI value, but in the event it is integrated with numerous other configurations, the outcomes from this study may differ.

In conclusion, the necessary data and outcomes will be establised when the actual tests or experiment will be done. With the latest thechnology and advanced systems in place, the expected results will be lot easier to obtain and will show a higher accuracy.

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Biographies

Saif ALQaydi was born in Sharjah, UAE. He is a PhD student at the Sharjah University in Engineering Management. He earned a B.S. in Electrical Engineering from Higher colleges of Technology, United Arab Emirates, Master of Business Administration in Canadian University, UAE. He is a member of the Society of Engineers. He has published journal and conference papers. He works in the Ministry of Energy and Infrastructure as the head of the engineering supplier's registration department. It conducts research experiments on federal roads in the United Arab Emirates for the sake of great benefit and development work from the construction and maintenance of roads to the Ministry of Energy and the infrastructure responsible for these roads.

Waleed Zeiada has been teaching in higher education and performing research for more than 20 years. He is currently an assistant professor of Pavement Engineering in the Department of Civil and Environmental Engineering at University of Sharjah. He received his PhD (2012) from Arizona State University, USA. He is an associate editor of the Innovative Infrastructure Solutions Journal and a reviewer in major international journals and conferences. He also served as a young member of the AFK-40 standing committee (Transportation Research Board, the National Academies of Sciences, Engineering, and Medicine, Washington D.C., USA) and an associate member of the Association of Asphalt Paving Technologists (USA). Dr. Zeiada is also a life time fellow of the International Road Federation, IRF (Washington D.C. USA). He has been participating in various service activities for his profession including technical, scientific, and conference committees. His research focuses mainly on the areas of pavement analysis and design, advanced material characterization, sustainable pavement strategies, pavement performance and rehabilitation, and pavement management system.

Daniel Llort is received the MSc University of Cadiz, Spain (Environmental Sciences applied to Entrepreneurship) and his PhD Researcher. Polytechnic University of Madrid, Spain since September 2000. From August 2010 to July 2012, he held the position of Technical Director for RAUROSZMCOM, S.L. in

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Ahmed Elwakil was born in Cairo, Egypt. He received the B.Sc. and M.Sc. degrees in Electronics and Communications from Cairo University and his Ph.D. in Electrical and Electronic Engineering from the National University of Ireland, University College Dublin. Since September 2000, He has been with the Department of Electrical and Computer Engineering, Sharjah University, United Arab Emirates, where he is currently a Professor. Prior to that, he was with the Egyptian Nuclear Research Centre. His research interests are primarily in the areas of Circuit Theory, Nonlinear Dynamics, Chaos Theory, as well as Fractional-Order Circuits and Systems with diverse interdisciplinary applications ranging from the modelling of oscillatory networks to energy devices and bio-materials. He has served as a reviewer, review committee member and organizing committee member for many international conferences including ISCAS, NOLTA, ICECS, ECCTD, ICM, NDES and ISSPA and currently serves as an Editor for the Int. J. of Circuit Theory and Applications (Wiley). He is also an Associate Editor of the Int. J. Bifurcation & Chaos, (World Scientific), the J. of Nonlinear Theory and its Applications (NOLTA), published by the Institute of Electronics, Information and Communication Engineers of Japan (IEICE-Japan) and the Int. J. of Electronics & Communications (Elsevier).