Journal of Traffic and Logistics Engineering Vol. 3, No. 2, December 2015

Analysis on Faults and Maintenance Uncertainties at Traffic Signal Junctions in the City of Johannesburg

Phalanndwa L. Makhwathana
Department of Electrical and Mining Engineering, University of South Africa, Florida, South Africa, 1710
Email: 47307075@mylife.unisa.ac.za

Shengzhi Du
Department of Mechanical Engineering, Tshwane University of Technology, Pretoria, South Africa, 0001
Email: DuS@tut.ac.za

***Abstract*—Like any other metropolitan municipality or roads authority in South Africa or other countries, traffic signals implementation is one of the recommended junction optimization techniques. Road traffic mobility can be negatively affected by various factors which degrade the effectiveness of signals control and monitoring systems. The more malfunctioning and congested the traffic intersections, the more frustrated the motorists. Among these negative factors, systematic faults and maintenance uncertainties are serious at intersections in the City of Johannesburg (CoJ) municipality. This paper analyses the challenges of existing road Intelligent Transport Systems (ITS) at more than 200 major intersections, and it also proposes the strategies and factors to be considered for improvement.**

***Index Terms*—intelligent transport systems, artificial intelligence, traffic control unit, uninterruptable power supply, efficiency**

I. INTRODUCTION

Major intersections are situated along major and minor arterial routes, within the City of Johannesburg (CoJ) municipality. Other intersections are along the collector or local routes, especially in Johannesburg CBD. Fig. 1 below, shows the CoJ map, with its arterial, collector and local routes.

More than 60% of the selected intersections have four or more street lanes, regardless of the direction of such lanes. Some of them have right-turning lanes, with special traffic signal light heads installed to accommodate the signal timing plans. Considered junctions can be categorized as 2-way, 4-way and T-junction. Their signal heads are also implemented accordingly, to comply with [1]. The length around such intersections is between 70 and 100 meters in approximation. Fig. 2- Fig. 5 show the layout of traffic signalized intersections with four or more street lanes.

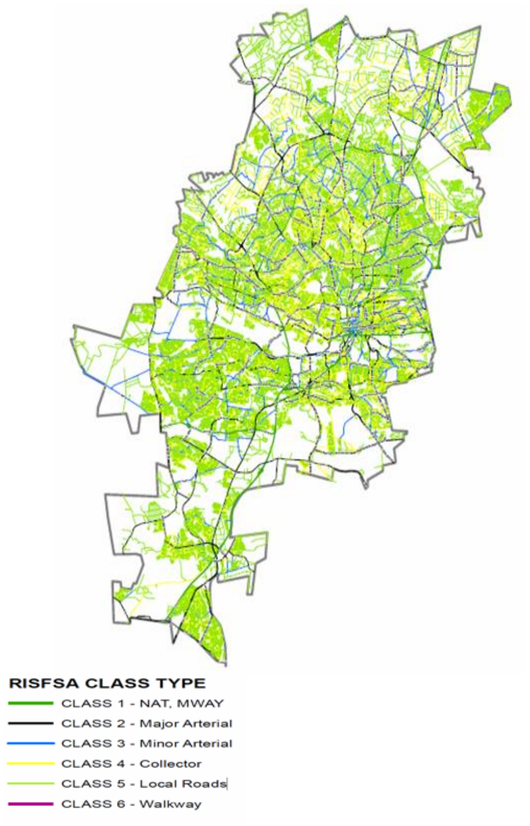

Figure 1. CoJ metropolitan municipality map

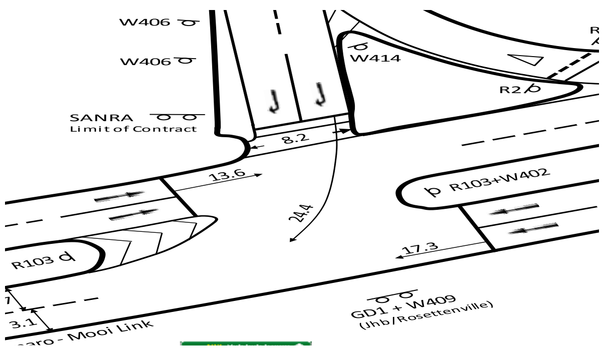

Figure 2. Junction with 2-way 4-lane street.

Manuscript received December 10, 2014; revised April 20, 2015.

doi: 10.12720/jtle.3.2.162-167

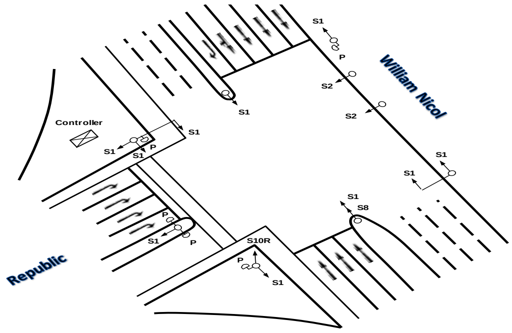

Figure 3. Junction with 2-way 7-lane street.

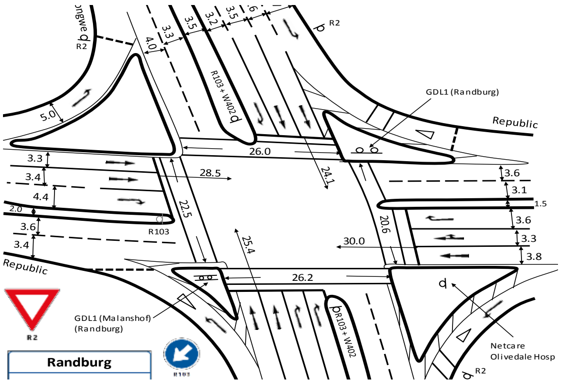

Figure 4. Junction with 2-way 5-lane streets and right-turn lane.

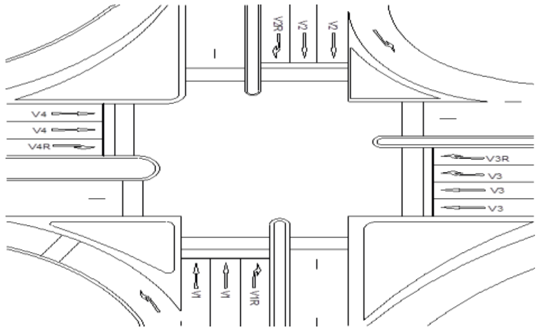

Figure 5. Junction with 2-way 5-lane streets and right-turn lanes.

Fig. 6 shows, in block diagram, the current ITS architecture of concern to this paper.

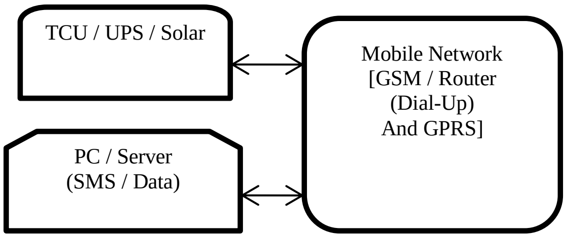

Figure 6.Current road ITS architecture.

Table I shows the information collected on alternative energy supply, at major intersections. The output power is of pure sine wave.

TABLE I: INFORMATION ON JRA'S TRAFFIC SIGNALS BACKUP AND ALTERNATIVE POWER SUPPLY SYSTEMS

Type	Power Out	Config.	η	Estimated autonomy	Maximum estimated load	Battery cutoff level
UPS	600VA	Line-interactive	67%	4 hours 2*54Ah 12V battery	500W @ 220Vac	10~20%
UPS	700VA	Line-interactive	67%	4 hours 2*54Ah 12V battery	500W @ 220Vac	10~20%
UPS	1500W	Stand-by	85%	7 hours 4*102Ah 12V Battery	500W @ 220Vac	10~20%
UPS	2000VA	Line-interactive	67%	4 hours 2*54Ah 12V battery	500W @ 220Vac	10~20%
UPS	3000VA	Line-interactive	70%	4 hours 2*54Ah 12V battery	500W @ 220Vac	10~20%
Solar	1500W	Hybrid (Solar &Gri)	85%	3 days Various batteries	500W @ 220Vac	10~20%
Solar	2300VA	Stand-alone	90%	7 days Various batteries	500W @ 220Vac	10~20%

Table II shows information gathered about the traffic control and communication components and the power supply.

TABLE II: TRAFFIC CONTROL AND COMMUNICATION COMPONENTS.

System	Components	Power source	Power rating
Traffic Control	Traffic signal controller	AC	+/- 70W
	LED	AC	< 15W
SCADA Communications	Modem	DC	24Vdc
	MCU	DC	12Vdc
	Router	DC/AC	12~50Vdc / 85~264Vac

II. FAULTS ANALYSIS

Systematic faults of concern in this research, which are reported by the public and through remote monitoring systems (RMS), as part of ITS, are all-out and flashing red. Such faults result from systematic interruptions on traffic signals. The interruptions may be caused by electrical power instability or fluctuations. Sometimes the utility grid may just be off, but when it is on, the Traffic Control Unit (TCU) may detect an error and keep the signals on flashing mode. [2] also give the relevant list of power line disturbances.

Johannesburg Roads Agency(JRA), the entity of CoJ, gets power supply for ITS, from Electricity Supply Commission (ESKOM), South Africa's main grid utility company or City Power, CoJ's entity for electricity, depending on area or region. Other junctions get electrical power from standalone solar systems [3].

It has been discovered and confirmed by utility companies' technical teams that in industrial areas, supply voltages are increased at mini-substations to cover up on the supply volt drops caused by heavy operations. Such mitigations, however, negatively affect the traffic signals operation as the voltage may rise above the maximum or decrease below minimum required input A voltage during peak and off-peak hours respectively.

At intersections with solar or uninterruptable power supply systems, there exist stored energy losses during supplying time. The lost energy is due to DC/AC power conversion as the main ITS is driven by AC power.

It should be noted that about 10~ 20% of stored energy must be retained per full battery bank discharge cycle, to maintain storage lifespan. So the energy to be used during grid supply off is very limited.

TABLE III: SEPTEMBER 2013 TRAFFIC SIGNAL FAULTS DATA.

Date (Sept 2013)	Daily faults recorded	All Out	Flashing Red
2	36	32	4
3	39	31	1
4	62	47	4
5	63	58	1
6	57	47	4
9	73	51	8
10	56	41	4
11	44	33	5
12	52	37	5
13	62	40	10
16	61	42	5
17	72	48	7
18	89	59	11
19	58	36	6
20	41	35	2
23	34	27	1
24	No data	No data	No data
25	45	38	1
26	38	27	8
27	No data	No data	No data
	Average daily faults	**Average A/O**	**Average F/R**
	52.74	39.42	5.63
		74.74%	10.68%

Table III shows traffic signals faults data recorded during September 2013, at major intersections. More than 95% of initial reports per junction were coming from members of the public instead of installed RMS.

Fig. 7- Fig. 8 are graphical analysis to show and confirm that of all daily faults recorded, an average of about 75% of all-out and 11% of flashing-red faults are reported, making a total of about 86%. The recorded data for months before and after September 2013 also confirm the analysis.

It is also deduced that recorded systematic faults affected almost 25% of major intersections, in average, during September 2013. This also negatively affects maintenance target of less than 1% of malfunctioning traffic signals per day.

The following formula was used when planning for existing alternative energy implementation:

$$Qreq = Qbb - Qoff \tag{1}$$

where, $Qreq$ = Required charge

Qbb = Battery bank charge

$Qoff$ = Cut-off charge

The stored energy Q is expressed in amp-hour (Ah) where

$$Q = I * t \tag{2}$$

for I = Charging current

t= Charging time

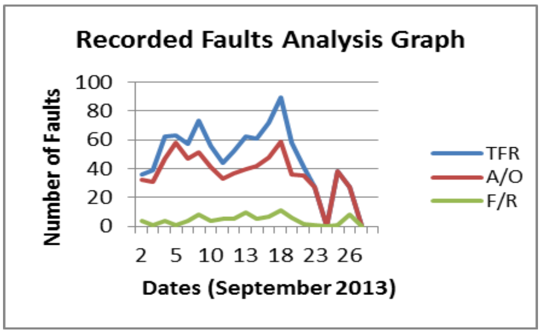

Figure 7. Recorded traffic signals faults analysis.

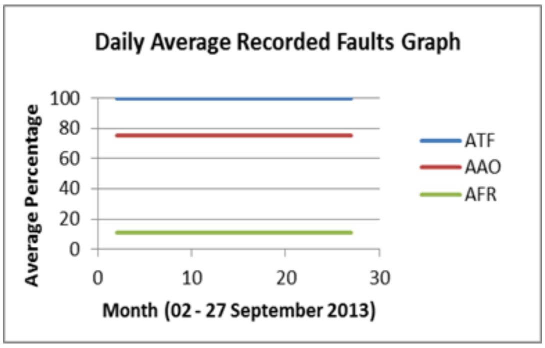

Figure 8. Daily Average traffic signals faults occurrence analysis.

From (1), it is further deduced that the load supplied power is derived as follows:

$$Pl = Vs(Qbb - Qoff) * \eta \tag{3}$$

where, Pl = Load supply power

Vs = Supply voltage in Vdc

η = inverter efficiency

Traffic signal intersection load can be obtained:0

$$Lt = L5(1+n) + L3(1+n) + Lp(1+n) + Ltcu \quad (4)$$

where *Lt*= Total load

L5 = 5-light head load

L3 = 3-light head load

Lp = pedestrian light head load

Ltcu = TCU load

1+n = quantity.

In the existing ITS, three UPSs of equal lead-acid battery banks have been charged to the maximum charge level, at intersections of different layouts and fixed timing plans. When the grid supply was switched off, their operating times were different. This is due to efficiency and timing plans related load per intersection. For instance, when many preview signal heads are used at other junctions, like four-way junctions, and the turning arrows are implemented for specific timing plans, such junctions require more electrical energy than others.

In traffic signals control systems, many controllers are very sensitive to the power supply. Such high sensitivity causes the intersection signals to flash red, then result in traffic congestion. The feedback from many light emitting diode (LED) lights has been found as one of causes of the problem.

Steps taken, by technicians and electricians, to eliminate such a problem, have always increased considerably high load against energy saving approach. Transformers, incandescent and halogen lamps have been installed inside controllers which could not withstand the feedbacks from LED lights. Such devices, however, have increased load with their high energy consumption. Therefore, such maintenance procedure is not energy efficient.

The additive load model in (5) is casually supported for quick maintenance that turns out to be permanent, for TCU stability:

$$Lab = Lt + Lx \quad (5)$$

where *Lab* = Abnormal load

Lx = Extra load

However, (5) ignores energy efficiency initiatives at traffic signal intersections as the alternative energy or backup storage is subjected to abnormal load and against expected autonomy.

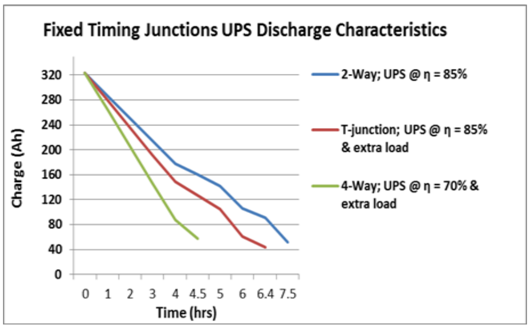

Figure 9. UPSs discharge characteristics

Fig. 9 shows the discharge curves of fully charged UPSs, at different intersections, starting at the same time.

From Fig. 9, we can concur with [4], that the lower the discharge time, the lower the efficiency.

Battery energy efficiency is described as a function of discharge current [5]. With the aid of discharge current characteristics of lead acid battery, he shows that low efficiencies are caused by high discharge currents. It is also a similar case, as can be analyzed from figure 9, of this paper. The higher the load, the higher the required current and shorter the backup time becomes.

From Table I, elimination of electrical energy double conversion can add approximately 15~30% of backup operating time per respective junction. At assessed junctions, extra loads constitute 15~30% of maximum estimated traffic signal junction load, resulting in wasted energy.

Considering traffic signals junction layout is very important, for synchronization and reliability support modeling. If the three examined UPSs where along the same main road, one after another, traffic signal junctions synchronization would be completely out, allowing for traffic congestion, especially during peak hours.

III. Maintenance Uncertainties

Current ITS systems experience a variety of maintenance uncertainties. Some of them are listed as follows.

- Different Supervisory Control and Data Acquisition (SCADA) systems have been implemented. Depending on the manufacturer of the traffic control system, some dashboard information does not give the true reflection of real-time technical information received from the intersections. An example of that is when the dashboard shows that the intersection is online, while showing the communication networks signal strength at zero.
- Some devices are of dial-up operation, which makes it difficult to receive real-time information. The worst is that a server connected to multiple in-station devices may have been allocated for groups of out-station devices, which causes confusion and inefficiency in ITS monitoring and energy saving respectively. Short Message Service (SMS) communication is used but some messages take longer to be delivered to their destination, so it is not always helpful.
- When power fluctuations take place, some intersections get to be reported as off, however, maintenance personnel may find the traffic signal system in good working condition. Sometimes, the grid power may be below the required minimum supply voltage.
- Available energy capacity per intersection is not measured per downtime, for maintenance priority. It makes it difficult to prioritize faulty intersections for maintenance against set standards.

IV. The Proposed Solution

There is a need to eliminate systematic faults interference through integrated and energy efficient ITS. According to the faults and uncertainties discussed in the paper, the following strategies are proposed.

Since the length around many assessed intersections is estimated between 70 and 100 meters, it is proposed that power distribution from the traffic controller to traffic light heads should be of regulated direct current (DC), in ring feed. According to [6], to reduce the risk of power supply distortion, uninterruptable power supply (UPS) systems are often incorporated in electrical networks. [7] also outlines different types of UPS, however, this paper proposes that UPS double conversion of electrical energy supply to traffic control systems must be eliminated.

Principles of maximum power point tracker (MPPT) have been demonstrated by [8], for photovoltaic (PV) generator special interface measures, to ensure that there is maximum energy transfer from the generator to the battery..It is therefore, recommended that intersections with solar systems need charging controllers with MPPT features. This will also increase the efficiency and autonomy of energy storage. Negative effects of utility grid instability shall also be eliminated. Fig. 10 below shows the standard AC/DC and DC/DC converters concept.

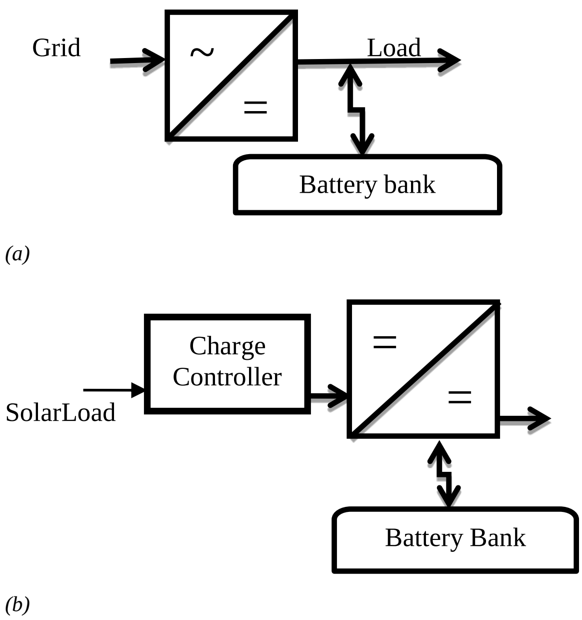

Figure 10. Standards conversion concept: (a) AC/DC; (b) DC/DC.

A model related to figure 10(b) has been developed by [9], for their ultra-low consumption traffic signals.

From Table I, elimination of DC/AC transfer function can increase 10~33 % of efficiency on currently implemented backup and alternative power supply systems. Confirmation can also be noted from [10] of approximately 15% increased power efficiency on its 357 ITS v2 cabinet model that operates on 48Vdc supply.

It is important to extract information from the intersection's backup power systems and signal timing plans, for performance time estimation when prioritizing energy restoration at intersections which are running on alternative or backup power. The complexity of processing such information needs some forms of artificial intelligence methods, such as Fuzzy Logic (FL) and Neural Networks (NN).

[11] also state that an artificial neural network (ANN) as a computing system is made of a number of simple and highly interconnected processing elements, which processes information by its dynamic state response to external inputs.

Such information is also important for on-road motorists' awareness, through Advanced Traffic Management System (ATMS).

Remote monitoring communication systems should also be configured in energy efficient manner. This includes having an in-station device that accommodates all out-station devices. Automated real-time information system configuration is important, for simultaneous multiple monitored and controlled traffic signal junctions. It is emphasized by [12] that in real time computing, the distinguishing feature of real-time communication is the fact that the value of the communication depends upon the times at which messages are successfully delivered to the recipient.

V. Conclusion

The recurring faults and maintenance uncertainties in the CoJ continue to show that there is a need for further improvement than just traffic signal and traditional maintenance culture. It should be noted that nowadays drivers have high expectations about traffic signals operations, as opposed to [13] who stated that from a driver's perspective, a traffic signal is just a collection of light emitting devices [usually incandescent bulbs or light-emitting diodes (LEDs)] and lenses that are housed in cases of various configurations (referred to as heads) whose purpose is to display red, yellow and green full circles and/or arrows.

The following are proposed, in this paper:

- Energy efficiency modeling should increase system reliability for road traffic mobility. Intersection optimization technique by using traffic signals should consider such models important, for sustainability and elimination of maintenance uncertainties. Double energy conversion and addition of abnormal loads decrease the expected autonomy of backup power storage, and this paper discourages such methods. Therefore, DC cabinets should be used.
- Junction layout should be considered during backup power supply and load planning and estimation.
- The complexity of extracting and disseminating advanced road transport relatedinformation should incorporate the application of artificial intelligence methods.
- The need for automated simultaneous multiple traffic junction real-time monitoring and control

needreal-time data communication for effective reactive maintenance.

REFERENCES

[1] *South African Road Traffic Sign Manual*, 3rd Edition. Traffic Signal Design, vol. 3, April 2001

[2] N. Mohan, T. M. Undeland, and W. P. Robbins, *Power Electronics. Converters, Applications and Design*, John Wiley & Sons, Inc., 2003.

[3] City Of Johannesburg. (September 29, 2011). Joburg chooses solar power. [Online]. Available: http://www.joburg.org.za/index.php?option=com_content&view=article&id=7238:joburg-chooses-solarpower&catid=131:transport&Itemid=213

[4] A. B. Cultura II and Z. M. Salameh, "Performance evaluation of a supercapacitor module for energy storage applications," *IEEE Trans*, 2008.

[5] S. Krauter, *Solar Electric Power Generation. Photovoltaic Energy Systems*, Springer-Verlag, 2006.

[6] Types of Uninterruptable Power Supply (UPS) Systems. [Online]. Available: http://www.thomasnet.com/articles/electrical-power-generation/ups-system-types

[7] N. Rasmussen. *The Different Types of UPS Systems*, White Paper 1, Revision 6. 2010, pp. 1-10.

[8] T. Markvart, *Solar Electricity*, England: John Wiley & Sons Ltd. 1994.

[9] H. Shiranaga and S. Ogawa, *Development of Ultra Low Power Consumption Traffic Signals with Magnetic Inversion Method*. 2012, pp. 1-8.

[10] Intelight. Intelight Cabinet Model 357 ITS v2. [Online]. Available: http://intelight-its.com/product/cabinets/item/98-intelight-cabinet-model-357-its-v2.html

[11] K. Y Lee, Y. T. Cha, and J. H. Park. February, "Short-term load forecasting using an artificial neural network," *Transaction on Power Systems*, vol. 7, no. 1, pp. 124–132, 1992.

[12] C. M. Aras, J. J. Kurose, D. S. Reevesand, and H. Schulzrinne, "Real-time communication in packet-switched networks," *Proceedings of IEEE*,vol. 82, no. 1, pp. 122–139, January 1994

[13] F. L. Mannering, S. S. Washburn, and W. P. Kilareski, P*rinciple of Highway Engineering and Traffic Analysis*. Fourth edition. USA: John Wiley & Sons, Inc. 2009.

Phalanndwa L. **Makhwathana** received N. Diploma from Vaal University of Technology in 2004, B. Tech degree from the University of South Africa, Florida, Johannesburg, in 2013, all in Electrical Engineering. He also obtained Civil Engineering technical certificate from Central Johannesburg College, Johannesburg, South Africa, in 2012.

He is currently completing M. Tech degree in Electrical Engineering at the University of South Africa. He has 11 years of ITS related experience, of which 7 years have been spent in the City of Johannesburg municipality, under Johannesburg Roads Agency, Gauteng province, South Africa. His research interests include energy efficient intelligent transportation systems (ITS).

Shengzhi Du received M.S degree in control theory and control engineering from Tianjin Poly Technology University, Tianjin, China, in 2001 and PhD degree in control theory and control engineering from Nankai University, Tianjin, in 2005.

He was a professor in the department of Electrical and Mechanical Engineering, University of South Africa, Florida, Johannesburg. He is now a professor in the department of Mechanical Engineering, Tshwane University of Technology, and Pretoria. He is also a member of IEEE. His research interests include control systems and pattern recognition.