Fuzzy Rule Based System (FRBS) assisted Energy Efficient Controller for Smart Streetlights: An approach towards Internet-of-Things (IoT)

Kiran Sultan
Dept. of Computer and Information Technology, JCC, King Abdulaziz University, Jeddah, Saudi Arabia
Email: kkhan2@kau.edu.sa

Abstract —In this paper, a dynamic and energy efficient controller based on Fuzzy Rule Based System (FRBS) is designed for controlling the light intensity of streetlights (SLs). As a matter of fact, the climate all across the world along with sunrise and sunset times are not the same, therefore, this paper targets the city of Islamabad, Pakistan as a reference for designing the controller. However, FRBS assisted controller is very flexible to extend and modify the rules to any other city with different weather conditions. It is capable of adjusting the SL's intensity level taking into account the month of year, time of day and environmental condition (clear sky, cloudy, foggy and traffic density). The rule surfaces are provided to demonstrate the careful application of fuzzy rules keeping in view even minor environmental variations.

Index Terms—Dynamic street lighting, fuzzy rule based system

I. Introduction

Smart Cities stands as a popular slogan, which describes a motivation to increase the comfort and safety of citizens while achieving energy savings. This concept has gained tremendous attention during the last several years and it involves the integration of citizen participation, Information and Communication technology (ICT) and intelligent management. In order to implement this versatile idea in real world, one of the necessary steps is the study of conventional installations and new intelligent innovations, so that traditional and modern techniques can be aggregated to offer the citizens a new taste of living [1].

In a step towards smart cities, intelligent street light (SL) system plays a vital and critical role regarding comfort and safety of both pedestrians and vehicles' drivers. Through careful and unobstructed line-of-sight (LoS) positioning of SL poles, the road-safety can be enhanced many-fold. However, the maintenance, monitoring and operation of conventional SLs involves a lot of human effort and consume a lot of energy. Surveys show that up to 38% of a typical city's total energy is consumed by streetlights [2], even for Europe, it goes high up to 60% [3]. One potential solution is Dynamic Street Lighting (DSL), i.e. making SLs smart enough to adapt to the dynamically changing environmental conditions. [4]-[5] are two examples of DSL proposals. One of the outstanding technology advancements towards the goal of reducing energy consumption is the invention of light emitting diode (LED), a technology giving 20 times more efficiency in contrast to the fluorescent lamps and other conventional light sources [6]. Furthermore, they have an advantage of long life, and being solid state devices LEDs are capable of getting dimmed [7], which is the prime requirement of this work.

Another recent technology advancement is Internet-of-Things (IoT), which aims to equip the things with cognitive intelligence enabling them to smartly observe, think, plan, decide and act accordingly [8]. These objects are embedded with hardware, software, sensors, and network connectivity and can connect with Anything at Any-time and Anyplace through any available network service [9]. With every passing day, hundreds of heterogeneous physical things are getting into the loop to share local information in real-time through the Internet, and thus, IoT is already into different domains of life including industries, healthcare, transportation system and personal data. It is estimated that IoT will surpass about 50 billion objects by 2020 [10]. Moreover, the reports of McKinsey Global Institute showed future confidence on IoT to generate a revenue of $3.9 trillion to $11.1 trillion per annum by 2025 [11].

Applying the concept of IoT to SLs, significant energy can be saved during late-night and/or low traffic hours while maintaining the quality-of-service (QoS) of streetlight system [12]. As traffic density and time of day need to be carefully catered for energy saving on one hand, however, on the other hand, the variation in weather such as cloudy or foggy during the sunny hours demand the SLs to be switched on even at daytime due to the decreased visibility under these severe conditions. Therefore, the SL system needs to be smart enough to be a best compromise between these diverse scenarios. The intelligence of IoT blended with automatic control to on, off and dim the SL based on environmental observations can raise the energy saving efficiency up to 50% [13]. Few contributions regarding IoT-based SL systems include [14] – [16]. [17] proposed intelligent LED driver for SLs loaded with self-diagnostics functions. Furthermore, an IoT-based control unit was developed with a sensor and communication interface for lighting

Manuscript received February 20, 2018; revised August 20, 2018.
Corresponding author email: kkhan2@kau.edu.sa
doi:10.12720/jcm.13.9.518-523

control and for physical layer-independent data transfer. In [18], the authors proposed a framework for IoT (FIoT) based on embodied cognition concept and configured the embodied agents for autonomous operation using Evolutionary Algorithm (EA) for smart SLs. Furthermore, for control system, Artificial Neural Networks (ANN) is employed. Yoshiura *et al*. proposed another low-cost, adaptable self-diagnostic smart SL system in [19], which turned on conditionally on the detection of vehicle or pedestrians.

L.A. Zadeh's concept of fuzzy sets has already flourished as a soft computing tool standing on strong foundations to intelligently handle the environmental uncertainties. Fuzzy Rule Based System (FRBS) is considered among the dominant and efficient Artificial Intelligence (AI) tools well capable of providing knowledge representation of human thinking. It involves learning, interpretation, thinking and decision making based on reasoning [20]. This papers aims to provide maximum visual comfort to the citizens while reducing the energy consumption. For this purpose, a weather and traffic density adaptive FRBS-assisted controller is proposed for smart SLs. The controller operates in a centralized manner controlling a cluster of SLs. The motivation behind central control is the synchronous operation of the SLs. Regarding weather conditions, the city of Islamabad, Pakistan is targeted. Thus, the Membership Functions (MFs) and fuzzy inputs need to be modified for any other city, however, the proposed concept of controller design will remain the same. Furthermore, for remote supervision, the controller can be accessed anytime from anywhere following the principle of IoT. Few standard communication standards for inter-streetlight communication are Wireless sensor networks (WSN), ZigBee and GSM.

The plan for the remaining paper is as follows. Section II explains the scenario for controller design followed by section III which explains the FRBS-assisted smart SL controller. Finally, the paper concludes in Section IV.

II. Scenario for Controller Design

The average power shortfall in Pakistan is increasing day by day and the people are facing this chronic power shortage in the form of long load shedding hours. One of the efforts towards power consumption control is the deployment of Smart SLs adaptive to the natural environmental conditions. The city of Islamabad, Pakistan is targeted due to the following two reasons. First, it experiences flavors of five seasons during one complete year, i.e. Winter (November-February), Spring (March-April), Summer (May-June), Rainy Monsoon (July-August) and Autumn (September-October). Second, during the months of late December and January, fog is observed in the mornings which needs to be catered in assigning the MFs to the consequent. Another important factor in addition to increasing LI during fog/haze is the correlated color temperature (CCT) of the LED. Generally, humans feel comfortable under low CCT, however, luminous efficiency of light source reduces significantly at low CCT value. On the other hand, an LED lamp with high CCT has less fog penetration capabilities. Therefore, CCT value should be carefully selected as a best compromise [21]. However, the selection of SL is beyond the scope of this paper.

Regarding twelve months, December and January observe minor time difference in sunset and sunrise times so they are combined as a single input in order to increase the computational efficiency of FRBS controller. The minimum and maximum time $(t_{\min}, t_{\max})$ for sunset and sunrise during the whole year is as follows. For sunrise, $(t_{\min}, t_{\max}) = (4:58am(June), 7:13am(January))$ .Similarly, regarding sunset time in Islamabad, we have, $(t_{\min}, t_{\max}) = (4:59pm(December), 7:22am(June))$.

As the target location is Islamabad (GMT+5hours), the other prominent factor of expected weather variation is Western Disturbances, apart from Rainy Monsoon, which cause rainfall almost every month with peaks in winter months. Therefore, "Clear Sky" and "Cloudy" are included as separates inputs to the controller. Finally, heavy fog in winter months is reported. However, fog is a definite phenomenon of winter, thus, it is incorporated by assigning a high intensity level at the output of FRBS Controller during the morning hours in December-January, rather than dedicating a separate MF and consuming more memory and computation time.

Finally, during night hours, the traffic density varies and significantly reduces after 22:00hours in Winter and 24:00hours in Summer in Islamabad, with number of pedestrians almost NONE. According to [22], traffic density stands among the other mandatory factors focused by international as well as local standards in the design of SL systems to save useful electrical energy. Different governments use different ways to implement it. As an example, some highway operators or governments switch every third lamp off, however, in this work, dimming of lamps will be done rather than switching off.

III. FRBS-Assisted SL Controller

All the observations spread over the complete year time are intelligently plugged into the FRBS-assisted controller in this section. Standard MATLAB Fuzzy Logic (FL) toolbox is used. The block diagram of Fuzzy Control System (FCS) is shown in Fig. 1.

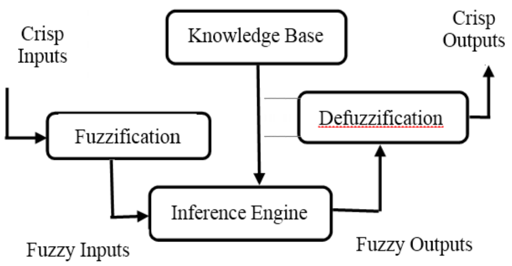


Fig. 1. Fuzzy control system

The control actions of FCS are based on fuzzy reasoning. The variables in the fuzzy system range over states that are FL based fuzzy sets. As illustrated in the figure, the fuzzy system translates the crisp inputs for fuzzy representation and converts back the outcomes into the crisp form after processing. The Knowledge Base is a demonstration of fuzzy vision of the outside environment to relate the inputs with the possible outputs. Each input/output variable in the Knowledge Base is characterized by a) a domain also known as Universe within which it takes values, b) its qualitative representation in terms of linguistic attributes, and c) MF.

Thus, FRBS-assisted optimization mainly comprises of the following steps [23]-[24]. First, for fuzzification, i.e. converting input linguistic variables from crisp form into fuzzy numbers, triangular and trapezoidal MFs are used in this work. Furthermore, AND defines the min and OR defines the max in this process. For every control cycle, this process repeats. These fuzzy numbers are fed to the second stage which is the brain of FL system known as Fuzzy Inference Engine (FIE). Standard Mamdani FIE is employed. The FIE is responsible to relate each input fuzzy variable to a particular fuzzy output using IF-THEN rules. Logic connectors and predicates combine to form IF conditions, while THEN statements indicate the most appropriate fuzzy attribute for the output variable.

As an example, suppose A and B are the input variables and C is the output variables and (A_1, A_2), (B_1, B_2) and (C_1, C_2) be the MFs covering the whole range of A, B and C respectively. Then, our rule base will consist of four rules of the form,

$$Rule: if \;\; A \; is \; A_1, \;\; B \; is \; B_2 \;, C \; is \; C_1$$

Finally, after all processing of the inputs by FIE, the defuzzifier generates actual output of the system in crisp form. Center of Area (COA) Defuzzifier is preferred in this work for its computational simplicity. For the above example with C as the output variable, the process of Knowledge Base and Inference Engine select the most appropriate MF $C(c)$ for the output. Thus, the eq. representing the COA defuzzifier to generate crisp output is given as:

$$\bar{c} = \frac{\int c\mu_C(c)dc}{\int \mu_C(c)dc} \qquad (1)$$

Therefore, summarizing the whole process of FCS:

i. Variables' identification
ii. IF-THEN Fuzzy Rules Formulation
iii. Defining MFs for the input variables
iv. Defining MFs for the output variables
v. Applying Rule Base
vi. Generating crisp outputs

The Fuzzy Logic System (FLS) for the SL controller is shown in Fig. 2. It takes Month, Time and Weather as inputs and generates the required LI at the output.

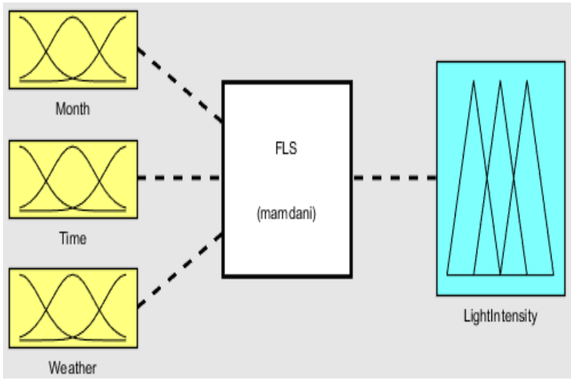
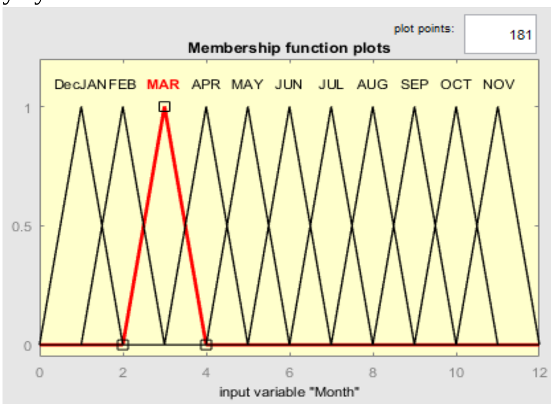
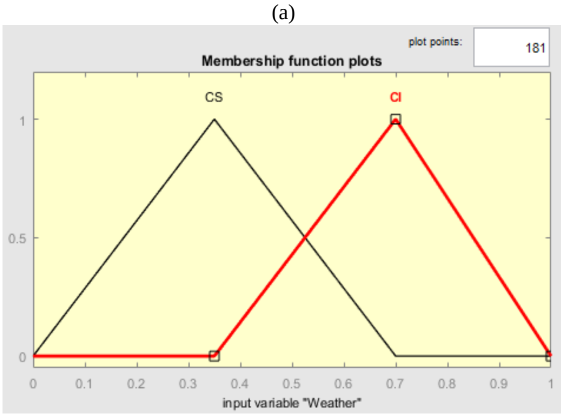


Fig. 2. Fuzzy logic system

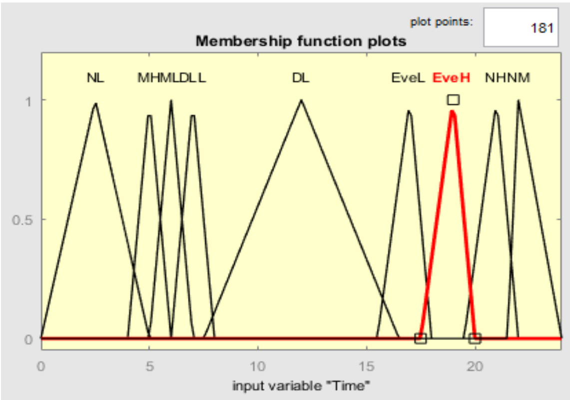
The MFs for the antecedents and the consequent are shown in Fig. 3. MF for any fuzzy set X in a universe U is defined as:- $\mu_X : U \rightarrow [0, 1]$. Referring to Fig. 3, regarding antecedents, eleven MFs define the month of year (due to the reason explained in Section II), nine for the time of day and two for weather conditions i.e. cloudy (CL) or clear sky (CS). As a matter of fact, the triangular functions of uniform and non-uniform widths represent the month of the year and time of day respectively. Regarding the output variable, i.e. LI, trapezoidal MFs are considered as a preferred choice to make an accurate decision by allocating a significant area under each MF for every combination of inputs. The dimming module controlled with Pulse Width Modulation (PWM) duty cycle will define nine MFs between 0(OFF) and 1(Full ON) for the consequent LI. Fig. 4 shows various PWM duty cycles.



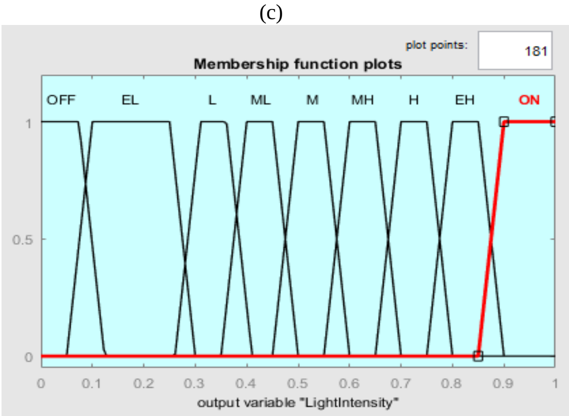
(a)



(b)



(c)



(d)

Fig. 3. Membership functions

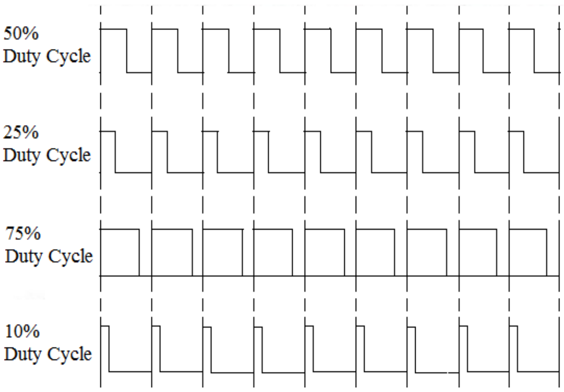


Fig. 4. PWM duty cycles

Referring to Fig. 3, there are total $11\times9\times2=198$ if-then rules for the FLS. For the convenience of reader, two rules are provided as an example to understand the decision taking phenomena of FRBS.

$$R^k : if \;\; Month^k \;\; is \;\; JAN, \;\; Time^k \;\; is \;\; EveL \;, W^k \;\; is \;\; CL$$

$$then,$$

$$LI^k \;\; is \;\; ON$$

$$R^l : if \;\; Month^l \;\; is \;\; JUN, \;\; Time^l \;\; is \;\; DL \;, W^l \;\; is \;\; CS$$

$$then,$$

$$LI^l \;\; is \;\; OFF$$

where, k and l are the indices of the above two rules in the Rule Base to be evaluated by FIE. The sophisticated selection of set of nine MFs each for time of day and output LI are provided in Table I below. For vehicle detection, LDR (Light Dependent Resistors) sensors stand as a suitable choice.

TABLE I: MEMBERSHIP FUNCTIONS

Time of day	*MFs*	*Light Intensity*	*MFs*
23:00-5:00	Night Low (NL)	≤0.1	Off (OFF)
5:00-6:00	Morning High (MH)	0.1-0.3	Extremely Low (EL)
6:00-7:00	Morning Low (ML)	0.3-0.4	Low (L)
7:00-8:00	Day Light Low (DLL)	0.4-0.5	Moderately Low (ML)
8:00-16:30	Day Light (DL)	0.5-0.6	Medium (M)
16:30-17:30	Evening Low (EveL)	0.6-0.7	Moderately High (MH)
17:30-19:00	Evening High (EveH)	0.7-0.8	High (H)
19:00-22:00	Night High (NH)	0.8-0.9	Extremely High (EH)
22:00-23:00	Night Medium (NM)	≥0.9	Full (ON)

The flow chart of the proposed model is given in Fig. 5.

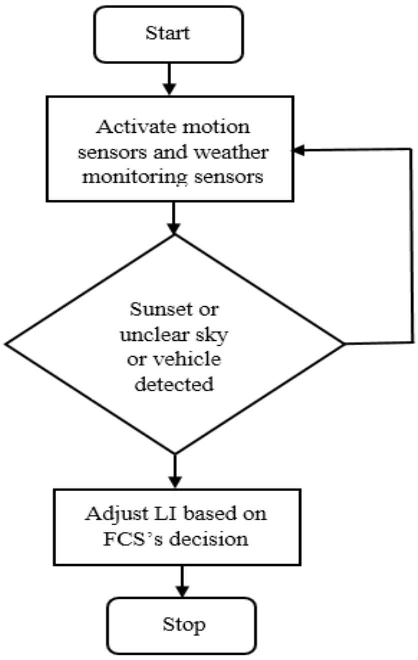
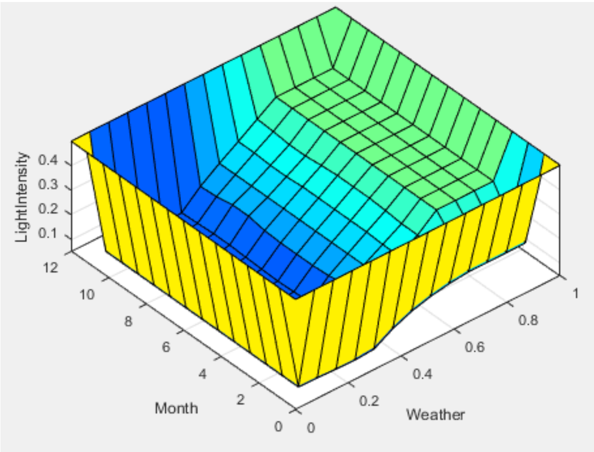
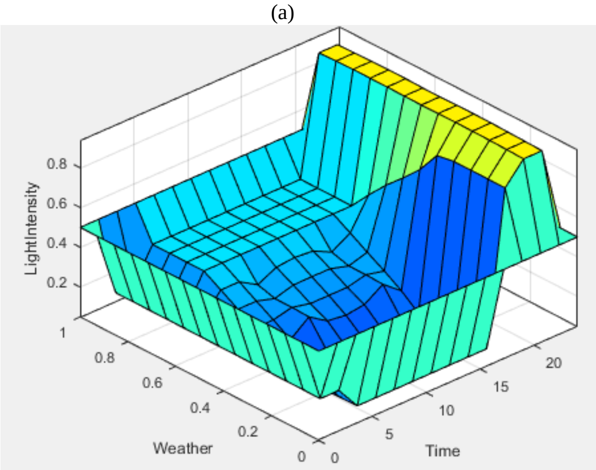


Fig. 5. Flow chart of proposed model

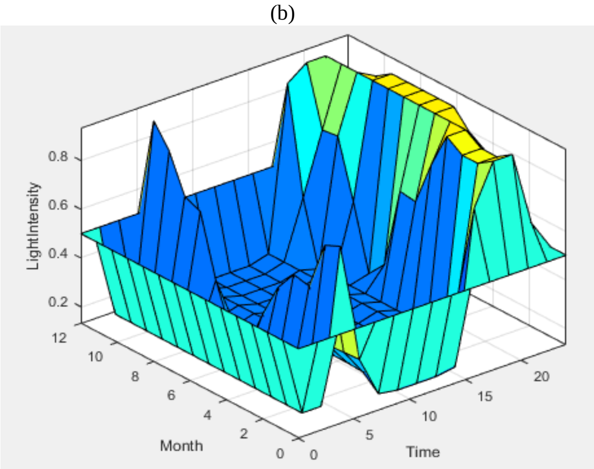
The rule surface is shown in Fig. 6 below. Fig. 6(a) demonstrates the relationship of LI with weather conditions over the whole year. The smooth transition of SL intensity from dim to maximum on sensing the cloudy weather condition can be clearly observed. Fig. 6 (b & c) illustrate the variation over one complete cycle of 24hours clock. In addition to the early sunset hours, the sharp peaks are observed in winter mornings and cloudy weather also which makes SLs to glow conditionally with high intensity at day time also. During late night hours, SLs are dimmed which does not pose any security risk to the pedestrians or vehicle drivers due to very low traffic density in those hours in the city of Islamabad. Furthermore, in contrast to conventional SLs, $LI \geq 0.9$, i.e. FULL (ON) condition is not set for all sunset hours which is a solid positive step towards energy saving. Fig. 6(c) clearly demonstrates the peaks of LI in early day hours during the winter months, however, during Summer, SLs are not required to switch on in those times except CL condition. Further energy savings can be achieved by careful handling of luminosity characteristics and actual temperature of LEDs.



(a)



(b)



(c)

Fig. 6. Rule surface

IV. Conclusion

Efficient city planning and intelligent resource management for energy savings while not compromising on the quality of life of citizens is one of the hot area of research. In this context, Fuzzy Rule Based System (FRBS) assisted controller is designed for streetlight control. FRBS stands as a classic Artificial Intelligence (AI) tool to efficiently handle the uncertainties. The energy savings are demonstrated by the dips and peaks of the rule surfaces taking into consideration the month of year, time of day and weather conditions. In future, this work will be extended to include cooperative spectrum sensing for detection and estimation of the speed and distance of the vehicles as well as pedestrians for more accurate control of the light intensity. Detection and estimation will be performed by passive sensor array at each SL, and individual results from SLs will be fused by the Fusion Center for final decision. Furthermore, numerical evaluation of energy consumption by SLs under different environmental conditions will be performed.

References

[1] M. Beccali, M. Bonomlo, and A. Galatioto, "Smart lighting in a historic context: a case study," *Management of Environmental Quality: An International Journal*, vol. 28, no. 2, pp. 282-298, 2017.

[2] V. K. Bhangdiya, "Low power consumption of LEF street light lased on smart control system," in *Proc. IEEE International Conference on Global Trends in Signal Processing, Information Computing and Communications*, 2016.

[3] European Commission, Lighting the Cities: Accelerating the Deployment of Innovative Lighting in European Cities, June 2013.

[4] R. Husin, S. A. Al-Junid, Z. Othman, K. K. M. Shariff, and M. F. Saari, "Automatic street lighting system for energy efficiency based on low cost microcontroller," *International Journal of Simulation Systems, Science & Technology*, vol. 13, no. 1, pp. 1473-8031, 2012.

[5] D. Kapgate, "Wireless streetlight control system," *Int. Journal of Computer Applications*, vol. 41, no. 2, March 2012.

[6] J. K. Kim and E. F. Schubert, "Transcending the replacement paradigm of solid-state lighting," *Opt. Express*, vol. 16, no. 26, pp. 21835-21842, 2008.

[7] M. Shahidehpour, C. Bartucci, N. Patel, T. Hulsebosch, P. Burgess, and N. Buch, "Streetlights are getting smarter," *IEEE Power & energy Magazine*, pp. 67-80, April 2015.

[8] H. Ning, H. Liu, J. Ma, L. Yang, Y. Wan, X. Ye, and R. Huang, "From Internet to smart world," *IEEE Access*, vol. 3, 2015.

[9] A. Khan, M. Rehmani, and A Rachedi, "Cognitive-Radio-Based Internet of Things: Applications, architectures, spectrum related functionalities, and future research directions," *IEEE Wireless Communications*, vol. 24, no. 3, pp. 17-25, June 2017.

[10] M. K. Patra, "An architecture model for smart city using Cognitive Internet of Things (CIoT)," in *Proc. Second Int. Conf. on Electrical, Computer and Communication Technologies*, 2017, pp. 1-6.
[11] S. Bhattarai and Y. Wang, "End-to-End trust and security for internet of things applications," *Computer*, pp. 20-27, April 2018.
[12] P. D. Toit, C. Kruger, G. P. Hancke, and T. D. Ramotsoela, "Smart street lights using power line communication," in *IEEE African 2017 Proceedings*.
[13] M. T. Koroglu and K. M. Passino, "Illumination balancing algorithm for smart lights," *IEEE Trans. Control System Technology*, vol. 22, no. 2, pp. 557-567, May 2013.
[14] B. Abinaya, S. Gurupriya, and M. Pooja, "IoT based smart and adaptive lighting in street lights," in *Proc. IEEE 2nd Int. Conf. on Computing and Comm. Tech.*, 2017.
[15] N. Ouerhani, N. Pazos, M. Aeberl, and M. Muller, "IoT-based dynamic street light control for smart cities use cases," in *Proc. IEEE Int. Symposium on Networks, Computers and Commun*., 2016.
[16] G. Cacciatire, C. Fiandrino, D. Kliazovich, F. Granelli, and P. Bouvry, "Cost analysis or smart lighting solutions for smart cities," in *Proc. IEEE ICC Green Communications Systems and Networks Symposium*, 2017, pp. 1-6.
[17] A. Szalai, T. Szabo, P. Horvath, A. Timar, and A. Poppe, "SmartSSL: Application of IOT/CPS design platforms in LED-based street-lighting luminaries," in *Proc. IEEE Lighting Conference of the Visegrad Countries*, 2016, pp. 1-6.
[18] N. M. Nascimento and C. J. P. Lucena, "Engineering cooperative smart things based on embodied cognition," in *Proc. IEEE NASA/ESA Conference on Adaptive Hardware and Systems (AHS)*, 2017.
[19] N. Yoshiura, Y. Fujii, and N. Ohta, "Smart street light system looking like usual street lights based on sensor networks," in *Proc. 13th IEEE Int. Symposium on Comm. and Info. Tech*., 2013, pp. 633-637.
[20] S. L. Blond and R. Aggarwal, "A review of Artificial Intelligence techniques as applied to adaptive autoreclosure, with Particular Reference to Deployment with Wind generation," in *Proc. Universities Power Engg. Conference*, 2009, pp. 1-5.
[21] H. Jin, S. Jin, L. Chen, S. Chen, and K. Yuan, "Research on the lighting performance LED street lights with different color temperatures," *IEEE Photonics Journal*, vol. 7, no. 6, Dec. 2015.
[22] A. Burgio and D. Menniti, "A novel technique for energy savings by dimming high pressure sodium lamps mounted with magnetic ballasts using a centralized system," *Electr Power Syst Res*, vol. 96, pp. 16–22, 2013.
[23] G. Fang, "A Survey on analysis and design of model-based fuzzy control systems," *IEEE Trans. Fuzzy Systems*, vol. 14, no. 5, pp. 676-697, Oct. 2006.
[24] J. M. W. Kickert and H. Koppelaar, "Application of fuzzy set theory to syntactic pattern recognition of handwritten capitals," *IEEE Trans. Systems, Man and Cybernetics*, vol. SMC-6, no. 2, pp. 148-151, 1976.

Kiran Sultan is currently associated with Department of Computer and Information Technology, JCC, King Abdulaziz University, Jeddah, Saudi Arabia. She did her Ph.D. from Air University, Islamabad, Pakistan in 2013 with major research area Signal Processing in Relay-assisted Cognitive Radio Networks (RCRNs). Previously, she did her Masters and Bachelors from UET Taxila, Pakistan in 2008 and 2003 respectively. Her research interests include Cognitive Radio Networks, Cooperative Communication, Detection and Estimation, Evolutionary Algorithms, Soft Computing and Internet of Things (IoT).