Sensor-Actuator Smart lighting System

System Organizational Concept and Challenges

Adnan Al-Anbuky

Electrical & Electronics Department
Auckland University of Technology
Auckland, New Zealand
Adnan.anbuky@aut.ac.nz

Abstract—the emergence of LED public lighting systems have encouraged offering wider range of public light utilization for services other than ambient lighting. Existing literature has highlighted engagement with issues relevant to energy management, visual health, environmental pollution, public security, and other. They have also looked into the communication standards and protocols from the management and maintenance perspective. Formulating a sensor-actuator network around the public lighting and integrating that with the Cloud computing should facilitate powerful environment for smart systems. This could offer ability to establish wide range of services. It should open up doors for researchers to evolve with intelligent concepts for smart cities. The system should interact with public space needs while looking into the energy saving.

The paper provides inside into the concept of possible sensor-actuator system for public space lighting system. The scope of the system operation and potential services has opened the door for suggesting an organization for public spaces data management and information handling. The Autonomic & heterogeneous system involves multiple levels of learning and optimization. The nature of the various services imposes the different level of criticality and promotes the delay tolerance approach in data management over the network organization. While at this stage the paper offer limited quantitative assessment to the approach, available indicators suggest that widening the scope of public space lighting to provide other publically needed services should offers better interaction with the public spaces. It should also make a more effective utilization to the investment made on the existing infra-structure.

Index Terms— LED light, Sensor-actuator network, Public-space services, Smart lighting, Energy Efficient lighting, Virtual Sensor-actuator Cloud.

I. INTRODUCTION

Lighting systems are important part of public spaces like parks, streets, and shared space. They facilitate sense of comfort and security to the user of these public facilities. Conventional lighting systems suffer from excessive energy consumption and lack of flexibility in manipulation. While street lighting goes back to 4000 BC or so (see table 1), since the late 19th century there has been significant improvement in electric street lighting system. Figure 1 reflects the progressive stages from the Arc lamps used late 19th century into the LED lights early 2000.

The advancement made in LED lighting systems demonstrates the potential for overcoming the conventional lightings issues. Energy saving of 70% or so is not uncommon [3]. LED light allow better manipulation and switching performance to the extent of utilizing them for optical communication purposes on top of the variable lighting functions. Recently there have been significant moves towards changing street lights into LED.

TABLE I. LIGHTING LANDMARK (SUMMARIZED FROM [1])

Events	Year
Lamps fuelled by oil	4000 BC
Candles	400 AD
Gas produce light	1792
Incandescent Lighting	1879
LED discovered	1927
Fluorescent Lamps	1937
LEDs	1965
High Pressure Sodium	1970
The LED revolution begins	2009

The feasibility studies prepared by the Remaking Cities Institute of the University of Carnegie Mellon in 2011 http://www.cmu.edu/rci/projects/closed-projects/led-street-lighting.html [3] has suggested the need for changing 40,000 street light for the city of Pittsburgh within the next 5 to 10 years. Here in Auckland, the New Zealand Transport Agency NZTA that looks after the lighting of public facilities is planning to replace around the same number of street lights for Auckland within New Zealand [4]. They have already dealt with areas like the surroundings of Eden park stadium where the International Rugby competition took place in late 2011. They did use the lighting management facility for presenting some sense of celebration.

Most of the research relevant to LED Street light has been around the energy efficiency, impact on human health and

operational reliability. Recently there has been some research work around enhancing LED street lights with wireless communication. Maintenance and Energy saving is the main motivation here. Street lighting is responsible for 19% of global use of electrical energy, and accounts for about 6% of the total emissions of greenhouse gases [5].
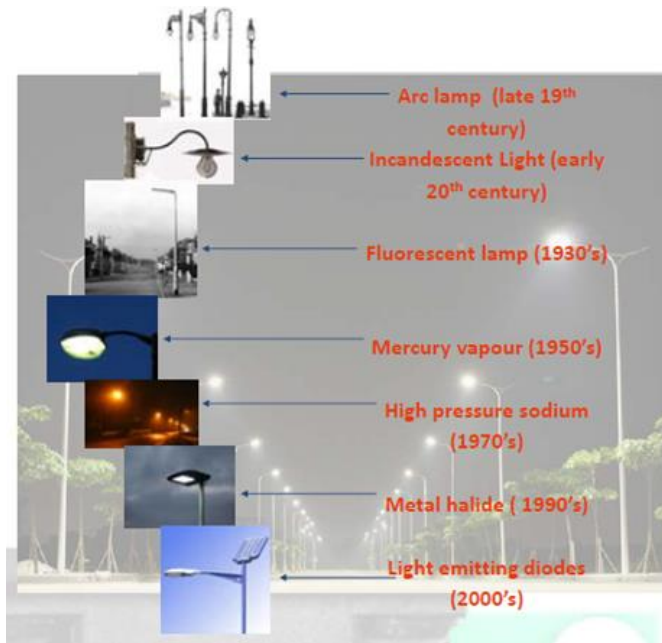

Fig. 1. History of electric street lighting [2]

Early research projects were carried out for investigating the effects of improved street lighting on crime in Dudley and Stoke-on-Trent of UK. In Dudley, they claim that crimes decreased by 41% in the experimental area, compared with a 15% decrease in a controlled area. In Stoke-on-Trent, crimes decreased by 43% in the experimental area and by 45% in two adjacent areas, compared with a decrease of only 2% in two control areas. In the two projects, the financial savings from reduced crimes exceeded the financial costs between 2.4 and 10 times after one year. It is concluded that improved street lighting can be extremely cost-effective [6].

A remote management system for street lighting has been presented by Domingo-Perez et al [7]. In this study they used Wireless Sensor Networks (WSN) along with the DALI protocol to expand the DALI initial constraint of 64 devices to a number big enough to be used in a remote street lighting management system. They looked into the prospect of saving energy and maintenance purposes, as it can detect any single lamp fault, allowing predictive maintenance and group replacement in the area of the failing lamp. Their future work recommendation is to integrate this wirelessly remote functionality into other lighting control protocols. This follows up the guidelines defined by the IP for Smart Objects Alliance (IPSO Alliance) in order to implement an interoperable

semantic level for the street lighting, and describes the integration of the communications and logic over the existing street lighting infrastructure [8]. An interoperable Smart Lighting solution over the emerging M2M protocols such as CoAP built over REST architecture described an implementation of a semantic layer for smart lighting. For that reason, this work has presented the example of the description for the IPSO Profile for Advanced Lighting Control [8].

Current literature reflects significant development to the way we equip, understand the essence of and deal with lighting in general and public space in particular. The inclusion of sensing, energy harvesting and communication into the lighting system has encouraged the smartness to be embedded into the system. Further enhancement to the infrastructure can enable the lighting system with further capability for providing other services apart from just lighting. Services like event monitoring, space condition inspection, Google map live support, interaction with public space local users and others. The later could also leverage on the infrastructure to allow for further saving in energy consumption. The combination of image, sound and thermal sensing accompanied with light management and Camera activation could play important role in capturing significant events related to crime or accidents. The data and information communication plays important role in integrating the information at different levels of the public space or event at multiple interrelated spaces.

The paper is organized in five main sections. The role of sensing within a public space is discussed next. This follows a section on the typical electronics involved at the lower level of the system organization. The concept for the overall system architecture is provided in section IV. Discussion around the possible organization that could facilitate an evolvable solution is given here. Conclusion remarks are then presented at section V.

II. ROLE OF SENSING THE SURROUNDINGS

The use of sensors can help significantly in supporting number of activities. Of these activities are:

1. Interaction with natural light in providing timely switching and appropriate dimming.
2. Interaction with public space users in facilitating and modulating the lighting level with the presence and absence of the users
3. Interaction with public space events relevant to accidents or crimes
4. Interaction with the surrounding sub-spaces and lighting system condition in facilitating remote coordinated monitoring purposes.

Ambient light sensors could be used for detecting the changes in natural lights. This could be either weather related like dark clouds or the transition of sun-set or sunrise. The 400

Lux are normally required for outdoor public space lighting. Dark clouds could also be confused with sunset. This problem can be elevated by the addition of a Real Time Clock. Table 2 below reflects the luminance of natural light in different condition [9]. The 400 Lux is considered as standard require luminance at night with the minimum of 20 Lux. The duration for the sunset and until reaching total darkness or sunrise and up until reaching the 400 Lux of ambient light could be around 30 minutes or so. Ramping the light up or down for these regions may contribute to the energy saving. Although the behavior may be represented by a polynomial, the extra gain may not worth the complexity involved. It has been estimated that around 3% of light energy saving could be gained through ramping the light up or down during the sunset and sunrise respectively.

TABLE II. SUNLIGHT WITH REFERENCE TO LUX [9]

luminance (Lux)	Conditions
110,000	Bright sunlight
20,000	Blue sky, Midday
10,000 – 25,000	Overcast day, Midday
<200	Dark storm clouds, Midday
400	Sunrise or Sunset on a clear day
40	Fully Overcast, Sunset/Sunrise
<1	Dark storm clouds, Sunset/Sunrise

The infrared or human sensor is another useful type of sensors that could help in identifying presence or absence of objects in the space. The light in a street for example could be dimmed to the minimum of 20 Lux during the night if there are no objects in the space. Otherwise the light will be set up to 400 Lux. Figure 2 illustrate the possible savings in energy when interacting with the users. Here using LED instead of HPS lamps could drop the need for energy to 48%. Further 3% drop due to gradual change in the luminance level up and down with sunset and sunrise respectively. Up-to another 12% could be gained by interacting with absence and presence of public space users. Further gain could be obtained through energy harvesting using solar, wind or other natural energy means.

Another sensor that can interact with the surrounding and influence the effective utilization of light is the sound sensor. Table 3 summarize the decibel level of sound related to number of relevant activities. The sound could differentiate the type of public space user. It could also identify hazardous situations like car crash or criminal act like firing a shotgun. Such identifier could be associated with the required lighting service. For example detection of crash or gunshot may require full light to be switched on associated with action like activation of a camera or alarm. On the other hand detection

of human object within the space may result in raising the level of light from dimmed to full for the duration of the human presence.
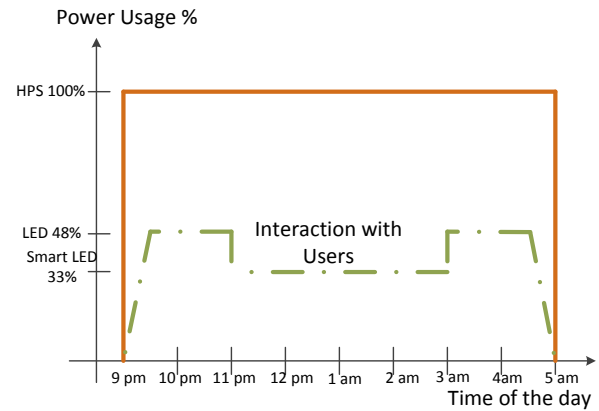

Fig. 2. LED light energy consumption relative to HPS lights [2]

Associating sensor-actuator network with the light system should help providing a flexible environment that could facilitates multiple services. Light manipulation together with motion, sound and image sensing may allow for interaction with public space users. This in effect could offer timely and customized lighting for the type of users and associated functionalities.

TABLE III. SOUND LEVEL IN DBA FOR DIFFERENT SITUATIONS [10]

Sound Level (dBA)	Conditions
35	Very quiet room fan at 1 m distance
45	Noise of normal living; talking
60	Noisy lawn mower at 10 m distance
75	Passing car at 7.5 m distance
85	Traffic noise of passing trucks at 7.5 m distance
130-160	Shotgun Firing

III. ELECTRONIC ORGANIZATION FOR SUPPORTING LED LIGHTS

The argument here is that most of the ruler public lights may not be used for good part of the night, so why having full light all the time. On the security ground, capturing and tracing the event using infrared, sound and image sensing at appropriately chosen distributed locations should significantly help. This should facilitate enough data for constructing the necessary forensics of a particular event. Using the coordinated actions of sensing and lighting helps gathering sufficient bits of information that will provides a baseline for

removing the noise and constructing clearer picture on the event. This in effect facilitates an environment for the development of public space ambient intelligent system. The facility may provide further services like dynamic support for Google map, public facility monitoring for maintenance purposes or even remote monitoring of facility condition for tourist purposes.

Other aspects that support the argument of sensor-actuator-lighting system are that of weather condition monitoring and vehicular driving. Manipulating street light according to weather condition is also another area of importance. Light color rendering is gradually becoming affordable and hence facilitating better visibility at times when the surrounding atmosphere is fogy. Literature has indicated that this would significantly help reducing road accidents [4].

Figure 3 suggests an example for a node of sensor-actuator system. This has been used as a basic building block for facilitating flexibility and smartness in street lighting systems. On the sensing side the light, motion and sound sensors are used. On the actuation side the LED light, the Camera and the energy harvester units are suggested. These devices are managed by the wireless controller unit. Both sound and image sensing are data-intensive and may require local signal and image analysis when it comes to real time services. Smart cameras for example would be more effective when it comes to visual event sensing. Trade off here depends on cost involved and how the space is to be monitored.
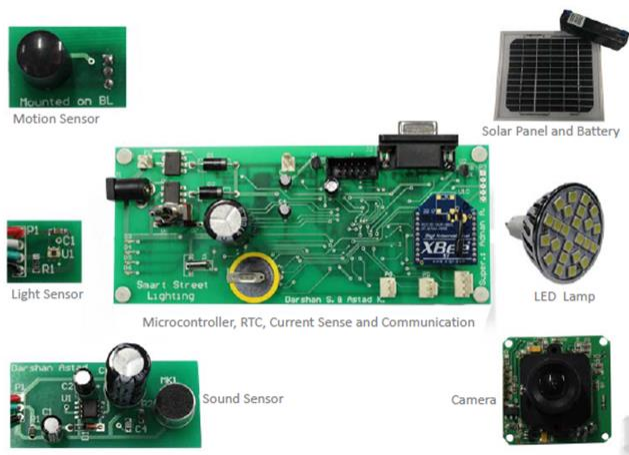

Fig. 3. Elements of a sensor-actuator smart LED light system [2]

While the use of LED light and related intensity management can save significant amount of energy, the use of energy harvesting could provide the remaining necessary energy. We have tested a 5 watt solar collector in a mild wintery day in Auckland. Figure 4 reflects the trend of output current during 8:00 am to 4:00 pm. With a 12 ohm, 50 watt load attached to the panel (simulating the battery) an approximate harvesting of 0.02 kW or 1.35 Ah. While this could cover good percentage of the energy required, it is only used for demonstration purposes. The steady progress in the technologies of both LED lights and Energy harvesting devices encourage improvement in the system form factor which also leads to improvement in cost.
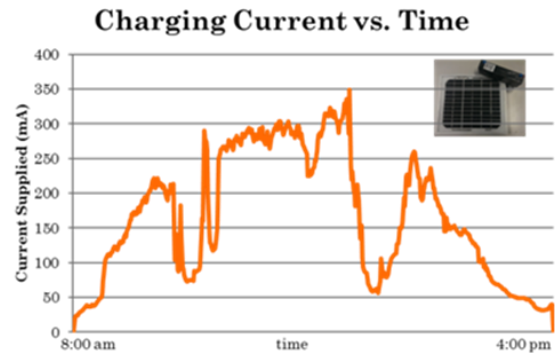

Fig. 4. Typical energy harvesting profile using an example 5W solar panel during an Auckland Winter day [2]

Further important element into the architecture is that of the wireless controller. This enables the two way communication among lighting posts to take place within the sensor-actuator network, facilitating the flow of sensed data and enabling remote management of the system to take place ubiquitously. The sensor-actuator network architecture would then be tailored to suit the basic coverage of the related space. The concept has been prototyped and tested successfully on small network of 4 nodes [2].

Figure 5 reflect an example of street lighting distribution. One may consider interaction with the lighting system on individual lamp posts basis. It may also take the form of predefined groups of post. This will basically be driven by the availability of a logically complete unit for spatial information. If we have all type of sensing available at each pole, then the pole is considered as logically complete even though it is considered as incremental part of the bigger space.

Fig. 5. Lamp posts could be bundled as groups in representing road sectors

However if the heterogeneous sensors are distributed over the poles, then the group that contains complete set of sensors is considered logically complete. It will have the ability to interact with the sensors data and work out relevant information. Grouping may also align with the functionality of the space like a road junction, a shared space, a small park and others. The organization may be formulated virtually through the network and computational resources while utilizing the sensing and actuation infrastructure. While the structured organization of the lighting management system is not the subject of this paper, the data communication system will benefit significantly from the synergy with the nature of system operational requirement. For example if the application is to manage lighting of pedestrian walkway for energy saving purposes, then lamp-post level management is acceptable. However, if the application is relevant to a vehicular highway, then grouping of poles will be more appropriate.

IV. FUTURE PROSPECTS IN SYSTEM ARCHITECTURE

Wireless communication facilitate conduit for sensing, management and control data flow. The network topology should help in formulating group management when it comes to interaction with public spaces functionalities and uses. Depending on the degree of involvements required and the way a given lighting sector (see for example at Figure 5) is organized, the lights may be organized in groups. Each of these groups covers a given sector. This could work as a way of clustering the system to run the various services. A sector head may have involved functionality. It could act as a gateway to the GSM network or an IoT enabled node. Meanwhile the remaining members have reduced functionalities. This is basically related to the type of sensing coverage required. It should also relate to how the solution may scale up. If for example the system is dealing with visual events that require forensic analysis before presentation to the end user, then there will be significant amount of data and processing involved. This in effect will have its impact on the network performance and hence the required quality of service.

Take for example management of lighting and data for a public park like Albert Park at city center of Auckland city (see figure 6 below). The park is adjacent to two major New Zealand Universities. These are Auckland University (~30,000 students) and Auckland University of Technology (~ 18,000 students). Public and in particular students and staff of these two Universities enjoy using the park as a short cut to the city's public transport. While at day time the park is quite pleasant to use, it is quite hazardous at night time and in-particular for young ladies. Security wardens run regular patrols throughout the park during late evening hours. The park is populated with lighting poles alongside the walkways. Complementing these lights with distributed heterogeneous sensing will help providing sufficient data on a given event.

This park for example can be partitioned physically into sectors. Each of these sectors may offer monitoring of the region around one of the key accesses to the park. Dynamic real time traceability of hazardous movement within the park would require analysis of numerous mixed types of data, signals and images coming from various sectors of the park. Using the remote servers for the analysis and alarming may prove challenging. It is therefore essential to look into the physical sensor cloud as the main provider of the early warning while waiting for the data to travel over the various networks.

Fig. 6. Typical public park (Albert park, Auckland-NZ)

Figure 7 suggest an organizational model for the data flow of sensor actuator smart lighting network. Sensors relevant to a given physical sector of the public space may be clustered to formulate logically complete functional unit. The unit performs the necessary sensing and actuation when interacting with relevant physical sector. For example the light may be modulated according to the presence and absence of users or natural light conditions. It may also interact with abnormal events like accidents or crime to facilitate the necessary ambient lighting for deterring the crime and also visually capturing the event. Analysis of sensing data relevant to given sensors may promote activation of light or image sensing.

Each sector may coordinate communication with all members and prepare the necessary bundle of information about that sector. While these units tend to have limited resources, it does make sense to have some level of data processing that allows important feature to be extracted. This in effect helps providing timely alarms specially when dealing with data intensive sensing like vision or vocal sensing. The sector coordinator may route its data (row and processed) through either the private communication network of the physical space, communication available for the smart grid, or the local cellular network. The sector may act as a member of the Internet of Things IoT and route its data through the Internet to any local or global users. It may also coordinate with other sectors in preparing an environment for dynamic event traceability.

Operational management and information processing that takes place at the physical sensor networks level should

provide good indication to important features of key events. Raw data transportation over the wider network should formulate feed to the structure of data repository within the virtual sensor cloud. This in effect helps analysing more involved features, facilitate learning and optimization parameters for the system to be adaptive, and feed the various relevant end user services.
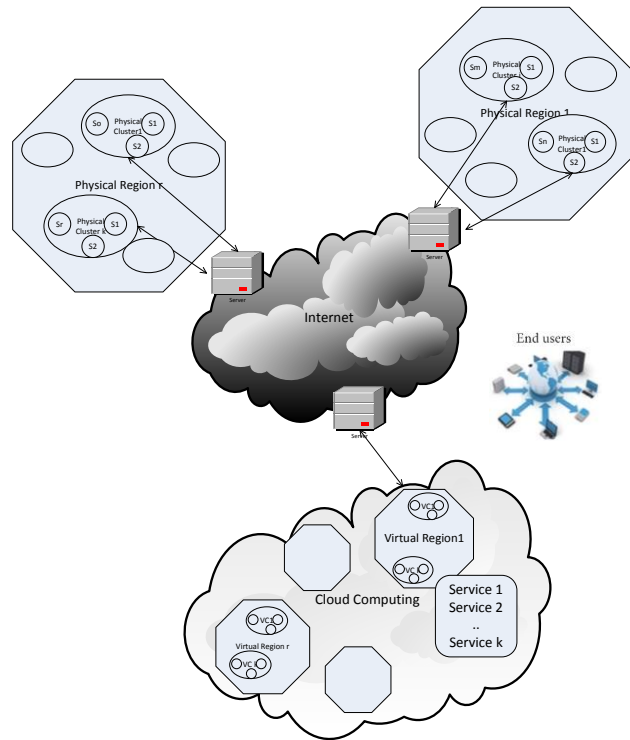

Fig. 7. Perception for public space data management network organization

The above organization may take the form of a highly distributed system supported by delay tolerant network. Dynamic optimization and learning will support evolving the system to be an efficient provider for multiple services. This should take place in an autonomic form at various levels from the physical cluster to the virtual cloud. Key challenges involve critical services like that relevant to hard real time services. Real time traceability of crime event within a public space is a valid example here. In this case optimizing the use of the physical sensor-actuator network should help. Here providing rough or even indicative forensic and event analysis while forwarding the data to the virtual cloud will formulate the basis for early warning. The System should then take the time for data transportation and thorough analysis. Local servers may provide the essential real time data handling on functionality of the defined spaces like for example small district, public parks, or shopping cluster. It will help integrating the clusters' information and reveal information relevant to the traceability of the event. The organization should facilitate an environment for evolving the intelligence in spatial event capture and data handling.

V. CONCLUSION

The paper discussed the role of sensor-actuator smart public lighting network in facilitating range of public services on top of the energy saving. Public lighting formulates an important part of any modern city infrastructure. On average it consumes around 20% of the city's overall consumed energy. There have been numerous attempts for interacting with public lights and from various perspectives. These includes energy saving, security aspect, health, management, communication standards and protocols and others. Defining an integrated solution that allows the infrastructure to offer various intelligent services will in effect increase the level of effective utilization to the existing investment. This will open up doors for research to maturing the architectural solution on various grounds. In effect it will improve the energy efficiency, evolve the intelligence, increase the level of automation and improve the human-machine performance significantly.

REFERENCES

[1] Wikipedia, "The Timeline of lighting Technology" http://en.wikipedia.org/wiki/Timeline_of_lighting_technology

[2] A. Kapadia & D. Singh "Sensor-Actuator Street lighting" Report submitted to School of Engineering, AUT as part of the fulfilment for the degree of BE, Nov 2013

[3] Remaking Cities Institute, "LED Street Light Research Project" Pittsburgh, Pennsylvania, September 2011, http://www.cmu.edu/rci/projects/closed-projects/led-street-lighting.html

[4] G. Bridger, B. King, "Lighting the way to road safety – A policy blindspot?" Australasian Road Safety Research, Policing and Education Conference 2012, 4-6 October 2012, Wellington, New Zealand

[5] International Energy Agency, "Light's Labour's Lost", OECD/IEA, 2006.

[6] K. A. Painter and D. P. Farrington, "The financial benefits of improved street lighting, based on crime reduction", Lighting Research and Technology 2001 33: 3, DOI: 10.1177/136578280103300102

[7] F. Domingo-Perez, A. Gil-de-Castro, J. M. Flores-Arias, F. J. Bellido-Outeirino and A. Moreno-Munoz "Low-rate wireless personal area networks applied to street lighting" Lighting Research and Technology 2013 45: 90 originally published online 14 December 2011, DOI: 10.1177/1477153511431129

[8] M. Castro1, A. J. Jara1 and A. F. G. Skarmeta1, "Smart Lighting solutions for Smart Cities ", 2013 27th International Conference on Advanced Information Networking and Applications Workshops, 25-27 March 2013, Barcelona, Spain, DOI 10.1109/WAINA.2013.254

[9] S. S. Paul Schlyter, (2009, March 18). "Radiometry and photometry in astronomy" Retrieved 03 21, 2013, from stjarnhimlen: http://stjarnhimlen.se/comp/radfaq.html#10

[10] Glen Carol Audio, "Sound Loudness Comparison Chart", http://www.gcaudio.com/resources/howtos/loudness.html