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Development of an improved traffic control system by lighting system

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ABSTRACT

The deployment of light emitting diodes (LEDs) based traffic system control created the problem of dim displays when ambient light is similar to traffic lights. It causes some drivers' disability of seeing and obeying traffic signs. This makes drivers violate traffic rules. In this paper, an attempt to use hybrid lighting technology to mitigate this problem was developed. Incandescent lightings with deployed halogen bulbs provided an instantaneous source of highly efficacious illumination which is brighter than the drivers' ambient lights (both daylight, electrical lights and their reflections), which can help drivers get access to enough warning and help them initiate traffic safety warning as necessary. The halogen lightings also offered the required high current draw needed in electrical circuitry to help brighten the LED displays. The problem of heat generated was eliminated by aerating the T-junction traffic light control unit designed for this technology. The result of hybrid lighting system design was found to be high luminosity and capability of gaining driver attention in real-time. It also allowed enhanced sign's image detection and processing for smart based technologies by providing the "light punch" needed for a wide range of visual concerns

Introduction

wasting and accidents in road junctions and curvets have witnessed a lot of changes over years although the basic color signs retained. Most of these changes have been focused on the type of power utility. Others have been focused on the red, yellow and green sessions timing, and in the compatibility or shape of deployment. Most L-junctions, T-junctions and 4- way junction have different traffic lights in most urban cities in the world nowadays. These traffic control lights which previously used incandescent lights with watts ranging from 20 to 100 W have gradually been replaced with light emitting diodes (LEDs). These LEDs which reduced the power consumption of the traffic lights to a very few watts also created another problem, which is drivers' disability of seeing or interpreting these lights as they approach to the traffic lights on nominal speed. This could be caused as a result of several factors including but not limited to solar glare, different re- flections and refractions occurring in real-time in front of the driver. These factors tend to contribute to the drivers' decisions, actions and inactions. Virtual black out of driver's vision when faced to the floodlights of approaching vehicles (light glare) is another reason of drivers not being able to interpret traffic signs. This is because it takes some time for a driver who experiences light glare to adjust to normal lighting since the human eye possesses varied response to light in the visible range of the electromagnetic spectrum. Though in most cases, drivers' error in traffic light interpretations may lead to accidents, much can be done to reduce these accidents because of the low lumen radiated by LEDs comparing with the ambient lighting. The LEDs intensities compared to ambient lighting's intensity created by the sun and the numerous reflections and refractions occurring in front of the driver are very low and not strong enough to give the driver the required command or direction, as the retina of the eye in motion will only respond to brighter light. Also, the pupils of the eyes tend to dilate in order to interpret dimmer lights and this dilation will require the driver to slow down or even completely stop to fully interpret the sign and then take appropriate actions. This is practically difficult as most drivers are in haste or at high speed especially in some countries where speed limits are not regulated or enforced. The hybrid lighting technology (HLT) proposed in this work hopes to eliminate these issues and also provide an option for drivers contending with various solar glares during the daytime and reflections from floodlights in the night. The increasing design and development of intelligent systems capability of adapting to several parameters in real-time has continued to emerge. Traffic lights in these intelligent systems are designed to literally be adjusted by the traffic itself at any time (i.e., both peak and off peak periods). Several developed countries in the world also rely on centralized and integrated control that allows dynamic control of all traffic from a point using central administration models. Presently, rigorous researches are geared towards the disappearance of traffic lights in the "smart cities" with dependence on autonomous vehicles for identifying and interpreting the traffic signs. Diaz et al. (2015) proposed the use of a priori maps to identify and pre-locate traffic lights stating that the "detection and interpretation of traffic lights meaning remains an active problem for industries and research groups". Desai and Somani (2014), Hegyi et al. (2009) and Kuhne (1991) enumerated different vehicle detection techniques based on sensor readings in real-time to aid computer vision in solving traffic congestion; Chiang et al. (2011) also advocated the use of genetic algorithms for in-car systems in detecting and recognizing traffic lights including the identification of problems such as partial occlusions and LEDs malfunction inherent in such autonomous systems at ranges of 10e115 m to these signs. Li (2013) considered recognition of traffic lights in the night and Diaz-Cabrera et al. (2015) designed algorithms for daytime and night traffic lights interpretation with dependence on fuzzy filtering using one camera. The authors, though applied various morphological operations for image feature extraction, enumerated several limitations in their experiments which including confusion in processing and estimation due to solar glare, changing lights and opaquing lamps in extreme conditions. However, the HLT when deployed along with these futuristic technologies promises to reduce a lot of computational power, enhance better interpretation of detected signal and help correct significant errors which are likely to be generated due to image deterioration, weather conditions and other uncertainties in image acquisition and processing.

Analysis of a typical traffic intersection

n a report which analyzed the existing backup systems for traffic lights available in New York discovered that traffic light units uses approximately 400 W continuously with short power transients as high as 1800 W (Rensselaer Polytechnic Institute-Advanced Energy Conversion, 2009). The units consisted of sensors, controllers, lamps, etc., which operates at voltages derived from the 120 V utility power supplies. These equipments according to the research failed to minimize energy requirements because some of these units combined energy saving LED lamps and high energy consumption incandescent lamps without proper load sharing scheme. The incandescent lamps were primarily added to the traffic light circuit to provide the necessary large current draw to help brighten the LEDs during operation (Hart, 2011). A typical area view of the vicinity of a 4-way junction traffic control system showing the traffic at daytime according to Rensselaer Polytechnic InstituteAdvanced Energy Conversion is shown in Fig. 1. The total power consumption of a traffic light control system (TLCS) was identified by Coetzee et al. (2008), based on the number of traffic lights operating at any given time and the type of lamp used in the design of the TLCS. The authors used a relatively typical intersection which is shown in Fig. 2 to illustrate power distributions and the type of lightings deployed in such a layout in an urban area in South Africa (SA). In Fig. 2, S1 shows signal face type and arrows indicate traffic flow. They pointed out that "most traffic signals in SA still have halogen lamps, with a power consumption of 55 W". South

Fig. 1 – Area view of a 4-way junction.

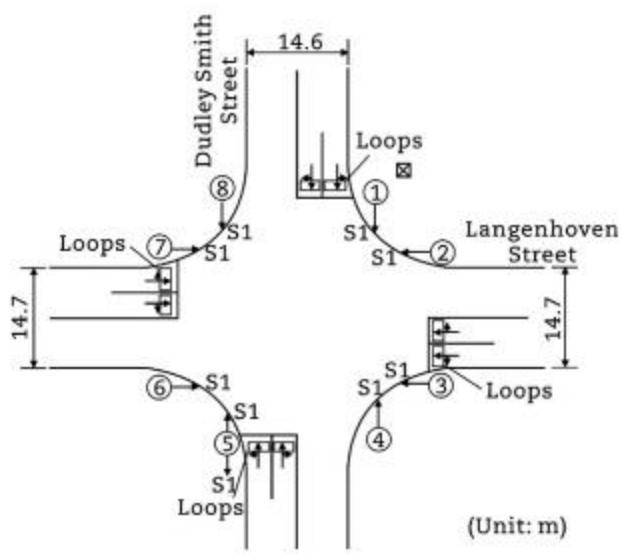

Fig. 2 – A typical 4-way junction.

Africa also used LEDs which typically consume 15 W per lamp and a controller circuit of approximately 60 W. The controller circuit wattage is independent of the type of lamp(s) in its circuitry. The average difference in power consumption of both lamps according to the source is as shown in Table 1. The incandescent lamps used coiled tungsten filament which is enclosed within an inert gas such as argon and produced electromagnetic radiation when heated by the passage of an electric current. However when temperature is higher than 2700 K, the tungsten filament begins to evaporate and blacken the inside of the lamp envelope (European Lamp Companies Federation, 2009). The halogen incandescent lamps contain added halogen to the inert gas. This addition allows the lamps' temperature to reach and exceed 3000 K, provides higher illumination and allow significant reduction in the lamp envelopes. The improved luminosity (luminous flux, measured in lumens) which is available in these halogen bulbs but not in the LEDs counterpart was investigated by Pacific Northwest National Laboratory (2008) and found to be high. The authors used the commercially available led product evaluation and reporting (CALiPER) testing program for their study. They pointed out that the luminosity of the LEDs fall significantly short of the halogen benchmark levels even when the authors used the lowestwattage (20 W) halogen MR16 Lamps. But their work identified the fact that LEDs will continue to be advanced with improvement in technology, provide significant reduction in energy consumption and still be useful where dim or lower light levels are desirable. According to the source, even using multiple LEDs to improve luminosity, comparing to that of halogen lamps, the potential energy savings of these LEDs will still diminish. Also supporting the LEDs choice in designing and deployment is their source efficacy which is given by Eq. (1) and expressed in lumens per watt (lm/W) and found to outperform that of the halogen lamps (Pacific Northwest National Laboratory, 2008). S ¼ L=P (1) where S is source efficacy, L is light output, P is power usage. Moghbeli et al. (2009) showed that the luminous efficacies of various light sources have continued to be improved with increasing technology over time as shown in Fig. 3. As seen from the figure, though sodium lightings (both high and low pressured) possess very good efficacies however they have the disadvantage of only producing yellow light. The efficacy of LEDs is steadily high due to the low power consumption in its operation comparing with incandescent lights such as halogen lights. The low power needed for the LEDs operation comes from the fact that LEDs are made from semiconductor PN junctions requiring very low voltage (0.7 V for Silicon and 0.3 V for Germanium based diodes) during a forward bias. Even when connected together each LED still needs this minimum forward bias voltage to operate from the power source. The term hybrid lightings have been used to describe lighting technologies related to the use of both daylight and electrical lighting for energy saving purposes according to Osigwe et al. (2011). The authors admitted that such hybrid (or integral) lighting systems are niche applications with their market penetration, and it's too small to play a role in lighting and energy. However, special consideration may require such hybrids to be deployed to solve specific needsPacific Northwest National Laboratory (2008) observed from their testing that most manufacturers of lamp's claims or specification data were over-bloated or highly exaggerated when compared with their measured performance results. The directionality of lights which measures the beam angle of lamps and their color characteristics were also investigated by the authors and halogen lamps tipped with

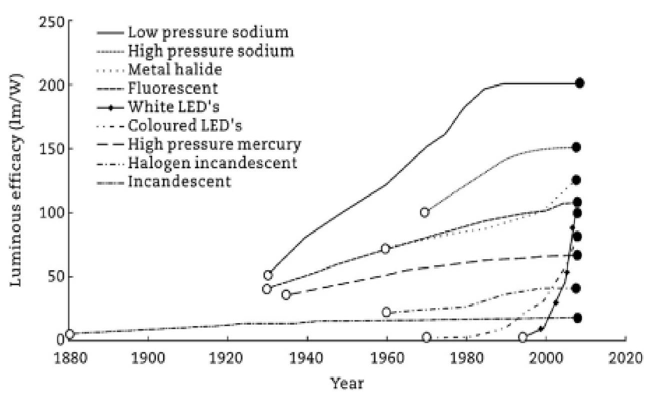

Fig. 3 – Improvement in luminous efficacy of various light sources.

higher values over LEDs. Fig. 4 shows this dim nature of LEDs lighting and the susceptivity of this type of lighting to produce error in image acquisition systems with respect to distance and other adverse weather conditions. The power factor (PF) of a light source which is an indication of how efficiently a load uses the current from the power system was also analysed by the work. The PF of LEDs was found to be considerably smaller than that of halogen lamps under alternating current supply which is true based on the fact that most current is used up, reduced or stored by other components interconnected with it. Table 2 gives a summary of these parameters. A comparison of the performance metrics of both lamps shows that halogen which causes increased expense of power consumption, provides better beam and floodlight control and necessitate its choice for the current research

Fig. 4 – Illumination of LED based traffic lighting system.

While concluding this review, it should be pointed out that the power consumption of a TLCS could also be based on solar energy through the deployment of solar panels and their corresponding battery for charging using a charge controller (Elechi et al., 2014; Moghbeli et al., 2009). The current produced, however, from this combination of solar panels or charged battery backup will be overwhelmed by the current “draw” needed for halogen lamps' operation for long periods. An attempt to solve the problem of road traffic congestion in big cities through simulation have been investigated by Osigwe et al. (2011), which proposed an intelligent system hybrid design based on a structured system analysis and design methodology (SSADM) and fuzzy logic technology to improve traffic in real-time. However, the simulated fuzzy logic system's control on real traffic which is essentially stochastic in behavior and control by mostly driver perception and judgment was not investigated. Reliability analysis by Ayyub (2003) showed that from failure data, halogen incandescent lamps are more susceptible to failure than LED lamps based on failures per million hour's

estimation. The collection and analysis of traffic data in metropolitan cities (both overhead and in-ground) and the rudiments involved in the cost of traffic light deployment, maintenance and management were elaborated by Garber and Hoel (2010) and Klein et al. (1997). The authors pointed out that such management strategies must be a highly effective and continuous process employing all the available technology in ensuring a flawless and highly effective traffic control system.

2. Materials and methods

The improved traffic light control system proposed in this research while helping to meet up with traffic impact assessments also follows the guidelines for design and operational issues outlined by the Department of Infrastructure, Energy and Resources (DIER) Guide (2007). This design involves the use of the high energy halogen incandescent lamps as complementary lightings to the normally preferred low-energy consumption LEDs in a hybrid lighting system (HLS). The hybrid system allows a dual operation. For each sequence of red, yellow and green (RYG) sign periods, a third of the lighting duration is allowed to be powered by the halogen incandescent lamps while the remaining period of each transition is powered by the LEDs. The three 100 W halogen lamps corresponding to the RYG circuits used 220 V mains voltage and the LEDs uses 12 V full wave rectification of the mains supply using a step down transformer mounted on the mainboard. The power supply unit also provides the 24 V full wave rectification which is necessary to power the unit's cooling fan. The controller circuit uses 12 V direct current (DC). TLCS can use fixed timed sessions while intelligent TLCS designs uses dynamic timing of the RYG circuits based on feedback control systems that is based on the traffic density at any particular time in a metropolis. Though the latter is used for this research, the results are applicable to dynamicfeedback systems. The needed switching of the various circuits which provided by bipolar transistors and electromechanical all relays on the TLCS mainboard in such a way that the entire unit fits into a T-junction unit. It is ensured that the design does not create “false directions” and no two lights operate at the same time according to the safety guidelines (Huang and Chung, 2008). In the guidelines “a traffic light control system model must have certain features for proper and safe operation. For example, the controller should not lock up (deadlock) due to some unexpected combination of actions, it should not allow conflicting movements to have right of way simultaneously, it should be able to serve all signal phases and return to some initial state”

The timed sessions in the HLS are provided by the counter circuit with astable generated pulses (Tokheim, 1999) and reflectors are used to concentrate the beams to a point according to viewing angle of drivers. Electronic components are mounted on the printed circuit board (PCB) as shown in Fig. 5 (Floyd, 1996; Loveday, 1995; Solberg, 1996). The LEDs are protected with series connection of 1 kU current limiting resistors and arranged to provide lighting for the remaining part of each timed session of lights. The designed system is essentially static since it depends mainly on discrete components to ensure that timed session does not result in errors or malfunctioning commons with programmable integrated circuit based lightings which can easily reach saturation points and cause freezing of intended normal circuit operation. Current spikes generated by the rapid switching of the electromagnets in the display control session during operation are cushioned by the high resistance provided by the halogen bulb filaments. To avoid the circuit board's rapid aching, most of the coupling to mains supply and the halogen bulbs terminal and verse versa is done with electrical connectors outside the PCBs

Results and discussion

The intensity of the halogen lighting when investigated using the 100 W, 220 V mains supply bulb during operation was found to be of favorable luminosity as shown in Fig. 6 at

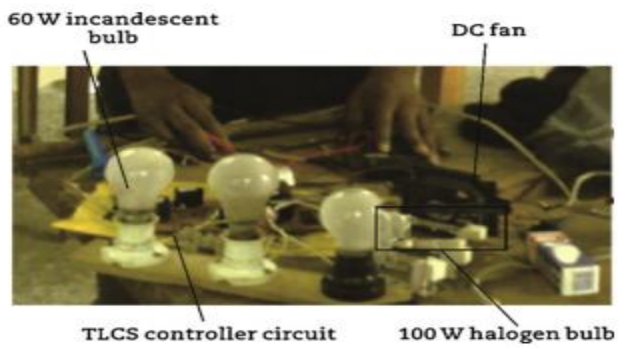

Fig. 6 — T-junction experimental setup at power-off mode.

power-off mode and Fig. 7 at power-on mode. At normal operation, the halogen incandescent lighting used about 85% of the power consumption to produce heat and about 15% for light production. This necessitated the T-junction TLCS that was designed and built for the purpose of this analysis to be properly aerated by a 5 W, 24 V DC fan. The action of this fan helped to ensure that heat from the halogen bulbs did not build up in the enclosure that could create a meltdown by maintaining the unit's temperature around ambient. Interfacing of high and low voltages using connectors while ensuring no current leakage especially to the housing unit was maintained. The TLCS's circuit which was designed as prescribed by the guidelines of Osigbemeh (2012), Electrical Engineering and Automation Department Aalto University (2011) and Onuu and Nkanu (2006) was ensured to take safety paramount at all times during its operation. The LEDs providing the backup lighting for the remaining two thirds of the lighting periods were designed and mounted in such a way that it appeared to have a continuous lighting effect on the driver or viewer as they approach the traffic light. The final project is shown in Fig. 8 and captured the high luminosity obtained by the design for all the signal face types and their duration of lights respectively at one-third the full duration of each session. The high lumens radiated by the design was seen to preserve the RYG screens and color of the various displays so that the approaching driver even on top speed can see and interpret the traffic sign as a clear and crisp signal thus improving the time for appropriate actions such as stoping, accelerating or slowing down to be taken. The halogen bulbs were mounted away from the direction of mount of the LEDs to avoid opaquing its light rays and heat dissipation on the diodes. The remaining two-third duration of each session of lighting was provided by the LEDs to save energy consumption of the TLCS when apparently most drivers have adjusted to the sign. This will be very useful at very busy traffic junctions on sunny days and in the night where there is a lot of cross reflection from floodlights, advertisement boards, streetlights, etc. Also, an enhanced image perception of light detection and acquisition systems will be improved for the numerous techniques being investigated for future smart cities' traffic control. In a random sampling poll conducted which involved the displays and operation of the TLCS hybrid design in a public square for validation and testing purposes for three consecutive days, it was observed that over 95% of about 250 viewers attested to the design to be timely and beneficial to safety in today's traffic junctions and that of the future. Image detection and acquisition using XH A1 canon camcorder showed crispy outputs. Such crisp images will make image processing and interpretation easier for computer vision systems for deployment in in-car technology or in autonomous vehicles.

Conclusions

The high luminosity obtained by this hybrid lighting of traffic lights will help eliminate situations where drivers' error in judgment causes violation of traffic rules or even accidents. The proposed technology was found to be effective in drawing drivers' attention to obeying traffic signs when compared with conventional only LEDs design as was attested to by over 95% respondents viewing the hybrid technology's deployment in a public square. The respondents viewing the operation of the hybrid design in the public square as a virtual test bed, affirmed that if would be an improvement in overall safety on the road if the design were to be deployed to real traffic junctions. The design also allowed significant energy savings since the halogen lights were used only at a third of the duration of each color session based on the timing of the control circuitry. The energy savings attained while still preserving the needed illumination necessary to avoid preventable accidents and casualties made this design of TLCS of practical applicability in even modern cities such as Las Vegas (city famous for its extravagant neon-lighted streets). The designed HLS also provided an enhanced source of signal for image detection, acquisition and processing technologies of futuristic smart cities and in-car autonomous systems.

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