Street Light Monitoring Using Smartphones

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Abstract: Rapid urbanization poses challenge to the maintenance agencies in monitoring and maintaining city-wide services. Traditional ways, to monitor the services, involve huge manpower and time. Technical revolutions opens up smarter ways of monitoring the civic services with the use of miniature sensors embedded in smart devices and potentially covers wider area. Over the past decade, the smart city concept has emerged as a potential research area where many devices work in a network and has been applied as city-wide smart monitoring technique. In this paper, author has highlighted the use of mobile crowd sensing though smart phones to devise civic infrastructural monitoring application specifically for monitoring street lights conditions and generating heat maps accordingly. A client-server based mobile crowd sourcing framework has been proposed where the client represents smart phones equipped with devised phone application to crowd sense data and the open-source server is used for data analysis and distribution of results. The framework works in sequential manner with three key modules i) data harvesting, ii) analyze and iii) visual reporting module. Smartphones are used to harvest city-wide contextual data and transfer it to the server. Effective measures to protect privacy of the user have been applied during data harvesting. Server analyzes the harvested data and retrieves useful metrics as computed luminous index which are communicated back to clients (phones) as heat maps visualized on Google® maps. The proposed mobile crowd sourcing framework helps in quick data sensing and spotting the poor street light conditions. The resulted maps potentially disseminate the information to the city residents and the administration to respond accordingly. Whether there is need to install more street lamp posts or to repair the malfunctioning lamp post. A better lighting condition in the streets enhances the visibility and thus the safety of the residents, as the dark areas are prone to accidents or promotes crime.

Index Terms: Community participation, Data visualization, Google Maps

I. INTRODUCTION

With rapid urbanization more cities are being developed and 70% of the population across the world is expected to dwell in the urbanized area. In developing economy like India, almost 30% of the population is city resident and further this rate is increasing. With increased shift of public to reside in cities, there is increased demand of civic facilities for their use. Almost every city provides basic civic facilities, but in developing economies, there is scarcity of sophisticated equipment to continuously monitor these facilities which directly impact the living standard of residents. Moreover, a limited budget and lack of experienced manpower hinders the continuous monitoring of civic facilities. Most of the developed nations have resources to monitor and maintain civic facilities. Use of specialized equipment and manpower has been witnessed in the past. For quick monitoring of facilities, there is shift from manual to automated techniques that includes vehicles laden with precise equipment. There is paradigm shift from standard engineering practices to mobile crowdsourcing in the recent years that allows the involvement of the stakeholder (public) in monitoring various urban contexts. The use of community owned smartphones to monitor the infrastructural facility (road roughness) and environmental noise has been reported in [1,2].

Recently, Information and Communications Technology (ICT) has emerged as an integrated network of sensors, communicating devices, data storage and analytics that further supports the decision making. It opens up new research avenues to use smart devices like smartphones to be explored as sensing, storing, analyzing and deciding nodes connected as a network. With mobile crowdsourcing, citizens adapt to use smartphones as sensing and reporting devices. Further, the increased computational power and storage capabilities fortify the use of smartphones as an economical substitute to monitor city-wide facilities. The implicit features of a smartphone enable researchers to devise an integrated local network of smartphones to monitor the city in smarter way and distribute the data analytics to the public. With an increased willingness of citizens, an effective city monitoring system can potentially be developed. This paper explores the novel concept of developing a city-wide sensor network using smartphones to monitor a common civic facility- street lighting system. National highways are continuously being monitored and maintained by various agencies like NHAI in India, but local roads in a city are not monitored effectively. Limited budget and lack of information are the main constraints for local municipalities to deploy a city-wide monitoring system to spot poor lighting conditions in a street. Municipality may constitute a team that manually inspects the street lights through periodic visits, but it will lack scalability and reliability. Though the use of sophisticated equipment to monitor the street lights will produce reliable information, but it will take long to cover a wider area. Thus, there is need to develop a scalable and widely deployed street light monitoring system that continuously monitors street lights to facilitate timely maintenance activities. With the increasing trend of smart city, it would be possible to develop such a monitoring system. Unfortunately, the smart city project is not widely executed in the developing nations, including India. Further, in the state Punjab situated in the northern part of India, where study is conducted, the rate of implementation of the smart city project is negligible.

A pilot study has been conducted to develop a Mobile Crowdsourcing System (MCS) involving publicly owned smartphones in monitoring

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street light conditions. Large user base and the inherent mobility feature in smartphones helps in wide area coverage. Android Operating System (OS) based smartphones have been used to conduct experiment in this study because of its wide availability. Further, the availability of a rich application programming interface of Android Software Development Kit (ASDK) facilitated to develop useful mobile phone applications by exploiting various sensors embedded in smartphone. A specially developed mobile application exploits the inbuilt sensors of smartphone to monitor city-wide street lights. Experiment is conducted in the Khanna city situated in the northern part of India. The entire experiment is conducted in different phases as Sense and share, Analyze, and Distribute. In sense phase, data has been collected using privately owned smartphones laced with a specially developed application. The logged data is communicated to the server. The open source server is implemented to receive and process the sensor data. Threshold-based classifier is implemented at the server side to obtain class information. The class information is communicated to the community phones through web to visualize classified information. The resulted informative maps enable the public to report to the authorities about the malfunctioning street lights and the authorities may take corrective measures, accordingly. Thus, it leads to a report and respond system in the area under study that is not currently present. This research work is focused to monitor the lighting quality of roads in a city because good lighting conditions in the streets helps to avoid accidents or reduce crime. With the involvement of community participation in monitoring activity, the probability of correct reporting of contextual event like non-functional street lights is raised. The involvement of citizens is a challenging task as many may not be willing to participate. Author used peer interested group (called as volunteers) during the preliminary data acquisition task. The involvement of public is increased through counseling them to be part of crowdsourcing and in future more participants are expected. Another major challenge involved is to maintain privacy of the participants. Location data is used from crowd sourced data to visualize the results on map which may be considered as a privacy risk. The due care has been taken to hide the identity of the user while data acquisition and extracting location data for mapping. The reliability of obtained data is one of the concerns to be treated cautiously as there may be participants who may provide wrong data. The present research work thrives to tackle it by computing metrics from multiple records of reported data about same contexts that keep are continuously being updated at the server that helps in providing substantially accurate results.

II. RELATED WORK

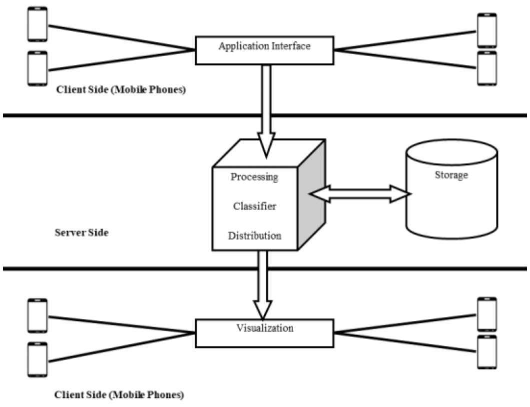
With urbanization the challenges to meet the expectations of residents about city-wide facilities alerted the maintenance agencies across the globe. The situation is more tragic in developing economies like India. City municipalities and maintenance agencies require a flawless effective city-monitoring system that can report the events for taking correcting measures. Manual inspection system is not only daunting but fails to cover larger area of the city in shorter period of time. Moreover, the reliability of this system depends on the expertise of the manpower. A quicker and smarter monitoring methodology is most sought and smart city concept empowered it. Smart cities are emerging as a novel and promising paradigm to tackle various city-wide issues. The inclusion of Internet of Things (IoT) concept further helps in actualization of smart cities for providing efficient services to the citizens [7,14]. Smart city concept is aimed to provide quality service for the citizens at a nominal cost to maintenance agencies or councils. The emerging nations like India have started to design and implement the smart city system. The system consists of sensors, data storage and computers for data analytics. The installation of these systems is time consuming and the successful execution involves expert manpower and heavy cost. Moreover, the volume of data is required for detailed analysis to obtain meaningful information. With dedicated equipment installed only at strategic locations the collection of large volume of data is a tedious task. With the emergence of Community Sensing (CS) phenomenon, there is the trend to involve citizens into continuous data harvesting and respond system to make cities smarter. Smartphones equipped with sensors are used to collect data and the people owning them are used as actuators to take action. A large area may be covered with the use of smartphones in data collection due to their mobility characteristics [4]. The pervasive and ubiquitous feature of smart devices including mobile phones has enabled community to collect and share data and coined as a term “Mobile Crowdsourcing (MCS) sensing”. MCS sensing can be applied to personal and community sensing applications. This paper exploits the community sensing paradigm where large numbers of individuals are asked to participate using their smartphones connected over the internet as sensor nodes to build a wide-scale community sensing network (CSN) for street lights.

Literature review on using MCS in the area of road quality measurement, noise monitoring and street light monitoring are discussed in the section. Smartphone based CSN had been used in road surface monitoring as reported in [10]. Fuzzy classifier was used to classify various road segments based on the computed roughness index and its corresponding impact to the driver’s comfort. The resulted informative maps were visualized on Google® maps. Authors in [13] devised RoADS system for anomaly detection and classification using support vector machines. Authors in [1] used a standard mobile device for detecting the quality and irregularities on the road. Traffic noise mapping using smartphones had been reported in [9] where the authors had used a community sensing framework for predicting the noisy areas in different regions. Researchers in [15] proposed and implemented a system based on MCS paradigm to monitor noise without using specialized sensors. In the paper [5], authors presented the OnoM@p participatory noise mapping system by collecting noise data using mobile phone application. Similarly, paper [3] proposed a CS system to detect defective street lights using specially equipped fleet of vehicles. The system computed the combined light intensity for a location and compared it with the baseline light intensity to determine any degradation in the performance of street light. The authors of paper [11] presented a mobile sensor platform to monitor urban street light infrastructure. A car-mounted sensor platform laced with precise lux sensor, GPS sensor, IMU and on board sensors. They presented signal processing techniques to identify street lights from video records. The authors in [8] presented the literature review on various participatory sensing application form different domains along with foresighted research challenges like data handling, data quality and privacy.

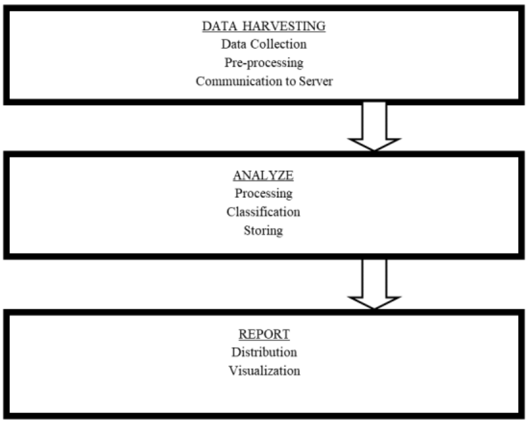
It is observed from literature review that a variety of street light monitoring system exists, but they either used precise instruments or static instruments near the street light poles. The present work exploited the use of smartphones as light sensors to monitor the street light illuminance. It is further observed from review that MCS is an attractive field to monitor various infrastructural and environmental contexts. A participatory framework is thus possible to devise city-wide monitoring in smarter way involving smart devices and technology. The present work favors the concept by presenting a MCS framework based on client-server architecture that involves city residents to monitor urban context like street lights and report the findings to stakeholders. Main factor that motivates the author to carry out this work is that the street lights remain non-functional for a longer period before they are repaired. During dark the safety of the residents is at risk and combination of street having open manholes or speed bumps and non-functional street light is more risky. The government initiates various smart city projects but mainly for metros and rest of the cities (especially northern India section where study is conducted) remains unattended. Residents are irked with the poor condition of street lighting system. Concerned local municipalities never perform monitoring of these infrastructural facilities in deep areas and they remain deprived of better facilities. The involvement of citizens to record data about the functioning of street lights along with position coordinates will result in quicker repair or response from maintenance agencies like municipalities. Smart city frameworks are motivated from this aspect and require huge cost to deploy at city-wide level. Further, the expert manpower and continuous maintenance of installed equipment would require additional cost resulting to constraints due to less allotted budgets to local municipalities. Author has proposed a MCS framework for monitoring urban contexts in the city located in the area of northern India. The framework exhibits features like pervasive and ubiquitous computing by exploiting recent computing technologies. Some of the research challenges faced are (1) How to build a sophisticated MCS framework to harvest city-wide data comprehensively? (2) How to treat and analyze the multi-sourced data in order to compute useful metric to identify various contexts related to street lights? (3) How to develop an easy to use reporting system? This paper addresses all these challenges through a proposed client-server based MCS framework involving various modules *viz.* a) Data Harvesting module that deals with the use of developed application to harvest or collect city-wide contextual data and pre-process raw data before communicating to server for processing. The nighttime after 10:00pm is selected to conduct study to avoid recording of illuminance caused by other sources other than the street lights, b) Analyzing module handles pre-processed data for analysis – where different algorithms are devised to compute features to classify the street lighting conditions, and finally c) Report module distributes the obtained results to the potential stakeholders including the maintenance agencies. This scenario witnessed citizens owning smartphones both as the producer of mobile crowd-sensed data and as the consumer of information obtained after computations performed at server-side. Another important task was to involve public in data sensing activity that was initially dealt with by involving volunteers who willingly performed data collection. The volunteers were selected from residents, peers and students. The proposed MCS framework has been deployed and tested in various places of a locality to conduct preliminary study and promising results are obtained. In the future increased public involvement in data collection activity will be planned to obtain better results and also to increase area coverage. Author is motivated to look ahead fusing street light data with local road surface conditions to predict safety of pedestrians in local streets, in near future. Internationally, there exist specific regulations to measure illuminance as reported in [12,6], but present work demonstrates specifically the study of widely deployed, feasible street light monitoring system to map and identify non-functional street lights. The system will be enhanced to identify illuminance only from street lights not considering other source of lights by using video camera in near future.

III. PROPOSED MCS FRAMEWORK

The proposed MCS framework consists of sensor nodes (smartphones), communication interface (internet), central server (for processing, storing and distributing) and finally the smartphones (to visualize maps) as shown in Figure 1a and the corresponding application modules are shown in Figure 1b. The data harvesting module is where smartphones lased with specific applications owned by the public are used to sense and collect city-wide data pertaining to different contexts. A bundled application is developed to implement this task. The interface of application includes sensor selection, data acquisition, data transfer and map visualization controls. User-interface is very friendly and easy to operate. The opening screen of the application provides user controls for selecting appropriate sensors (mainly GPS) to start data acquisition in real-time.



1a

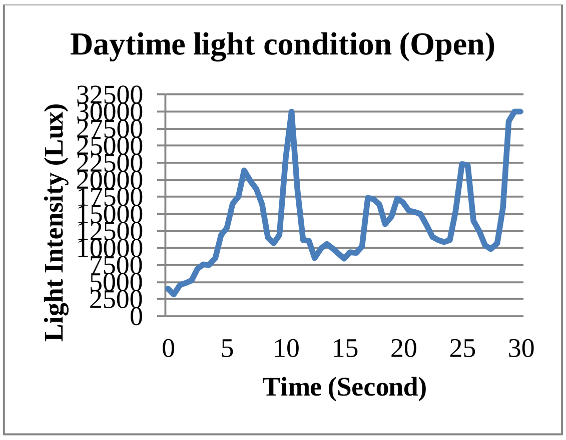


1b

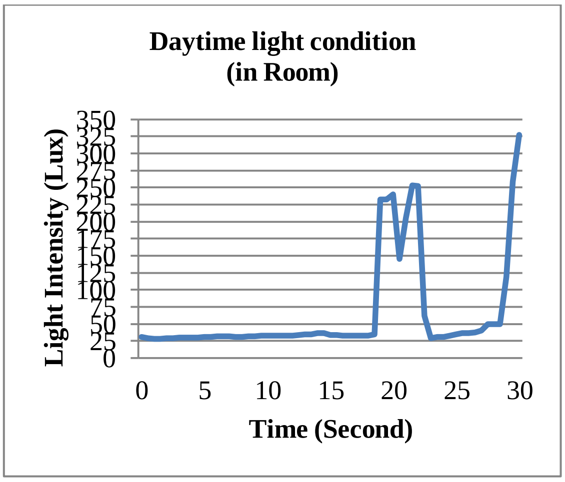
Figure 1. 1a) Architecture of MCS framework and 1b) Flow of application modules

A. Data Harvesting

Street lights are monitored by logging data in data harvesting module of using the specially developed mobile application. Before being used in data harvesting, the developed mobile phone application is tested in various lighting conditions like under day time and night time conditions and results are shown in Figures 2a and 2b. It is observed that the light sensor embedded in phone records value in range 2500-30000 lux under open sky and a range of values between 25-325 lux in room during daytime light condition. It is observed that the recorded light intensity increases as the phone is moved near light source as shown with high peaks in Figure 2b when the phone is deliberately moved towards or farther from light source. The trend in increased light intensity is proven in Figure 2c where phone is moved in smaller steps towards the light source. Although light sensor embedded in phone limits to maximum value of 30000 lux, it is able to detect light intensity changes precisely under varied light conditions and distance. The goal of the application is to monitor street light conditions during dark (from sunset to sunrise), so the application is further tested in closed room without any light. The graph is shown in Figure 2d where the recorded light intensity is 0 lux as desired. Hence, it is proved that the developed application potentially record correct luminous data.



2a



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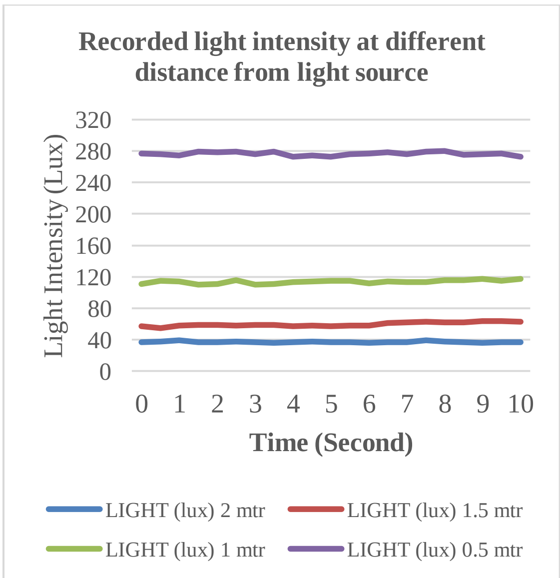
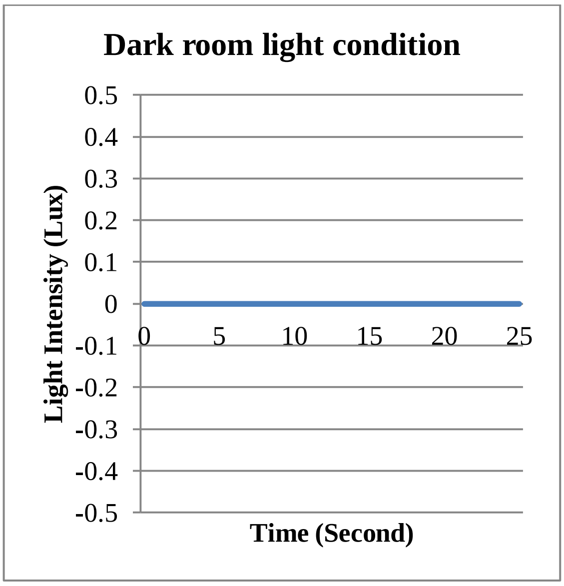


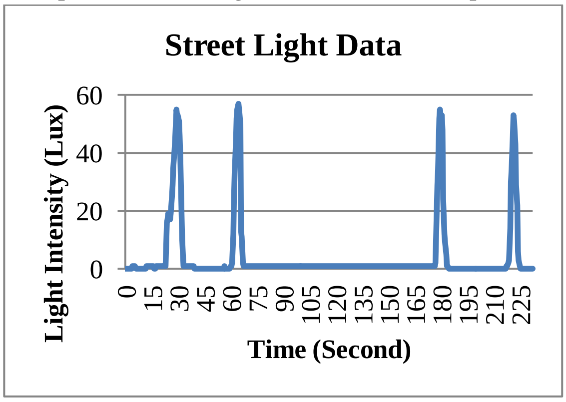
2c



2d

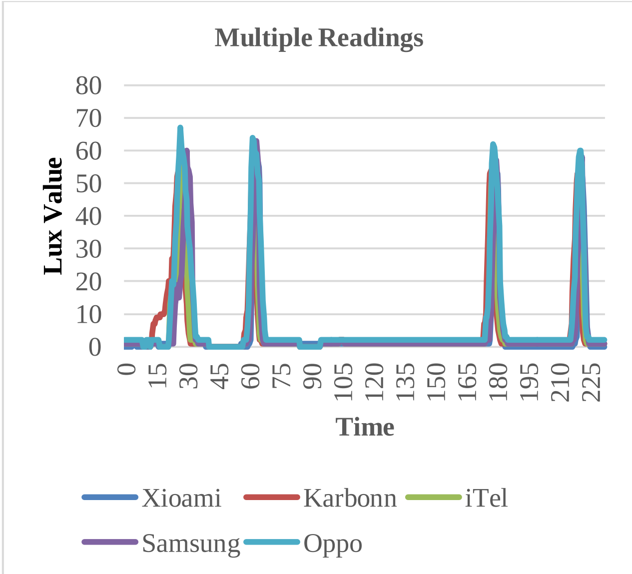
Figure 2 (a-d). Light intensity graphs in different scenarios

The application is tested under real-time conditions to record street light data in multiple recordings as shown in Figure 3a. The data is recorded while walking in the street with special instruction given to hold phone in a specific position such that screen faces upward direction. Total five street light posts were tested having one faulty street light (not working). The high peaks in the graph depicts when the volunteer was under the street light bulb and maximum lux value was recorded. After close examination of the data, it is observed that peaks are equally spaced over time which agrees to the assumption that street light posts are installed at a fixed distance from each other. Further, the data is analyzed to determine the possible maximum intensity (in lux) obtained from street light that is used as base limit to determine faulty or functioning street light. To test the stability of developed phone application, it is installed on variety of phones (five different brands in this preliminary study) to record street light data that is presented as graph in Figure 3b. It is observed from the plot that application on different phones is capable to record the street light data (in lux) with precision. Small variations in peaks and over time occur due to human factor involved and varied hardware of phones. Thus, application is stable and behaves akin in different phones according to the volunteer's experience.



3a

During preliminary phase, light intensity data (in lux) is recorded along with the instantaneous position coordinates (latitude, longitude) obtained from GPS sensor embedded in phone and also the time-stamp is recorded. Data is recorded at a sampling rate of 2Hz for light sensor and GPS operates at 1Hz frequency. The recorded data is stored on the SD-Card of the mobile phone as a .txt file. The logged data is later transferred to the central server for further processing.



3b

Figure 3: Data recorded from street lights a) averaged using multiple recordings b) recorded data with different phones

Data transfer is preferably initiated when a high speed Wi-Fi hotspot is available as compared to mobile data connection, to keep data transfer cost to minimum. The proposed framework is mobile crowd sourced that poses a unique challenge of handling spurious records or misleading data from mobile crowd sourced records. The application module is enhanced to maintain separate counters for records between a specified range and the outliers. The critical analysis of counters determines whether to keep the record for further processing as good record or discard as spurious record. Later the selected lux data (good record) and associated instantaneous GPS coordinates are stored in the database. The same method is adopted to store data pertaining to dark events (non-working street light).

3.2 Analyze

At the server side, the received lux data is pre-processed to retrieve a threshold value. Threshold value is retrieved from crowd sourced data recorded for same location by observing the trend line of lux values obtained around street light, refer Figure 4. It is observed from Figure 4 that as phone passes under the light source the lux value increases and reverse trend is observed when phone is away from the light source. Further, there are variations in lux value recorded over different trials which is treated using upper quartile computed from recorded lux values according to equation 1 and set as the threshold value to be used in classifier.

$$Q_3 = \frac{3}{4}(n+1)^{th} \quad \dots (1)$$

where n is the number of data points, Q_3 is the third quartile.

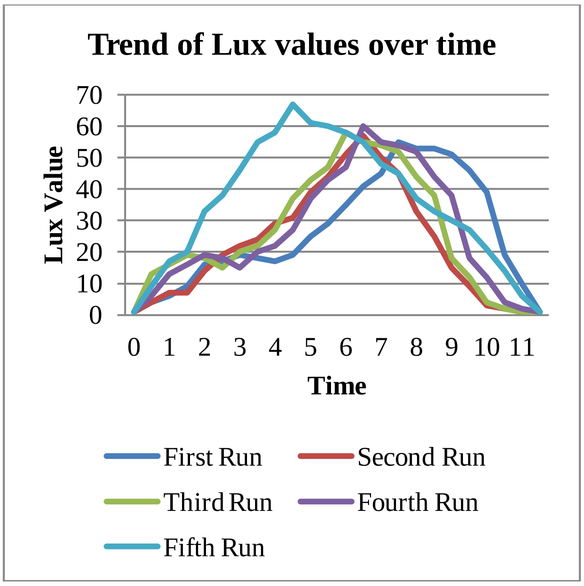


Figure 4. Trend of lux value (repeated readings) around single street light

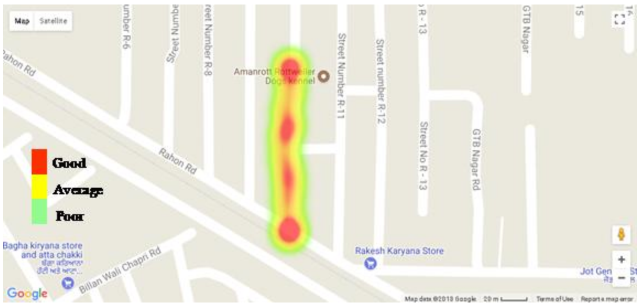
It has been observed from volunteer's experience that lighting conditions varied even among working street lights. The choice of upper quartile as threshold helps to separate street lights into faulty or working. A simple threshold classifier is implemented in Java at server. The classifier is trained on data records over a period of three months. The data values satisfying the threshold criteria are given high intensity color (towards red) and the data not fulfilling threshold criteria is presented as low intensity color (towards green). Later, some datasets from training datasets are used as test data and class information is generated.

3.3 Report

The class information is communicated to the mobile phones in Java Script Object Notation (JSON) format where the application parses it into class and location values visualize street light conditions as heatmap. Google® maps are used to visualize the resulted information. The heatmap values are adjusted according to the computed instantaneous illuminance from crowdsensed data. Heatmaps are generated using Google Maps API and the resulted maps are shown in Figure 5 under results section.

IV. RESULTS AND DISCUSSIONS

Figure 5 is generated by testing the proposed framework in different streets to study the illuminance in a locality. In future, the geographical area will be increased to include more localities and finally a city. It is observed from Figure 5 that the illuminance in street is dispersed around the street lights showing red colour in center that is slowly shifting to yellow and then finally to green. Red colour represents that volunteer was under the street light during recording which slowly faded away as moved away from the street light pole.



5a

5b

5c

5d

Figure 5 (a-d). Resulted heatmaps representing lighting conditions in different streets of a locality

It is also observed from the Figure 5a that the street light poles are installed at equal distances (approximately) and overall visibility is there in the street monitored although some area is little dark. Figure 5b shows an area where few street lights, as indicated by red region on map, were installed and dark (as shown in green color) region was observed in some part. Figure 5c represents a street with two street lights (as reported by the volunteer) and the generated map works inline by providing the two dark red spots. The overall illuminance in the street was witnessed with average visibility and no dark region was observed. Figure 5d represents main street connecting different streets on its left and right. It is observed from the Figure 5d that the street has many street lights in working conditions that caused the overall illuminance in the street and almost no dark area is observed. Author is continuously collecting the community sensed data and a single interesting illuminance map of the entire locality will be produced in near future. The observed illuminance is dependent on human physiological factor like eye-sight and tolerance to light intensity, so a fuzzy classifier will be proposed in near future than the crisp classifier.

V. CONCLUSIONS AND FUTURE SCOPE

The proposed MCS framework has been implemented in northern Indian area where no street light conditions monitoring system exists and promising results are obtained by using an Android OS based smartphone's sensors only. It is an economical substitute to a monitoring system using sophisticated equipment or vehicles and also supports intrinsic mobility feature. The illuminance of streets is presented as heat maps visualized on Google® maps. The presented maps are very useful in identifying the dark area where illuminance is poor (represented as green colour) and the area where illuminance is good (represented by red colour). The volunteers were selected from peer-interested groups only. The study poses various challenges like maintaining privacy, dealing with spurious recordings and the appropriate algorithms have been implemented in the proposed framework. It was challenge to maintain past records of faulty lights if they were repaired. The proposed system dealt with this problem by taking the averaging of lux values obtained from same street light.

Fused with data from other sensors like accelerometers will enhance the capability of the proposed system to predict the risk caused in dark due to open manholes or non-standard speed bumps that are unmarked also. Author is looking to work in this regard in the near future and results will be presented soon. The involvement of the public potentially helps to collect data in preliminary study. The more strategies will be considered to involve more public from other areas to scale the application of proposed framework to prepare a city-wide street light illuminance map. Threshold based classification system will be replaced with some suitable and more concrete classifier as future enhancement.

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