

SYSTEM AND METHOD FOR ANALYZING STREET LIGHT PERFORMANCE ON A ROAD

FIELD OF INVENTION

[001] The present invention relates broadly, but not exclusively, to systems and methods for analyzing street light performance on a road.

BACKGROUND

[002] A streetlight (also known as a lamp post or street lamp) is a raised source of light that is typically situated on the edge of a road or walkway. Many roads have streetlights to keep streets and walkways lit at night. Currently, the light source of a streetlight is a light bulb (commonly a high-intensity discharge lamp) or a light emitting diode (LED). These light sources have a finite lifespan and their performance may vary during the lifespan. As such, there is a need to analyze the performance of these light sources. Light sources with unacceptable performance (e.g. inadequate illumination) can be replaced.

[003] Traditionally, brightness of streetlights is manually measured with a handheld light meter. Typically, the measurement is performed by measuring the brightness at a number of discrete spots (e.g. nine spot readings across one lane and between two street lamps). However, there are several challenges associated with this measurement method. For example, this method is an extremely labour intensive manual process that is very inefficient and prone to errors since readings are manually recorded at night in less than optimal safety conditions. Moreover, technicians usually sample two street lamps and that is meant to be representative of an entire road. An entire brightness measurement of a road is cost-prohibitive. Furthermore, brightness measurements in between the discrete spots are not recorded.

[004] A need therefore exists to provide a system and/or a method for analyzing street light performance on a road that seek to address at least one of the above-mentioned problems.

SUMMARY

[005] According to a first aspect, there is provided a system for analyzing street light performance on a road, comprising: a sensor module configured to: measure light intensity at various times and output corresponding temporal light intensity data; determine a spatial location of the sensor module at the various times and output corresponding spatial location data; and generate messages comprising the temporal light intensity data and/or the spatial location data; and an analytics engine in communication with the sensor module, wherein the analytics engine is configured to: receive the messages from the sensor module; generate spatial light intensity data based on the temporal light intensity data and the spatial location data; retrieve, from a database having stored therein spatial locations and their corresponding road name, the road name corresponding to each spatial location associated with the spatial light intensity data; and generate an indication of street light performance of at least a portion of the road with the retrieved road name based on the spatial light intensity data.

[006] In an embodiment, the sensor module may comprise: at least one light sensor configured to measure the light intensity; a timing module configured to generate a time-stamp for each light intensity measurement for facilitating output of the temporal light intensity data; and a spatial locator module configured to determine the spatial location of the sensor module at the various times. The spatial locator module may comprise a Global Positioning System (GPS) receiver.

[007] In an embodiment, the analytics engine may be configured to generate the spatial light intensity data by appending the temporal light intensity data having a particular time-stamp with the spatial location data having the same particular time-stamp. In another embodiment, the analytics engine may be configured to generate the spatial light intensity data by interpolating the temporal light intensity data having a particular time-stamp based on the spatial location data having a time-stamp at a time before and after a time of the particular time-stamp.

[008] In an embodiment, the sensor module may be further configured to obtain inertial measurements at the various times and output corresponding temporal inertial data, and wherein the analytics engine may be further configured to generate the spatial location data based on at least the temporal inertial data. The sensor module

may comprise at least one inertial measurement unit (IMU) configured to obtain the inertial measurements.

[0009] In an embodiment, the sensor module may further comprise: a memory module for storing the messages; and a communications module configured to wirelessly transmit the messages to the analytics engine via a mobile communications network, wherein the messages are held in the memory module when a signal strength of the mobile communications network is below a pre-determined level and transmitted to the analytics engine when the signal strength is above the pre-determined level.

[0010] In an embodiment, the analytics engine may be further configured to: retrieve, from an additional database having stored therein street light identifiers and their corresponding spatial location, each street light identifier corresponding to each spatial location associated with the spatial light intensity data; and generate an indication of street light performance of a street light with the retrieved street light identifier based on the spatial light intensity data.

[0011] In an embodiment, the analytics engine may be further configured to: determine an average distance to a road section line based on the spatial location data; and determine a lane number associated with the portion of the road based on the average distance to the road section line.

[0012] In an embodiment, the sensor module may comprise a plurality of light sensors and the analytics engine may be further configured to determine a plurality of average light intensities, and wherein each average light intensity may be based on an average of the light intensity measured by each of the plurality of light sensors during a particular time interval based on the temporal light intensity data.

[0013] In an embodiment, the analytics engine may be further configured to: filter away average light intensities that are less than a pre-determined threshold and retain average light intensities that are equal to or more than the pre-determined threshold; and register a highest value of the retained average light intensities.

[0014] In an embodiment, the sensor module may comprise a plurality of light sensors and the analytics engine may be further configured to: filter away light intensity measurements that are less than a pre-determined threshold and retain light intensity

measurements that are equal to or more than the pre-determined threshold; and register a highest value of the retained light intensity measurements.

[0015] According to a second aspect, there is provided a method for analyzing street light performance on a road, comprising: measuring light intensity at various times using a sensor module and outputting corresponding temporal light intensity data; determining a spatial location of the sensor module at the various times and outputting corresponding spatial location data; generating messages comprising the temporal light intensity data and/or the spatial location data; generating spatial light intensity data based on the temporal light intensity data and the spatial location data; retrieving, from a database having stored therein spatial locations and their corresponding road name, the road name corresponding to each spatial location associated with the spatial light intensity data; and generating an indication of street light performance of at least a portion of the road with the retrieved road name based on the spatial light intensity data.

[0016] In an embodiment, the method may further comprise generating a time-stamp for each light intensity measurement for facilitating output of the temporal light intensity data.

[0017] In an embodiment, the method may further comprise appending the temporal light intensity data having a particular time-stamp with the spatial location data having the same particular time-stamp to generate the spatial light intensity data.

[0018] In an embodiment, the method may further comprise interpolating the temporal light intensity data having a particular time-stamp based on the spatial location data having a time-stamp at a time before and after a time of the particular time-stamp to generate the spatial light intensity data.

[0019] In an embodiment, the method may further comprise obtaining inertial measurements at the various times and outputting corresponding temporal inertial data; and generating the spatial location data based on at least the temporal inertial data.

[0020] In an embodiment, the method may further comprise: providing a mobile communications network for wirelessly transmitting the generated messages from the sensor module to an analytics engine that is configured to generate the spatial light

intensity data based on the temporal light intensity data and the spatial location data; holding the messages in a memory module of the sensor module when a signal strength of the mobile communications network is below a pre-determined level; and transmitting the messages to the analytics engine when the signal strength is above the pre-determined level.

[0021] In an embodiment, the method may further comprise: retrieving, from an additional database having stored therein street light identifiers and their corresponding spatial location, each street light identifier corresponding to each spatial location associated with the spatial light intensity data; and generating an indication of street light performance of a street light with the retrieved street light identifier based on the spatial light intensity data.

[0022] In an embodiment, the method may further comprise: determining an average distance to a road section line based on the spatial location data; and determining a lane number associated with the portion of the road based on the average distance to the road section line.

[0023] The sensor module may comprise a plurality of light sensors. In an embodiment, the method may further comprise: determining a plurality of average light intensities, wherein each average light intensity is based on an average of the light intensity measured by each of the plurality of light sensors during a particular time interval based on the temporal light intensity data.

[0024] In an embodiment, the method may further comprise: filtering away average light intensities that are less than a pre-determined threshold and retaining average light intensities that are equal to or more than the pre-determined threshold; and registering a highest value of the retained average light intensities.

[0025] In an embodiment, the method may further comprise: filtering away light intensity measurements that are less than a pre-determined threshold and retaining light intensity measurements that are equal to or more than the pre-determined threshold; and registering a highest value of the retained light intensity measurements.

BRIEF DESCRIPTION OF THE DRAWINGS

[0026] Embodiments of the invention will be better understood and readily apparent to one of ordinary skill in the art from the following written description, by way of example only, and in conjunction with the drawings, in which:

[0027] Figure 1 shows a schematic of a system for analyzing street light performance according to an embodiment of the invention;

[0028] Figure 2 shows a schematic of an exemplary computing device suitable for implementing / realizing at least a supervisory controller and analytics engine according to an embodiment of the invention;

[0029] Figure 3 is a flow chart illustrating a method for analyzing street light performance according to an embodiment of the invention;

[0030] Figure 4 is a flow chart illustrating a method for message transmission according to an embodiment of the invention;

[0031] Figure 5 is a flow chart illustrating a method for interpolating light intensity readings according to an embodiment of the invention;

[0032] Figure 6 is a flow chart illustrating a method for averaging and/or filtering light intensity measurements according to an embodiment of the invention; and

[0033] Figure 7 is a flow chart illustrating a method for lane determination according to an embodiment of the invention.

DETAILED DESCRIPTION

[0034] Embodiments of the present invention will be described, by way of example only, with reference to the drawings. Like reference numerals and characters in the drawings refer to like elements or equivalents.

[0035] Some portions of the description which follows are explicitly or implicitly presented in terms of algorithms and functional or symbolic representations of operations on data within a computer memory. These algorithmic descriptions and functional or symbolic representations are the means used by those skilled in the data processing arts to convey most effectively the substance of their work to others skilled in the art. An algorithm is here, and generally, conceived to be a self-consistent sequence of steps leading to a desired result. The steps are those requiring physical manipulations of physical quantities, such as electrical, magnetic or optical signals capable of being stored, transferred, combined, compared, and otherwise manipulated.

[0036] Unless specifically stated otherwise, and as apparent from the following, it will be appreciated that throughout the present specification, discussions utilizing terms such as "scanning", "calculating", "determining", "replacing", "generating", "initializing", "outputting", or the like, refer to the action and processes of a computer system, or similar electronic device, that manipulates and transforms data represented as physical quantities within the computer system into other data similarly represented as physical quantities within the computer system or other information storage, transmission or display devices.

[0037] The present specification also discloses apparatus for performing the operations of the methods. Such apparatus may be specially constructed for the required purposes, or may comprise a computer or other device selectively activated or reconfigured by a computer program stored in the computer. The algorithms and displays presented herein are not inherently related to any particular computer or other apparatus. Various machines may be used with programs in accordance with the teachings herein. Alternatively, the construction of more specialized apparatus to perform the required method steps may be appropriate. The structure of a computer will appear from the description below.

[0038] In addition, the present specification also implicitly discloses a computer program, in that it would be apparent to the person skilled in the art that the individual steps of the method described herein may be put into effect by computer code. The computer program is not intended to be limited to any particular programming language and implementation thereof. It will be appreciated that a variety of programming languages and coding thereof may be used to implement the teachings of the disclosure contained herein. Moreover, the computer program is not intended to be limited to any particular control flow. There are many other variants of the computer

program, which can use different control flows without departing from the spirit or scope of the invention.

[0039] Furthermore, one or more of the steps of the computer program may be performed in parallel rather than sequentially. Such a computer program may be stored on any computer readable medium. The computer readable medium may include storage devices such as magnetic or optical disks, memory chips, or other storage devices suitable for interfacing with a computer. The computer readable medium may also include a hard-wired medium such as exemplified in the Internet system, or wireless medium such as exemplified in the GSM mobile telephone system. The computer program when loaded and executed on such a computer effectively results in an apparatus that implements the steps of the preferred method.

[0040] Embodiments of the invention may also be implemented as hardware modules. More particular, in the hardware sense, a module is a functional hardware unit designed for use with other components or modules. For example, a module may be implemented using discrete electronic components, or it can form a portion of an entire electronic circuit such as an Application Specific Integrated Circuit (ASIC) or Field Programmable Gate Array (FPGA). Numerous other possibilities exist. Those skilled in the art will appreciate that the system can also be implemented as a combination of hardware and software modules.

[0041] Figure 1 shows a schematic of a system 100 for analyzing street light performance on a road according to an embodiment of the invention. The system comprises a sensor module 102 and an analytics engine 120 in communication with the sensor module 102. The sensor module 102 is configured to measure light intensity at various times and output corresponding temporal light intensity data. The sensor module 102 is also configured to determine a spatial location of the sensor module 102 at the various times and output corresponding spatial location data. The sensor module 102 is further configured to generate messages (or data packets) comprising the temporal light intensity data and/or the spatial location data.

[0042] The sensor module 102 may comprise (i) at least one light sensor (for example, three light sensors 104a, 104b, 104c are shown in Figure 1) configured to measure the light intensity, (ii) a timing module 106 configured to generate a time-stamp for each light intensity measurement for facilitating output of the temporal light intensity data, and (iii) a spatial locator module 108 configured to determine the spatial location of the

sensor module at the various times. In this context, "light intensity" refers to light readings from street lamps and/or the ambient environment (e.g. sunlight, moonlight, car lights, lights from buildings, etc.)

[0043] The sensor module 102 may be mounted on a vehicle (e.g. on a roof of the vehicle) or inside a vehicle (e.g. on the dashboard as an in-vehicle unit), and the vehicle is driven along a road on which street light performance is to be analysed.

[0044] The spatial locator module 108 may comprise a Global Positioning System (GPS) receiver for determining the spatial location (e.g. latitude / longitude) of the sensor module at the various times. Alternatively and additionally, the spatial locator module 108 may also use other types of spatial positioning technologies such as different types of satellite-based navigation systems (e.g. GLONASS, Beidou and Galileo).

[0045] In order to supplement the spatial location readings from the spatial locator module 108, the sensor module 102 may be further configured to obtain inertial measurements at the various times and output corresponding temporal inertial data. Accordingly, the sensor module 102 may further comprise at least one inertial measurement unit (IMU) (for example, one IMU 110 is shown in Figure 1) for obtaining the inertial measurements. The IMU 110 comprises one or more of a gyroscope, accelerometer, and magnetometer. In this manner, the IMU 110 is used for dead reckoning in the event that the spatial locator module 108 is unable to determine the spatial location of the sensor module (e.g. due to lost fix on GPS satellites). The IMU 110 can also be used to measure road conditions, traffic conditions and behaviour of the driver of the vehicle that is carrying the sensor module 102.

[0046] The sensor module 102 may comprise a microcontroller unit (MCU) 112 for generating the messages comprising the temporal light intensity data, the spatial location data and/or the temporal inertial data. If there are three light sensors 104a, 104b, 104c, two of the three light sensors may be configured to be extended from the MCU 112. For example, light sensor 104b may be directly coupled with the MCU 112, and light sensors 104a, 104c are extended out using extra cabling. In this manner, the three light sensors 104a, 104b, 104c can be mounted on a roof of a vehicle so that light across the width of the vehicle can be captured.

[0047] In an implementation, the sensor module further comprises a memory module 114 for storing the messages and a communications module 116 configured to

wirelessly transmit the messages to the analytics engine 120 via a mobile communications network. The messages are held in the memory module 114 when a signal strength of the mobile communications network is below a pre-determined level / threshold and transmitted to the analytics engine 120 when the signal strength is above the pre-determined level / threshold. In this manner, reliable transmission of the messages may be achieved. Further details on this message transmission procedure will be provided below with reference to Figure 4.

[0048] The messages may be compacted and/or encrypted in-flight before transmission. Encryption algorithms may be based on the Transport Layer Security (TLS) protocol. This protocol allows a server and client to authenticate each other and to negotiate an encryption algorithm and cryptographic keys before data is exchanged.

[0049] The system 100 may comprise a supervisory controller 121 configured to manage and monitor the activity of the sensor module 102. The supervisory controller 121 is similar to a sensor network management system based on a publish-subscribe model. It will be appreciated that the system 100 may comprise more than one sensor module 102, analytics engine 120 or supervisory controller 121. For the sake of brevity, only a single sensor module 102, analytics engine 120 and supervisory controller 121 is shown in Figure 1.

[0050] The analytics engine 120 and supervisory controller 121 may be implemented / realized using a computer server. The server design may be based on a REST (Representational State Transfer) architecture, i.e., a RESTful service allowing for a completely modular and decoupled system design. The RESTful service allows open application programming interfaces (APIs). This enables data to be accessed anytime and anywhere by any authorised device (e.g. computers, mobile phones, mobile computing devices, tablet PCs 140). Further details on the computer server will be provided below with reference to Figure 2.

[0051] The analytics engine 120 is configured to receive the messages (comprising the temporal light intensity data, the spatial location data and/or the temporal inertial data) from the sensor module 102. The analytics engine 120 is also configured to generate spatial light intensity data based on the temporal light intensity data and the spatial location data. The spatial light intensity data provides an indication of light intensity at a particular spatial location (e.g. geographical co-ordinate).

[0052] In the implementation where the sensor module 102 comprises the IMU 110 for obtaining inertial measurements at the various times and output corresponding temporal inertial data, the analytics engine 120 is further configured to generate the spatial location data based on at least the temporal inertial data. In this implementation, an initial reference GPS position is required. For example, initially, a GPS position is available. Subsequently, GPS satellite fix is lost. Thereafter, IMU data (i.e. temporal inertial data) is used to infer spatial location. Errors may build up due to a drift in IMU sensor readings. In such an event, road snapping, i.e., GPS points snapped to the most likely roads the vehicle is traveling along, can be used to help reduce the drift effect. Once GPS satellite fix is regained, the position may be re-corrected.

[0053] In an example implementation, the analytics engine 120 is configured to generate the spatial light intensity data by appending the temporal light intensity data having a particular time-stamp with the spatial location data having the same particular time-stamp. That is, the time-stamp is used as a common reference for appending the two distinct types of data (i.e. the temporal light intensity data and spatial location data).

[0054] In a further implementation, the analytics engine 120 is configured to generate the spatial light intensity data by interpolating the temporal light intensity data having a particular time-stamp based on the spatial location data having a time-stamp at a time before and after a time of the particular time-stamp. This implementation is useful when the spatial locator module 108 is unable to provide the spatial location of the sensor module at certain times, e.g. when there is a weak or no GPS signal. Further details on the interpolation process will be provided below with reference to Figure 5.

[0055] The analytics engine 120 can have an integrated memory module or be in communication with an external memory module 122. In either case, the integrated memory module or external memory module can have a database having stored therein spatial locations and their corresponding road name. For example, database can contain a plurality of spatial locations (e.g. geographical co-ordinates), and each spatial location can be associated with a road name. More than one spatial location can be associated with a road name, especially if the road is relatively long. For example, the spatial location defined by latitude N 1.29996° and longitude E 103.85973° is associated with "Beach Road".

[0056] The analytics engine 120 is configured to retrieve, from the database, the road name corresponding to each spatial location associated with the spatial light intensity

data. The analytics engine 120 is further configured to generate an indication of street light performance of at least a portion of the road with the retrieved road name based on the spatial light intensity data.

[0057] The indication of street light performance may include, but is not limited to, uniformity, minimum, maximum and average light intensity levels corresponding to a spatial location. Uniformity may be derived by dividing the minimum light intensity levels by the average light intensity levels (i.e. $\text{uniformity} = \text{minimum} / \text{average}$). In this manner, it is possible to determine sub-optimal road lighting conditions.

[0058] In an implementation, there may be provided an additional database having stored therein street light identifiers and their corresponding spatial location. The database may be the same database as the database mentioned above, or may be a different database. In this implementation, the analytics engine 120 is further configured to retrieve, from the additional database, each street light identifier corresponding to each spatial location associated with the spatial light intensity data and generate an indication of street light performance of a street light with the retrieved street light identifier based on the spatial light intensity data. For example, the additional database can contain a plurality of street light identifiers, and each street light identifier can be associated with a spatial location (e.g. pole ID 123 is associated with "N 1.29996°; E 103.85973°"). In this manner, a street light that is exhibiting sub-optimal performance may be easily identified.

[0059] In an implementation, to more accurately analyze street light performance, shadows and other ambient lighting are filtered out as much as possible so that only light from streetlights is taken into account when determining streetlight performance. For example, an averaging technique may be used wherein various measured light intensities are averaged across a fixed or variable longitudinal interval.

[0060] Accordingly, the analytics engine 120 may be further configured to determine a plurality of average light intensities, wherein each average light intensity is based on an average of the light intensity measured by each of a plurality of light sensors (e.g. 104a, 104b, 104c) during a particular time interval based on the temporal light intensity data. Thereafter, the analytics engine 120 may be further configured to (i) filter away average light intensities that are less than a pre-determined threshold and retain average light intensities that are equal to or more than the pre-determined threshold, and (ii) register a highest value of the retained average light intensities. Further details

on this averaging and filtering technique will be provided below with reference to Figure 6.

[0061] In another embodiment, the analytics engine may be further configured to (i) filter away individual light intensity measurements (e.g. from light sensors 104a, 104b, 104c individually) that are less than a pre-determined threshold and retain light intensity measurements that are equal to or more than the pre-determined threshold, and (ii) register a highest value of the retained light intensity measurements. Further details on this filtering technique will be provided below with reference to Figure 6.

[0062] Some roads may have more than one lane. If there is more than one lane, light intensity may vary across the various lanes. As such, it is beneficial to supplement spatial light intensity data with road lane information. That is, besides obtaining spatial location data using the spatial locator module 108, it is beneficial to associate the road lane with the spatial location data. In an implantation, the analytics engine 120 may be further configured to determine an average distance to a road section line based on the spatial location data and determine a lane number based on the average distance to the road section line. Here, it is assumed that the spatial location data of the road section line is known. In this implementation, lane numbers are determined based on the mean perpendicular bisector of the traversed path and road section line. Further details on this lane determination technique will be provided below with reference to Figure 7.

[0063] As mentioned above, the analytics engine 120 and the supervisory controller 121 may be implemented / realized using a server.

[0064] Figure 2 depicts an exemplary computer / computing device / server, hereinafter interchangeably referred to as a computer system 200, where one or more such computing devices 200 may be used for implementing / realizing at least the supervisory controller 121 and/or analytics engine 120 according to an embodiment of the invention. The following description of the computing device 200 is provided by way of example only and is not intended to be limiting.

[0065] As shown in Figure 2, the example computing device 200 includes a processor 204 for executing software routines. Although a single processor is shown for the sake of clarity, the computing device 200 may also include a multi-processor system. The processor 204 is connected to a communication infrastructure 206 for communication

with other components of the computing device 200. The communication infrastructure 206 may include, for example, a communications bus, cross-bar, or network.

[0066] The computing device 200 further includes a main memory 208, such as a random access memory (RAM), and a secondary memory 210. The secondary memory 210 may include, for example, a storage drive 212, which may be a hard disk drive, a solid state drive or a hybrid drive and/or a removable storage drive 214, which may include an optical disk drive, a solid state storage drive (such as a USB flash drive, a flash memory device, a solid state drive or a memory card), or the like. The removable storage drive 214 reads from and/or writes to a removable storage medium 244 in a well-known manner. The removable storage medium 244 may include an optical disk, non-volatile memory storage medium, or the like, which is read by and written to by removable storage drive 214. As will be appreciated by persons skilled in the relevant art(s), the removable storage medium 244 includes a computer readable storage medium having stored therein computer executable program code instructions and/or data.

[0067] In an alternative implementation, the secondary memory 210 may additionally or alternatively include other similar means for allowing computer programs or other instructions to be loaded into the computing device 200. Such means can include, for example, a removable storage unit 222 and an interface 240. Examples of a removable storage unit 222 and interface 240 include a removable memory chip (such as an EPROM or PROM) and associated socket, a removable solid state storage drive (such as a USB flash drive, a flash memory device, a solid state drive or a memory card), and other removable storage units 222 and interfaces 240 which allow software and data to be transferred from the removable storage unit 222 to the computer system 200.

[0068] The computing device 200 also includes at least one communication interface 224. The communication interface 224 allows software and data to be transferred between computing device 200 and external devices via a communication path 226. In various embodiments of the inventions, the communication interface 224 permits data to be transferred between the computing device 200 and a data communication network, such as a public data or private data communication network. The communication interface 224 may be used to exchange data between different computing devices 200 which such computing devices 200 form part an interconnected computer network. Examples of a communication interface 224 can include a modem, a network interface (such as an Ethernet card), a communication port (such as a serial,

parallel, printer, GPIB, IEEE 1394, RJ45, USB), an antenna with associated circuitry and the like. The communication interface 224 may be wired or may be wireless. Software and data transferred via the communication interface 224 are in the form of signals which can be electronic, electromagnetic, optical or other signals capable of being received by communication interface 224. These signals are provided to the communication interface via the communication path 226.

[0069] As shown in Figure 2, the computing device 200 further includes a display interface 202 which performs operations for rendering images to an associated display 230 and an audio interface 232 for performing operations for playing audio content via associated speaker(s) 234.

[0070] As used herein, the term "computer program product" may refer, in part, to removable storage medium 244, removable storage unit 222, a hard disk installed in storage drive 212, or a carrier wave carrying software over communication path 226 (wireless link or cable) to communication interface 224. Computer readable storage media refers to any non-transitory, non-volatile tangible storage medium that provides recorded instructions and/or data to the computing device 200 for execution and/or processing. Examples of such storage media include CD-ROM, DVD, Blu-ray™ Disc, a hard disk drive, a ROM or integrated circuit, a solid state storage drive (such as a USB flash drive, a flash memory device, a solid state drive or a memory card), a hybrid drive, a magneto-optical disk, or a computer readable card such as a SD card and the like, whether or not such devices are internal or external of the computing device 200. Examples of transitory or non-tangible computer readable transmission media that may also participate in the provision of software, application programs, instructions and/or data to the computing device 200 include radio or infra-red transmission channels as well as a network connection to another computer or networked device, and the Internet or Intranets including e-mail transmissions and information recorded on Websites and the like.

[0071] The computer programs (also called computer program code) are stored in main memory 208 and/or secondary memory 210. Computer programs can also be received via the communication interface 224. Such computer programs, when executed, enable the computing device 200 to perform one or more features of embodiments discussed herein. In various embodiments, the computer programs, when executed, enable the processor 204 to perform features of the above-described

embodiments. Accordingly, such computer programs represent controllers of the computer system 200.

[0072] Software may be stored in a computer program product and loaded into the computing device 200 using the removable storage drive 214, the storage drive 212, or the interface 240. Alternatively, the computer program product may be downloaded to the computer system 200 over the communications path 226. The software, when executed by the processor 204, causes the computing device 200 to perform functions of embodiments described herein.

[0073] It is to be understood that the embodiment of Figure 2 is presented merely by way of example. Therefore, in some embodiments one or more features of the computing device 200 may be omitted. Also, in some embodiments, one or more features of the computing device 200 may be combined together. Additionally, in some embodiments, one or more features of the computing device 200 may be split into one or more component parts. The computing device 200 may be implemented as a local server or hosted on the Internet using cloud-computing models.

[0074] Figure 3 is a flow chart illustrating a method 300 for analyzing street light performance on a road according to an embodiment of the invention. One or more of the steps of the method may be performed in parallel rather than sequentially. Also, the steps of method 300 are in no particular order. For example, step 304 may be performed before step 302. At step 302, a sensor module is used to measuring light intensity at various times and output corresponding temporal light intensity data. At step 304, a spatial location of the sensor module is determined at the various times and corresponding spatial location data is outputted. At step 306, messages comprising the temporal light intensity data and/or the spatial location data are generated. At step 308, spatial light intensity data is generated based on the temporal light intensity data and the spatial location data. Step 310 involves retrieving, from a database having stored therein spatial locations and their corresponding road name, the road name corresponding to each spatial location associated with the spatial light intensity data. Step 312 involves generating an indication of street light performance of at least a portion of the road with the retrieved road name based on the spatial light intensity data.

[0075] Figure 4 is a flow chart illustrating a method 400 for message transmission according to an embodiment of the invention. As mentioned above, the

communications module 116 configured to wirelessly transmit the messages to the analytics engine 120 via a mobile communications network. At step 402, a signal strength of the mobile communications network is checked. If the signal strength is below a pre-determined level / threshold, the messages are held in the memory module 114 as per step 404. However, if the signal strength is above the pre-determined level / threshold, the messages are transmitted to the analytics engine 120 as per step 406. The value of the threshold level may be arbitrarily defined.

[0076] Figure 5 is a flow chart illustrating a method 500 for interpolating light intensity readings according to an embodiment of the invention. Each GPS reading has a timestamp and geolocation (e.g. latitude / longitude), i.e. *GPS reading* = {*timestamp*, *geolocation*}.

[0077] Assuming each sensor module has a plurality of light sensors (e.g. three light sensors, *Lux1*, *Lux2*, *Lux3*), each measurement from each light sensor has a timestamp and a light intensity reading, i.e. *Lux₁*, *Lux₂*, or *Lux₃* = {*timestamp*, *light intensity*}. It is also possible to aggregate the measurements from all the light sensors in the sensor module. These aggregated measurements may be referred to as Lux readings, i.e. *Lux readings* = {*timestamp*, *Lux₁*, *Lux₂*, *Lux₃*}.

[0078] At step 502, timestamps (*t* and *t+1*) for two consecutive GPS readings are extracted. At step 504, lux readings, *L_i* (*i* = 1,...,n) with timestamps between *t* (*inclusive*) and *t+1* are searched. At step 506, each element in a set *L* is interpolated, for example, linearly at an angle. For example, for points (a, b) and (c, d) and *n* intervals (i.e. *n-1* intervening points), the interpolated points are (a + (*i/n*) * (c-a), b + (*i/n*) * (d-b)) for *i* = 1, 2, 3...*n-1*.

[0079] Figure 6 is a flow chart illustrating a method 600 for averaging and/or filtering light intensity measurements according to an embodiment of the invention. At step 602, initialize the values *max_lux* and *max_lux_avg* = 0. Assume each sensor module has three light sensors (*Lux1*, *Lux2*, *Lux3*) that take readings simultaneously (*Lux₁*, *Lux₂*, *Lux₃*). Also, assume that a particular road has three lanes on each side (i.e. six lanes in total, three lanes for traffic in each direction), designated as "lane 1", "lane 2", and "lane 3". To measure light intensity along all three lanes, three separate runs may be performed, where each run measures light intensity for one lane along a stretch of the road. That is, each run *i* (*i* = 1, 2, 3) comprises *j* (*j* = 1,...,m) readings. At step 604, for a set of lux readings from each light sensor *lux_{ijk}*, *k* = 1, 2, 3, the average light intensity reading *lux_avg_{ij}* is computed (i.e. *lux_avg_{ij}* = (*lux_{ij1}* + *lux_{ij2}* +

$lux_{ij3})/3$). lux_{ijk} is used to denote that each run i has j readings, and each j reading is associated with a light sensor k . For example, lux_{ij1} is read as: for run i , all light intensity readings j from light sensor 1.

[0080] At step 606a, the value of lux_avg_{ij} is checked to determine whether it is equal to or greater than a first pre-determined value. If the value of lux_avg_{ij} is less than the first pre-determined value, step 601 is initiated where i is incremented. If the value of lux_avg_{ij} is equal to or more than the first pre-determined value, step 608a is initiated.

[0081] At step 606b, the value of lux_{ijk} is checked to determine whether it is equal to or greater than a second pre-determined value. If the value of lux_{ijk} is less than the second pre-determined value, step 601 is initiated where i is incremented. If the value of lux_{ijk} is equal to or more than the second pre-determined value, step 608b is initiated. The first and second pre-determined values can have the same magnitude or have different magnitudes.

[0082] There may be rare instances where an area of the road is too dark (e.g. extreme shadowing caused by trees or a light sensor is obstructed by a fallen leaf), and some of the values may be less than the pre-determined value. As such, steps 606a and 606b seek to filter out these outlier values to avoid skewing the results.

[0083] At step 608a, the average lux is summed, an index is increased, and the value of lux_avg_{ij} is compared to the value of max_lux_avg and the larger of the two values is assigned max_lux_avg . The corresponding pseudocode is as follows:

```

For each i
  buffer = 0
  index = 0
  For each j
    buffer = buffer +  $lux\_avg_{ij}$ 
    index = index + 1

 $max\_lux\_avg = max(lux\_avg_{ij}, max\_lux\_avg)$ 
e.g.,  $max\_lux\_avg = max(10, 0) = 10$ 

```

[0084] At step 608b, the lux is summed, the index is increased, and the value of lux_{ijk} is compared to the value of max_lux and the larger of the two values is assigned max_lux . The corresponding pseudocode is as follows:

```

For each i
  buffer = 0
  index = 0

  For each j

```

For each k
 buffer = buffer + lux_{ijk}
 index = index + 1

 $max_lux = \max(lux_{ijk}, max_lux)$
 e.g., $max_lux = \max(10, 0) = 10$

[0085] At step 610a, if the index is more than 0, the average is taken, otherwise max_lux_avg is selected. At step 610b, if the index is more than 0, the average is taken, otherwise max_lux is selected.

[0086] At step 612, if i is less than $n+1$, step 601 is initiated. Otherwise, the method 600 ends.

[0087] The method 600 may also include a step of obtaining a minimum light intensity (min_lux) or average minimum light intensity (min_lux_avg) so that uniformity of light intensity can be derived.

[0088] The method 600 may further comprise generating a time-stamp for each light intensity measurement for facilitating output of the temporal light intensity data.

[0089] The method 600 may further comprise appending the temporal light intensity data having a particular time-stamp with the spatial location data having the same particular time-stamp to generate the spatial light intensity data. Alternatively or additionally, the method 600 may further comprise interpolating the temporal light intensity data having a particular time-stamp based on the spatial location data having a time-stamp at a time before and after a time of the particular time-stamp to generate the spatial light intensity data.

[0090] The method 600 may also comprise obtaining inertial measurements at the various times and outputting corresponding temporal inertial data; and generating the spatial location data based on at least the temporal inertial data.

[0091] The method 600 may further comprise: providing a mobile communications network for wirelessly transmitting the generated messages from the sensor module to an analytics engine that is configured to generate the spatial light intensity data based on the temporal light intensity data and the spatial location data; holding the messages in a memory module of the sensor module when a signal strength of the mobile communications network is below a pre-determined level; and transmitting the

messages to the analytics engine when the signal strength is above the pre-determined level.

[0092] The method 600 may further comprise: retrieving, from an additional database having stored therein street light identifiers and their corresponding spatial location, each street light identifier corresponding to each spatial location associated with the spatial light intensity data; and generating an indication of street light performance of a street light with the retrieved street light identifier based on the spatial light intensity data.

[0093] The method may further comprise determining an average distance to a road section line based on the spatial location data; and determining a lane number associated with the portion of the road based on the average distance to the road section line.

[0094] The sensor module may comprise a plurality of light sensors. Accordingly, the method 600 may further comprise: determining a plurality of average light intensities, wherein each average light intensity is based on an average of the light intensity measured by each of the plurality of light sensors during a particular time interval based on the temporal light intensity data. Thereafter, the method 600 may further comprise: filtering away average light intensities that are less than a pre-determined threshold and retaining average light intensities that are equal to or more than the pre-determined threshold; and registering a highest value of the retained average light intensities.

[0095] The method 600 may also comprise: filtering away light intensity measurements that are less than a pre-determined threshold and retaining light intensity measurements that are equal to or more than the pre-determined threshold; and registering a highest value of the retained light intensity measurements.

[0096] Figure 7 is a flow chart illustrating a method 700 for lane determination according to an embodiment of the invention. Assume that a particular road has three lanes on each side (i.e. six lanes in total, three lanes for traffic in each direction), and for each side, "lane 1" is the rightmost lane that is closest to a road section line, "lane 2" is the middle lane and "lane 3" is the leftmost lane. To accurately determine the streetlight performance for the road, it is preferable that the light intensity is measured along all three lanes. Measuring light intensity for only one lane out of three and taking

that measurement to be representative of the streetlight performance for the entire road may not yield an accurate performance result. For example, on lane 3, there may be relatively more shadows resulting from trees.

[0097] To measure light intensity along all three lanes, three separate runs may be performed, where each run measures light intensity for one lane along a stretch of the road. Each run i ($i = 1, 2, 3$) comprises j ($j = 1, \dots, m$) readings. At step 702, for a set of GPS readings, r_{ij} , the perpendicular distance, $d_{r_{ij}}$ from point r_{ij} to the road section line, R , is computed. Here, it is assumed that R is known. At step 704, the average perpendicular distance $d_{r_{i_avg}}$ is computed across i . At step 706, respective lane numbers are assigned based on $d_{r_{i_avg}}$. That is, if $d_{r_{1_avg}} < d_{r_{2_avg}} < d_{r_{3_avg}}$, assign lane numbers 1, 2 and 3 respectively. At step 708, if i is less than $n+1$, i is incremented and step 704 is initiated. Otherwise, the method 700 ends.

[0098] It will be appreciated by a person skilled in the art that numerous variations and/or modifications may be made to the present invention as shown in the specific embodiments without departing from the spirit or scope of the invention as broadly described. The present embodiments are, therefore, to be considered in all respects to be illustrative and not restrictive.

CLAIMS

1. A system for analyzing street light performance on a road, comprising:
 - a sensor module configured to:
 - measure light intensity at various times and output corresponding temporal light intensity data;
 - determine a spatial location of the sensor module at the various times and output corresponding spatial location data; and
 - generate messages comprising the temporal light intensity data and/or the spatial location data;
 - an analytics engine in communication with the sensor module, wherein the analytics engine is configured to:
 - receive the messages from the sensor module;
 - generate spatial light intensity data based on the temporal light intensity data and the spatial location data;
 - retrieve, from a database having stored therein spatial locations and their corresponding road name, the road name corresponding to each spatial location associated with the spatial light intensity data; and
 - generate an indication of street light performance of at least a portion of the road with the retrieved road name based on the spatial light intensity data,

wherein the sensor module comprises a timing module configured to generate a time-stamp for each light intensity measurement for facilitating output of the temporal light intensity data, and wherein the analytics engine is further configured to: determine an average distance to a road section line based on the spatial location data; and determine a lane number associated with the portion of the road based on the average distance to the road section line.
2. The system as claimed in claim 1, wherein the sensor module comprises:
 - at least one light sensor configured to measure the light intensity;
 - and
 - a spatial locator module configured to determine the spatial location of the sensor module at the various times.
3. The system as claimed in claim 2, wherein the analytics engine is configured to generate the spatial light intensity data by appending the temporal light intensity data having a particular time-stamp with the spatial location data having the same particular time-stamp.
4. The system as claimed in claim 2, wherein the analytics engine is configured to generate the spatial light intensity data by interpolating the temporal light intensity data having a particular time-stamp based on the spatial location data having a time-stamp at a time before and after a time of the particular time-stamp.

5. The system as claimed in any one of the preceding claims, wherein the sensor module is further configured to obtain inertial measurements at the various times and output corresponding temporal inertial data, and wherein the analytics engine is further configured to generate the spatial location data based on at least the temporal inertial data.

6. The system as claimed in claim 5, wherein the sensor module comprises at least one inertial measurement unit (IMU) configured to obtain the inertial measurements.

7. The system as claimed in any one of the preceding claims, wherein the sensor module further comprises:

a memory module for storing the messages; and

a communications module configured to wirelessly transmit the messages to the analytics engine via a mobile communications network,

wherein the messages are held in the memory module when a signal strength of the mobile communications network is below a pre-determined level and transmitted to the analytics engine when the signal strength is above the pre-determined level.

8. The system as claimed in any one of the preceding claims, wherein the analytics engine is further configured to:

retrieve, from an additional database having stored therein street light identifiers and their corresponding spatial location, each street light identifier corresponding to each spatial location associated with the spatial light intensity data; and

generate an indication of street light performance of a street light with the retrieved street light identifier based on the spatial light intensity data.

9. The system as claimed in claim 2, wherein the sensor module comprises a plurality of light sensors and the analytics engine is further configured to determine a

plurality of average light intensities, and wherein each average light intensity is based on an average of the light intensity measured by each of the plurality of light sensors during a particular time interval based on the temporal light intensity data.

10. The system as claimed in claim 9, wherein the analytics engine is further configured to:

filter away average light intensities that are less than a pre-determined threshold and retain average light intensities that are equal to or more than the pre-determined threshold; and

register a highest value of the retained average light intensities.

11. The system as claimed in claim 2, wherein the sensor module comprises a plurality of light sensors and the analytics engine is further configured to:

filter away light intensity measurements that are less than a pre-determined threshold and retain light intensity measurements that are equal to or more than the pre-determined threshold; and

register a highest value of the retained light intensity measurements.

12. The system as claimed in claim 2, wherein the spatial locator module comprises a Global Positioning System (GPS) receiver.

13. A method for analyzing street light performance on a road, comprising:

measuring light intensity at various times using a sensor module and outputting corresponding temporal light intensity data;

generating, using a timing module of the sensor module, a time-stamp for each light intensity measurement for facilitating output of the temporal light intensity data;

determining a spatial location of the sensor module at the various times and outputting corresponding spatial location data;

generating messages comprising the temporal light intensity data and/or the spatial location data;

generating spatial light intensity data based on the temporal light intensity data and the spatial location data;

retrieving, from a database having stored therein spatial locations and their corresponding road name, the road name corresponding to each spatial location associated with the spatial light intensity data;

generating an indication of street light performance of at least a portion of the road with the retrieved road name based on the spatial light intensity data;

determining an average distance to a road section line based on the spatial location data; and

determining a lane number associated with the portion of the road based on the average distance to the road section line.

14. The method as claimed in claim 13, further comprising: appending the temporal light intensity data having a particular time-stamp with the spatial location data having the same particular time-stamp to generate the spatial light intensity data.

15. The method as claimed in claim 13, further comprising: interpolating the temporal light intensity data having a particular time-stamp based on the spatial location data having a time-stamp at a time before and after a time of the particular time-stamp to generate the spatial light intensity data.

16. The method as claimed in any one of claims 13 to 15, further comprising:
obtaining inertial measurements at the various times and outputting corresponding temporal inertial data; and
generating the spatial location data based on at least the temporal inertial data.

17. The method as claimed in any one of claims 13 to 16, further comprising:
providing a mobile communications network for wirelessly transmitting the generated messages from the sensor module to an analytics engine that is configured to generate the spatial light intensity data based on the temporal light intensity data and the spatial location data;
holding the messages in a memory module of the sensor module when a signal strength of the mobile communications network is below a pre-determined level; and
transmitting the messages to the analytics engine when the signal strength is above the pre-determined level.

18. The method as claimed in any one of claims 13 to 17, further comprising:
retrieving, from an additional database having stored therein street light identifiers and their corresponding spatial location, each street light identifier corresponding to each spatial location associated with the spatial light intensity data; and
generating an indication of street light performance of a street light with the retrieved street light identifier based on the spatial light intensity data.

19. The method as claimed in any one of claims 13 to 18, wherein the sensor module comprises a plurality of light sensors, and the method further comprises the steps of:

determining a plurality of average light intensities, wherein each average light intensity is based on an average of the light intensity measured by each of the plurality of light sensors during a particular time interval based on the temporal light intensity data.

20. The method as claimed in claim 19, further comprising:

filtering away average light intensities that are less than a pre-determined threshold and retaining average light intensities that are equal to or more than the pre-determined threshold; and

registering a highest value of the retained average light intensities.

21. The method as claimed in any one of claims 13 to 18, wherein the sensor module comprises a plurality of light sensors, and the method further comprises the steps of:

filtering away light intensity measurements that are less than a pre-determined threshold and retaining light intensity measurements that are equal to or more than the pre-determined threshold; and

registering a highest value of the retained light intensity measurements.