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Automatic washing system of LED street lighting via Internet of Things

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The illumination of the streets and public area in metropolitan cities is a vital service, which is not only related to the type of the light but also the dirtiness of the surface of the light. In this paper, both subjects are considered to increase the productivity of the light. To achieve this goal, a novel Automatic washing system (AWS) of LED street/public light surface was designed, manufactured and installed practically. The proposed mechanism consists of two main parts comprising mechanical and electrical systems. AWS operates based on internet interconnection technique known as Internet of Things (IoT) with a high productivity. The system has the potential to be designed and employed by four types of control system; *(i)* using a timer switch, *(ii)* using a GSM 900, *(iii)* using a push button manually by an operator, and *(iv)* using a remote-control module such as GSM, SIM 808 or GPRS/GPS/SMS through the Ethernet network. A practical system has been manufactured and installed in Kermanshah city in Iran, due to its low cost, low maintenance, upgradability, and feasibility of installing different recognition sensors such as rain and dust sensors.

1. Introduction

The rapid increase of urbanization and constructions at large cities around the world caused the expansion of the industrial activities and transportation, which significantly have produced a huge amount of pollutants and dusts. This is one of the main challenges in metropolitan cities [1] in which pollutants are spread everywhere widely and the street light surfaces are not exceptional. Interestingly, due to the humidity and heavy materials, the quality and quantity of pollutants and dusts have different persistent deposition [2] even on the surface of the street lights. Therefore, the influence of deposition can be irreversible on the lights both in the reduction of the illumination and increase the temperature, which damages the lights and electrical connections. It is obvious that the reduction of illumination in cities has negative effects on safety, which can increase crimes and accidents. In addition, due to the dirt accumulation of the lights, the required illumination significantly reduces without more power saving. It has been shown that the illumination of lights is reduced up to 60% due to the dirt accumulation and surface deposition [3].

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A relatively new analytical investigation performed by researchers have shown that dusts and heavy materials that are the consequences of hydrocarbons could be the result of different kinds of dirt accumulation such as dry and humid depositions [4–6]. Dry deposition stands for the mechanism in which the transport of particles and dusts to a surface is determined. As a result, the deposition speed of particles can be defined and evaluated as follow [7]:

$$v_d = \frac{F}{C(z)}, \tag{1}$$

where, F represents the flow removed particles per square meter (g m^{-2} s^{-1}) and $C(z)$ is pollutant concentration near the ground (g m^3). Consequently, the unit of the deposition speed (v_d) on the surface of objects such as buildings and the street light surface is (m s^{-1}).

On the other hand, wet deposition can be considered for the mechanism or condition in which atmospheric contaminants are transported due to the divers' forms of precipitations such as fogs, rains, and snows. Thus, in this type of dirt accumulation, the interaction of dusts with humidity can be evaluated by the amount of pollutants and dusts, $Q(t)$, at instant t as follow [8]:

$$Q(t + dt) = Q(t)e^{l_w(t)dt}. \tag{2}$$

Here, $l_w(t)$ stands for the coefficient of washout, and it is expressed in terms of precipitation intensity, $P(t)$ with the unit of (mm/h) as follow:

$$l_w(t) = l_{w0}(t)P(t)^a. \tag{3}$$

In the above equation, $l_{w0}(t)$ is a constant value and it varies by the type of pollutant. The exponent of 'a' varies from 0.75 up to 1 [8]. It is seen that the deposition of the surface of the street or public lights directly depends on the time and the weather condition of the large cities. Thus, employing an appropriate automatic washing system based on these conditions can overcome and solve the dirtiness of the street lights in metropolitan cities around the world.

There are two main methods of the cleaning system for the street light surfaces: (i) manual cleaning and (ii) industrial elevators and/or climbing robots. Manual cleaning of the street lighting is an annoying solution and it is costly and time-consuming, particularly, in large cities. In addition, the truck and vehicles, which are employed in this method, can cause traffic congestion or accident. Therefore, this method is not suggested and very efficient for the large cities. A relatively new method is employing industrial elevator or climbing robot. These tools are mostly used as suitable facilities for the cleaning and maintenance of the street light surfaces [3,9]. While employing the robots provided its own merits such as reduction of the traffic congestion and car accidents, they are still very costly and must be operated by two or more operators. Furthermore, the operation of the robots is limited to the environmental conditions. For instance, they are not able to be operated in the rain, wind, and very high or very low temperatures [3]. Therefore, there is a need for a new, feasible and cost-effective solution to eliminating all the above drawbacks.

While, the illumination of the street lights depends on the cleaning the surface of the lights, choosing a suitable lamp type is significantly important. The European Commission report [10] has shown that between 30% and 50% of the electricity used for lighting can be stored and saved by supplying high energy lighting systems. Till last decade, the majority of street and road lights were either metal-halide lamps or pressure sodium bulbs. However, these days LED street lighting system model is fast growing due to its higher efficiency rather than the traditional lighting models [11]. Additional advantages of LED lights such as reduced maintenance cost, reduced energy consumption, no toxic chemical like mercury also caused that this system is becoming increasingly popular [12].

Fortunately, the real-time control capability of LED employing networked infrastructure provides a platform for the connection of the street lights to various data sources using Internet of Things (IoT) [13]. Providing automation between different devices employing a remote control and sensory applications by IoT can reduce the labor work and increase the accuracy of operation. Recently, IoT is providing remarkable opportunities for novel applications that improve the quality of our lives. Smart homes, smart parking sections, smart lighting systems, and smart roads are only a few examples that can be considered here among a pool of applications of IoT. Following the previous cleaning systems, in this article, IoT technique is used as a suitable application for AWS of the street or public lighting surface at different weather conditions.

To the best of the authors' knowledge , there is no existing fully automatic system can be found for cleaning the surface of the street or public lights in the literature. The above considerations yield to innovate an automatic washing system (AWS), which capable to remove the dirt accumulation and surface deposition automatically, which is easily controlled in different weather conditions. The details of the mechanism are explained in the next section.

2. Details of mechanism

AWS was designed and fabricated with very high-performance capability. In addition, due to the low cost, simplicity and customer-friendly feature of the system, recently, this production has been installed and used in Kermanshah, one of the large cities of Iran (Fig. 1).

The IoT-based washing system is a smart and automatic mechanism that cleans the surface of the street lights remotely. The washing system can be designed and operated in full-automatic and/or semi-automatic employing four types of control systems. The full-automatic system, sending the commands is performed through the IoT technology, for instance, by a GSM

Fig. 1. A photo of the installed LED light in the airport of Kermanshah city, including the zoon of headlight for AWS.

Table 1
Descriptions of the main components of the automatic washing system (AWS).

Main components	Description	Technical information	Cost (USD)
Mechanical components of AWS	Motor-gearbox (ZWL-FP 1650)	T_{max} = kg cm, $\dot{W}$ = 15 W $\omega_{out\,put}$ = 15 RPM	
	Water pump (12 V-DC)	Q = 450–800 L/h	
	Relief valve	½ inch, Pressure resistance 20 bar	
	Linear rack gear mechanism	410 mm × 20 mm × 10 mm	
	Water sprinkler	External diameter = 12 mm Internal diameter = 8.4 mm	
	The water tank	2–5 L	
	Pipes	12 mm	
Electrical components of AWS	SIM900 GSM Shield	Quad Band: 850; 900; 1800 and 1900 MHZ	
	Arduino board (microcontroller) With USB cable	Digital I/O pins 14: (ATmega328) R3 SMD	
	Fuse	10 A	
	Power supply	DL-30 W900-MP, 50/60 Hz, IP 67	
	5 V 2 A power adaptor with DC Jack	5 V power adaptor that provides 2 A with charger jack size of 2.1 mm	
	Timer switch	TB5630187NJ, Weekly	
	Writing circuit	2 × 2.5 mm	
	2-Channel relay module with opt coupler	• High current relay, AC250V 10A, DC30V 10 A • 2 LEDs to indicate when relays are on • Works with logic level signals from 3.3 V or 5 V devices • Opt insulation circuitry • PCB size: 50 × 45 mm	
Total Cost			98.00

control kit by the command center or an operator (in the form of SMS, call, etc.). However, the semi-automatic system is used for the cases without the water pipes. In such cases, a water tank can be installed next to the light's tower and filled manually. In this method, control commands can be sent to the system by an operator using a push-button. The details of four control systems of AWS are explained in the next section.

The proposed mechanism comprised two main parts including mechanical and electrical units as shown in Table 1. The design and the prototype of the mechanism are also shown in Fig. 2.

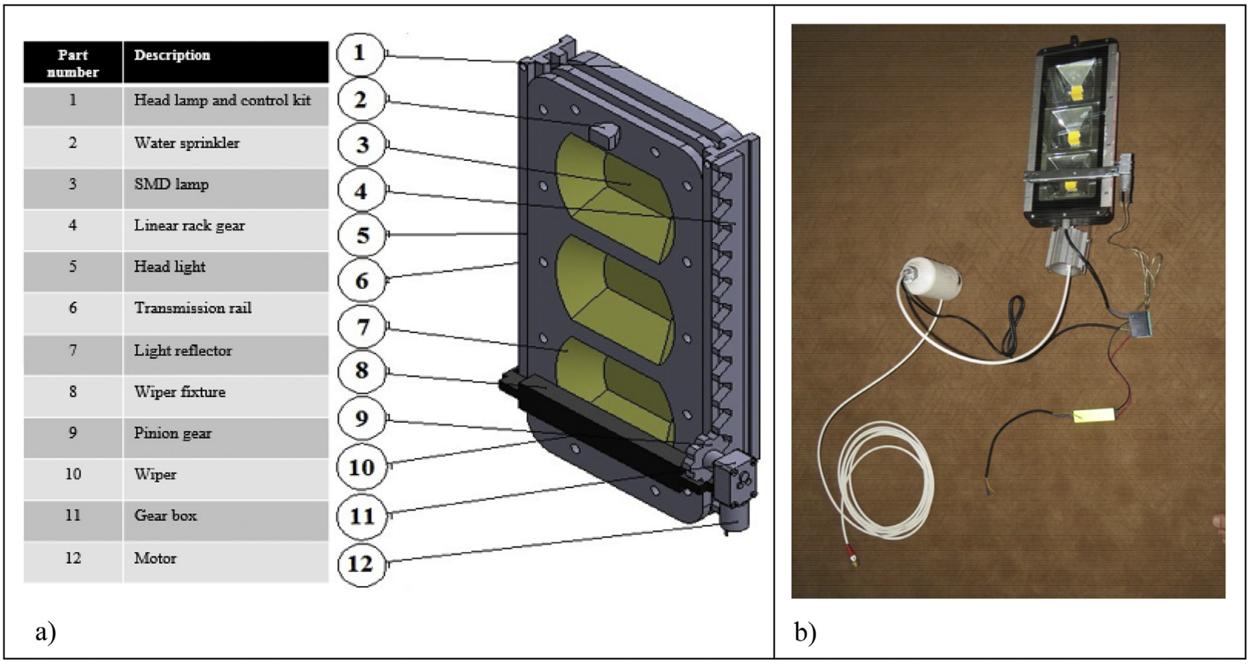

Fig. 2. Design of automatic washing system; (a) solid works design including the description of each part, (b) the prototype of the system mounted on the street light.

The mechanical components include motor-gearbox, water pump, relief valve, linear rack gear mechanism, water sprinkler, water tank (this part is optional and depends on the type of the system) and pipes. The electrical unit consists of SIM 900, Arduino board, fuse, power supply and wiring circuit. Table 1 also shows the technical information in details and the total cost of the components.

Once it is detected that the surface of the lamp is dirty, the water is pumped from the embedded water tank and sprayed on the surface of the light. The water pump can be connected to the urban water piping system or can be fed by a water tank, which can be filled manually or using raining water. The water tank can be installed at a desirable height. At the same time, a headlight wiper is driven by a motor-gearbox, which is coupled with a linear rack-gear mechanism. The 12V-DC worm gear motor (ZWL-FP 1650) was used. Employing this type of motor–gearbox provides a relatively high torque ($T_{max} = 5$ kg.cm) with the output ratio velocity of 1/10. Therefore, 15 RPM output and a reversible motion are produced. This allows the wiper to clean the surface of the headlight after a few reciprocating motions, which is controlled by a controller. The number of reciprocating motions can be defined and embedded in the program.

3. Networked automatic washing streetlight system

The GSM modem (SIM 900) was used for controlling the street light via SMS. An interface has been embedded inside the modem, which allows providing a connection with a PC as well as microcontroller employing a SIM Card. By sending an SMS or a call to a mobile network, the message was analyzed using AT Command (which stands for “ATTENTION”) via an AVR microcontroller. Finally, the request command was accomplished via the circuit (relay). Each relay can send turn ON/OFF command to one or a few hardware simultaneously, such as light and AWS.

The GPRS Shield was based on SIM900 and it was used due to both its straightforwardness and low-cost. The module used in the proposed system was SIMCOM, which was compatible with Arduino boards. This board has 14 digital input/output and a reset button. A USB connection port was used to connect the board to a computer. The GPRS Shield can be communicated with cell phone network using the GSM. The shield allows the operator to achieve SMS, MMS, and GPRS and Audio via UART by sending AT commands (GSM 07.07, 07.05 and SIMCOM enhanced AT Commands).

Fig. 3 shows the flowchart of circuits of AWS of the street headlight. The operator via SMS can send a command signal to SIM 900 using the wireless network. Then the command transfers to the Arduino board, and then, the command is analyzed. In the next step, the relay turns on or off and the current transfers to the consumer. There are two consumers; the first one is the street light and the second one is the automatic washing system comprising motor-gearbox and water pump. The system can operate instantly using three analog sensors: PIR (Passive Infra-Red) sensor, the dust sensor and rain sensor. The PIR sensor was used to turn on/off the light switch based on the motion of a movable unit. It is important to note that another two sensors were used for cleaning, if necessary. In the smart method, these two sensors were installed for

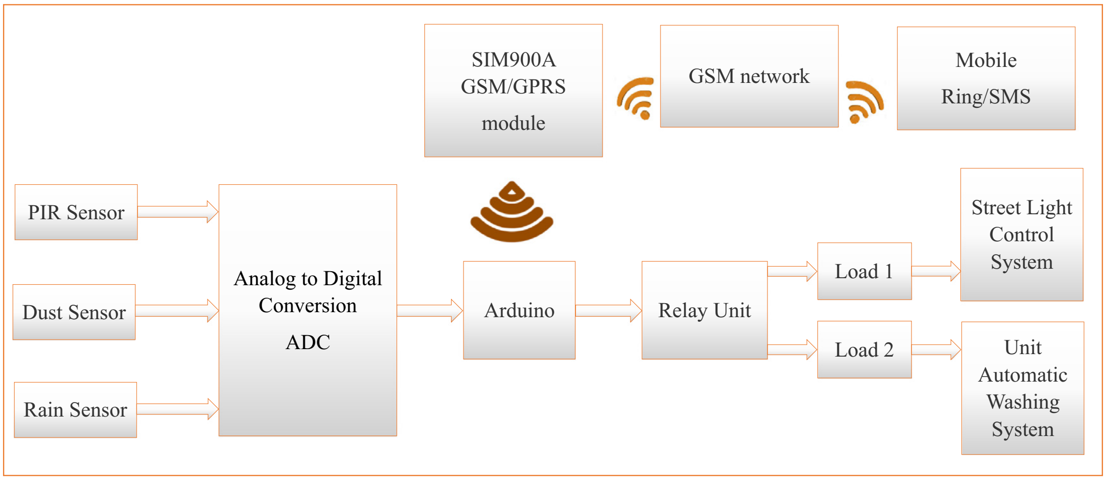

Fig. 3. Flowchart of the automatic washing system.

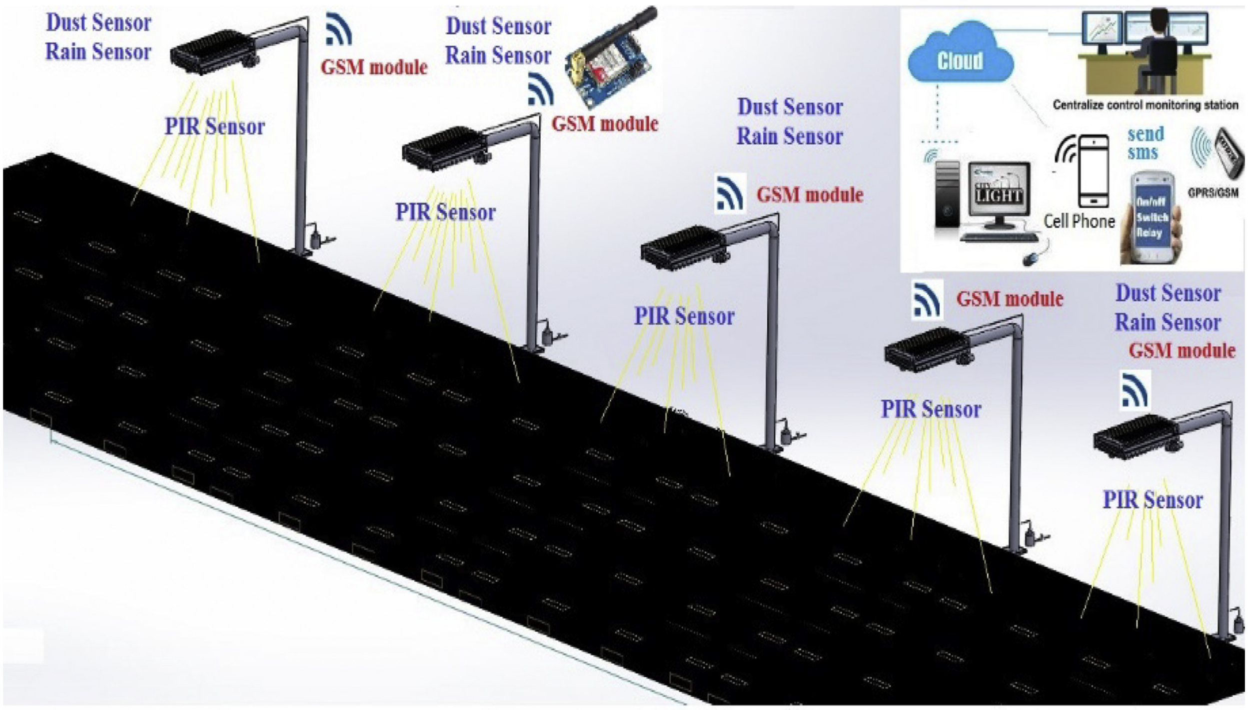

Fig. 4. Schematic of the Internet of Things for lighting control and automatic washing system of lighting lamps surfaces.

detecting pollutants, including the rain and the dust sensors, which were connected to the control board as inputs. Once the surface of the light is detected wet or dusty by the sensors, AWS starts to clean the light.

AWS is also capable to be set based on the predefined schedule for the sensors to clean the surface of the light according to a desirable timetable. In this design, a timer switch can be used to execute the washing operations by the washing system in a scheduled time regardless of detection of pollutions on the lamp surface. Employing a timer allows that the automatic washing system clean the surface of the lamps in the predefined scheduled times, such as daily, weekly, etc.

Fig. 4 shows the architecture of the proposed washing system, which is associated with flowchart of Fig. 3. As mentioned earlier, the detection of dust on the surface of the lamps is accomplished by two detective sensors namely: the rain and the dust sensors. In addition, the Passive and Active Infra-Red (PIR or AIR) are designed and used to control the lamps as a detector unit and input to the control of the light system.

To detect the dirtiness of surface of the lamps, four types of the control system can be designed and employed for AWS, separately:

(1) ***Timer switch***: in an automatic and scheduled manner at specific times in three instantaneous, continual, and with timer: in this design, the mechanism is independent of the identification of spread pollution on the light surface and it works based on the predefined time.
(2) ***GSM900 module***: employing GSM900 by the user or a central unit can be performed through SMS.
(3) ***Push-button***: the embedded push-button allows the operator to control AWS manually.
(4) ***Using other remote-control modules***: remote control modules such as: GSM, SIM808, GPRS/GPS/SMS, through an Ethernet network and applying TCP/IP commands, ETH8020, RF Solutions releases, ESP8266 WIFI, Raspberry Pi IOT Shield Family: 3 G and 4 G; GPS, GPRS, and XBEE.

Having a few design and approach of the control system can be considered as extra advantages of the system.

4. SMS control commands of SIM900 GSM/GPRS modem

In this section, the design of AWS is explained in detail based on SMS notification. Once the SIM900 modem is given SMS notice, a new SMS notification is sent to the microcontroller. The microcontroller, then, reads the new SMS notification from the modem memory. After processing the notification, the command will be compared with the predefined command. If received SMS matches with any of the predefined commands, the microcontroller will send the required control signal to the relay of the water pump and the motor-gearbox (ZWL-FP 1650) to drive the linear rack mechanism accordingly. However, if the SMS does not match with the predefined command, then no command will be sent to the supplier of the DC motor.

For all SMS notification received by the street light system, the system is sent a reply SMS to the mobile number from where the control SMS is received through the SIM900 GSM/GPRS modem. The reply SMS contains a valid control notification for the automatic washing system.

5. Conclusions

In this paper, a novel IoT based automatic washing system for the street lighting surfaces was designed, built and installed in Kermanshah city in Iran. This system is an appropriate substitute mechanism for the conventional methods of cleaning systems, such as industrial elevators or climbing robots.

The key features of the innovated automatic washing system can be highlighted as follows:

Simplicity and inexpensive operations,
Connectable to the urban water system or using a separate water tank,
Remotely controllable,
System upgradability,
Employing sensory devices such as rain and dust sensors at different weather conditions,
Can be mounted at different types of power lighting poles/ towers,
Employing SMD and LED lights for energy saving purposes,
No need for the labor work.

It is important to note that in addition to the above advantages, AWS can be designed and controlled by four types of control systems, including:

(i) Timer switch: in an automatic and scheduled manner at specific times in three instantaneous, continual, and with timer; independent of identification of pollution on the lamp surface and in the default timing.
(ii) GSM900 module by the user or a central unit through SMS.
(iii) The embedded push-button allows the operator to control the AWS manually.
(iv) Employing other remote-control modules, such as: GSM, SIM808, GPRS/GPS/SMS, through an Ethernet network and simple TCP/IP commands, ETH8020, RF Solutions releases, ESP8266 WIFI, Raspberry Pi IOT Shield Family: 3 G and 4 G; GPS, GPRS, and XBEE.

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