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A Scalable Smart Lighting Framework to Save Energy

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Abstract. In the past few decades, the urbanization area increased significantly, requiring enhanced services and applications to improve the lifestyle of its citizens. Lighting is one of the most relevant infrastructures due to its impact on modern societies, but it is also complex to manage them in cities since it involves a massive number of widespread posts and is costly as the result of the consumption of significant amounts of energy.
In that regard, this work proposes a scalable framework to manage a significant huge number of lamp posts. Its purpose is to give support to collecting large amounts of sensor data to help to analyze and efficiently fit the light intensity level to the space the posts are covering. Luminosity sensors are used to optimize the intensity of light needed in the urban areas. The proposed framework explores the concept of smart cities by combining the data collected from sensors plugged into IoT (Internet-of-Things) devices. The proposed framework offers the capability to extend and integrate new services to different domains with each other which enhances the quality and performance of urban services. To demonstrate the feasibility of the framework, a simulation was put in place.

Keywords: Smart Cities, smart lights, sensors, scalability.

1 Introduction

IoT is evolving and improving our lifestyle, being part of almost every aspect of our daily lives, from health care, driving, and transit, groceries, energy consumption, wearable technology, smart cities, etc. The term ”smart” refers to a lighting system in a smart city environment and refers to its being autonomous and efficient which is achieved by the features of the IoT technology [1].

Even the simple systems of yesterday, like buildings, roads, and bridges, are today interconnected systems of physical and online services. Particularly, one of those aspects is the way we illuminate our cities. Smart Cities use a street luminaries management system, so they can be controlled and monitored remotely through a centralized application. The main problem is the constantly increasing number of people migrating from rural areas to urbanized areas increasing the need on managing the city resources at scale.

In 2018, 55% of the global population lived in urban areas. According to forecasts developed by the Population Division of the United Nations Department of Economic and Social Affairs (UN DESA), in 2050, this share will increase to 68%. The global urban population in 2018 was 4.2 billion. The growth of this share combined with the general increase in the global population means that by 2050, urban areas will accommodate another 2.5 billion people (nearly 90% of this increase will take place in Asia and Africa) [2]. According to these forecasts, the expected increase in terms of the population living in cities will generate a need to find new and innovative ways on managing such an amount of resources and complexity of urban life.

Such efficient management resources reduce the environmental impact. Besides the need to manage the energy consumption there is another problem is the light pollution in cities, which has demonstrated effects on the behavioral and population ecology of organisms in natural settings, as a whole, these effects derive from changes in orientation, disorientation, or miss-orientation, and attraction or repulsion from the altered light environment, which in turn may affect foraging, reproduction, migration, and communication [3]. City lighting represents about 19% of the world's total electricity consumption and accounts for about 6% of the total emissions of greenhouse gases [4]. It is, however, very important to have the ability to provide an adequate level of light for citizens in cities to improve their way of life and their security throughout the public spaces.

This work proposes a framework to fulfill the aforementioned challenges in managing urban resources at scale. That consists of a system gathering and processing data from light sensors embedded in a smart lamp. After analyzing the data it's calculated an output that allows for regulating the intensity of lights of the lamp posts.

The remainder of this work is structured as follows. Section 2 presents the related work. Section 3, describes the proposed reference architecture. Section 4 presents the experimental work. Section 5 presents and discusses achieved results. Section IV discusses the achieved results. Finally, section 6 concludes this paper and presents the future work.

2 Related Work

This section presents the related work on the topic, focusing on subjects such as smart-lighting, energy consumption, and city management by municipalities.

Currently, public lighting consumes between 30% to 40% of all energy costs in the city and these values are increasing as the population in cities increases as well [5], local governments and utility providers are seeking new ways to decrease energy usage and reduce costs [6].

Pasolini et al. [7] provided a thorough discussion on network architectures and communication technologies that could be adopted for smart public lighting applications. They also outline the steps required for the deployment of a smart public lighting infrastructure and introduce some additional services that a smart public lighting infrastructure could support and discuss the benefits that would arise from integration with the upcoming 5G cellular network.

Carli et al. [8] proposed a decision-making procedure that supports the city energy manager in determining the optimal energy retrofit plan of an existing public street lighting system in wide urban areas. They aimed maximizing the energy consumption reduction and achieving an optimal allocation of the retrofit actions among the street lighting subsystems, while efficiently using the available budget.

Castro et al. [9] work presented an interoperable Smart Lighting solution over Machine to Machine (M2M) protocols such as CoAP built over REST architecture. They followed the guidelines defined by the IP for Smart Objects Alliance (IPSO Alliance) in order to implement and interoperable semantic level for the street lighting. They also described the integration of the communications and logic over the existing street lighting infrastructure.

One way to decrease energy consumption is to change the type of lamp from halogen to LED, which in itself saves about 50% to 80% in energy consumption, but we can go even further and install smart LEDs that can generate an additional 10% to 20% savings by adjusting output to ambient light levels, dimming or brightening as needed. By introducing different sensors (for example, light sensor and image sensor) and combined with efficient communication schemes, the lighting system can be even more efficient and autonomous. Another important fact is the simple IoT ecosystem integration with other components of the smart city concept, such as a central management system responsible for presenting relevant data from across the city, for example with the central management system is possible to reduce the maintenance costs since faults in the lamps can be easily detected and fixed [6].

This work [6] presented a solution to integrate sensors to streetlights already distributed throughout the city, creating a network of sensors that will solve the problems of high energy consumption and the high difficulty of managing all aspects of a city.

Using existing poles, cities can add sensors like light sensors, image sensors, water sensors, and seismic activity sensors to them.

Plugging sensors into the lamp poles will help cities to manage the city in ways never seen before, with the smart light system it will be possible to monitor traffic flow, parking, pedestrian crossings, seismic activity, or atmospheric changes.

3 Architecture

This architecture of the proposed framework includes the simulation of the real world and has three main layers. The first one generates simulated data from sensors and processes them returning an output (back end). An API layer that receives requests from the front end and communicates with the back end, to gather the data, and returns it to the front end. The presentation layer sends requests to the API that returns the data and then this layer presents the returned data on a table on a website (Figure 1).

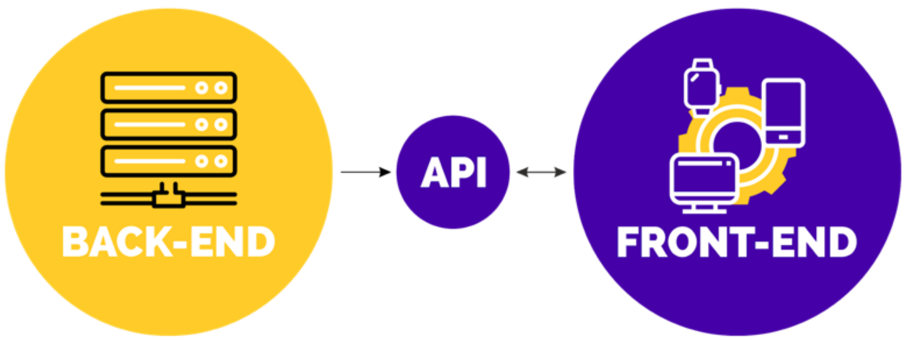

Fig. 1. Architecture

This architecture includes three layers: the data production and processing layer (back end), the data results presentation layer (front end), and the other layer is the Application Programming Interface (API) that receives requests from the front end and returns the collected data in the backend. Each layer is isolated in containers created with Docker. To generate and process the data, it was used nodeJS. The results were then passed to the display layer through the API that presents the results in an HTML page with tables that allow the analysis of the data. As result, this work allowed to reduce the amount of energy spent in lightning cities and reduce some light pollution.

The first layer generates data from sensors within a range of values for luminosity and then processes them by applying rules and, in the end, returns the respective output. Each layer is deployed as a container in Docker that has a port available in the Docker network that allows the communication directly between the layers. The API layer needs to communicate with the presentation layer to receive requests and return the data generated and processed by the back end for those same requests. All the services were developed in nodeJS.

4 Experimental Work

As already mentioned, containers were created for each one of the layers of the framework. The Docker engine was installed in a computer with the following specifications: Intel i5 processor and 8 gigabytes (GB) of Random Access Memory (RAM). To generate the data, in a specific range, of the intensity of luminosity during the day in the first layer have used the nodeJS library 'faker'. This range goes from less than 1 lux, which corresponds to dark conditions at night or extreme storm clouds at sunrise/sunset, to 120 000 lux, which corresponds to the brightest sunlight. Then this data is processed in the same layer using a ruling system that returns an output of the intensity of light (in lumens) needed to illuminate the city, from 1000 lumens to 30000 lumens. These generated outputs are sent to the presentation layer, through the API, that presents this data on a table allowing us to analyze the relationship between the inputs and the outputs that we will show and explain later in the paper.

Figure 1 presents an example of collected data in a hourly basis for one lamp in a single day, including the description of the weather conditions, the values for sensor (Lux) and the light intensity set to that lamp (Lumens).

D	**Weather**	**Sensor (Lux)**	**Light Intensity (Lumens)**
1	Cloudy Night	0.3692	30000
2	Cloudy Night	0.1295	30000
3	Cloudy Night	0.2145	30000
4	Cloudy Night	0.1572	30000
5	Cloudy Night	0.4476	30000
6	Cloudy Night	0.7826	30000
7	Cloudy Night	0.9893	30000
8	Cloudy Day	263.5391	1000
9	Full Daylight	1778.2344	0
10	Cloudy Day	381.7536	1000
11	Cloudy Day	490.9209	1000
12	Full Daylight	1100.7103	0
13	Cloudy Outdoors	11685.8432	0
14	Cloudy Day	573.0798	1000
15	Cloudy Day	898.4679	1000
16	Cloudy Day	756.8474	1000
17	Full Daylight	1659.2585	0
18	Cloudy Day	345.5175	1000
19	Cloudy Night	0.3395	30000
20	Cloudy Night	0.6598	30000
21	Cloudy Night	0.0383	30000
22	Cloudy Night	0.1483	30000
23	Cloudy Night	0.8808	30000
24	Cloudy Night	0.6844	30000

Table 1. Results

This work has implemented an IoT-enabled smart lighting framework [1] to manage the lights across a city. This work proposes an approach to scale the solution by implementing its core components in containers.

5 Discussion

With the containers created and running, the results are displayed in website to analyze the results obtained. When opening the website, displays the collected the daily data for lamps in a hourly, as depicted in Table 1. Those results include sensor input in lux; the description of the weather and part of the day; the respective outputs in lumens (computed with a rule system based on the input) and finally two columns with the date and hour of the received input from the sensor. These results present the data from that day hour by hour resulting in 24 lines (from 00:00 to 23:00). Analyzing those results, it is possible to verify that during the night, between 22:00 to 05:00 there is not much difference because there are no variations in the inputs of the sensor in these periods, so there is not that much impact compared with the traditional lighting systems. The main impact is at dawn and nightfall when the luminosity of the environment can vary a lot. Instead of having the lights around 14 or 15 hours a day on a traditional system, with our smart lighting system we can reduce these hours by 2 to 3 hours and at the same time reduce the intensity of light needed reducing the electricity consumption. Furthermore, with this system, we would need to replace the lamp posts replacing the old lamps with LED lamps would reduce even more energy consumption. The old halogen lamps have an efficiency of around 20 lumens per Watt while LED lamps have an efficiency of around 90 lumens per watt. The change of the lamps alone would reduce the energy consumption by about 60 to 80%.

The implementation of the proposed framework will contribute to reducing the energy consumption by 5 to 10% resulting in a total of around 65 to 90 % of reduction, considering that the old lamps were halogen and the new ones are LED.

6 Conclusions and future work

The main goal of this work was to help to scale the reduction the electricity consumed on the city lighting by controlling the light intensity in the lamp posts according to the values read by the light sensors installed in the lamp posts. The proposed framework can contribute to reducing the number of hours of lighting and the intensity of the light and consequently the electricity consumption.

In the future, the framework can be extended to include new sensors (e.g. smoke), plugged to lamp posts to monitor the quality of the air, or humidity to control these values and alert people in case of floods. By implementing each one of the core components in microservices and deployed as containers can contribute to scale the smart cities solutions and leverage the development of innovative business models managing at scale.

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References

[1] Amit Kumar Sikder et al. “IoT-enabled smart lighting systems for smart cities”. In: *2018 IEEE 8th Annual Computing and Communication Workshop and Conference (CCWC)*. IEEE. 2018, pp. 639–645.

[2] UN DESA. *United Nations Department of Economic and Social Affairs (2018) World population projected to reach 9.8 billion in 2050, and 11.2 billion in 2100— UN DESA— United Nations department of economic and social affairs*. 2018.

[3] Travis Longcore and Catherine Rich. “Ecological light pollution”. In: *Frontiers in Ecology and the Environment* 2.4 (2004), pp. 191–198.

[4] Paul Waide, Satoshi Tanishima, et al. *Light’s labour’s lost: policies for energy-efficient lighting*. Vol. 12. OECD Paris, 2006.

[5] Ganireddy Tilak Aditya and N Krishna Prakash. “Smart and Efficient Outdoor Lighting System”. In: *2018 Second International Conference on Intelligent Computing and Control Systems (ICICCS)*. IEEE. 2018, pp. 1598–1602.

[6] Solution Brief. “Smart Street Lights for Brighter Savings and Opportunities”. In: *Available on: https://www.intel.com/content/dam/www/public/us/en/documents/solution-briefs/smart-street-lights-for-brighter-savings-solutionbrief. pdf* (), pp. 1–4.

[7] Gianni Pasolini et al. “Design, deployment and evolution of heterogeneous smart public lighting systems”. In: *Applied Sciences* 9.16 (2019), p. 3281.

[8] Raffaele Carli and Mariagrazia Dotoli. “A dynamic programming approach for the decentralized control of energy retrofit in large-scale street lighting systems”. In: *IEEE Transactions on Automation Science and Engineering* 17.3 (2020), pp. 1140–1157.

[9] Miguel Castro, Antonio J Jara, and Antonio FG Skarmeta. “Smart lighting solutions for smart cities”. In: *2013 27th International Conference on Advanced Information Networking and Applications Workshops*. IEEE. 2013, pp. 1374–1379.