UDC 621
DOI: 10.15587/1729-4061.2022.260077

USING DEEP LEARNING TO DESIGN AN INTELLIGENT CONTROLLER FOR STREET LIGHTING AND POWER CONSUMPTION

Bilal Ibrahim Bakri
Corresponding author
Assistant Lecturer
Department of Informatics Systems Management*
E-mail: b.bakri@uoitc.edu.iq
Yaser M. Abid
Lecturer
Department of Business Information Technology*
Ghaidaa Ahmed Ali
Assistant Lecturer***
Mohammed Salih Mahdi
Lecturer, Head of Department
Department of Business Information Technology**
Alaa Hamza Omran
Lecturer
Department of Informatics Systems Management*
Mustafa Musa Jaber
PhD, Lecturer
Department of Medical Instruments Engineering Techniques
Dijlah University College
AlMasafi str., Baghdad, Iraq, 10021
Department of Medical Instruments Engineering Techniques
Al-Farahidi University
Qatr al-Nada str., Baghdad, Iraq, 10021
Mustafa A. Jalil
Lecturer***
Roula AJ. Kadhim
Assistant Lecturer***
*College of Business Informatics**
**University of Information Technology and Communications
Al-Nidhal str., Baghdad, Iraq, 10068
***Department of Computer Techniques Engineering
AL Esraa University College
Al karadah str., 52, Baghdad, Iraq, 00964

Street lighting is very important now-days especially at dangerous areas and highways but it consume a lot of power and it became challenging for many researchers in the past few years. Enormous efforts have been placed on the issue of reducing power consumption in illuminating cities and streets, researchers had various approaches and methods in tackling this challenging matter, till now there is no ideal system that has been developed to reduce the electricity usage. In this paper intelligent controller based on deep learning proposed to control the light at the street from sunset to sunrise, the system will decrease the light used to illuminate the streets in the absence of movements, the network trained based on deep learning with several image of different objects to help the system detecting any moving objects in the street to provide the street with the exact amount of light needed in order to reduce the waste of electrical energy resulting from street lighting and to help reduce accidents hence high percentage of criminal activity and life threatening conditions occur in the absence of light. The system was trained with a vast and diverse dataset to assure the accuracy and efficiency of the proposed system, the trained system showed a result of 90 precision of detecting moving objects, the proposed system was tested with a new dataset to assure the reliability and dependency of the system and reducing the errors to the minimum, the system shows promising results in detecting movements and objects, after the detection being complete, the system will send a pulse width modulation causing a 20 % light dimming, leading to enormous reduction in the power consumption, adding to that the proposed system is easy to use

Keywords: street lighting, object detection, intelligent controller, deep learning, power consumption

Received date 17.05.2022
Accepted date 20.06.2022
Published date 30.06.2022

How to Cite: *Bakri, B. I., Abid, Y. M., Ali, G. A., Mahdi, M. S., Omran, A. H., Jaber, M. M., Jalil, M. A., Kadhim, R. AJ. (2022). Using deep learning to design an intelligent controller for street lighting and power consumption . Eastern-European Journal of Enterprise Technologies, 3 (8 (117)), 25–31. doi: https://doi.org/10.15587/1729-4061.2022.260077*

1. Introduction

Reducing energy consumption is an urgent need because the great development in technology requires large amounts of electrical energy in addition to the costs and efforts made to produce this energy [1–4]. Lighting began to appear on the streets decades ago, as it was initially dependent on street lighting through torches, which is considered one of the main factors of pollution due to its accompanying emissions [5]. The development continued to search for ways to light the streets, and renewable energies were among the most important elements of this revolution, as they were pure energies [6–8]. In order to light the streets, it needs many lamps and electric energy that feeds these lamps.

Street lighting begins when the sun goes down and until the sun rises. Street lighting systems were used for a few accidents that occur due to lack of visibility and other negative aspects. When installing street lighting, one of the most important obstacles that accompany the proposed systems is energy consumption in large quantities at times when there is no need for street lighting where there is no traffic.

A vast amount of power consumption worldwide is due to the necessity to lighten cities, streets and highways to avoid many threatening conditions faced in daily life due to many risks and dangerous situations that occur in absence of light [9, 10], therefore the balanced controller between power consumption and street lightening is essential for saving lives and reducing illumination cost.

2. Literature review and problem statement

In the past years researchers focused on solving the problem of street lighting via proposing many approaches and methods, many lighting grid had spread worldwide, causing a great challenges regarding power consumption hence global warming.

Many systems have been proposed that solve the problem of street lighting as much as possible. The paper [11] discussed the benefits of streetlights in Sheffield and how different councils address the issue through various lighting strategies. To explore various proposed method used in 'smart' street lighting infrastructure, a study of current implementations of information and communication technologies (ICT) such as Internet of Things (IoT) in streetlights will be required. Nevertheless, in order to establish its full capacity, its suggested approach will need to be further investigated.

The paper [12] main objective was to investigate the lighting networks quality of high-power based on LED and lamps of high-pressure sodium. Both electromagnetic and dimmable electronic ballasts, which can dim the lamp output smoothly and uniformly, have been used in conjunction with high-pressure sodium lamps. High-pressure sodium lamps connected to electronic equipment were evaluated with various levels of arc power utilizing dimming on a 230 V of power supply, the researcher only tackle the issue of dimming the lights without going further into any mechanism of dimming according to movements detection. The paper [10] conducted a concentrated research on lighting systems adaptive behavior, an appropriate software domain was used to propose a smart street light control system that is based on adaptive behavior rules. The results demonstrate that when the lighting system implements a desired behaviors rather than a rigid, predetermined behavior, energy savings of up to 35 % can be realized, the paper discussed only the matter of adapting street lights to the environmental conditions while providing information about the time that each lamppost spends in each intensity state, without discussing or trying to find a new approach for developing a system that could be trained to be adaptive to any movement. The paper [13] proposed an intelligent system for controlling street lighting and improving energy efficiency. It is designed to detect the movement of a vehicle on the road and switch on a block of street lights ahead of the vehicle. The system switches off the trailing lights as the vehicle passes by. As a result, there is a reduction in energy consumptions while ensuring long-term street lighting, but the system is based on sensors that detect movements without knowing what kind of objects is passing by, hence any object or obstacle could change the condition of the lights, furthermore, the system is restricted to "on" and "off" status only, the researcher didn't take into consideration the importance of dimming the lights to assure the safety of the streets. The paper [14] focused on using IOT technology to monitor a smart street light system. It was connected to a sensor device called "Ultrasonic" then it was linked to a microcontroller device via Wi-Fi. Furthermore, it is using cloud storage services and an application of mobile to supply the administrator of the system with required system information, the researcher tackle the issue of reducing the power consumption via turning "on" and "off" the lights by using sensors, the system is considered rigid because it doesn't detect moving objects in the street and also it doesn't provide any kind of flexibility in changing the intensity of lights according to movements. The paper [15] goal was to suggest a system in which street lights can be automated and information from the lights can be transmitted via the internet. The lights in this smart street light system can be turned on and off automatically based on the weather conditions. An artificial power source, including solar panels, can power the entire system. The researcher used sensors to detect the weather, humidity and temperature of the environment then change the lights of the streets accordingly, the system also turn "on" and "off" the lights according to the environment, the researcher didn't solve the issue of reducing power consumption based on the exact need of the objects in the street. The paper [16] focused on solving the issue of traffic using supervised feed-forward neural networks and Particle Swarm Optimization The results of the two methods was able to control the traffic light that allows the vehicles on each street to be moving or waiting its turn without focusing on the power consumption of traffic lights, the researcher main focus was on traffic lights of smart streets without tackling the issue of street lights or objects detection, hence the researcher didn't dim the lights according to the detected objects in the streets. The paper [17] used an ANN model to reduce energy consumption of street lights. It is determined for various possible inter-distances offered by International Commission on Illumination, the paper focused on volumes on the road with minimum mean square error. The results of the proposed approach was promising but it didn't focus on dimming the lights or to build a controller to detect and recognize the passing objects, the system main concentration on traffic loads. The paper [18] focused on smart cities scenarios to reduce the power consumption of the street lighting, an ANN based energy efficient smart street lighting systems was proposed, the system was implemented and executed only in a residential area and Hosur, the proposed model used only five levels of scenarios without focusing or paying attention to objects detection, different streets and lights dimming process. The paper [19] developed a data model for optimizing, analyzing the ability of different artificial neural network (ANN) architectures to simulate a simple public lighting design, the measuring of performance with respect to the fitness function, training speed, and goodness of fit was done with a dataset generated with different conditions. The experiments focused on identifying the most appropriate number of iterations required without tackling the issue of detection, illuminating and dimming the lights of the streets. The paper [20] discussed the costs of energy consumption in any project especially in terms of effective operating time; staff salaries; the volume of output; calculation of the prime cost of products; prices for products and energy resources, which should all be taken into consideration to improve the management of the energy. The paper [21] listed and illustrated the challenges and social responsibility during Covid-19, which lead to the emphasized necessity of reducing the consumption of electricity to light streets and countries that applied curfew on their citizens. The paper [22] examined the minimization of the total consumption of energy resources and operating costs, especially in renewable energy sources, which could be used to examine the economic benefits of the proposed system in terms of sustaining the life cycle of batteries in solar street lights due to the less operating hours and the intensity of light in the absence of movement.

The papers above used vast techniques and approaches to reduce the power consumption of street lights via turning lights "on" and "off" using rigid sensors that detect movements without having the ability of detecting the kind of objects and changing the intensity of lights accordingly. Researchers didn't tackle the issue of detecting moving objects and dimming the lights accordingly, the technique of dimming the lights is essential to assure safety of people, turning lights off could promote many life threating conditions.

3. The aim and objectives of the study

The aim of this study is to design an intelligent controller for street lighting and power consumption. This will make it possible to reduce energy consumption of street lighting in the absence of movement, which will have a significant impact on the economical aspect of reducing the costs of lighting the streets.

To achieve this aim, the following objectives are accomplished:

– collecting dataset images;

– training the system with the dataset to enhance the system ability to detect objects;

– testing the accuracy and reliability of the trained model;

– investigate a dimming process based on pulse width modulation.

4. Materials and methods of research

The objective of the research is to street lighting and power consumption.

The main hypothesis of the study is to intelligent controller for street lighting and power consumption will make it possible to reduce energy consumption of street lighting in the absence of movement, which will have a significant impact on the economical aspect of reducing the costs of lighting the streets.

The method of the research was conducted by going through three stages, each stage has its own criteria and procedures so that the proposed model will be accurate and agile, the method conducted was based on collecting dataset then training the model with the dataset, then testing the artificial intelligence capabilities in detecting object, finally sending a pulse width modulation signal to control the intensity of the street illumination. The proposed model could be divided into three stages:

First stage, Camera: in this stage a camera has been used to provide the system with real-time images of various types of streets and alleys.

Second stage, artificial intelligence: artificial network based on deep learning has been trained with a vast dataset to assure the agility and accuracy of the proposed system, after the training is completed, the trained network will have the ability to detect any movement and decision making process will be achieved accordingly

Stage three: using Pulse width modulation signal for power reduction that will dim the lights according to the decision obtained by the trained network in stage two.

When the trained system detect an identified object it will send a Pulse Width modulation signal that effect the applied electrical current, through which it can control the intensity of the street lighting, if there is a lot of movement in the street, the proposed system will be provided with PWM to fully illuminate the street, and if there is no movement in the street, the proposed system reduces the intensity of street lighting to 20 % by equipping the LED with PWM to keep the intensity of lighting dim in the street.

The three stages of the system is shown in Fig. 1.

The system shown in Fig. 1 will be able to detect any movement, and the smart controller based on trained artificial network will send signals to the illumination controller to raise and reduce the intensity of the street lighting accordingly.

In order for the use of deep learning to be good, the system must be provided with many high-quality images. In this research, deep learning was provided with images of more than 10,000 images of cars, people, bicycles, and other objects that could be necessary for street lighting, so that the designed system can capture any movement in the street during sunset and until sunrise. A code in python programming language was developed to adjust the dimensions of the images used for training the proposed model, the images size were 640×640.

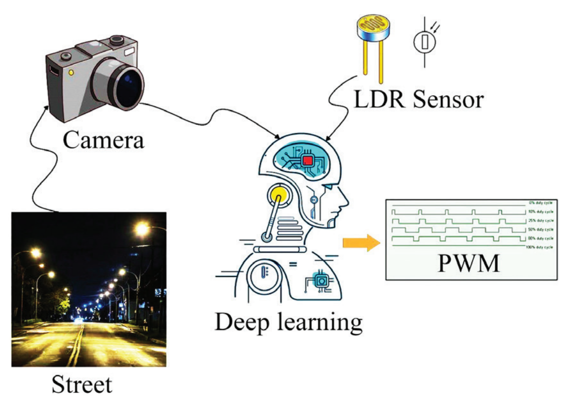


Fig. 1. The proposed system

5. Research results of design an intelligent controller

5. 1. Dataset preparation

The efficiency of deep learning increases rapidly based on the size of the dataset being used to train the proposed model, hence increasing number of images in dataset will increase the accuracy of the results after training, and in the proposed model the dataset being used have a vast diversity of images that simulate actual cities and street, example of the images being used in the training is shown in Fig. 2.

All images of the dataset will go through an annotation process that will help the system to label each object in the dataset, the process of annotation will start by boxing shapes that contains a recognizable objects, and then .txt files will be obtained from the annotation process to be used for training purposes.

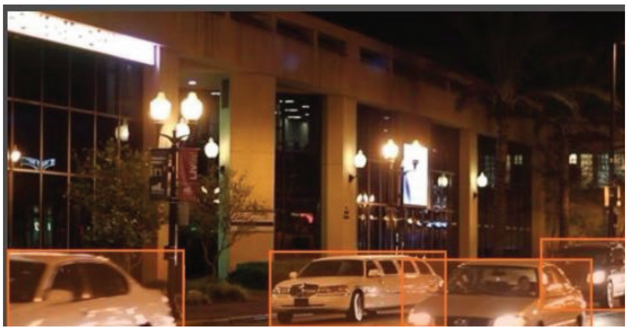


Fig. 2. Dataset annotation

A dataset consist more than 10,000 images were gathered from the internet and real-time images to cover most objects' states, viewing angles, percentage of appearances, and aspect ratios so that the proposed model could be adequately subjected and prepared to most angles and conditions. The dataset was divided into three training folders: training, validation, and test. 80 % of the images were used for training purposes, while 10 % were used for validation and the remaining 10 % were used for testing the system.

5. 2. Trained network

The network was trained with the dataset, 100 epoch was done to achieve the best results, each epoch has its own benefit in increasing the training precision and recall, it was observed that the number of epoch has a direct effect on increasing the precision and recall, the training continuous until the results show 90.26 precision and 82.91 recall, which is considered as a good result to deal with in such system as shown Table 1.

Table 1

The training results

Classes	Precision	Recall
All	90.26	82.91

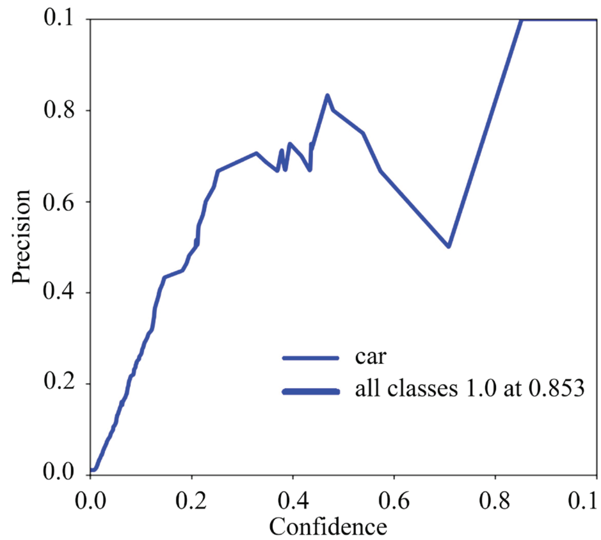
The percentage of the precision and recall were reached after the continuous training of the network, the precision and recall increased rapidly after each training process as shown in Fig. 3, *a*, *b*.

There are many aspects in deep learning that should be considered so that the system could be certified as accurate and efficient, the first aspect is precision which is shown in Fig. 3, *a*, the second aspect is recall, which is shown in Fig. 3, *b*, while Fig. 3, *c* shows the relation between precision and recall.

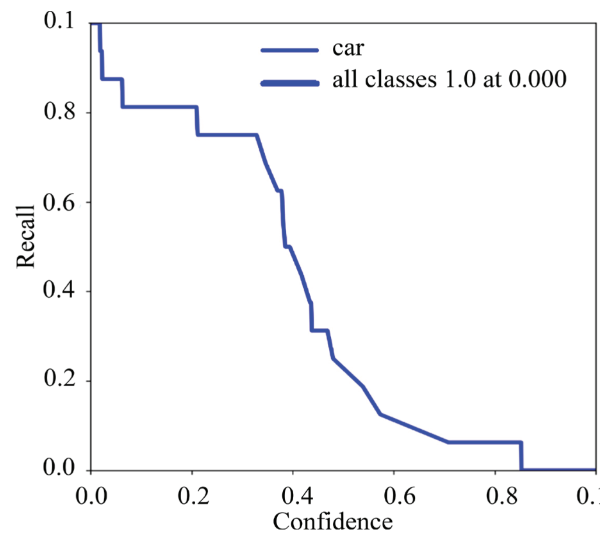
Intelligent system accuracy increases within iteration, in the proposed system 100 epoch have been used to train the intelligent network to work as a controller to manage street lighting, as shown in Fig. 4, *a* which represent box losses of training, while Fig. 4, *b* shows the object loss of training, Fig. 4, *c* – the results of precision, Fig. 4, *d* – the results of recall, Fig. 4, *e* – box loss validation, Fig. 4, *f* – objective loss of validation, Fig. 4, *g* – mAp-0.5, Fig. 4, *h* – mAP 0.5:0.95.

The model was continuously trained with epochs, through which the model started to enhance gradually after each epoch, the targeted results was achieved after several training reaching to epoch number 100 as shown in Fig. 4.

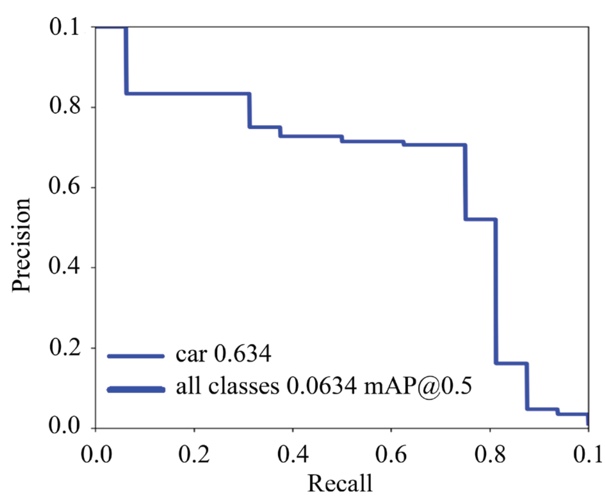
Reaching a precision of (90.26) means that the system has a high ability of detecting objects in the training dataset without identifying the nature of the object, hence the recall process reaching (82.91) which means that the system is also highly accurate om identifying the type of object located in the images of the dataset.



a



b



c

Fig. 3. Simulation result of training: *a* – precision curve; *b* – recall curve; *c* – precision and recall curve

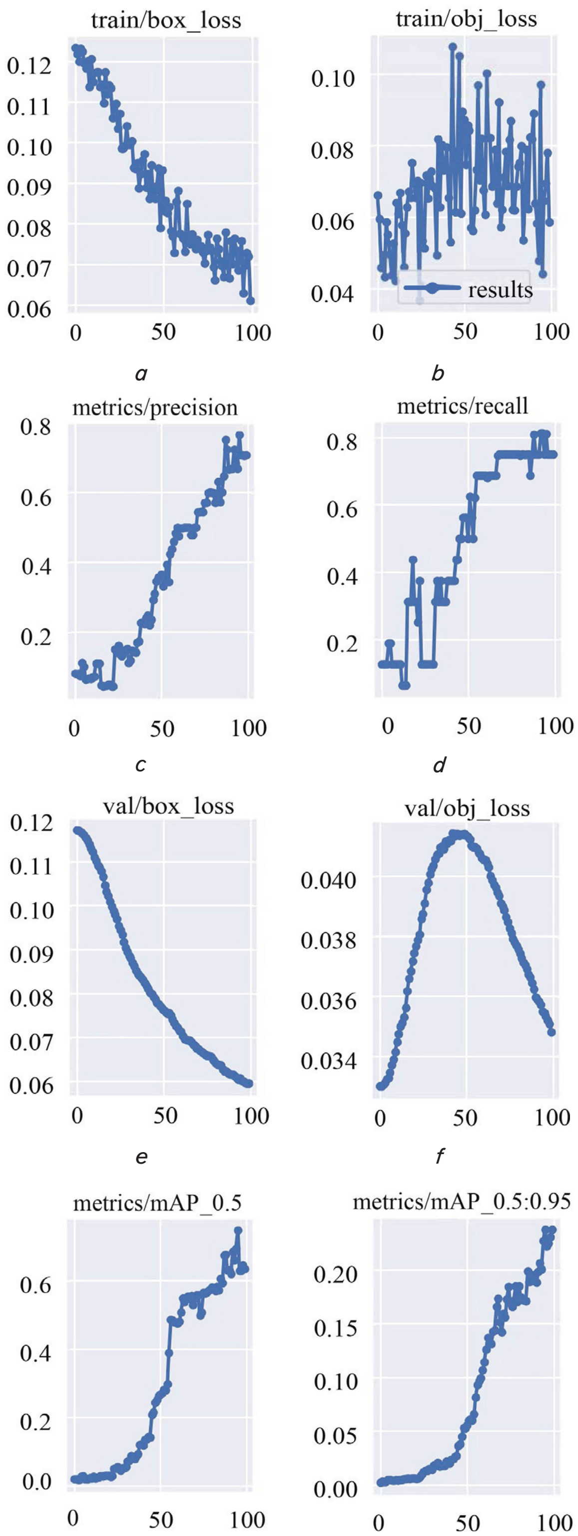
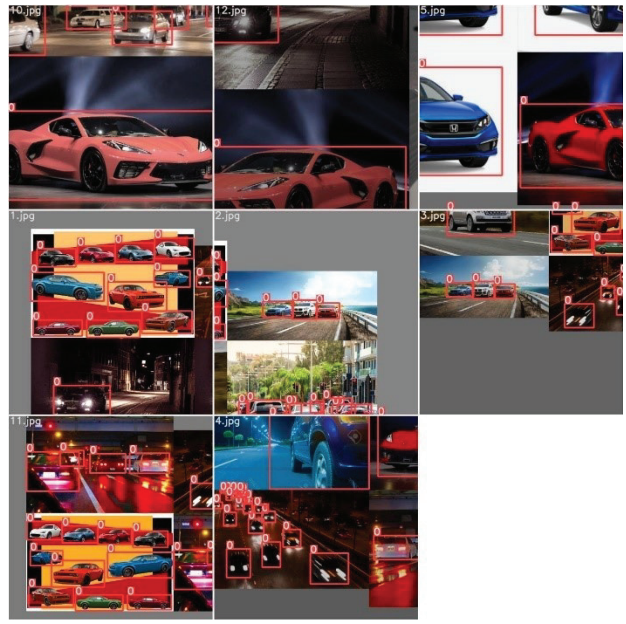


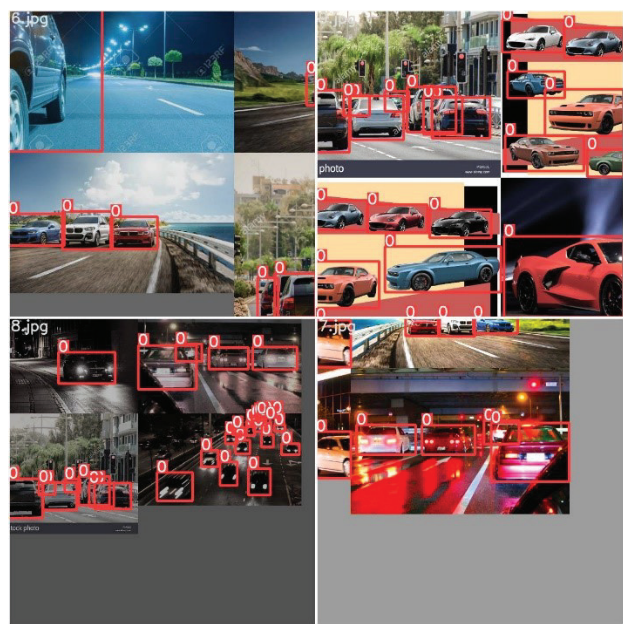
Fig. 4. The results of training and validation: *a* – box losses of training; *b* –shows the object loss of training; *c* – the results of precision; *d* – the results of recall; *e* – box loss validation; *f* – objective loss of validation; *g* – mAp-0.5; *h* – mAP 0.5:0.95

5. 3. Testing of trained network

After training the proposed model with the dataset, a new set of data has been used to test the model to figure out the reliability of the trained model, Fig. 5 shows the ability of the trained model in detecting cars in the streets hence the system is reliable and easy to use.



a



b

Fig. 5. The trained model detecting cars in streets: *a* – set of images used for testing; *b* – different set of testing images

The trained model is detecting, recognizing, and boxing objects based on the annotation process the network went through during training. The testing process used 10 % of the dataset, the mechanism were introduced to the train system to check the ability of the system in boxing hence recognizing objects. The results was promising in detecting and recognizing all type of object even when there are many objects in the same image.

5. 4. Dimming process based on pulse width modulation

When the trained system detect an identified object it will send a PWM, through which it can control the intensity of the street lighting according to the quantities required for the lighting, only depending on the nature of the movement accompanying the street. If there is a lot of movement in the street, the proposed system will be provided with PWM to fully illuminate the street, and if there is no movement in the street, the proposed system reduces the intensity of street lighting to 20 % by equipping the LED with PWM to keep the intensity of lighting dim in the street, an example of timed simulation is shown in Fig. 6.

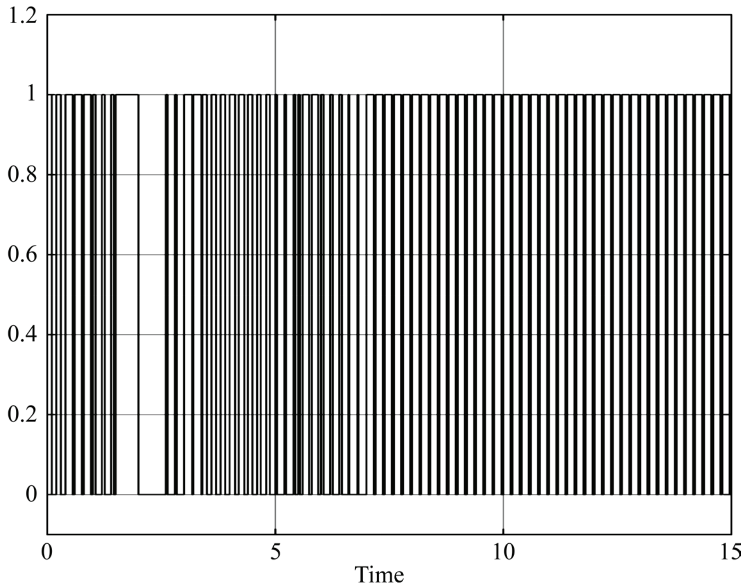


Fig. 6. Pulse width modulation results

The timed simulation shows a variation in PWM intensity based on the movement detected in real time manner.

6. Discussion of intelligent controller for street lighting

A vast and diverse dataset containing more than 10,000 images was collected, the dataset covered most types, point-of-view, and conditions of objects, the diversity of the dataset assured the efficiency of the system. The example of the images being used in the training is shown in Fig. 2.

The dataset was introduced to the system, and the system accuracy start increasing rapidly according to each training epoch, until the training reached 100 epochs, the training results were sufficient and reliable (Table 1, Fig. 3, 4).

As illustrated in the paper, about 10 % of the dataset was isolated to be used in the testing process, and the isolated images were introduced to the trained network, the testing asserted the ability and the efficiency of the trained network in detecting objects (Fig. 5).

Since the testing process assured that the trained network is reliable, the decision-making process will take control of providing the sufficient amount of power to change the intensity of street lights and dimming them according to the detected objects.

The results of the system is very promising especially in terms of accuracy and reliability of the proposed system adding to that, the system is easy to install and use, the system can be implemented into any existing street illumination infrastructure.

When comparing with existing models that has been discussed in the literature review, the methods used in this intelligent system is novel, especially in terms of simplicity of installation, real time detection, the number of epoch used to train the model and the decision making process of the system is fast, agile and accurate, since the system can be installed in any street lighting infrastructure however the implementation of the proposed system may face some difficulties with outdate cameras that has limited resolution, the detection and decision making process of the system must rely on up to date camera infrastructure. Also for the system to be more efficient a larger dataset must be used that contains an enormous images of objects conditions with high resolution.

There is an infinite number of objects and objects angel of detection to be considered, intensive and more thorough training could be used if necessary to get an even better results, this disadvantage can be overcame via increasing the number of objects that the system will be trained with to assure that much more accuracy and reliability will be introduced which will later help in making the system fully automated without any kind of dependency.

The proposed system is expected to have some limitations, especially in the conditions of sand storms which will reduce the camera capabilities to the minimum and will cause some challenges to the detection process, but this short-come won't affect the necessity and benefits of the proposed system since the need of street lights in sand storms is not essential.

The proposed model can developed via integrating facial and car plate number recognition system that could be used to calculate the consumption power used to illuminate a certain alley for the residence and frequent passers in the alley. The difficulties could be faced in such system development is that ethical and social issues could be raised from our work, especially in terms of people privacy.

The proposed model can also be developed, used and applied in many aspects of object recognitions, such as security recognition purposes and checkpoints, by sending a signal of opening or closing a gate base on the object detected, this employment method could vast the uses and necessity of the model.

7. Conclusions

1. The dataset used to train the model was collected from the internet and real-time images, more than 10,000 images were gathered to cover most objects' states, viewing angles, percentage of appearances, and aspect ratios so that the proposed model could be adequately subjected and prepared to most angles and conditions.

2. The dataset was divided into three training folders: training, validation, and test. The image sets of training and validation were used in the process of training the model, the training continued till reaching a 100 epoch to assure the model's accuracy.

3. The image sets of testing were introduced to the trained model to check the reliability and accuracy in detecting objects, the test showed promising results in terms of detection, recognition, and decision-making process.

4. The training process led to successfully tackling the challenges of reducing power consumption in street lighting, the intelligent controller was able to dim the lights and illu-

minate the streets according to needs and types of objects detected, the system is reliable and automated and can be implemented Easily, the precision is about 90 % which means that the system is self-dependence and accurate.

References

1. Li, C.-H., Wang, S.-T., Chang, H.-Y., Shen, C.-Y. (2010). An Efficient Approach for Reducing Power Consumption in a Production-Run Cluster. 2010 Third International Joint Conference on Computational Science and Optimization. doi: https://doi.org/10.1109/cso.2010.31
2. Luo, X., Wang, J., Dooner, M., Clarke, J. (2015). Overview of current development in electrical energy storage technologies and the application potential in power system operation. Applied Energy, 137, 511–536. doi: https://doi.org/10.1016/j.apenergy.2014.09.081
3. Puri, V., Jha, S., Kumar, R., Priyadarshini, I., Hoang Son, L., Abdel-Basset, M. et. al. (2019). A Hybrid Artificial Intelligence and Internet of Things Model for Generation of Renewable Resource of Energy. IEEE Access, 7, 111181–111191. doi: https://doi.org/10.1109/access.2019.2934228
4. Mohamad, F., Teh, J., Lai, C.-M., Chen, L.-R. (2018). Development of Energy Storage Systems for Power Network Reliability: A Review. Energies, 11 (9), 2278. doi: https://doi.org/10.3390/en11092278
5. Lokhande, H. N., Markande, S. D. (2018). Adaptive Street Light Controlling For Smart Cities. International Journal of Applied Engineering Research, 13 (10), 7719–7723. Available at: https://www.ripublication.com/ijaer18/ijaerv13n10_65.pdf
6. Shaikh, M. R. S. (2017). A Review Paper on Electricity Generation from Solar Energy. International Journal for Research in Applied Science and Engineering Technology, V (IX), 1884–1889. doi: https://doi.org/10.22214/ijraset.2017.9272
7. Darwish, A. S., Al-Dabbagh, R. (2020). Wind energy state of the art: present and future technology advancements. Renewable Energy and Environmental Sustainability, 5, 7. doi: https://doi.org/10.1051/rees/2020003
8. Neill, S. P., Angeloudis, A., Robins, P. E., Walkington, I., Ward, S. L., Masters, I. et. al. (2018). Tidal range energy resource and optimization – Past perspectives and future challenges. Renewable Energy, 127, 763–778. doi: https://doi.org/10.1016/j.renene.2018.05.007
9. Subramani, C., Surya, S., Gowtham, J., Chari, R., Srinivasan, S., Siddharth, J. P., Shrimali, H. (2019). Energy efficiency and pay-back calculation on street lighting systems. AIP Conference Proceedings. doi: https://doi.org/10.1063/1.5112267
10. Escolar, S., Carretero, J., Marinescu, M.-C., Chessa, S. (2014). Estimating Energy Savings in Smart Street Lighting by Using an Adaptive Control System. International Journal of Distributed Sensor Networks, 10 (5), 971587. doi: https://doi.org/10.1155/2014/971587
11. Dizon, E., Pranggono, B. (2021). Smart streetlights in Smart City: a case study of Sheffield. Journal of Ambient Intelligence and Humanized Computing, 13 (4), 2045–2060. doi: https://doi.org/10.1007/s12652-021-02970-y
12. Gil-de-Castro, A., Moreno-Munoz, A., Larsson, A., de la Rosa, J., Bollen, M. (2012). LED street lighting: A power quality comparison among street light technologies. Lighting Research & Technology, 45 (6), 710–728. doi: https://doi.org/10.1177/1477153512450866
13. Al-Smadi, A. M., Salah, S. T., Al-Moomani, A. A., Al-Bataineh, M. S. (2019). Street Lighting Energy-Saving System. 2019 16th International Multi-Conference on Systems, Signals & Devices (SSD). doi: https://doi.org/10.1109/ssd.2019.8893160
14. Balushi, A. A. H. A., Kazmi, S. I. A., Pandey, J., Singh, A. V., Rana, A. (2020). The Intelligent Control of Street Light System in Oman through Internet of Things Technology. 2020 8th International Conference on Reliability, Infocom Technologies and Optimization (Trends and Future Directions) (ICRITO). doi: https://doi.org/10.1109/icrito48877.2020.9197855
15. Majumdar, R., Srivastava, A., Tulsian, D., Mishra, V. P. (2019). IOT based Street Light Controlling Mechanism. 2019 International Conference on Computational Intelligence and Knowledge Economy (ICCIKE). doi: https://doi.org/10.1109/iccike47802.2019.9004248
16. Aljuboori, A. F., Omran, A. H., Abid, Y. M. (2019). Novel intelligent traffic light system using PSO and ANN. Journal of Advanced Research in Dynamical and Control Systems, 11 (04), 1528–1539.
17. Sikdar, P. L., Thakurta, P. K. G. (2020). An energy efficient street lighting framework: ANN-based approach. Innovations in Systems and Software Engineering, 17 (2), 131–139. doi: https://doi.org/10.1007/s11334-020-00375-2
18. Mohandas, P., Dhanaraj, J. S. A., Gao, X.-Z. (2019). Artificial Neural Network based Smart and Energy Efficient Street Lighting System: A Case Study for Residential area in Hosur. Sustainable Cities and Society, 48, 101499. doi: https://doi.org/10.1016/j.scs.2019.101499
19. Garces-Jimenez, A., Castillo-Sequera, J. L., Del Corte-Valiente, A., Gomez-Pulido, J. M., Gonzalez-Seco, E. P. D. (2019). Analysis of Artificial Neural Network Architectures for Modeling Smart Lighting Systems for Energy Savings. IEEE Access, 7, 119881–119891. doi: https://doi.org/10.1109/access.2019.2932055
20. Drobyazko, S., Hilorme, T. (2022). Methods for evaluating technical innovations in the implementation of energy-saving measures in enterprises. MethodsX, 9, 101658. doi: https://doi.org/10.1016/j.mex.2022.101658
21. Drobyazko, S., Hilorme, T., Solokha, D., Bieliakova, O. (2020). Strategic policy of companies in the area of social responsibility: Covid-19 challenges. E3S Web of Conferences, 211, 04011. doi: https://doi.org/10.1051/e3sconf/202021104011
22. Nakashydze, L., Hilorme, T., Nakashydze, I. (2020). Substantiating the criteria of choosing project solutions for climate control systems based on renewable energy sources. Eastern-European Journal of Enterprise Technologies, 3 (3 (105)), 42–50. doi: https://doi.org/10.15587/1729-4061.2020.201527