THE DESIGN OF A LIGHTING SYSTEM FOR HONG KONG INTERNATIONAL AIRPORT APM TUNNEL FOR ENERGY SAVING WITH ARTIFICIAL INTELLIGENCE (AI) LIGHTING DEFECT DETECTION SYSTEM

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ABSTRACT

The current situation is that global climate change become grimmer, so it has become an important concern. Improving energy efficiency of our device is one of the measures to solve the threat of global climate change. In this circumstance, the first aims research project to design a lighting system to enhance the energy efficiency and the reliability of the lighting system of APM tunnel. Therefore, the replacement of fluorescent light to LED light is an effective way to achieve the target. In truth, substitution of fluorescent lighting to LED light has been promoted for a long time and have a lot of successful examples in the world. It is because LED light has better luminous efficiency to provide similar brightness with less power. In term of reliability, the lifespan of LED light is much higher than fluorescent light. However, the actual lifespan of LED is easily deteriorated by high temperature environment so provide a suitable environment for LED is very important to let LED light reach its theoretical lifespan. Artificial intelligence has been the hottest topic of technology industry in recent years. It has already applied in daily life such as speech recognition in Apple Siri and face recognition in security system. Consequently, the second aims of research project is using artificial intelligence technology to reduce the workload of frontline maintenance staff. The development of lightings inspection system based on 'Convolutional Neural Network' technology to analyst the image taken by camera to identify burnt out light tube inside the APM Tunnel.

KEYWORDS

Hong Kong International Airport, LED Lighting, Energy Saving, Artificial Intelligence, Convolutional Neural Network;

1. INTRODUCTION

Hong Kong International Airport locate at Chek Lap Kok and it is only one airport in Hong Kong. It has started operation for 24 years, HKIA is a large trans-shipment centres, passenger hubs and gateways for destinations in Hong Kong, greater China, Asia and the world. Over 118 airlines run their flights in the HKIA to travel over 220 cities in the world. In 2019, 71.5 million passengers visited HKIA and it was awarded the 4th busiest airport worldwide by international passenger traffic and the 13rd busiest airport worldwide by passenger traffic.

According to Airport Carbon Accreditation Annual Report 2017-2018 by ACI-Europe and WSP. The aviation industry produced around 2% of global human greenhouse gas emissions, while airport operations account for 2-3% of the total aviation emissions. [1] noted that airports are

amongst the most energy-intensive centres in modern society. Thus, airport sustainability entails a holistic approach to ensure economic viability, operational efficiency, natural resource conservation, and social responsibility. To target the goals of the Paris Agreement, the Hong Kong Airport Authority is committed to reduce the direct and indirect carbon emissions over the next 30 years to boost HKIA become a climate-resilient and low-carbon airport. The Hong Kong International Airport Automated People Mover is a automated electric train located in airport Level 1. It operated about 60 km per hour to travel between the Midfield Concourse and Terminal 1. Over 7200 passengers travel between the Midfield Concourse and Terminal 1 by Automated People Mover in each hour. Consequently, a reliable lighting system is the key point for operation and maintenance the surrounding rail in tunnel so that Automated People Mover can operate smoothly to travel different location in airport. Moreover, in term of maintenance, since Airport Automated People Mover start at 6:15 am and close at 1:15 am, the actual maintenance time in tunnel is only 3 hours that is not sufficient (the preparation time of its start and close require 2 hours).

Davis and Wilkerson conducted a trial LED installation for the apron lighting at Philadelphia International Airport (PHL), where lighting is the largest energy consumer in the entire airport, representing 25% of the airport's total energy usage in 2012. Some studies have reported that using LED lights is one of the most useful energy-saving measures at airports [2]. To sum up the above background, there are a lot of advantage of building a lighting system with higher reliability and more energy saving in APM tunnel by replacing fluorescent light to LED.

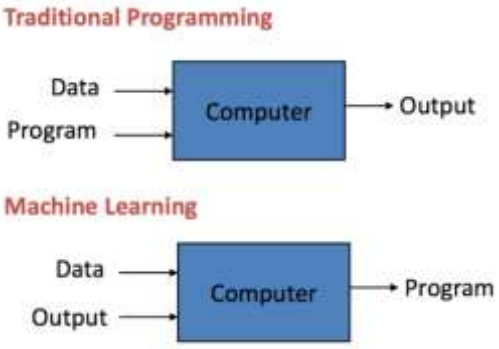
1.1. Aims and Objectives

To design and evaluate feasible lighting layout from Terminal 1 East hall to West Hall. The design base on Hong Kong Electrical and Mechanical Services Department requirement to improve the energy efficiency, maintenance cost and reliability

1. To design a lighting layout for Hong Kong International Airport APM tunnel to save 30% electricity
2. To compare the difference of present lighting system and designed lighting system
3. To identify the potential problem of the new design and provide possible solution
4. To coverage one AI Algorithms to apply on the lighting defect inspection to find the burnt-out lighting with 80% accuracy

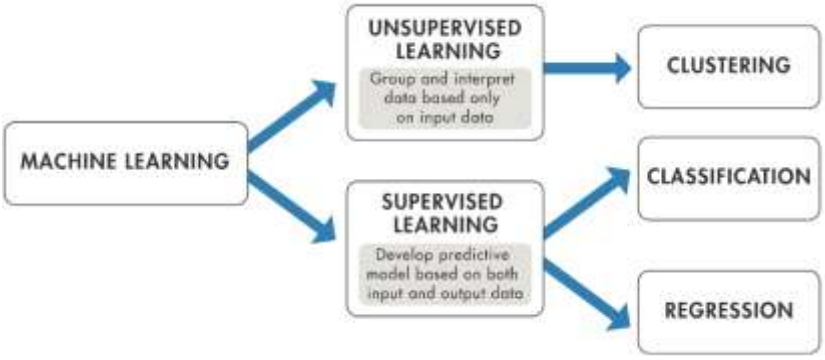
2. MACHINE LEARNING

[3] notes how to collect the valuable information from complex, high-dimensional data become more and more important with the advent of the era of big data. In this background, [4] agree that machine learning can gain insight into big data and obtain important data with the advance of deep learning. Machine learning is the division of computer science and artificial intelligence. Machine Learning focus on the development of computer programs that can access data and use it learn for themselves [5]. It uses number and calculation method to simulate human learning method. Machine learning algorithms use computational methods to "learn" information directly from data rather than calculate by prearranged equation. [6] notes that when the advantages of deep learning is that when the amount of data increases, The accuracy of algorithms increase gradually.



(Figure 1. Different between traditional programming and machine learning)

Machine learning uses two types of techniques:
- Supervised Learning
- Unsupervised Learning



(Figure 2. Unsupervised learning and Supervised learning)

2.1. Supervised Machine Learning

Supervised machine learning creates a model and the modal investigate evidence and then generate decision when the ambiguous appear. A supervised learning algorithm uses a recognized input data and recognized output data to train the model to make predictions during input new data. Classification and regression techniques is used in supervised learning to develop machine learning models.

[5] notes classification algorithm allocates items to predefined classes that train predetermined data. Classification techniques can be used to predict separate response such as determine a colour in photo is bule or purple, a picture is dog or cat. Classification models systematize input data into different groups. It usually uses in Image Recognition, speech recognition and Medical Diagnosis.

Regression techniques can be used to predict continuous data such as electricity load on the grid of power plant, battery state-of-charge or prices of stock. It usually use in estimation of water consumption in water plant, virtual sensing and algorithmic trading of financial asset.

2.2. Unsupervised Machine Learning

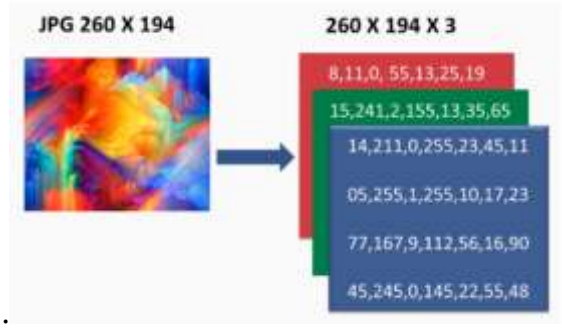
Unsupervised machine learning is used to evaluate and assemble unknown data. The algorithms find obscured trends and statistics groupings without the people involve. The process able to find resemblance and variations of data for investigation, pattern recognition, customer classification and cross-selling strategies in daily life. [7] success using unsupervised machine learning to detect the abnormality of elderly by evaluate the data from door magnetic sensor, temperature sensor, water flow sensor and smoke sensor in elderly home. Moreover, [8] also success using unsupervised machine learning to detect the fault in the wind turbine gearboxes by analyzing data of vibration and temperature of wind turbine.

2.3. Convolutional Neural Network (CNN)

Convolutional neural network is a deep learning neural network sketched for studying straightway from database, reduce the process to extract the feature by people. Convolutional Neural Network, CNN, is a feed-forward neural network. Its artificial neurons can respond to a part of the surrounding units in the coverage area and have excellent performance for large-scale image processing [9].

[10] mention deep learning techniques nowadays have been utilized in image classification such as Convolutional neural network. It is because CNN is able to apply straightway on a uncompleted photo without pre-handling. A convolutional neural network has rarely more than 20 feed forward neural network. The CNN intensity depends on number of convolutional layers. The convolutional layers gather each other and each layer can identify more complicated structures. If there are five or six convolutional layers, it is practicable to identify words that write by human. [11] success using CNN to classify Chinese news text with 93.69% accuracy. If there are about 24 layers, it is viable to identify human being looks. CNNs give a suitable infrastructure for discovery and key features identification in time-series statistics and picture. Nowadays, there are many CNNs applications in the society such as medical imaging, stop sign detection for automated driving and face recognition. Besides that, with the development of machine learning and computer vision, the practice of automatic defect classification has become more and more accepted by the industry [12].

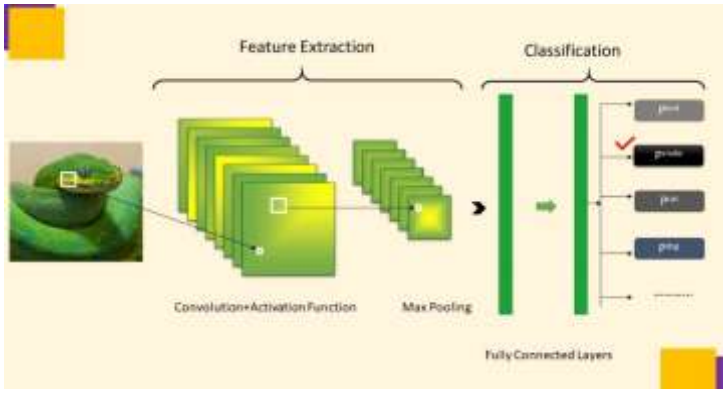
The image is represented to RGB image. An RGB image has three layers of matrix of pixel values while a black and white image only has one layer



(Figure 3. RGB color model in pixal)

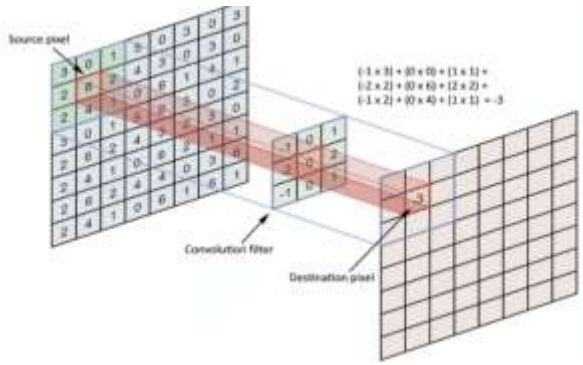
Convolutional neural network has six steps that categorized as following
- 1.Convolution
- 2.Padding

- 3.Rectified linear unit
- 4.Pooling
- 5.Flattening
- 6.Fully connected layers



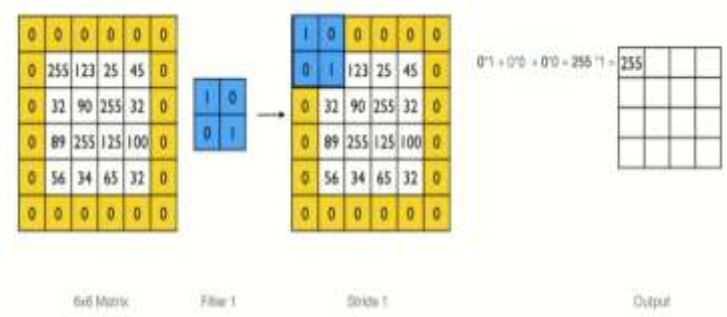
(Figure 4. Process of Convolutional neural network)

Convolution is a process that filter the images by convolutional filters, each of which activates particular features from the images



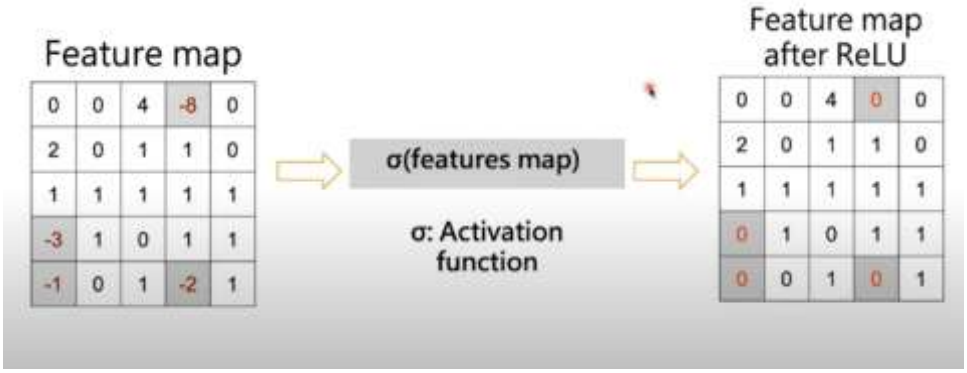
(Figure 5. Process of Convolution)

Padding overcome the problems that the sizing of the image diminishes after convolution when convolution operation is applied. In padding, layers of zeros around the feature matrix are added



(Figure 6. Process of Padding)

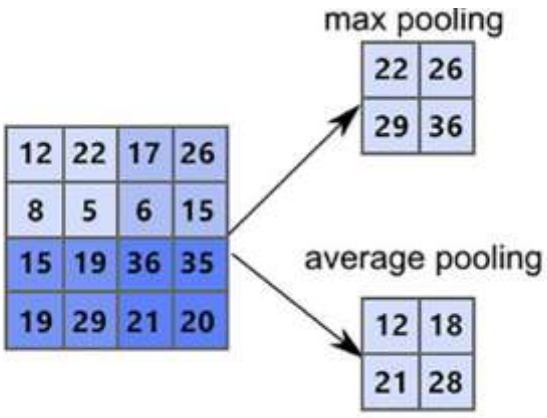
Rectified linear unit make the training more rapidly and more efficient because it changes the negative values to zero and remain positive values unchanged. This procedure also call activation as just the activated features can be put forward into the next layer.



(Figure 7. Process of Rectified linear unit)

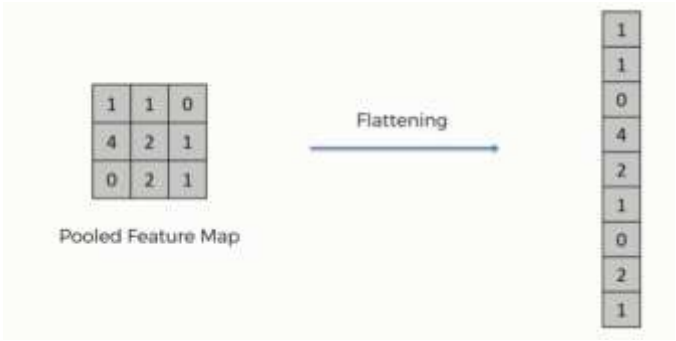
Pooling is a process and it diminish the quantity of parameters which the system requires to study. Therefore, it makes the output simpler by executing nonlinear down sampling. Max Pooling, Minimum Pooling and Average Pooling are frequently used.

1. Max Pooling: The highest number from the group of feature map is selected.
2. Minimum Pooing: The lowest number from the group of feature map is selected.
3. Average Pooling: The average number from the group of feature map is selected.



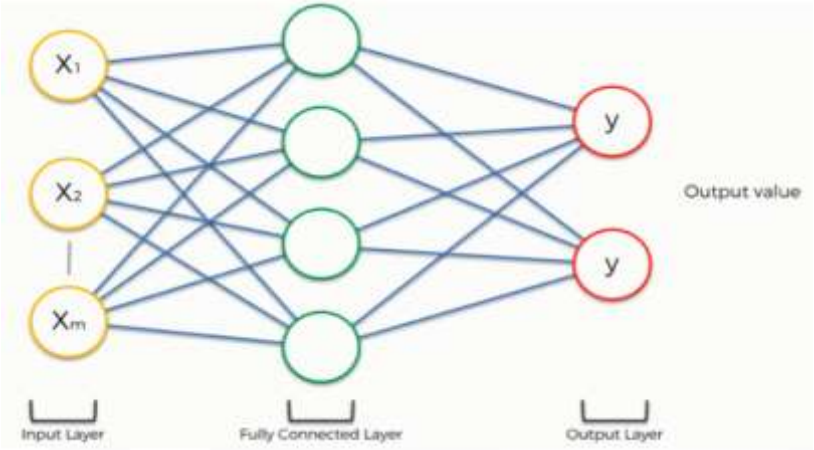
(Figure 8. Process of Pooling)

Flattening is a step to convert the pooled feature map (matrix) into a vector that act as input layer in the next step (Fully connected layers) .



(Figure 9. Process of Flattening)

The final output is given to the fully connected layer after finishing the task of convolution and pooling layers These is a network that each neuron is linked to another neuron in the preceding layer. Eventually, the neural network can accomplish recognition and classification.

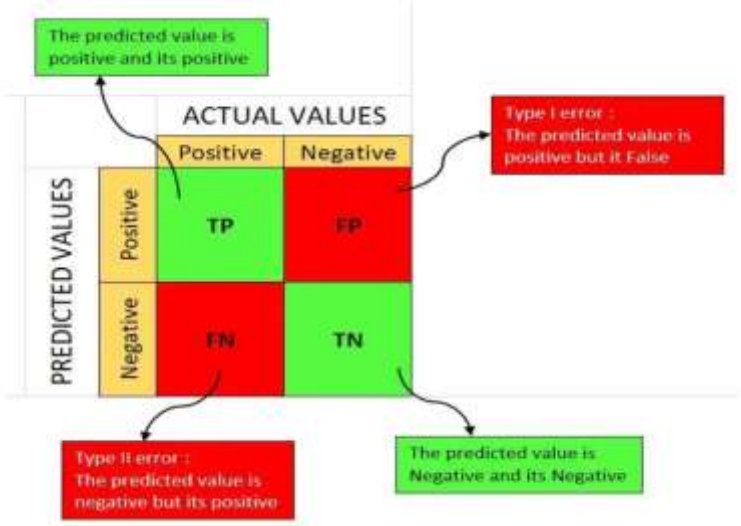


(Figure 10. Process of fully connected layers)

2.4. Confusion Matrix

The Confusion matrix is the matrix to present the visualization of algorithm performance in supervised learning in order to investigate whether predictions match the reality or not.

The performance of Confusion Matrix can be evaluated by finding its accuracy, precision, recall, and F1-score.



(Figure 11. Confusion Matrix)

The accuracy is the proportion of correct predictions made in all samples

Accuracy = (Ture Positive + Ture negative) / Total of Data X 100%

The precision is the proportion of the samples predicted to be positive, which are actually positive.

Precision = (True Positive) / (True Positive + False Positive) X 100%

The recall is the proportion of the actually positive samples that are predicted to be positive.

Recall = (Ture Positive) / (True Positive + False Negative) X 100%

F1 score weighted average of precision and recall.

F1 Score = 2 x (Precision x Recall) / (Precision + Recall)

2.5. Summary

Comparing with LED and fluorescent light, LED has better performance in the field of energy efficiency, lifespan and environmental-friendly. On the other hand, the initial cost of LED is more expensive but fluorescent light required external ballast to ensure it work properly while LED light tube contain LED driver inside the LED tube and don't need extra purchase.

In this circumstance, Replacement of traditional fluorescent light to LED light can bring a lot of benefit on maintenance and environmental-friendly. LED light tube with 4000K colour temperature is a suitable selection because it makes maintenance staffs see in the tunnel comfortably.

Convolutional neural network (CNN) is effective technology to extract useful information from a large amount of data. Therefore, it can assist maintenance team to identify the defect light tube in APM tunnel and save a lot of time in site inspection. There are many CCTV in tunnel and the image can be received from them.

3. AI LIGHTING DEFECT INSPECTION SYSTEM

3.1. Experiment Background

The programme operates in Window 11 system. The CPU is Intel(R) Core(TM) i7-12650H, 2.30 GHz and the memory size is 16GB. The programming language is Python-3.90 and the develop tool is Pycharm-community-2022.3.1. The deep learning framework used is Tensorflow_gpu-2.6.4.

(Figure 12. Pycharm-community-2022.3.1 interface)

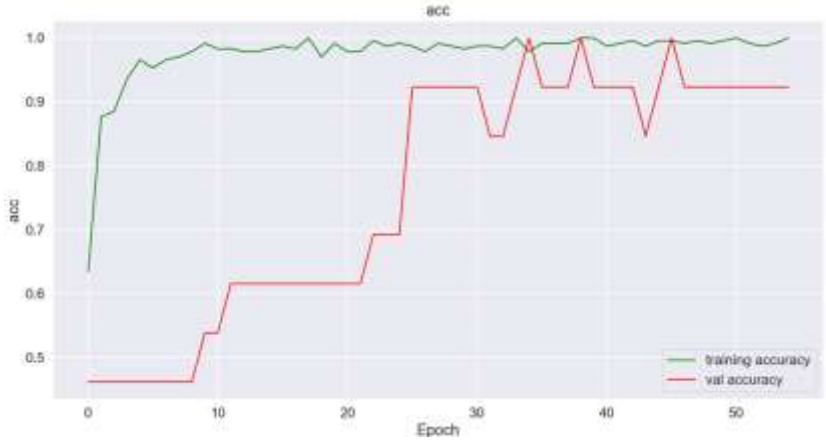
3.2. Experiment Methods

The purpose of experiment is to check the accuracy of programme to classify whether the lighting in photo is normal or abnormal. There are 262 photos for model training and the photos has already separated into two group- ‘Check normal’ and ‘Check abnormal’.

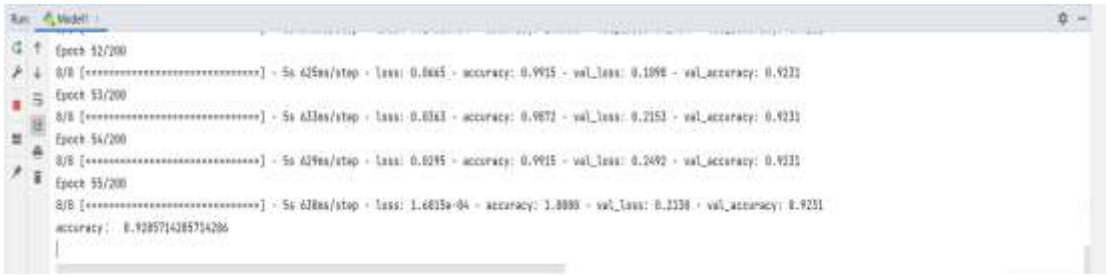
(Figure 13. Photo in ‘Check abnormal’ group)

(Figure 14. Photo in 'Check normal' group)

3.3. Training Result

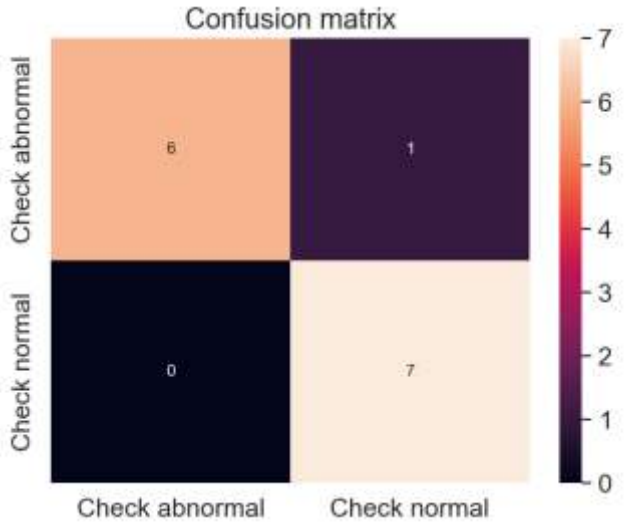


(Figure 15. training accuracy and validation accuracy of modal)



(Figure 16. Number of Epoch)

Both training accuracy and validation accuracy is lowest in starting and they are increasing with the number of epoch increase. Training accuracy reach its pack value in It is nearly 10^{th} epoch while result shows that the training modal have nearly 100% training accuracy while the validation accuracy is 92.31% after training 55 epoch.



(Figure 17. Confusion matrix of model)

Accuracy = (Ture Positive + Ture negative) / Total of Data X 100%
= (6+7) / (6+7+1) X 100%
= 92.86%

Precision = (True Positive) / (True Positive + False Positive) X 100%
= (6) / (6+1) X 100%
= 85.71%

Recall = (Ture Positive) / (True Positive + False Negative) X 100%
= (6) / (6+0) X 100%
= 100%

F1 Score = 2 x (Precision x Recall) / (Precision + Recall)
= 0.92

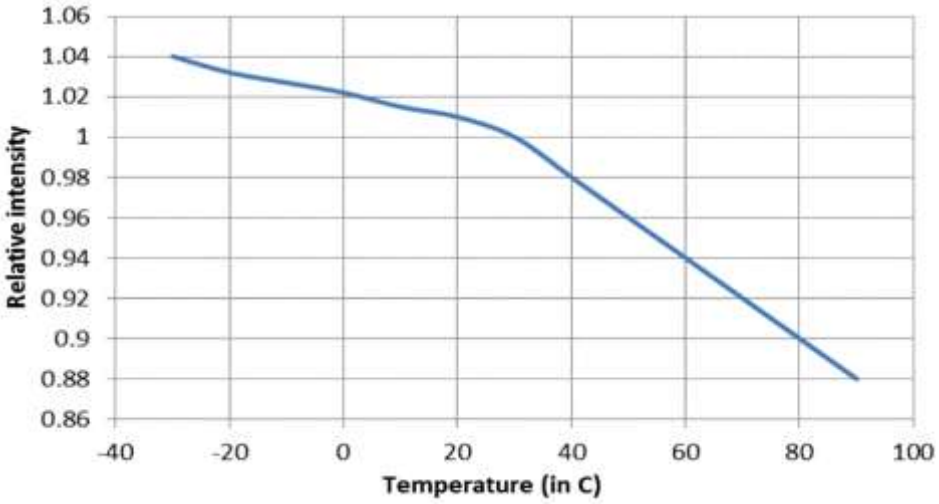
X-axis of confusion matrix represent actual classification and Y-axis of confusion matrix represent predicted classification. The accuracy of prediction result is up to 92.86% while the precision and recall are 85.71% and 100%. It is a satisfactory result especially the recall is 100% that mean all the burnt out lighting can be classified by the inspection system although a part of case is belong to 'Check normal' group. The 92.86% accuracy indicate that the prediction most likely matches the real situation in APM Tunnel. The F1 Score is 0.92 so it represents the great accuracy and recall of the model.

4. PROBLEMS AND RECOMMENDATION

4.1. Increasing Ventilation Efficiency in APM Tunnel

Lighting transfers electricity energy to light energy and heat energy. Although LED light can transfer high percentage energy to light energy, the remain heat energy has negative impact to LED light. The light intensity of LED light decreases when the temperature. increase. As a result, the LED light is dimmer in high temperature environment. The most LED light suppliers install compensation circuit in LED driver to regulate the current in LED driver to keep the constant light intensity in different surrounding temperature. It makes LED driver overdriving in high

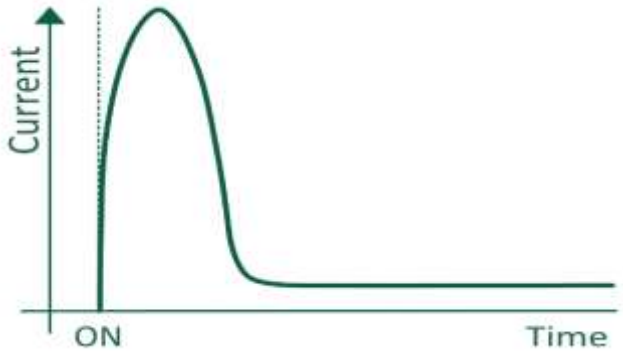
temperature environment and signification reduce the lifespan of LED driver. In general, the generated heat energy transfers from LED light to surrounding air by convection so heat transfer have better performance in spacious area. APM tunnel is relatively enclosed area so it is hard to transfer heat to surrounding environment. Therefore, increasing ventilation efficiency by HVAC in APM tunnel can transfer more heat to outside so that maintains the lifespan of LED equipment well.



(Figure 18. Relationship between and temperature)

4.2. Installation of Fixed Resistor Type Inrush Current Limiter

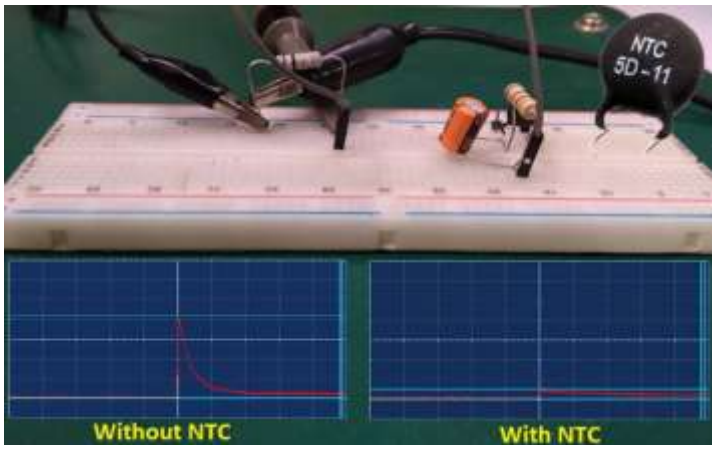
Inrush current is the instantaneous and extremely large amount of current generated when switch on the electrical appliance. LED light require small DC voltage to work and it transformed by LED driver from 220V power source. In fact, LED driver consists of capacitors that are charged when turn on the LED light and it cause generation of high inrush current. The inrush current can be up to 60 times of the operation current to cause Miniature Circuit Breaker (MCB) tripping or damage the light switch and LED driver in LED light tube.



(Figure 19. Relationship current of LED and time)

Installation of Inrush current limiter can reduce the inrush current. Inrush current limiter consists of negative temperature coefficient thermistor or fixed resistor. The resistance of NTC thermistor is higher in low temperature while the resistance is lower in high temperature. Therefore, when the LED light tube is switched on, the initial resistance is the highest to reduce the instantaneous

inrush current. With the current repeatedly pass through the circuit, the temperature increase and resistance decrease. Finally, it reaches the stable stage.



(Figure 20. Inrush current with NTC and without NTC)

Fixed resistor type inrush current limiter contains fixed resistor to reduce the inrush current. However, fixed resistor type inrush current limiter is more economical than NTC thermistor type inrush current limiter and fixed resistor type is more suitable for small power device. Therefore, Fixed resistor type inrush current limiter is better choice.

(Figure 21. Inrush Current Limiters)

4.3. Preassembled All Lighting Component to Batten Before Installation

As the working time is only about 3 hours so how to install more new lighting equipment in a limit time is very important. Therefore, If all the lighting component such as cable, light cap, charger and battery preassembled to batten in day time, it can save a great deal of time for installation because it is just required to mount the batten to wall and connect the cable for input power.

5. CONCLUSION

According to result of the chapter 3, the new design lighting layout can save 51.78 % electricity energy and electrical fee that achieve project target. The expected maintenance cost of LED

lighting system is more economical than present lighting system. In term of reliability, the theoretical lifespan of LED light is much greater than fluorescent light. However actual lifespan of LED light is easily affected by other factor such as high temperature environment and work beyond the rated current in long time. Therefore, keeping LED lighting work in relatively low temperature can increase its lifespan. However, the energy consumption of HVAC system for keeping relatively low temperature in APM tunnel during summer is high so how to balance both is worthwhile to further investigated.

The purpose of developing lighting inspection system is to substitute human to site checking the burnt out lightings. According to the training result, the training model has 92.71% accuracy and the F1 score is 0.92 that has satisfied performance in both precision and Recall. However, there are limitation exist in training model. The training model only separated two group – 'light tube illuminating' and 'lighting tube not illuminating'. In fact, the malfunction of LED driver inside LED lighting tube may cause LED light tube flashing and the training model cannot identify this situation.

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