Deep Learning-based Smart Street Lamps – A Solution to Urban Pollution

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***Abstract*—Smarter devices create an opportunity for numerous applications that contribute towards the welfare of the society. The system contributes in creating a street lighting system which focuses on solving the issues pertaining to environment, energy and public safety. The proposed system is a modular system having the components: LED module, PIR sensor, LDR sensor, Pollution sensor and a camera. The brightness of the lights is reduced to conserve energy in the absence of motion and when there is adequate ambient light. The Car tracking module of the system identifies the blacklisted cars using number plate identification. The number plate identification has been done using RCNN's along with some image processing algorithms. The air quality surrounding the street lamps can be detected and documented using the Pollution sensor. This data enables us to create a pollution heat map of the city and identifies areas of high traffic congestion. There is a charging port provided on a light pole for charging electric cars, which is the prepaid service.**

Keywords—Smart Street lamps; Intelligent lighting; Deep learning; EVSE; Number Plate Detection; Car Tracking

I. INTRODUCTION

Street lights consume major part of electricity approximately 20 to 40 % of the total electricity generated [1]. Most of these are CFL, metal halides or sodium vapor lights. These lights consume high power and are of high cost. The developing countries like India are facing challenges of rising demand of power; hence the conservation of electricity has become a great concern as most of the power generation stations in India use non-renewable resources like coal for electricity generation. There is a need of developing more efficient power distribution system and optimize power consumption through the use of technology. The key problems here are: Faulty lights, Electricity theft, public safety and unnecessary usage of electricity. Smart street lighting is considered as an important step for the growth of a smart city. Smart street lighting provides an opportunity for a range of interconnected city applications like traffic management, pollution monitoring in addition to reducing the energy consumed by street lights [5].

II. LITERATURE REVIEW

Some researchers have proposed a Zigbee based remote controlled system which provides a wireless Smart Street Lamp architecture. The data such as on/off control, power adjustment and fault monitoring from the sensors is sent to a control terminal, the data can then be analysed and street lamps that are not functional can be identified [3], [6]. In [2], authors proposed that the lights be turned on or off using proximity as a parameter, enabling efficient energy usage. In [15], the authors attempt to decrease the energy usage of the street light system, by using the neural network to anticipate the demand for energy required. Using image processing, street cameras are used for traffic monitoring and vehicle tracking in [7]. In [8] the authors demonstrated the impact of increase in air pollution due to increase in traffic congestion over the health of population near and on-road. In [16], a Netudino module is used for sending moisture, temperature, sunlight and humidity data to a server for a greenhouse system.

III. PROPOSED SYSTEM

The system focuses on designing the smart street lights that do more than just providing the lighting in the streets. Following are the main aspects that the system focuses on:

A. Public Safety.

- The camera monitors the street for safety for the public 24x7.
- The smart street light system provides a panic button that can be used by pedestrians to alert the appropriate authorities in case of any crime or emergency.
- The system also detects the lamp failure [3], [6] and notifies the concerned authority about the failure of the lamp. This will help authorities to take corrective actions as soon as the fault is notified.
- Speed detection functionality is provided for finding cars which are over-speeding.

- The Car tracking module of the system identifies the blacklisted cars using number plate identification. This may help in reducing the crime rate.

B. Energy Conservation

- The system implements adaptive lighting. The control system will trigger the street lamp when needed. For example, when there is enough ambient light present, the system automatically dims the lamp.
- Lights will be dimmed when there is no motion detected in the vicinity. This helps in optimizing the light output given by the LED lights hence conserving energy [4].

C. Environment Conservation

- Pollution sensors will detect air quality in particular areas and alerting authorities in case of abnormal rise, hence aiding in the conservation of the environment.
- Currently there is a shortage of detailed open source data for air quality statistics. This system aims of providing data for research and analysis of this data
- Car charging system installed at light poles will encourage adoption rates of electric vehicles, thus reducing global warming.
- Use of LED bulbs will further reduce the carbon footprint.

D. Overview

The smart street light controller box is installed on the light pole which consists of a micro controller along with various other sensors and a wireless module. The main components of the system are: LED lamp, Power sensor, PIR sensor, a LDR, high resolution camera, Pollution sensor and the Charging Port module. Air quality is measured by the pollution sensor and uploaded to the cloud. The PIR sensor detects movement; if no movement is detected for a fixed interval of time then the LED is dimmed [4]. The LDR is used to detect the failure of the lamp; this is then sent to the cloud. Camera feed is captured and sent to the server for processing and storing the vehicle number plates in the frame. The smart street lamp has a vehicle charging system (EVSE) that is activated on scanning a QR code at the bottom and making a payment, the vehicle can only be charged on making a payment. Vehicle speed is detected using the sent frames, if the speed crosses a certain threshold it is flagged. A web console is provided by the system to track the data sent by the smart street lamp sensors and the camera feed to the server. The data sent by the different onboard sensors from multiple smart street lamps is visible here. The system is designed to be scalable, hence a Publish/Subscribe model using Mosca message broker. Message Queuing Telemetry Transport (MQTT) is used as a lightweight communication protocol for data transfer from the smart street lamp sensors to the server in the cloud. A vehicle tracking system is provided to be used by law enforcement authorities for tracking criminal vehicles.

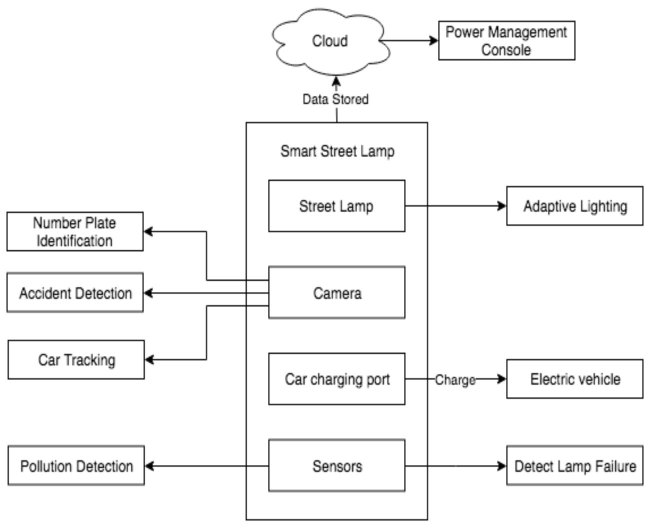


Fig. 1. Smart Street Lamp System

E. Hardware Overview

1) Power Sensor: The Power Sensor sends the power consumed by the Smart Street Lamp after a fixed interval of time.

2) Pollution Sensor: The data of the pollution sensor is also sent to the server after fixed intervals of time. The data can be used for better traffic routing, as the traffic congestion is correlated with the air quality of the surrounding area [8]. The data from the Pollution sensor is sent over to the Mosca server which then stores the data on the cloud server for further analysis. The system sends an alert to the authorities when the pollution limits are exceeded.

- The air quality sensor used in the application is Libelium Waspmote plug and sense device. This device uses Inter-Integrated Circuit (I2C) communication. Hence is integrated with our microcontroller with ease. Since availability of detecting all the gases in a single sensor is not possible, this device provides solution to the problem.
- The sensor has the option of selecting probes which can be attached to the device. These probes help in detecting the gases responsible for pollution which may have been caused due to traffic, etc.
- The probes available detect Carbon Monoxide(CO), Carbon Dioxide (CO_2), Oxygen (O_2), Ozone(O_3), Nitric Oxide (NO), Nitric Dioxide (NO2), Sulfur Dioxide (SO_2), Ammonia (NH_3), Methane (CH_4), Hydrogen Sulfide (H_2S), Particle Matter (PM1 / PM2.5 / PM10) - Dust, Temperature, humidity, pressure and Luminosity.

3) Energy Saving System: The Passive Infrared (PIR) sensor measures infrared (IR) light emitted from objects. It works on the principle of the Pyro-electric effect which helps in detecting human movement. The output of this sensor is basically a digital pulse which can be read by any microcontroller, through which a controlling action can be taken. PIR sensors have a wide range of angle through which they can detect heat. To converge the rays of heat a Fresnel lens is used. A light dependent resistor (LDR) is a variable resistor controlled by light. The LDR resistance varies inversely with light. Due to this LDR's are used in a number of switching applications. Our energy saving system uses a

PIR and an LDR to detect movement or ambient light and reduce the output of the street lamp [4].

4) Car Charging System: Many countries have planned to phase out traditional cars in an effort to conserve the environment. Electric cars need a supporting infrastructure to support fast charging and convenience of charging. This paper proposes an EVSE (Electric Vehicle Supply Equipment) system to be attached to the street lamps to provide a complete charging infrastructure. This system was tested by us in Proteus software and implemented. [9] EVSE is a standard protocol for safety of the individual and battery while charging. J1772 is used in the current generation of Electric Vehicles. Using two-way communication between car and the charger, the specified charging current is determined based on the maximum current provided by the charger along with the maximum current that could be received by the car. As per the protocol standard, a safety lock-out exists, preventing current from flowing when the charger is not connected to the car. It ensures that if a cable is inserted in an improper manner, power will not flow through it. [9] Hardware defects can be detected by EVSE, thereby disconnecting the power and preventing battery damage, electrical shorts or worse still, fire. The main advantage of using the J1772 protocol is that it does not require user input. EVSE eliminates all user interaction beyond plugging the J1772 connector in. The charger takes care of the rest. [9] The EVSE cord consists of 5 main slots i.e. Power (L and N), Safety, Ground and Communication. The Arduino based EVSE implementing the J1772 protocol is one of the cheap and efficient way to build an electric charging station. The Arduino EVSE can charge at any J1772 rate from 6 Amps to 80 Amps.

Fig 2. Evise System

F. Software Overview

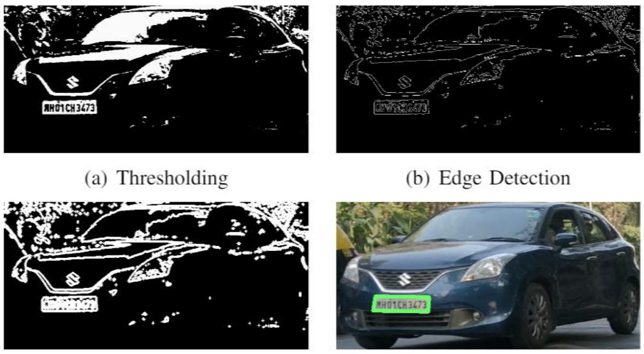
1) Video Feed Processing: The dataset used consists of the UCSD Car Dataset, combined with images extracted and labelled from video recordings taken by us. Due to the continuous stream of data, the video feed should be processed in near real time speed. Due to the shortage of labelled data, the approach of first extracting the cars from the video is used, followed by extracting number plates by using standard image processing techniques. After this, OCR is performed on the number plates. Table 1 contains a comparison of the different methods used to extract the images of cars in a video stream, these values were tested on an Nvidia GTX 1060. Single Shot Detectors (SSD) could not provide us with the required accuracy and haven't been included in the results. Later it is discovered that the Region based Convolutional Neural Networks (RCNN) algorithm to suit our requirements.

TABLE I. DIFFERENT APPROACHES FOR VIDEO FEED PROCESSING

Algorithm	*Batch Size*	*Frames per second*	*IOU*
Faster RCNN ResNet	8	12	0.81
Faster RCNN VGG-16	8	14	0.75
Faster RCNN ResNet	1	5	0.80
Faster RCNN VGG-16	1	8	0.71

Algorithm 1: Number Plate Detection Algorithm

Result: Individual Characters of the Number Plate
initialization;
while *Video Stream is Active* **do**
  exec Faster RCNN algorithm to detect Vehicles ;
  if *Vehicle detected* **then**
    Crop and Save Image According to Bounding Box;
    Threshold Image;
    Find Rectangular Area with 4 sides and 4:1 ratio;
    Crop and Save Number plate;
    Run Number Plate through OCR;
    Save Number plate;
  end
end



(a) Thresholding (b) Edge Detection (c) Image Dialation (d) Number Plate

Fig 3. Steps of Processing the Image

2) Car Detection Algorithms: The proposed testing has found the following algorithms to suit the purpose of car detection.

a) Fast RCNN: [10] The Fast RCNN algorithm extracts a fixed number of regions from the image called region proposals and then it applies the selective search algorithm, this algorithm generates candidate regions in which the object can exist. It then stitches together the regions to create larger regions. The regions are then generated to produce the final candidate region proposals. The object detection was not suitable for real time object detection.

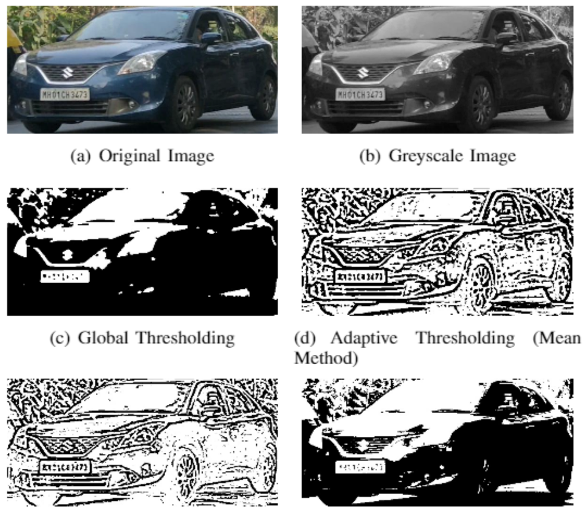
b) Faster RCNN: [11] The Faster RCNN algorithm improved upon the Fast RCNN algorithm by sending the input image into a CNN directly to generate a feature map. From this feature map, region proposals are identified and then transformed into squares using a Region of Interest Pooling layer, which is then fed into a fully connected layer. It works faster since a huge number of region proposals need not be fed into the CNN.

3) Number Plate Detection: After the extraction of the car images, the thresholding is applied to the grayscale images for binarization. After this an edge detection algorithm is applied to give us the edges followed by dilation of the image to enhance the edges. The process of dialation, reduces noise by increasing the size of pixels in the foreground and reducing the size of pixels in the background (white pixels increase in size and black pixels decrease in size). A simple image processing method is used to extract the number plate through its aspect ratio and minimum size since it would be a rectangle with a fixed aspect ratio. The number plates can be extracted using a CNN if provided with enough data. Following are the different algorithms tried for thresholding:

a) Global Thresholding: If an input pixel value is greater than a predefined threshold value, then it is assigned one colour (white/black), else it is assigned the other colour (black/white).

b) Adaptive Thresholding: The global thresholding method does not work for all lighting conditions since the threshold needs to be pre-set for every condition. Hence, in Adaptive Thresholding the image is divided into multiple sections and the thresholding values are calculated individually for each section. The threshold is calculated by either a simple mean or by using the weighted sum of neighbourhood values by assigning weights as a gaussian function.

c) Otsu Thresholding: For a bimodal image, it automatically calculates a threshold value by calculating the mean from the image pixel value histogram.[12] Otsu thresholding produced more uniform results when the noise of the image is blurred using Gaussian blurring.



(a) Original Image (b) Greyscale Image
(c) Global Thresholding (d) Adaptive Thresholding (Mean Method)
(e) Adaptive Thresholding (Gaussian Method) (f) Otsu Thresholding

Fig 4. Different Thresholding Methods Applied to Dataset

4) Optical Character Recognition: The final part of the problem was converting the number plate data into a sequence of characters, for this first the number plate is divided into different characters and put the individual characters into a simple CNN to detect the characters.

5) Speed Detection Algorithm: [13] The speed detection algorithm uses the dlib library to track a particular vehicle across frames [14]. In case the number plate is not visible a unique id is assigned to the vehicle. The position of the vehicle is obtained by calculating the center of the bounding boxes. This identifies the position of the vehicle in terms of the pixel values in a particular frame. The change in pixels is calculated using the coordinates obtained. The distance covered is in terms of pixel units are converted in terms of metres. A pixel per metre (ppm) value is used to convert the distance in terms of metre units. Ppm value denotes the number of pixels covered in the video for one metre distance in real world scenario. Time elapsed is obtained by the camera's frame rate setting. The distance is calculated via the distance formula:

$$dist_{pixel} = \sqrt{(X_1 - X_2)^2 + (Y_1 - Y_2)^2} \quad (1)$$

This distance is converted to its corresponding value in meters through:

$$dist_{meter} = dist_{pixel} \,/\, ppm \quad (2)$$

The speed is calculated in meters per second via the formula, the Frames per Second (FPS) of the camera is the sampling rate of the camera:

$$speed = dist_{meter} \times FPS \times 3.6 \quad (3)$$

Through this method law enforcement authorities can identify speed limit violators. This method also enables an effective surveillance system of interconnected cameras for effective criminal tracking.

Fig 5. Multiple Vehicle Speed Detection

IV. Conclusion

The smart street lamp system provides a framework of how the cities of the future would look like. The system is multi-component system that makes the use of technologies such as deep learning algorithms, Internet of Things and EVSE. The advantages of this system are that, huge amount energy can be saved without having an impact on the visibility of the road. The system can monitor the smart street light system and it can be used to alert authorities about a failure in the system. It also measures the pollution in a particular area and if the pollution level increases beyond some threshold, it sends an alert to the concerned authorities. The system also provides automatic license plate identification of a vehicle for crime detection. If the number plate is blacklisted then the vehicle will be tracked on the map. Speed detection is provided for detecting vehicles that are over speeding. Also, this research work encourages the use of electric cars by providing car charging points through the EVSE at each light pole.

V. Future Work

- Due to the modular structure of all components of the system, new algorithms can be implemented to achieve better accuracy.
- Microphones could be added to the lamps for scream detection or car crash detection.
- If more labelled data of video frames and number plates would be made available the number plates could be directly extracted from the frames, instead of following the steps mentioned in the paper further increasing the number of frames per second processed.
- More data could be collected during night times, for increasing number plate detection accuracy.
- The algorithm could not detect vehicles with extremely high speeds, since the number of frames sampled by the camera was low. Where it could gain a better real world performance by using a camera with a higher FPS sampling rate.
- The proposed work has faced issues with the detection of number plates of different aspect ratios on Indian streets, due to a lack of standardization of the number plate. A dataset with cars and number plate bounding boxes on the cars would significantly increase accuracy, since then a neural network is trained on the data.

Acknowledgment

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