Visible Light Communication: Detection of LED Traffic Light Using Image Processing in Real Time

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***Abstract*—The project stands on the intersection of Image processing , Visible light Communication (VLC) and Intelligent Traffic System (ITS). Our main objective here is to implement the concept of VLC and Image processing to detect the LED (VLC Transmitter) traffic light. LEDs used in the system are operating in 500Hz and image processing is done on each frame using frame by frame analysis with the help of a high speed camera (1000 fps) which work as a receiver.We improved the efficiency of the earlier algorithm and proposed a new way of communication in real time with proper synchronization. Real time analysis of the information from traffic signals is done using the algorithm which will be discussed in the later section.The project's algorithm is designed with the aim of real-time analysis in particular.**

***Index Terms*—visible light communication(VLC), Real Time Analysis, Digital Image Processing, Intelligent Traffic System (ITS).**

LITERATURE REVIEW

A. Introduction/Motivation

Modern world is witnessing fast growth in terms of transportation usage. Technologies in the transportation industry have evolved over the years. This evolution is supported by the fact that the 21st century has increased demand for vehicles with new models having new features. This increased demand and usage has led to overcrowding of roads with traffic and the number of accidents on roads are also increasing. This situation demands the introduction of smart systems for traffic management and systems which will ensure the on road safety of the people. Introduction of Intelligent Transport System (ITS) with intersection with visible light communication (VLC) has attracted many minds in recent years. This project is about highlighting those advantages of using VLC and why this is an area of interest to many people. [1][3]
This project proposes the benefits of amalgamation of VLC and Digital Image Processing (DIP) to detect LED Traffic Light in VLC systems. LEDs used in the system are acting as transmitters which are working in 500Hz and images of the same are captured by high speed cameras [1000fps]. The processing of the images captured are processed in the real time with frame by frame analysis. Algorithm for detection is analysed for the project along with the implementation of important concepts from VLC. [2],[3] Main advantage in dealing with VLC are following:

- VLC supports larger bandwidth which overcomes bandwidth limitation.
- VLC system is a power efficient system does not radiate harmful radiations.

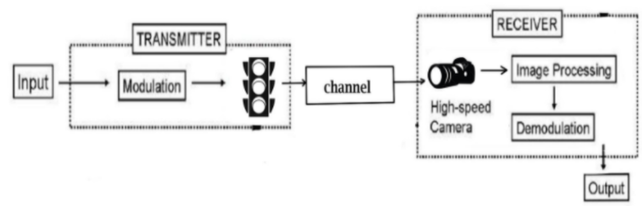


Fig. 1: Flow of VLC

B. Analysis

For the project we have referred to three related papers, our main aim with it is to be able to implement the project in real time using frame by frame analysis as a noval component. Brief overview/analysis of the three papers has been done below :-
As we are dealing with Images and light communication, emphasis is given on the modulation part as well. On the transmitter side modulation is carried out after taking input and demodulation is carried out after image processing on the receiver side. The whole process is dependent on the communication and image processing part. The project can be classified into two broad methods/steps which are again divided into subtopics:-

- *Finding Detecting Transmitter*

Our aim is to detect transmitters which are square in shape 256 (16x16) LEDs. All the LEDs are working with 500Hz and are either in ON stage or OFF stage. The transmitters emitted are in four different levels with 500Hz range. Since this project is based on the frame by frame analysis, here we are subtracting two consecutive frames to approximate the transmitter's exact point. This process is followed by binarization and noise reduction to get the exact location of the ON transmitter LED. This procedure is followed by cropping the image for efficient processing of LED.[1]

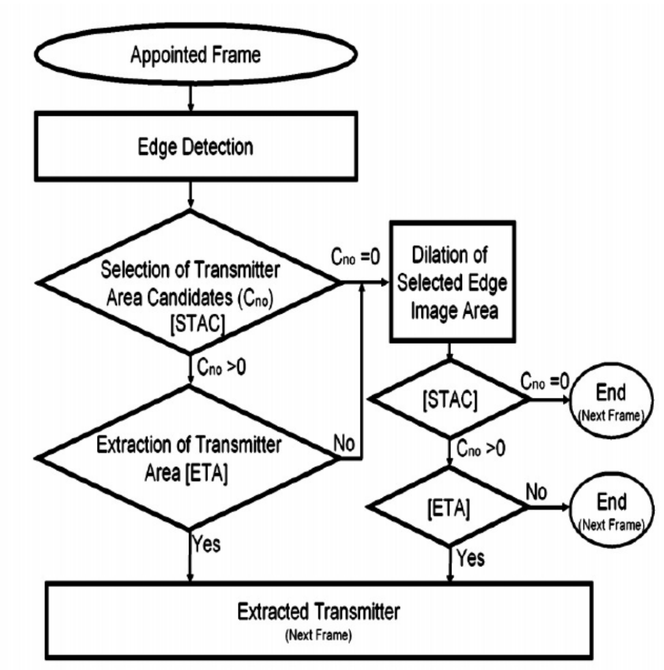


Fig. 2: The Algorithm to find the transmitter in Literature

- *Consecutive detection of found transmitter*

For the detection of edges, the project uses the typical canny edge detection technique which helps us to detect the sharp ends to work on. After this process we have (Cthreshold1 $>$ Cthreshold2). Pixels with gradients greater than Cthreshold1 and between Cthreshold1 and Cthreshold2 are taken as edge points. **[Here :- Cthreshold1 $=$ 250 Cthreshold2 $=$ 180 Found experimentally for the project]**

Among the detected edges, candidates are selected with condition :

$$|Height - width| <= 2pixels \tag{1}$$

Goal here is to detect shapes which are approximately square in shape.
The transmitter is considered an ideal candidate if its side length (L) difference is not more than 2 pixels and middle point (M) movement is not more than 5 pixels. If we have more than one eligible candidate then we do probability analysis which is followed by :

$$P(L, M) = P(L) + P(M) \tag{2}$$

The candidate with highest P(L,M) is selected as the transmitter for that frame. If no candidate is found then we carry the dilation process and then the above process is repeated and still nothing is found then we move to the next frame.
In our second paper[3] there are some added and modified new methods to verify the transmitter area. Here in this step they have introduced two quantities i.e. differences density (Dden) and average intensity(Lavg
(Dpix)= number of differences pixels
(Tpix) = number of pixels inside the candidate
(Lpix) = intensity values of the pixels inside the candidate

$$Dden = Dpix/Tpix \tag{3}$$

$$Lavg = \sum_{pixi} /Tpix \tag{4}$$

$$Dden * Lavg > threshold \tag{5}$$

The candidate which satisfies equation 5, will be considered for the next treatment. Here, the threshold value can be changed accordingly. For tracking the transmitter,the 2nd paper[3] had proposed two methods, i.e. Edge-based tracking method and Optical flow-based tracking method. Edge-based tracking is almost similar to that of the steps we discussed above. They used Lucas Kanade optical Flow if the Edgebased tracking is failed to captured the transmitter. In this method, Gaussian Low pass filter is applied, and at every pixel of the extracted candidate, they calculated the deformation matrix(D) and respective eigenvalues are calculated followed by NMS(non maxima suppression)

$$D = \begin{bmatrix} dxx & dxy \\ dyx & dyy \end{bmatrix} \tag{6}$$

Here (dxx),(dxy),(dyx),(dyy) are the second derivatives. With help of eigen values of deformation matrix(D) we can change find the features points which helps us to determine the transmitter area of the base frame.

In our third paper[2], the algorithm for the detection process is given with some experiments to back it up. The paper proposes the process of two main techniques for detection of transmitters using VLC - Frame Subtraction method Template Matching method. The paper highlights one of the major disadvantages of the camera-Led setup which is the fact that the frame rate of the camera used in the project is much lower than the photodiode' reaction rate used in other systems.

Though the system was able to detect and analyse the vehicles at 30 km/h but we have traffic operating beyond the limitation of the camera proposed. Other challenges of camera setup is that it is the real time analysis and modulation procedure. Paper constructively highlights the importance of the VLC system in ITS and creates a need for the efficacy of the proposed system.

C. Closure

The Intelligent Traffic System is the matter of great interest nowadays with the broader aspects of the system. Since the inception of communication using light, efforts have been made to overcome the constraints related to VLC.We compared the studies of 3 papers and reflected on the concepts and experiments discussed in the same. While the first second paper discusses the Visible Light Communication (VLC) with Image processing more mathematically, the third paper introduces us to the theoretical and algorithmic aspect of the topic.In this project we used LEDs as a transmitter (500Hz) and Camera (1000fps). There are several changes that can be made to enhance a variety of aspects, including various environment conditions. In this project, we redesigned the algorithm to track real-time transmitter coordinates and signal detection.

METHODOLOGIES

- *Canny Edge Detection*
The Canny method is the most effective edge detection method that edge offers. The Canny method differs from other edge detection methods in that it employs two thresholds (for detecting strong and weak edges) and only includes weak edges in the output if they are related to strong edges. As a result, this approach is less susceptible to noise than the others and is better at detecting true weak edges. We want the boundary of the approximate located transmitter by applying canny edge detection on cropped image.

- *Laplacian Filter*
The second derivatives of an image are computed using a Laplacian filter, which measures the rate at which the first derivatives change.The Laplacian of an image highlights areas of sudden intensity transition. We need to sharpen our grayscale image of our transmitter before removing its noise and edge detection.

- *Gaussian Noise Filter*
Gaussian 2-D filter is to forcely attenuate the high frequency signal. Mainly in the algorithm we used a gaussian filter to remove the noise in the unwanted region.The effect of this filter can be seen as a blurred image and wisely choosing the standard deviation is a crucial part.

- *Hough transform*
Hough Transform is used for detecting lines and circles by transforming every edge point in the edge map to all possible lines that could pass through that point. Circular Hough transform has been optimised to the maximum extent possible. It draws circles in voting space easily and without gaps using the midpoint circle algorithm. If a rough approximation of the circle positions is known, it also has the option of checking only a portion of the picture to speed things up. We use inbuilt function imfindcircles that use Circular Hough Transform(CHT) to detect the circle in our final cropped image and give us the centre and radius of the transmitter.

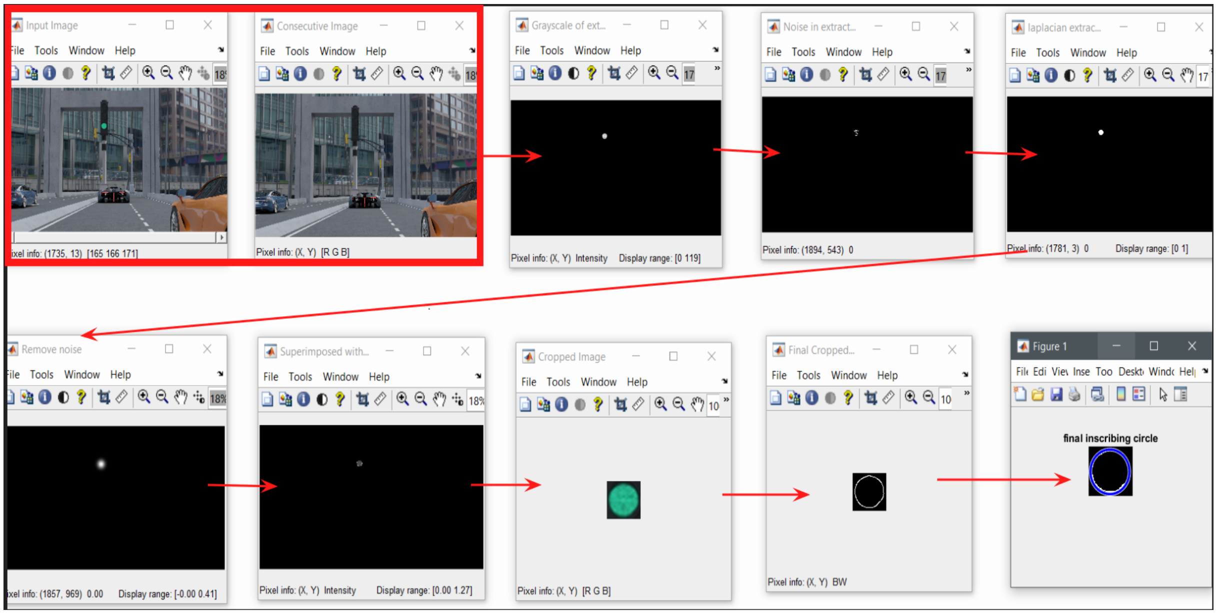
ALGORITHM FOR DETECTION OF TRAFFIC LIGHT IN REAL TIME

The traffic light (transmitter)will blink at the speed of 500Hz when any of the signals is in ON state. The camera(receiver) which will be used as a receiver can take images in 1000fps. So in the proposed algorithm first we initialize sampling instances and the algorithm will operate till we exhaust all the appointed frames from the sampling instances.After this, the images which has transmitter ON and OFF are subtracted from each other so as to cancelled out all identical pixels and obtain the estimated candidate region.Canny Edge detection can be promptly applied after this to extract the edge.

However, there's a high risk that noise and unintended edges could appear in the other region of image.So to highlight the edges Laplacian filter is used additionally gaussian filter is used to attenuate the high frequencies which are unwanted pixels in the image. After the noise is removed we can apply the canny edge to detect an approximate inscribing circle of the transmitter area.The radius and centre of the inscribing circle are calculated using the observed boundary.

We cropped the original appointed frame by using centre and radius obtained in the previous step. Now we convert the cropped image into grayscale. To remove the existing noise we use the gaussian filter on grayscale cropped image again.Now we apply the canny edge detection to get the circle of the previous cleaned image. We use imfindcircle method which uses Circular Hough Transform(CHT) to detect the circles in the final image and give us the centre and radius of the transmitter. With the help of the centre and radius of the transmitter we run a for loop on our appointed frame and calculate the pixel percentage of RED/YELLOW/GREEN in that area by applying RGB range. We also calculate the remaining pixels percentage(all pixels except RGY).

To make our algorithm efficient so as to avoid high time complexity we came up with a solution in which we stored the centre coordinates and radius of the transmitter from the previous appointed frame and tracked the transmitter of the next frames. The current appointed frame and detect the state of the traffic light. If it throws error then it will continue the whole process otherwise it updates the current appointed frame again and again until there is no detection (remaining pixels > 50).
After all the sampling instances are exhausted, the while loop breaks and we get the state of traffic light in real time with its percentage of pixels(RED/GREEN/YELLOW) in the transmitter area.The Algorithm and frame by frame analysis shown in below figure.



(a) Detection of traffic light(Intermediate Steps)

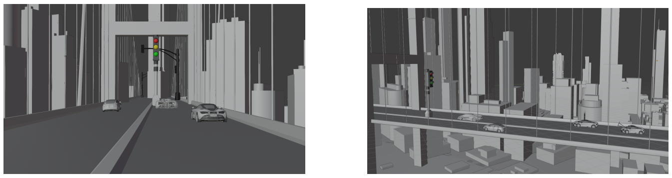
Algorithm Detection of traffic light in real time

```
1 Initialize sampling instances
2 K = length of the sampling instances
3 while(K>0) do
4     Read appointed image (Transmitter on) and consecutive image(Transmitter off)
5     Subtract the above images and get the approximate candidate area
6     Convert subtracted image to grayscale
7     Apply laplacian filter to sharpen the grayscale image
8     Apply Gaussian filter to previous image(for noise removal)
9     Apply Canny Edge Detection to get approximate boundary of the Transmitter
10    Find the centre , radius of the candidate area
11    Crop the appointed image using the above information
12    To get the precise area of the transmitter repeat 6,8 and 9 to the cropped image
13    By using hough transform detect centre , radius of transmitter
14    Detect the state of traffic light by RGB range from the transmitter
15    Get the percentage of Detected color pixels, remaining pixels in the candidate area
16     try
17       while(K>0 and remaining_pixels<50)
18           Read the next appointed image (Transmitter On)
19           Repeat 14 , 15 using the coordinates previous sampled transmitter
20       catch
21           continue
22 end
```

(b) Algorithm

Fig. 3

Simulation and Results



(a) Front view (b) Side view

Fig. 4: 3D Environment

Fig. 5: Rendered 3D Environment

Data collection: In order to simulate the real time scenario and to check the efficiency of the algorithm we constructed the whole environment in 3D software(autodesk Maya) which consists of a small city(5 square km size) and bridge where the automobile and traffic light communication will take place added with slight atmosphere scintillation as shown in Fig 4,5. **This is our 3D environment for sampling.**

By applying the proposed algorithm in the above section on data(instances) we obtain the state of traffic light in real time as shown in above fig 6.Here the sampling of the images is taken at the increment of 4 metres to get rid of the highly computational expensive rendering time while the automobile is approaching at 25-35 km/hr.

As we see in fig 7 we observed that as the car (receiver) approaches a traffic light (transmitter), the percentage of detection of traffic light is increasing from 54% - 82%.

From this we conclude that when the car is close to the traffic light there is more chance of (RGY) detection correctly. There is sudden decrease in percentage when car is about 70m away from transmitter which is due to the change in state of traffic light.

This is our github link for matlab code.

Distance	detect	percent
106	"RED is detected "	53.846
100	"GREEN is detected "	61.688
96	"GREEN is detected "	50.588
92	"GREEN is detected "	53.333
88	"GREEN is detected "	53.516
84	"GREEN is detected "	59.363
80	"GREEN is detected "	63.922
76	"GREEN is detected "	53.725
72	"RED is detected "	63.852
68	"RED is detected "	72.026
64	"RED is detected "	74.277
60	"RED is detected "	70.51
56	"RED is detected "	51.663
52	"RED is detected "	69.305
48	"RED is detected "	78.298
44	"GREEN is detected "	70.389
40	"GREEN is detected "	68.898
36	"GREEN is detected "	73.558
32	"GREEN is detected "	74.277
28	"GREEN is detected "	82.005

Fig. 6: Detection of Traffic Light in Real Time

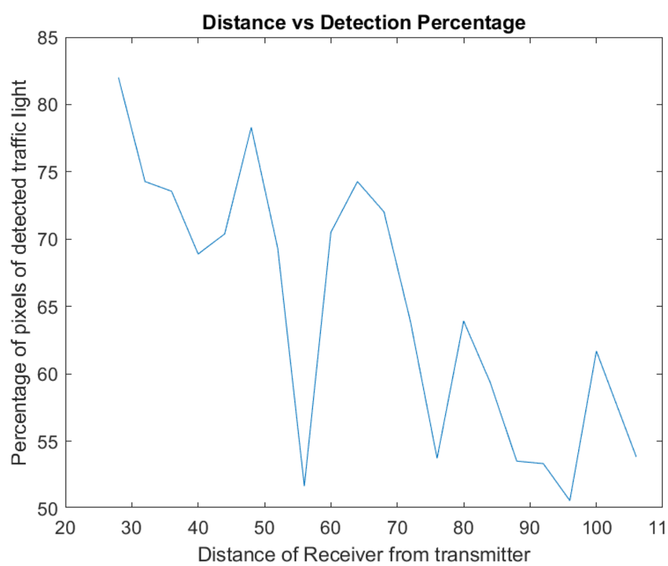


Fig. 7: Distance Vs Detection

Future Aspects

To come up with an enhanced version of the communication system the project can be extended by using the concept of the DARK Visible Light Communication. Using this concept, a transmitter can also transmit data successfully in the absence of light which is visible to naked human eye. Dark VLC is the modern concept in the VLC system which is still in the State of Art stage. We are convinced that VLC

has the potential to revolutionize sustainable and healthy communication.
In this concept, the light state is kept in such a way that it is not visible to the human naked eye. Though the light is not visible but it is still there in the communication system with ultra low duty cycle (approx 0.007 %) with on-time approximately 500 nanosecond.
Frequency and power is kept low with respect to standards which are described for the normal human eye light detection. These lights are not visible to the human eye but photo diodes which are present on the receiver end of the transmission section.[5]

Constraints of using Dark VLC in the project :-
There are some challenges and constraints we are facing in the project and are working on the same to deal with it and make possible assumptions which can be appropriately dealt with in future.
Detectable range for the Dark VLC is very less i.e 1.3 meters which is of no use in our system application. The range has to increase in order to interact with the vehicles involved in the communication.
Power and duty cycle (Less frequency and on time) of the light wave is very less which will be a major challenge in the way of transmission process.[4]

In our project we take two lane road with straight line of sight from receiver to transmitter with a particular environment. Further extension to this can be different environment such as foggy, polluted, rainy, night etc. with three or four lane roads of high and low altitudes.

Conclusion

With the wider aspects of the system, the Intelligent Traffic System is a subject of great concern nowadays. Efforts have been made to solve the constraints associated with VLC since the beginning of light communication. In the project, a new traffic light identification technique was developed for the development of a road-to-vehicle visible communication device using a traffic light as the transmitter and a high-speed on-vehicle camera as the receiver. We have improved the algorithm of earlier ones in the literature and rebuild the algorithm to achieve real-time detection of the traffic signal and extended the range of detection till 106m from 70m. For attaining close to physical, real-world environment simulation, we have constructed a city with the necessary assets (two lanes road, automobiles, buildings, etc.)in 3D software(Autodesk Maya). Experiments with sufficient consecutive appointed frames were carried out to validate the proposal's feasibility. The results demonstrated that the proposal was very successful for the desired detection.

Before Midsem	Implementation of traffic light detection for one frame (Code/Debug).
After Midsem	Real Time Analysis of traffic light detection (Code /Debug/Improvement/Novelty).

Fig. 8: Project Timeline

References

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