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Adaptive Traffic Control System Using SCADA

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Abstract: ***This paper proposes an adaptive traffic control system capable of efficiently handling the always changing traffic volume without any changes in the hardware. The system is designed using SCADA (*****Supervisory Control and Data Acquisition*****) for easy control and access of the historic sensor values. This system can be operated in two modes, one is the traditional mode of operation of the traffic signals and the other is based on machine learning prediction method. The system is also powerful enough to handle multiple junctions and can show the status of the sensors in real-time on the SCADA console. Using this system problems like congestion can be reduced in order to provide smooth flow of traffic.***

Keywords: Supervisory Control and Data Acquisition (SCADA), PLC (Programable Logic Controller), Traffic Control, HMI

1. Introduction

For developing countries like India, the traffic volume keeps on fluctuating daily and the current traditional traffic systems are not advance enough to handle a very large change in traffic volumes. This has led to problems like congestions, traffic accidents and overall delay of the traffic flow. Therefore, while calculating the signal timings the maximum traffic volume is taken and the cycle length is designed for it. But the traffic volume is not always the same at all times of the day, it can be the maximum during office hours and gradually decreases at late night. The weather conditions and festivals also play an important role in determining the traffic volume density. Due to this sometimes the calculated cycle lengths are too long causing unnecessary time loss per phase or they are short causing long waiting time.

In order to minimize the chaos, the traffic police use the current traffic condition for each lane and easily regulate the traffic. This is not practical throughout the day therefore a system was designed which can adapt to the changing volumes by varying its cycle length. This system is then further divided into two sub-systems. One is the Master SCADA where the main console is present and the other is the remote junctions with the traffic signals. The remote junctions can be fitted with various sensors to give real-time status of the environment. All the sub-systems are connected over a SCADA network and its data can be accessed using an HMI present in the main site.

The system can be operated in two modes:

a) Normal Mode: In this mode the operator can input the signal timings after calculating them using the I.R.C method. The SCADA main can be used to change the timings of the remote sub-systems easily.
b) Adaptive Mode: While in this mode Machine learning algorithm is used to predict the traffic volumes for the next few cycles which are then used to calculate the cycle lengths and fed to the sub-system.

2. System Design Overview

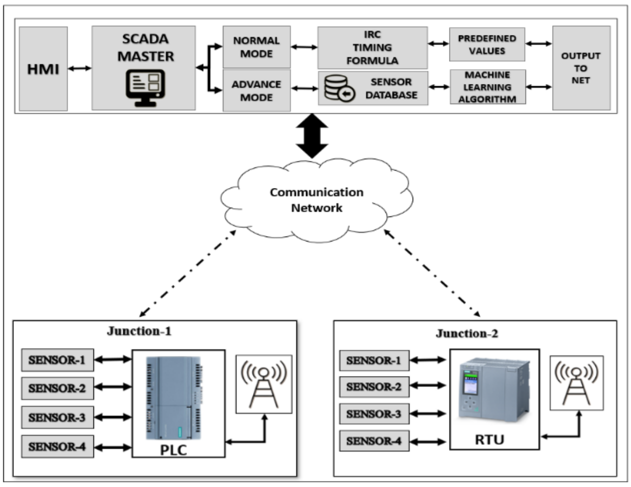


Figure 1: Block Diagram of the System.

The SCADA Master is the main part of the system through which the operator can communicate with the other sub-systems. It is installed in a primary location which also contains databases for storing of data. Various intersections can then be installed with unique PLCs or RTUs which handles the traffic lights and the sensors of that particular junction. These can be located in remote places far away from the master. These communicate with the master through a SCADA network or an OPC server. The sensors feed real-time data which is then stored in the database and used to train the machine learning algorithm.

The operator can interact with the system using a Human Machine Interface (HMI) found in the main site. This was designed using TIA portal and a Graphical User Interface (GUI) was established for the operator to easily control and monitor the system. There are various pages in the GUI each corresponding to a different aspect of the system. Fault identification was also embedded so that the operator can try to remotely fix the system.

3. Methodology

Using the rules laid out in the I.R.C formulae, using the intersection research the traffic signal timings can be found out. A padding of 4 seconds was given for the cycle length to account for start and end amber period.

3.1 Calculations

The optimum signal time C_0 was found using Webster's formula.

$$C_0 = \frac{1.5L+5}{1-\sum_{i=1}^{\emptyset} Y_i} \quad (1)$$

where
L= Lost time per cycle
Y=Volume/saturation flow for critical approach in each phase.
∅=Number of phases.

The lost time per cycle L is given by

$$L = \sum_{i=1}^{\emptyset} l_i + R \quad (2)$$

where R = All Red interval.
The saturation flow for roads with width above 5.5m can be taken as 525 per meter road-width. Therefore

$$Y_i = \frac{normalflow \quad (Q)}{saturationflow \quad (S)} \quad (3)$$

And the green time per phase is given by

$$G_i = \frac{Y_i}{y} * EGT \quad (4)$$

Where y = $Y_1+Y_2+Y_3+Y_4$ and EGT is the effective green time.

Using these formulae, the traditional signal timings can be calculated and can be then inputted in the timings page in the SCADA GUIthat I have designed provided the system is in normal mode as shown in the figure below.

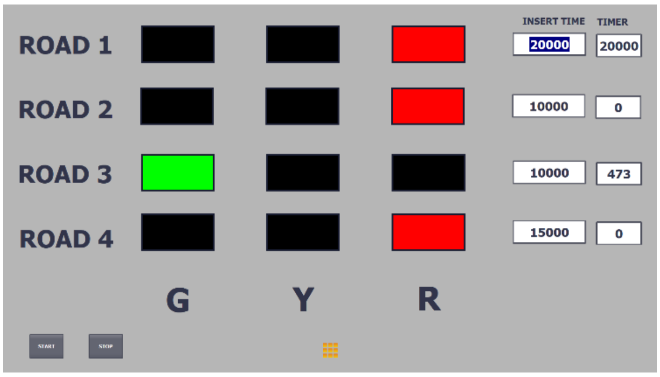


Figure 2: Timing Control Screen.

Figure 2 shows the interface for a 4-legged intersection sub-system, similarly a control screen was implemented for a T-junction sub-system.

Using the GUI dashboard each sub-system can be individually controlled and their operational mode can be selected.

3.2 SCADA Interface

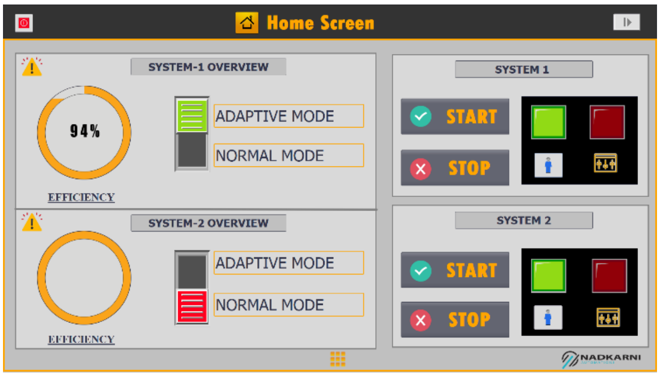


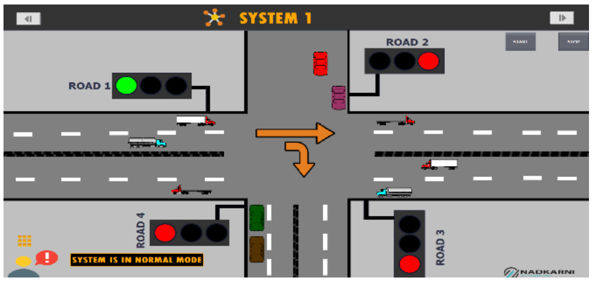
Figure 3: HMI Home Screen

Since there are multiple sub-systems independent of each other, the SCADA master should indicate each of their status in a simple manner without the need to dig through various pages.

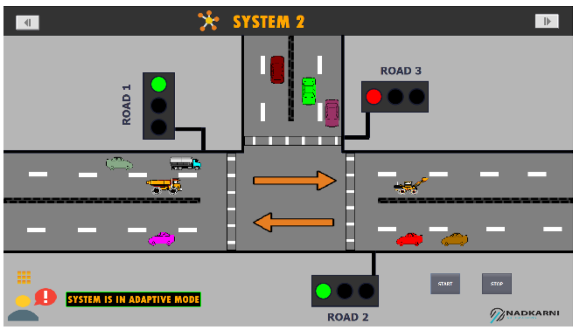
Figure 3 shows the home screen which I have designed such that with one look the operator can get the gist of the system. The operator can also select the mode of operation from this page. The separate sub-systems can also be started or stopped without even going near the junction.

The home screen can also be used to get the live feed of the visual sensors present near the junction. In case of any faults in the system an alert symbol starts to flash prompting the operator to go to the alarms page to find the nature of the problem.

Most HMIs are based on touch interface so the dashboard is designed for easy and precise control while using it. Pages can be browsed easily in a cyclic method and each page has a jump to home screen button to quickly return back.



(a) 4-legged intersection



(b) T-junction

Figure 4: Intersection Screen

The intersection screen can be used to see the placement of the volume sensors. This screen also indicates the phase of the cycle and shows which leg is open for the traffic.

While in adaptive mode the exclamation icon can be used to access the ML algorithm. The data collected by the sensors can be accessed over here. The data can then be plotted to show historic trends for better understanding of the system.

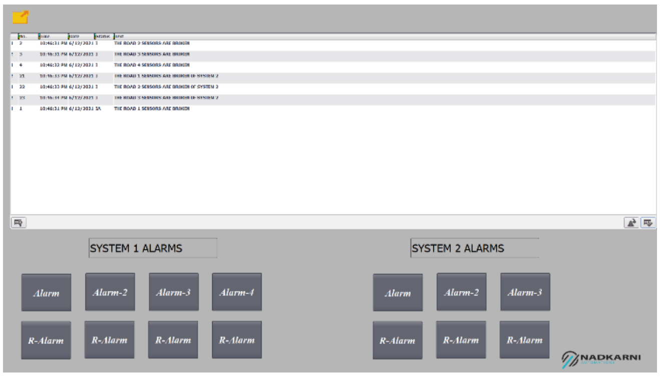


Figure 5: Troubleshooting Screen

In case of any alarms the operator can go to the troubleshooting screen. A detailed list is available of the nature and the status of the alarm. Unless and until the problem is fixed and the operator acknowledges the alarm, the status will keep on flashing prompting a quick repair of the system.

3.3 Proposed Algorithm

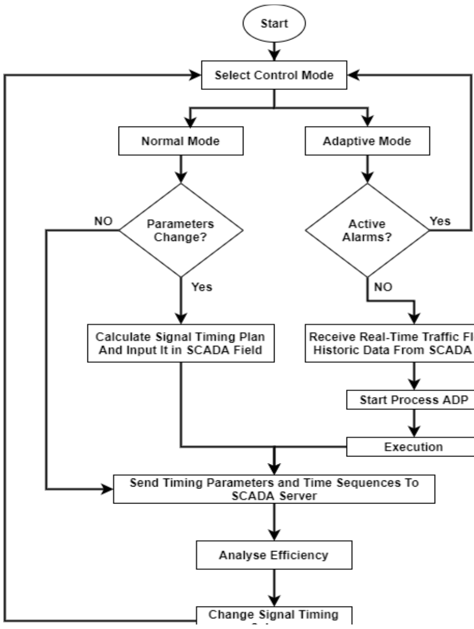


Figure 6: Control SCADA Running Process

Figure 6 shows the process flow of the SCADA sub-systems. After switching on the sub-systems, the operator is able to select its mode of operations. In normal mode the calculated signal timings can be used to run the system. Also, the system is flexible enough such that the operator can easily change the timings for morning session and evening session easily by going to the timings screen as shown in figure 2. No physical contact with the traffic signal is required in order to change the timings.

There is a feature designed in the system, preventing the use of the adaptive mode if there are any alarms in the system. This is done because the efficiency of the prediction algorithm is dependent on the values given by the sensors present in the environment. If any sensors are not functioning properly then the signal timings predicted will be erroneous. Therefore, the system automatically switches to normal mode for smooth flow of traffic.

If there are no alarms in the system then the adaptive mode is activated. In this mode decision tree and extreme gradient boosting algorithm of machine learning are used to predict the traffic volumes using the readings from the sensors. The past and present values stored in the SCADA database are used to train the system. The predicted timings are then sent to the SCADA in form of a csv file whose data is taken as tags by the PLC for its operation. The more the data the more is the efficiency of the algorithm.

This process will keep on running unless there is any problem in the system or the operator wants to change the mode of operation. I have designed the system in such way that while changing the modes the down time is almost close to zero as the signal timings are already given to the required PLC rom.

4. Results & Discussion

For simulation of the Machine Learning part a MATLAB code was written to generate multiple scenarios of traffic volumes. Using IRC codes their cycle lengths were found and the system was designed.

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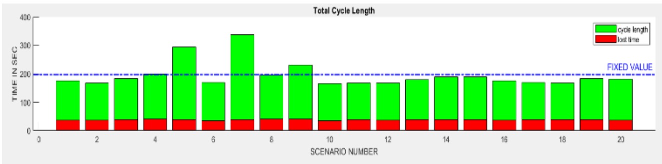

Figure 7: Time loss in traditional method

20 random samples were taken from the scenarios and their cycle length was plotted and the loss was calculated after their subtraction from the fixed cycle length. The plotted graph is shown in figure 7.

After summation of all the cycles it was evident that there is a lot of wastage of time due to fixed cycle length traffic signals. So, by varying the timings for every cycle this wastage can be reduced. To do that prediction algorithm was used to find the traffic volume for that particular hour of the day. Extreme gradient boosting values are shown in figure 8 below. The red line indicates the ideal values where the prediction accuracy is 100 %.

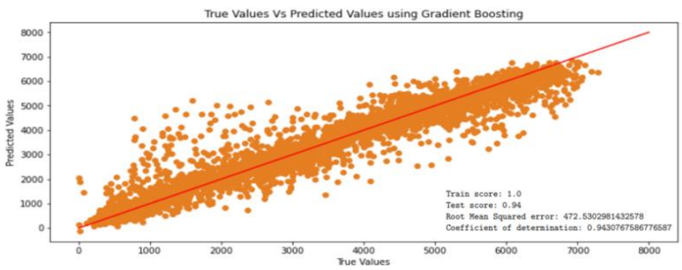

Figure 8: XGboost Accuracy

The closer to the red line the greater is the accuracy. Using decision tree, the accuracy was 86% but after using XGboost algorithm the accuracy was increased to 94%.

Since while calculating the cycle length the upper multiples of 5 are taken, the accuracy of matching the predicted cycle length to that found out using Webster's method is further boosted and the efficiency of the system increases.

The SCADA database accumulated with 600 days' worth of sensor readings was taken and both the algorithm modes were used on it. It was found out that by using traditional signal method around 534 hours were wasted, in contrast to only 30 hours wasted after using machine learning. This indicates that the system has reduced the time wastage by more than 94%.

5. Conclusion and Future works

The current traffic signals are not advance enough to reduce the wastage of time. This system proposed in this paper uses an adaptive approach by using machine learning to optimize the cycle lengths of the traffic signals thereby minimizing the delay at the intersections.

The system was simulated and tested using TIA portal and siemens PLCsim software. The database was created and used to predict future traffic volumes with an accuracy score of 94%. Also since there is a normal mode in the system the problems caused by sudden trend change in traffic for example during lockdowns when traffic volumes were close to zero can be solved. Also, the operator can remotely access the system from his house through a secured SCADA network server.

In future larger databases can be used to further reinforce the system. Multiple classifiers can be integrated for better accuracy. The system can also be modified to work in real-time with less latency as the hardware advances.

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