An approach of smart traffic lights system using computer vision algorithms at an isolated intersection to optimize traffic flow

Un enfoque de semáforo inteligente utilizando algoritmos de visión computacional en una intersección aislada, para optimizar el flujo vehicular

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Abstract. Nowadays the mobility is a problem of the cities [1] that can be supported by new technologies such as computer vision and optimization algorithms to design control systems that can adapt to the phenomena of traffic flow that exists in cities, to avoid congestion and optimize the vehicular flow, reducing wait times and improving coordination to the time distributions of traffic lights at intersections, for these reasons we propose an approach of smart traffic lights system control based on priorities measuring the number of vehicles passing with a video cam and spreading the time depending on the flow capacity of the streets at an isolated intersection, in the results it can be observed that the size of the waiting queues is reduced.

Keywords: Traffic Flow, Smart Traffic Lights, Computer Vision, Isolated System, Intersection.

Resumen. Hoy en día la movilidad es un problema de las ciudades [1] que puede ser resuelto por nuevas tecnologías como la visión computacional y algoritmos de optimización para diseñar sistemas de control que puedan adaptarse a los fenómenos de flujo vehicular que existen en las ciudades, para evitar la congestión y optimizar el flujo vehicular, reduciendo los tiempos de espera y mejorando la coordinación de distribución de los tiempos de espera de los semáforos en las intersecciones; por estas razones proponemos un enfoque de semáforo inteligente basado en prioridades que miden el número de vehículos que pasan en las calles con una cámara de video y distribuyen el tiempo dependiendo de la capacidad de flujo de las calles en una intersección aislada, en los resultados se puede observar que el tamaño de las colas de espera y los tiempos se reducen significativamente.

Palabras clave: Flujo Vehicular, Semáforo Inteligente, Visión Computacional, Sistema aislado, Intersección.

1 Introduction

Actually, the cities are growing fast, for that reason one of the biggest problems is the mobility, it affects a lot of citizens that move at the same time to the same place. As another cities, Xalapa, Veracruz, is being affected by this phenomenon, its roads are insufficient to serve many vehicles and traffic control systems (traffic lights) are becoming obsolete in this situation.

That is why it is proposed a smart control system to make a better distribution in waiting times and service, this will make an improvement of the variables of traffic flow and a system which can adapt to the situation in real-time. Through computer vision we can help us with this task, detecting objects of interest and moving objects in image sequences, for what we will use two video cameras to acquire images and for detecting vehicles in one intersection and develop databases one with the counts of vehicles and another if the vehicle is moving or not. This will allow us to perform a simulator to evaluate and compare the results between the fixed-time control system and the proposed smart system control in the flow variables, queue size, number of vehicles served and number of vehicles waiting.

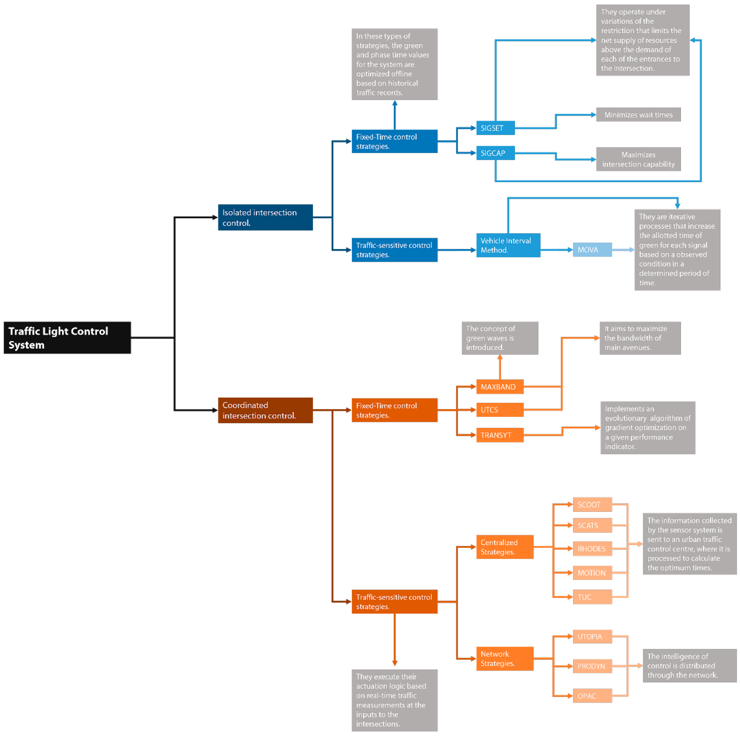

Figure 1. Control Systems diagram

2 State of Art

The following are terms and some research in the area of traffic control systems and vehicle detection.

2.1 Control system [2] [13]

As we can see in figure 1, the traffic control systems are divided into two parts: I) traffic control systems at isolated intersections and II) traffic control systems at coordinated intersections. I) It's a control strategy where the signals for an intersection work without considering any adjacent signals. In such case, each intersection will have signals times appropriated for that single intersection. II) It's a strategy in which the interaction between adjacent signals are considered. The objective of such strategies is often providing continuity across multiple intersections, allowing vehicles moving through successive signals without finding a red signal.

These strategies at time have two sub-parts which are the fixed-control systems and the dynamic controls systems. The first ones are characterized because their sequences of lights changes are programmed per the historical traffic flow measures of the intersections and they are no sensitive to demand, operate without considering fluctuations in traffic demand. The second ones are based on the measurement of traffic flow of the moment, which is monitored through sensors and adapt themselves to optimize the changes of the traffic light sequences and thus improve the vehicular flow and try to avoid congestion.

A. Object detection

In the field of object detection, there are two main strategies, some are based on motion, while other strategies use machine learning. Three algorithms based on motion were analysed according to the research that was made by Kothiya and Mistree (2015) [3] and were ordered according to their complexity.

I) Frame differencing [4] is a technique that detects difference between two consecutive frames, the aim of the approach is to detect moving objects from the differences of an existing frames and a reference frame.

II) Background subtraction is a method that extracts moving objects or objects in the foreground. They make a comparison of the background image (that is a model with the principal components of the background) with the current image and find the differences in pixel values between consecutive frames. When it detects the differences, it classifies the objects as a moving object.

III) Optical flow [5] as developed by Horn and Schunck [15] is a technique that presents an apparent change in the location of the object in motion between the frames of the video. It uses the field of motion that represents the directions and speed of each point in each frame.

As machine learning strategy, the Adaboost algorithm was introduced by Robert and Schapire (1996) [7] this algorithm is iterative and finds objects from a set of features with the use of weak classifiers that are trained with positive and negative features and then they combined to make a strong classifier. The features to train the algorithm can be obtained from the Haar-Like and HoG filters as we can see in [8], [9] and [10]. As part of the literature review, the Serrano's work [11] is about the phenomena of vehicle flow and pedestrians flow, that send signals to a traffic system control to determinate when to change the traffic lights. This work focuses on giving priority to pedestrians and was carried out in Madrid, Spain, this project is an example of a real-time traffic control system with techniques of computer vision. The work of Espinoza [12] makes detections of vehicles with the Adaboost algorithm and obtains results above 80% and 90% in the detection of vehicles. It seeks to optimize the vehicular flow by the development of a dynamic control system in the change of traffic lights with a fuzzy logic at the same time the traffic control system coordinate multiple intersections.

3 Methodology Dynamic system control proposed

In the intersection analysed, two cameras were placed in strategic zones, one focused on the main street (C1) with capacity of four lines but only three are useful because of the parked vehicles and the second one focused the secondary street (C2) with capacity of three lines but only one is useful because of the parked vehicles. With these sensors, we obtain videos which are sent to a computer for processing the information, execute the detection algorithm and the control system, to finally make the decision of when to change the traffic lights. To prove the methodology that we can see in the figure 2, a simulator was developed.

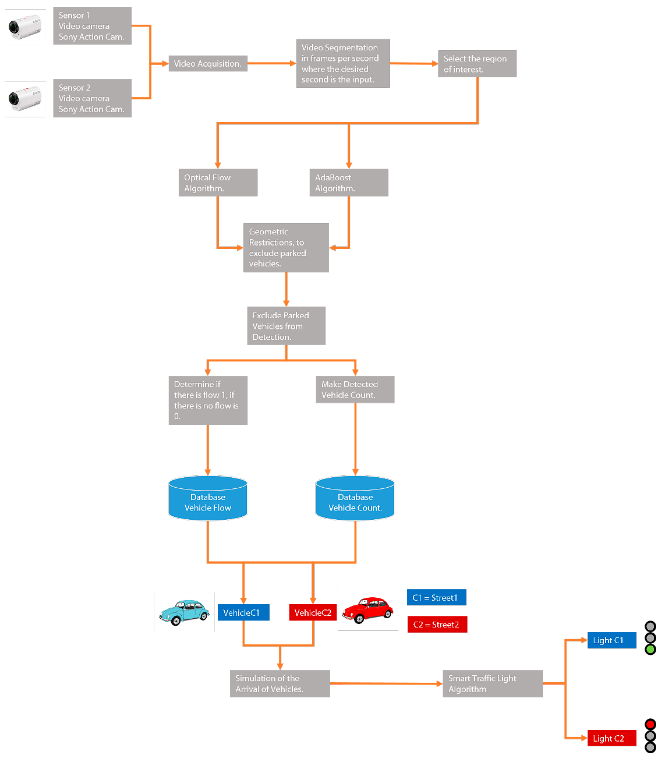

Figure 2. Diagram of the methodology

First the videos of the sensors are obtained and segmented in frames per second and then grouped in sequences, a region of interest is selected to support the algorithms of detection. Through the algorithms of optical flow of Horn and Schunk and Adaboost which is trained with the features of HoG, each segmented sequence is analysed to detect the vehicles and to detect if they are in movement. For situations of the environment its necessary to exclude from the detection the parked vehicles, for this reason geometric restrictions are made. After the exclusion of the vehicles the databases are filled with the number of vehicles and the databases of the motion vehicles. 1 in case that exist motion and 0 in case that it doesn't exist motion. Finally, these databases are used to simulate vehicle arrivals at the intersection which are necessary to simulate the smart system control that is described below. To design the intelligent control system (see figure 3) and its rules the following was done: First, take the role of a car driver and second the thinking of a priority management.

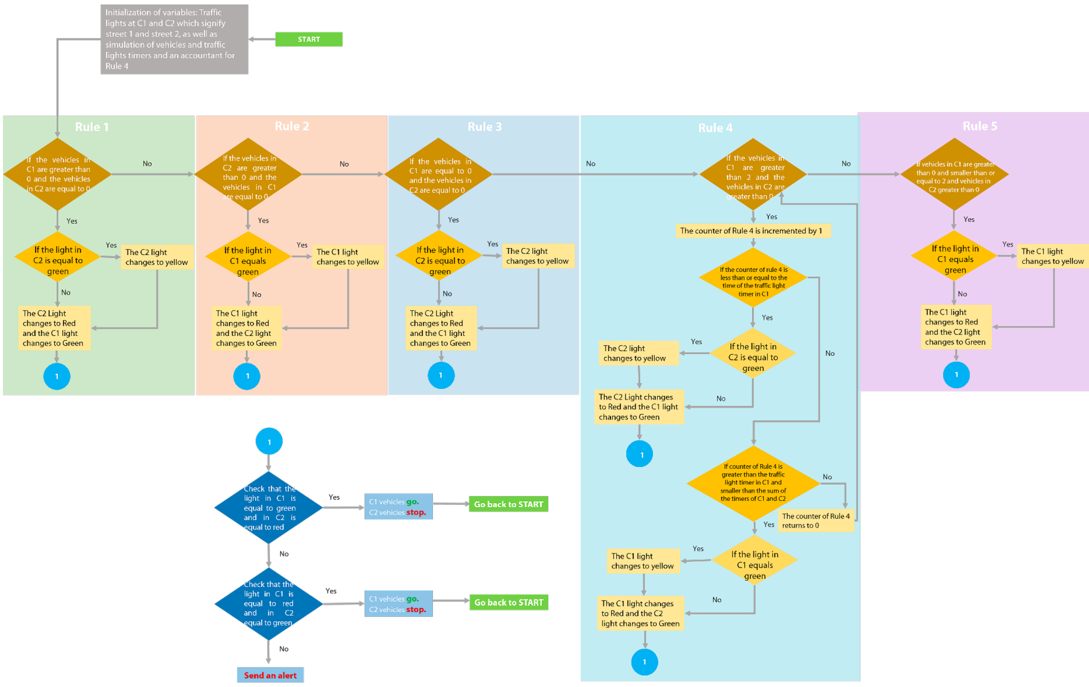

Figure 3. Diagram of the Smart Traffic lights system.

Rule 1: This rule evaluates the environment, and if it detects presences of vehicle in C1 and doesn't detect presence of vehicle in C2 it verifies in the first instance if the color of the light in C2 is equal to green if it so changes the light to yellow and next to red, if not, it means that the light in C2 is equal to red so it leaves it equal to finally change the light of the traffic light form C1 to green.

Rule 2: This rule evaluates the environment, and if it detects presence of vehicle in C2 and doesn't detect presence of vehicle in C1 verifies in first instance if the color of the light in C1 is equal to green if it so changes the light to yellow and next to red if not, it means that the light in C1 already is equal to red so it leaves equal to finally change the light from C2 to green.

Rule 3: This rule evaluates the environment, and if it doesn't detect presence of vehicle in C1 and doesn't detect presence of vehicle in C2 it verifies in first instance if the color of the light in C2 is equal to green if it so changes the light to yellow and next to red if not, it means that the light in C2 is already equal to red so it leaves it equal to finally change the light from C1 to green while waiting for vehicle in C1.

Rule 4: This rule evaluates the environment, and if it detects presence of vehicle in C1 greater than 2 and detects presence of vehicle in C2 greater than 0 creates a counter of the rule and increases it 1, it verifies if the counter is less or equal to the threshold called GtimerC1 = 7, if it is smaller, goes to check if the light of C2 is green if it so changes it to yellow and then to red, if it doesn't, mean that the light of C2 is already red so it leaves it equal and change the light form C1 to green. In the case that the counter is greater than GtimerC1, it continues to the next part of the rule where the counter is greater than GtimerC1 and less than GtimerC1 plus the other threshold called GtimerC2 = 3, in this part verify if the lights in C1 are equal to green if so change the light from C1 to yellow and then to red, if it doesn't equal to green means that the light in C1 is already red and doesn't change the it and the light in C2 change to green. In case the counter is greater than GtimerC1 plus GtimerC2 is reset and go to the beginning of the rule.

Rule 5: This rule evaluates the environment, and if it detects the presence of vehicle in C1 between 0 and 2, and in C2 it detects the presence of a vehicle greater than 0, it verifies if the color of the light in C1 is equal to green if it so changes the light to yellow and then to red if it doesn't means that the light in C1 is equal to red so it leaves it equal and then change the light in C2 to green.

4 Experimentation

The variables related to the traffic flow are the flow rate, q, which is the frequency that vehicle pass across a point or cross-section of a lane or roadway. It is the number of vehicles, N, that pass during a specific time interval T, less than one hour. In our case, less than the total time T of the simulator that is equivalent to the total of frames in the sequences. The flow rate, q, is calculated with the next expression:

$$\text{q} = \frac{N}{T} \qquad \textbf{(1)}$$

The simple interval traffic flow (hi)
It is the time interval between the pass of two consecutive vehicles, usually expressed in seconds and is the average between homologous points of the pair of vehicles, in this case we have how the vehicles pass between one time and another. The minimum time in this case is the number of vehicles in the frames grouped in sequences and they can be greater than two.

Mean interval traffic flow (ħ)
It is the average of all the simple intervals of traffic flow (hi), that exist between the various vehicles that circulate by a road. Because it is an average it is expressed in seconds per vehicle (s/veh) in this case (frame/veh) and it is calculated, per the equation flow, q, by the following expression, where N = total of vehicles that have passed.

$$\text{h} = \frac{\sum hi_{i=1}^{N-1}}{N-1} \qquad \textbf{(2)}$$

This equation help us to describe mathematically the vehicle flow of an avenue and is interpreted as follows: when the affluence of vehicles is greater in a certain time the result of the function is decremented. In the other case when the affluence of vehicles is less in a certain time the result of the function is increased. With the parameters of hi and ħ they were analyzed the arrivals of the simulated vehicles, which are represented by the graphs shown in figure 4 where the X axis is equal to the number of sequences, the Y axis represents the number of frames of each sequence and on the Z axis the interval time if each vehicle which passes and the spheres represent the number of vehicles passing in that interval of time.

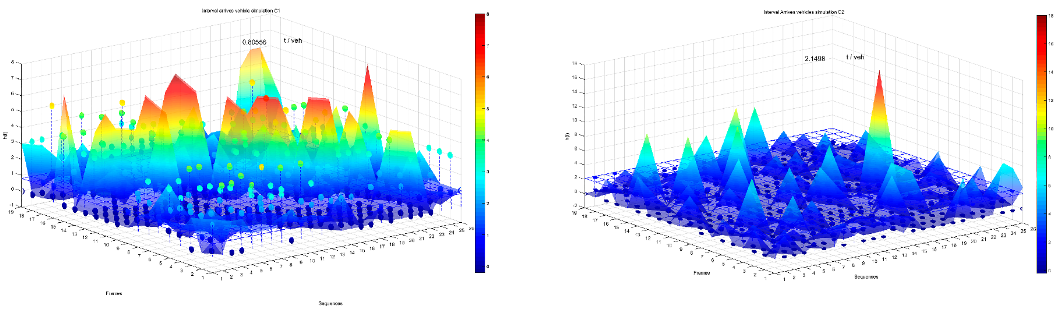

Figure 4. Interval traffic flow of vehicles arrives (C1 = a) (C2 = b).

4.1 Results

In the results section, we first present the evaluation of the detection algorithms to know the accuracy recognition which are obtained both and in the case of the algorithm Adaboost the percentage of false negatives and false positives. In the second section we present the results of the simulation of the smart traffic lights and the simulation of the traffic lights of fixed-time to compare them.

4.2 Detection results

Table 1. Adaboost Algorithm results

	Street	Hit rate (%)	False positive (%)	False negative (%)
Adaboost Algorithm				
	C1	77.69	0.35	0.11
	C2	85.9	0.13	0.02

Table 2. Optical flow algorithm results

	Street	Hit Rate (%)
Optical flow Algorithm	C1	82.39
	C2	78.95

The algorithm Adaboost in the case of the frames in sequence of street C1 was evaluated with a hit rate of 77.69%, the percentage of false positive is .35 and the percentage of false positive is .11. In the case of the frames in sequence of the street C2 the hit rate is 85.9%, the percentage of false positive is .13 and the percentage of false negatives is .02 as can be seen in Table 1. These percentages are acceptable compared to those obtained by Espinosa [12]. In the algorithm of optical flow for the detection of motion present a hit rate in the street C1 of 82.39% and in the street C2 of 78.95% which allow us to model the movement of the vehicle in the simulator with an average accuracy of 80%.

4.3 Results of the simulation

Table 3. System control Results

	Mean interval traffic flow (ħ)			Maximum number of vehicles in Queue	
	Vehicle Simulation frame/veh	Fixed-time system control	Smart traffic lights system control	Fixed-time system control	Smart traffic lights system control
C1	0.805	0.8	0.804	17	9
C2	2.14	3.32	2.15	82	10

The results of the simulation of the two systems control already mentioned were compared. First to get an idea of the intervals of traffic flows we calculate the mean interval traffic flow (ħ) of the simulation of the vehicles arrives in the street C1 and C2 without any type of system control and the results of this function are 0.805 (frame/veh) in street C1 and 2.14 (frame/veh) in street C2 these values give us an objective parameter to achieve at the time to evaluate the two control systems. The fixed-time control system get an (ħ) of .8 frames/veh in street C1 and 3.32 frames/veh in street C2 while the smart traffic lights system control get an (ħ) of .804 frames/veh in street C1 and 2.15 frames/veh in street C2. The ħ of the fixed-time control system in C1 decreased but in C2 increased while the smart traffic lights system control the ħ of C1 and C2 are like the ħ of the simulation of the vehicles arrives. That means that the smart traffic lights system control was better adapted to the vehicles flows in real time. Also, the waiting queue size decreased in comparison with the fixed-time system control from 17 to 9 in C1 and in C2 from 82 to 10. See table 3 and Figures 5 a) and b).

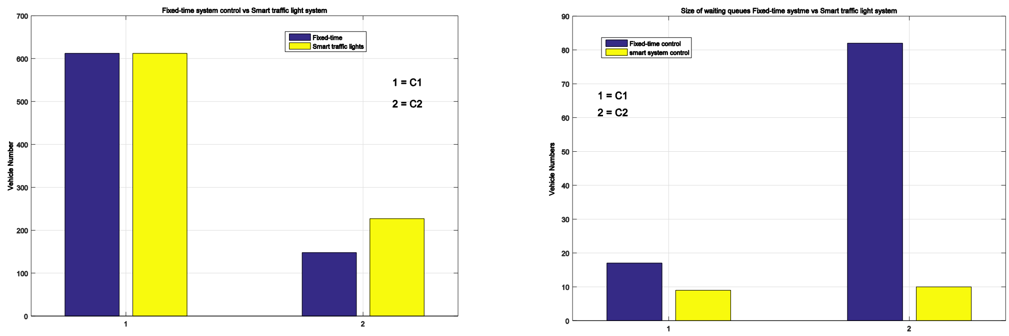

Figure 5. Comparison of control system results

5 Conclusion

The reason to use both algorithms is because they are complementary, the Adaboost algorithm is better for detecting objects from their edges and textures features so it also detects vehicles that are not in motion, while the optical flow is better for detecting objects in motion by changing tones and edges over time. This analysis help us to understand that both algorithms can be used to have a near model of arrives of vehicle simulations as in real time. The results of the simulation of the algorithms of the fixedtime system control and the smart traffic lights system control, show that the smart system control algorithm could better adapt to the vehicular flow of the simulated data because in the parts of higher concentration of vehicles it distributes the time better, the improvements that were obtained are the reduction of the size of the queues of waiting in 47% in the street of greater capacity and 88% in the one of smaller capacity this is due to the implemented methodology based on priorities which are obtained to through detecting cars with video cams and the flow of the passage of vehicles.

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