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THE USE OF SMART TRAFFIC LIGHT IN SUSTAINABLE URBAN MOBILITY: A SYSTEMATIC LITERATURE REVIEW[1]

O USO DA LUZ DE TRÁFEGO INTELIGENTE NA MOBILIDADE URBANA SUSTENTÁVEL: UMA REVISÃO SISTEMÁTICA DA LITERATURA

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Abstract

The fast growth of the population, especially in the urban areas, is accompanied by the restriction of the urban mobility, due to numerous factors such as the growth in the number of vehicles and the increased traffic generated by it. This is an issue that foment the search for solutions in many segments related to public policies, enabling a reduction in time wasted in traffic as well as the issues that come with it. The technological solutions have a key role in this scenario, the Smart Traffic Light (STL) is a great example of an efficient alternative for the mobility issues. With the growing technological advancement, many implementation possibilities that can dynamically serve the necessities created by traffic arise. Even though we can see that there are academic papers that study the growth of vehicles and the negative impacts generated by the traffic, there is still a gap when the subject is technological solutions for the traffic issue. With that in mind, this paper aims to present a systematic literature review related to STLs to identify which solutions are more feasible when attending the demand of each particular region, providing a tool in the elaboration of public policies. The selected papers primarily focus in sensors, cameras and Internet of Things as a way to detect the traffic volume and density as well as different ways of developing algorithms that based on the traffic conditions, will provide the best green interval for the traffic lights.

Keywords: Sensors; Cameras; Image processing; Internet of Things; IoT; Real Time.

Resumo

O crescimento expressivo da população, particularmente nas áreas urbanas, é acompanhado pela restrição na mobilidade urbana, ocasionada por distintos fatores, dentre eles pelo aumento de veículos nas vias e os consequentes congestionamentos no tráfego. Este problema impulsiona a busca

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por soluções, em vários segmentos relacionados as políticas públicas, que permitam diminuir o tempo despendido no trânsito e os problemas decorrentes desta exposição. As soluções tecnológicas desempenham um papel fundamental nesse cenário, à exemplo das soluções relacionadas a controles semafóricos inteligentes por se apresentarem como uma alternativa eficiente para os problemas de mobilidade. Com a crescente evolução tecnológica surgem várias possibilidades de implementação que atendem de forma dinâmica às necessidades impostas pelo tráfego. Contudo, analisando a literatura existente, verifica-se que existem trabalhos acadêmicos que estudam o aumento do número de veículos nas vias e os impactos negativos gerados pelo congestionamento nas cidades, porém, ainda se verifica uma literatura escassa quando se tratam de soluções tecnológicas para o problema de congestionamento. Nesse sentido, este artigo fornece uma revisão sistemática de literatura relacionada a semáforos inteligentes para identificar quais soluções são viáveis no atendimento às demandas características de cada região e que possam servir de insumo na elaboração de políticas públicas. Os estudos selecionados abordam prioritariamente temas como a utilização de sensores, câmeras e Internet das coisas como forma de detecção do volume e densidade do tráfego e estratégias distintas na elaboração dos algoritmos que, baseado nas condições do tráfego, fornecerão os melhores tempos de verde aos semáforos.

Palavras-chave: Sensores, Câmeras, Processamento de Imagens, Internet das Coisas, *IoT*, Tempo real

Introduction

Between 1950 and 2018, the World urban population grew more than four times, going from 0.8 billion to 4.2 billion people (UNITED NATIONS, 2018). Moreover, Kniess et al. (2019) project that by 2030 more than 60% of the population will live in urban areas, even reaching 6.7 billion people by 2050 (RITCHIE; ROSE, 2018).

It is known that the urban development is associated with the betterment of the quality of life; however, the unorganized, unsustainable and unplanned urban growth affects the social, economic and ambiental environment (ARAUJO; CANDIDO, 2014). This way, at the same time that the cities generate negative impacts in the environment, they can be the protagonists of a transformation process towards sustainable development (CONTI et al., 2019).

Metropolitan growth is clearly among the issues affecting urban mobility. The focal point of interest in our study concerns the challenges related to road traffic flows due to the significant increase in the number of vehicles. According to the World Health Organization (WHO), while the world population increased by 4% from 2010 to 2013, the number of motor vehicles increased by 16% in the same period, reaching in 2014 the expressive volume of 64 million new passenger vehicles in city streets around the world (WHO, 2015).

The search for solutions to make the traffic system more efficient has become more and more frequent, not being restricted to alternatives related to infrastructure, such as expansion, adaptation and construction of new roads. Thinking of mobility as an issue that needs broader planning beyond infrastructure, public transport, accessibility and social issues, among other actions, public policies need to be systemic, so that the traffic conditions meet the needs of the population (FUNDAÇÃO INSTITUTO DE ADMINISTRAÇÃO, 2018).

Incentive measures and development of public transport and non-motorized transportation options are perceived, but there are other alternatives that can contribute to the reduction of existing urban mobility problems and that can be added to such measures, therefore desertherefore deving further studies. Chief among these alternatives are the traffic light systems, fundamental devices to better manage current traffic flows (MAGABLEH; ALMAKHADMEH; ALSREHIN; KLAIB, 2020).

In this sense, these systems have been considered in the urban mobility plans, like the São Paulo plan (PLANO DE MOBILIDADE DE SÃO PAULO, 2015) as an alternative for improving urban mobility, considering that it is a technological solution capable of contributing to a better understanding of the changes in demand and traffic density caused by the increase in the number of motor vehicles on the roads (CUCCI, 2016).

Thus, the objective of this article is to present the state of the art of smart traffic control solutions developed to meet the changing demand of cities, serving as a subsidy for the definition of public policies related to urban mobility.

Such a study is justified since there are academic studies that analyze the increase in the number of vehicles on the roads and the negative impacts generated by congestion in cities, but when it comes to technological solutions to the problem of congestion, there is still a gap in the existing literature.

As this is a systematic literature review, in addition to this introduction, the article is structured by the methodology section containing information on the method used to identify the articles included in the analysis, followed by the results section, in which the articles are categorized and discussed and, finally, the conclusions section, as well as the bibliographic references used.

Metodology

The study was carried out through a systematic review of structured literature to analyze the state-of the-art technologies adopted for the implementation of intelligent traffic lights. Based on a structured and transparent process, systematic review allows greater impersonality on the part of the researcher and the non-ideological approach to the problem (THORPE et al., 2005) e (TRANFIELD; DENYER, 2009).

Information extracted from the Scopus database was used, applying the search string "smart traffic light". It is important to mention that studies were considered as long as the term "smart traffic light" appeared in its entirety, thus disregarding, within the scope of this article, works in which only part of the indicated search string appears.

The study was carried out from August 2020 to October 2020. The application of the string "smart traffic light" in the Scopus dabase resulted in 104 primary studies. All the titles, abstracts and sources of research were read and analyzed during this primary result and, based on the result obtained, inclusion (IC) and exclusion (EC) criteria were applied, considering the following criteria relevant to the research:

- Inclusion criteria for studies:
  IC1: Title clearly related to smart traffic
  IC2: Content related to intelligent traffic lights (in real time)
  IC3: Content related to real-time solutions
  IC4: Objective of the study to reduce jam
  IC5: Content related to Sensors including Cameras and IoT
  IC6: Comparative studies between traditional traffic lights and STLs
- Exclusion criteria for studies:
  EC1: Not related to STLs
  EC2: Related to low impact magazines or events
  EC3: Detailing of algorithms, making the study extremely technical

The identification of the articles detailed in the Results section went through two cycles of analysis, selecting 45 articles first and, finally, after reading them in full and applying the Inclusion and Exclusion criteria, 22 articles remained, which were categorized by themes and analyzed more deeply.

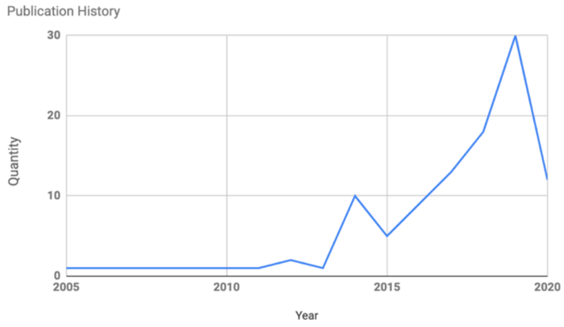
Results

This section presents studies related to STLs. Particularities of the research production were examined using data selected in the research. The historical research trend, the geographic areas in which it took place, as well as the research focuses are presented next.

Historical trend

According to the publications found in this database, the research related to STLs was not active until mid-2014, when the volume started to intensify, with 10 publications, as shown in Figure 1.

Figure 1: Number of studies per year



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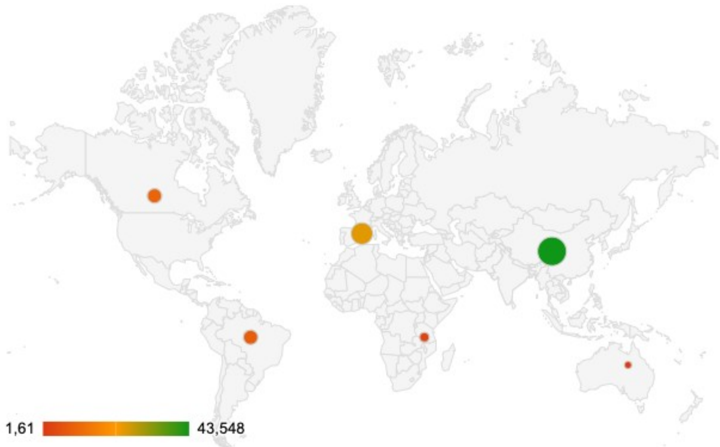
However, the frequency of publications began to grow in 2017, reaching, in 2019, an increase of 200% in the volume of searches compared to 2014 (30 vs. 10). Approximately 70% of the research is concentrated in the last 4 years (2017 to 2020), which can be attributed, on the one hand, to the fact that STLs are seen as one of the possible solutions to mitigate the impact of jams, to the mobility crisis and the increasing strenght of the theme of Smart Cities (PALSA; VOKOROKOS; CHOVANCOVA; CHOVANEC, 2019) and, on the other hand, to the technological development in the traffic control systems sector.

Geographic Patterns

Although the selected literature has a dispersion throughout the world, as shown in Figure 2, the studies were predominantly performed in Asia (approximately 43%), followed by Europe (25%), and North America with the third largest number of studies (11.3%). Together, they account for approximately 80% of the total publications of the present research study.

Figure 2: Geographical distribution of the studies



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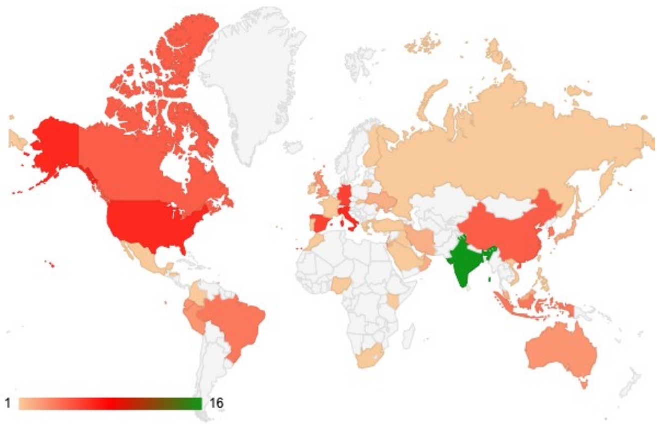
By deepening the geographic analysis, we can see the distribution of studies based on the countries, represented in Figure 3. India stands out as the country that most actively studied the topic of STLs. Of the 104 selected studies, India appears with 16 articles, with the United States and Italy in second place, both with 7 studies each.

Figure 3: Distribution of studies by country



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It emerges as a likely hypothesis that India, being the second most populous country in the world and with a population still growing, conducts more studies looking for alternatives to mitigate the impact generated by traffic jams. According to Kataria and Rani (2019), traffic in India is chaotic and not based on lane discipline, further aggravating congestion, thereby resulting in more waste of environmental, social and economic resources.

Research findings

By content analysis, the systematic review in relation to intelligent traffic lights covered a wide range of topics, which can be categorized into 6 main ones, namely: Cameras and Image processing, Mobile computing, IoT, Fuzzy Logic, Machine Learning and Sensors. Some articles discussed more than one identified topic, but the classification was carried out considering the main research interests. Table 1 shows the distribution of publications by period and identified by research topics and authors.

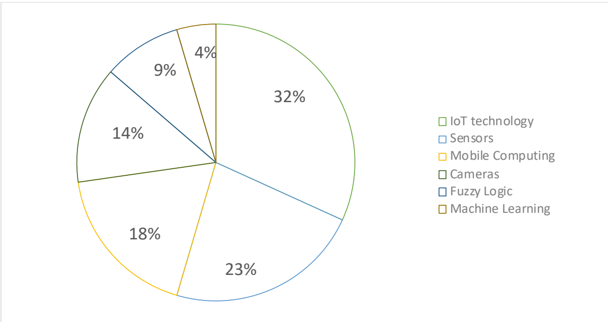
Table 1: Distribution of selected publications

Authors	Period	Research topics
Serrano Á., Conde C., Rodríguez-Aragón L.J., Montes R., Cabello E.	2005	Cameras
Kanungo A., Sharma A., Singla C.	2014	
Kataria P., Rani A.	2019	
Munst W., Dannheim C., Mäder M., Gay N., Malnar B., Al-Mamun M., Icking C.	2015	Mobile Computing
Ameddah M.A., Das B., Almhana J.	2018	
Al-qutwani M., Wang X.	2019	
Alkhatib A.A.A., Sawalha T.	2020	
Miz V., Hahanov V.	2014	IoT technology
Lin Y.-Q., Li M., Chen X.-C., Fu Y.-G., Chi Z.-W.	2016	
Nor R.F.A.M., Zaman F.H.K., Mubdi S.	2017	
Bui K.-H.N., Jung J.E., Camacho D.	2017	
El Hassak I., Addaim A.	2019	
Razavi M., Hamidkhani M., Sadeghi R.	2019	
Frank A., Khamis Al Aamri Y.S., Zayegh A.	2019	
Sangster N., Persad P., Duncan D.	2009	Fuzzy Logic
Hartanti D., Aziza R.N., Siswipraptini P.C.	2019	
Natafgi M.B., Osman M., Haidar A.S., Hamandi L.	2019	Machine Learning
Ghazal B., Elkhatib K., Chahine K., Kherfan M.	2016	Sensors
Nguyen-Ly T.T., Tran L., Huynh T.V.	2019	
Palsa J., Vokorokos L., Chovancova E., Chovanec M.	2019	
Manasi P.S., Nishitha N., Pratyusha V., Ramesh T.K.	2020	
Alaidi A.H.M., Aljazaery I.A., AlRikabi H.T.S., Mahmood I.N., Abed F.T.	2020	

Source: Created by authors

Based on Table 1, it can be noted that the selected articles had a greater concentration on the themes of "IoT" and "Sensors", representing 32% and 23% (approximate values), respectively, followed by the other themes, as shown in Figure 4.

Figure 4: Concentration of themes



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Researchers' view

Cameras

Serrano, Conde, Rodríguez, Montes and Cabello (2005) present in their study the use of cameras and image analysis for decision making, in real time, at intelligent traffic lights, particularly to assist pedestrian crossing with agility. These systems are capable of capturing the presence or absence of vehicles and pedestrians, as well as their trajectories and determining the duration of the green light to adapt it to the user's needs. The main focus in this case is not the optimization of traffic, but the safety of pedestrians, due to the greater occurrence of accidents and problems close to intersections (NATIONAL CENTER FOR STATISTICS AND ANALYSIS OF THE NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION, 2004).

Kanungo, Sharma and Singla (2014) address a system that consists of video cameras installed on top of traffic lights at intersections. These cameras capture and transmit the images to servers that process the videos and images obtained live, identifying vehicle density and employing an algorithm to change the timing of traffic lights, according to the real need.

Unlike other systems, calculations are not made according to the number of vehicles, but by the density of the vehicle, which determines, for example, that a truck with a higher density is equivalent to two cars, requiring more time than a normal vehicle to cross the intersection. According to the authors, this solution reduces traffic congestion and unwanted delays, as it works dynamically adapting to traffic in real time and has much lower installation and maintenance costs compared to intrusive sensors and infrared sensors. In most cases, the costs are insignificant or even non-existent because it uses equipment that is already available on the roads, the security cameras.

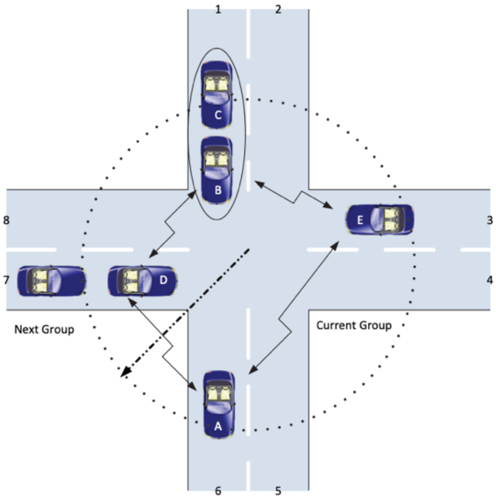
Kataria and Rani (2019), as well as Kanungo, Sharma and Singla (2014) bring in their article a system of classification of images in real time, calculating through density of live video, the density of the traffic and the number of vehicles, using an algorithm to make a decision on the duration of the green light times. However, this study considers the number of vehicles for calculating green times. Additionally, Kataria and Rani (2019) provided in the solution presented a control unit to deal with critical and emergency situations, generating manual interruptions. According to the researchers, the technology adopted does not generate any extra hardware costs, since it uses cameras already installed at the intersection. In this sense, the cost would be for image processing software. In tests carried out, comparing with fixed-time solutions (calculated from historical data), this solution proved to be more efficient, with less average waiting time in 75% of the situations.

Mobile Computing

Based on their studies about innovative technologies in the field of communication, information science and positioning, Munst, Mäder, Gay, Malnar, Al-Mamun and Icking (2015) proposed a highly automated traffic control system, especially considering information. The system considers autonomous and semi-autonomous vehicles, not using sensors at intersections, but making use of mobile networks and positioning technology, exchanging bidirectional information between vehicles and infrastructure. This alows an intelligent traffic crossing system, with virtual traffic lights, to have traffic management controllers in cloud receiving and processing vehicle data (geographic location, driving speed) and returning recommendation messages to vehicles, resolving conflicts and defining the speed.

According to the researchers, a crossing model with these characteristics is shown in Figure 5, where the vehicles collaborate and share information with each other about vehicle identification, size, position and speed, entry range and destination, calculated direction plan and emergency signal.

Figure 5: Intersection model considered in the study



Source: Munst, Mäder, Gay, Malnar, Al-Mamun and Icking (2015)

Therefore, communication and positioning must be extremely precise and reliable, ensuring a safe and adequate crossing of the intersection. To mitigate the risk ofaccidents and delays, redundancy of the controllers in case of failure was considered and the application of the concepts was applied in regions with little mobility.

Ameddah, Das and Almhana (2018) use Vehicular Ad-Hoc Networks (VANETs) in their study of intelligent intersectionmanagement, making higher priority vehicles pass the intersection before lower priority vehicles, based on communication among vehicles. To calculate the vehicle waiting time, several parameters are considered, such as distance from the intersection, vehicle density and priority. According to the researchers, the result of the simulation demonstrated better results using this algorithm.

Al-qutwani and Wang (2019) also use the VANET technology in their study to manage traffic at the intersection, but with a new architecture based on content name called named data networking (NDN). The system replaces conventional systems with an intelligent digital system. In this case, the physical traffic lights at intersections are replaced by virtual traffic lights that work in conjunction with a processing unit located next to the road, collecting orders of vehics near or at an intersection. After processing orders, this "type" of controller, instead of sending a light signal, sends a response message to each vehicle approving or rejecting their order. This solution is suitable for autonomous vehicles and, according to the researchers, it proved to be efficient for traffic.

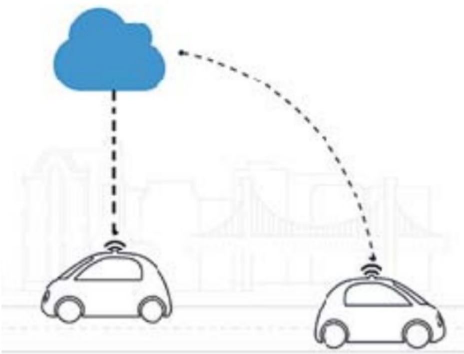
Alkhatib and Sawalha (2020) explored various for road traffic optimization solutions based on the technologies used to implement them, namely: smart and virtual traffic light systems. The STL system uses different application methods, highlighting: a. genetic algorithm — based on the theory of natural and evolutionary selection, constantly renewing decisions; b. neural networks — non-linear algorithm with an adaptation property; c. fuzzy logic — working similarly to human minds, processes information collected in real time and obtains relevant results. All of these methods were subjected to simulations and obtained positive results for traffic flow optimization, but they require a number of resources for computation and processing. Also, despite the good results achieved, the cost of installing, maintaining and operating STLs is high.

Hence, researchers focused their efforts on the development of virtual traffic lights (VTLs), taking advantage of the era of smart cities, IoT technology, and vehicle-to-everything (V2X) communication applications. According to the researchers, VTLs is the main trend of traffic optimization, using the different existing options: a. vehicle-to-vehicle (V2V) — technology that does not need infrastructure at intersections: the vehicles communicate with each other, and one of them, the leader, manages the others (represented by Figure 6); b. vehicle-to-network (V2N) — vehicles send data for processing in the cloud and return is performed to the traffic controller (represented by Figure 7); c. Infrastructure vehicle (V2I) — data is collected by equipment that is on the road and behaves like a traffic controller, processing and returning the information for each vehicle at the intersection (represented by Figure 8).

Figura 6: Vehicle-to-vehicle (V2V)

Source: Alkhatib and Sawalha (2020)

Figura 7: Vehicle-to-network (V2N)



Source: Alkhatib and Sawalha (2020)

Figura 8: Vehicle to Infrastructure (V2I)

Source: Alkhatib and Sawalha (2020)

IoT technology

According to Mocnej, Seah, Pekár and Zolotová (2018), the Internet of Things (IoT) is a highly discussed paradigm aimed at connecting everyday devices to the Internet. It strengthens systems by having the ability to control and feel the environment around us.

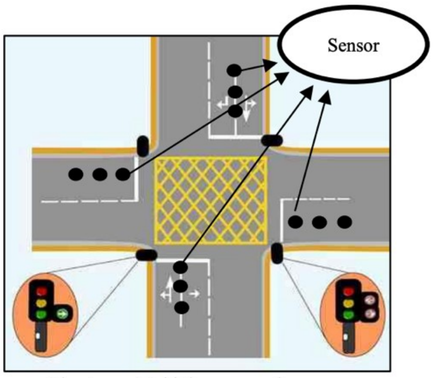
Miz and Hahanov (2014) bring in their article the need not to be restricted to connecting devices and systems, allowing the expansion of connections to the things that surround people in their daily lives, using the IoT for this purpose. Through IoT and Big Data, the processing and analysis of large quantities of data captured by sensors in real time becomes possible. The intelligent traffic lights integrated into the IoT as part of the Cognitive Traffic Management System (CTMS) enable greater efficiency in roads and traffic management, with constant analysis of data obtained from vehicles, road sensors and user data.

Lin, Li, Chen, Fu and Chi (2016) posited that STLs combine existing technology with artificial intelligence to define green times for traffic lights. With the objective of reducing vehicle waiting time and reducing traffic congestion, the strategy proposed in the study is based on the priority and expected traffic flow that is obtained using the data-driven belief rule base (BRB). Depending on the accuracy of its reasoning, this system can predict future flow based on historical traffic flow data. In this sense, the traffic flow considers traffic in real time at the previous moment and the forecast flow at this moment, based on BRB, and has shorter waiting times when compared to fixed-time traffic lights by approximately 46% (this study needs to analyze the network traffic, since a single intersection was evaluated).

Nor, Zaman and Mubdi (2017) focus their study on a solution that uses several sensors to calculate the number of vehicles and detect the presence of small vehicles such as motorcycles and bicycles, shown in Figure 9. According to the authors, a system using a single sensor it is not efficient because at peak times it will only indicate the presence of a vehicle. The use of radio frequency technology enables communication over long distances, with minimum energy consumption. All sensors can be accessed via radio frequency within a radius of 15 kilometers. This model, based on sensor reading, will transmit data records via Wi-Fi for storing and computing the algorithm that will identify the roads with the highest number of vehicles and, therefore, require more green time.

The technology is low cost and has secure bidirectional IoT and machine-to- machine (MtM) communication and its implementations are viable in Sart Cities (NOR; ZAMAN; MUBDI, 2017).

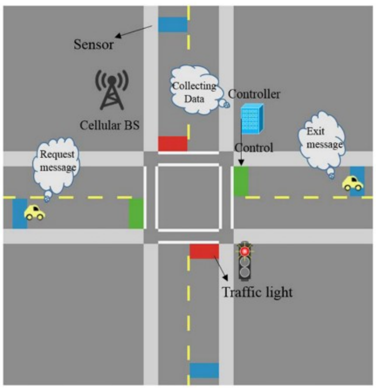
Figure 9: Multiple sensor installation model considered in the study



Source: Nor, Zaman and Mubdi (2017)

Bui, Jung and Camacho (2017) proposed that the IoT devices and data flows generated are starting a revolution in real-time analysis. With them, traffic controllers have more information about traffic flows, enabling better decision making. Seeking to minimize waiting times at intersections, Bui et al. (2017) conducted a study based on a traffic control system and data transmitted by connected IoT devices. For example, connected vehicles or sensors located on the roads gather real-time information and, based on the data transmitted by the connected vehicles, algorithms are executed to improve the traffic flow applying the game theory. As shown in Figure 10, sensors identify the movement of vehicles towards the intersection and a cell station enables communication between controlling vehicles. Based on the vehicle density data, the controller decides the green time to be given for that intersection.

Figure 10: Traffic connected object Architecture



Source: Bui, Jung and Camacho (2017)

To that end, algorithms called Algorithmic Game Theory based on the Internet of Things (AGT-IoT) are used to minimize the time of waiting of vehicles at intersections, based on dynamic decision making. The most important factor in determining the duration of green lights is the number of vehicles arriving at the intersection (BUI; JUNG; CAMACHO, 2017); these will be identified by receiving messages from vehicles when they arrive at the intersection area.

Additionally, the system distinguishes between two types of vehicles, non-priority and priority; the latter, when detected, will have their passage streamlined at intersections.

El Hassak and Addaim (2019) present in their studies a solution integrating IoT, Big Data, Machine Learning and Closed-Circuit TeleVision (CCTV) for the optimization of traffic management systems. The association of IoT and Big Data techniques, according to the researchers, was shown to be quite effective, since the data collected on traffic levels in real time is bulky, and Big Data has techniques to organize, classify and process large volumes of data, thereby enabling decision making to improve vehicle traffic flow.

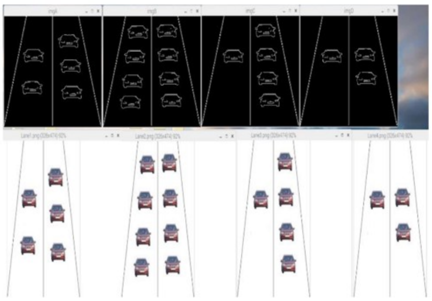
To that end, the data are collected by two sensors placed on the roads, separated by a predefined distance, determining the number of vehicles entering and leaving an intersection. In addition to these, other IoT sensors and the traffic lights gather data. With this, data processing is carried out and new light configuration parameters are sent to the traffic controller.

Additionally, the researchers developed machine learning algorithms that process and analyze the images collected by the cameras to determine the occurrence of accidents, informing the agents for proper decision making.

Razavi, Hamidkhani and Sadeghi (2019) developed a traffic light control method using IoT and image and video processing gathered from the roads. Traffic light programming determining the green time is performed by two different models, using the vehicle demand and number.

The model that exclusively uses vehicle demand is based on the images captured from all directions of the traffic conditions at each intersection, as shown in Figure 11. Image processing is performed by comparing the images with each other and identifying the percentage of overlap between them. The direction of the road that has the least overlap has the highest traffic and the algorithm dynamically determines the longest green time.

Figure 11: Vehicle demand assessment procedure



Source: Adapted by the authors from Razavi, Hamidkhani and Sadeghi (2019)

In the model based on density and number of vehicles, in addition to the model described, live video is captured by a camera and processed to determine the number of vehicles approaching the intersection. Based on the result of density and number of vehicles, the algorithm defines the new timing for the traffic light.

Frank, Khamis Al Aamri and Zayegh (2019) propose in their study the use of IoT to monitor and control traffic by determining traffic density using real-time video and image processing. Using digital image processing techniques, the image captured in real time by the camera at the intersection is compared with a reference image of the vehicle-free road. The greater the traffic density is, the greater the differences in this comparison are, as shown in Figure 12. This allows the density information to be processed and determine the times of the traffic signals.

Figure 12: Vehicle demand assessment procedure

Source: Adapted by the authors from Frank, Khamis Al Aamri and Zayegh (2019)

Fuzzy Logic

Fuzzy Logic has been widely applied for decision making in various research areas such as those of drones, nautical maneuvers and lighting control, and is particularly promising in traffic control in metropolises (Hartanti, Aziza and Siswipraptini, 2019).

Sangster, Persad and Duncan (2009) make use of Fuzzy Logic in their research to control the green times of traffic lights. Two variables were considered for decision making, the length of each of the rows of vehicles piled up at the intersection and the number of vehicles leaving the intersection during the green light. Additionally, the fuzzy logic system enables giving priority to certain traffic lanes, where the impact of the length of their lines is greater for local traffic. Based on this information, the system decides to increase or decrease the green time in the traffic lanes, depending on the detected congestion and the defined priority. The results obtained with the use of fuzzy logic were favorable in conditions of high density of vehicles, thus providing a reduction in local traffic.

Hartanti, Aziza e Siswipraptini (2019) applied the fuzzy mamdami method using number of vehicles, their speed, queue lenght and lane width as parameters for traffic optimization. The green time given to the traffic light is calculated using these parameters.

Machine Learning

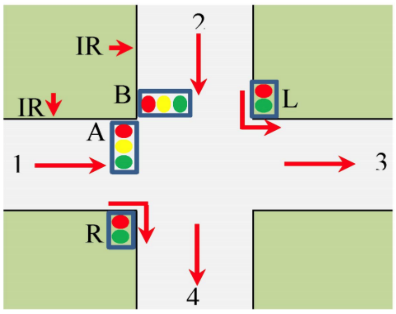
Natafgi, Osman, Haidar and Hamandi (2019) implemented an adaptive traffic light system (considering the traffic condition before decision making) with neural network, using reinforcement learning. For this purpose, ultrasonic sensors were installed on the roads to detect the passage of vehicles and the controllers used this data to calculate number of vehicles, queue lengths and queue times. Based on this data, the green times are calculated and updated in the traffic light control. Additionally, the collected data are stored in a database so that the behavior is studied and serves as input for neural network learning.

Sensors

According to Palsa et al. (2019), sensors are highly accurate in vehicle detection, playing an important role in developing smart technology and enhancing improvement and safety of traffic control.

Ghazal, Elkhatib, Chahine and Kherfan (2016) proposed a STL control system based on a microcomputer that manages the traffic lights of an intersection, monitoring traffic volume and density through infrared (IR) sensors installed on both sides of the roads, as shown in Figure 13. Based on this real time information the green times are extended when there is a large flow of vehicles, adapting to the need of the traffic. According to the authors, the system is low cost, in real time, and aims to improve traffic management.

Figure 13: Intersection model (monodirectional) considered in the study

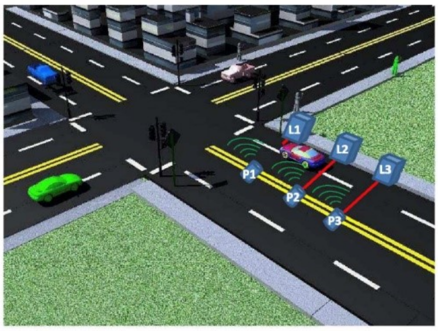


Source: Ghazal, Elkhatib, Chahine and Kherfan (2016)

In addition, the system grants priority passage for emergency vehicles by means of a portable device, available in these vehicles, which communicates wirelessly with the master traffic controller, in order to execute commands and grant the green light at intersections. The activation of this portable device is done manually when the vehicle approaches the intersection. It is important to note that this study did not consider several intersections and, therefore, did not perform a synchronization between them.

Nguyen, Tran and Huynh (2019) emphasized the importance of contemplating motorcycles in traffic density detections. Used in several countries in na intense manner, motorcycles are already the main mode of transport in countries like Vietnam, Thailand, Indonesia, India, Colombia and Paraguay. To measure traffic density, cameras are ineffective for motorcycles so the solution proposed by the study is based on sensors. As shown in Figure 14, the project considers pairs of transmitters (laser light), represented by the letter L and receivers (optical sensors), represented in Figure 15 by the letter P.

Figure 14: Sensor configuration proposal



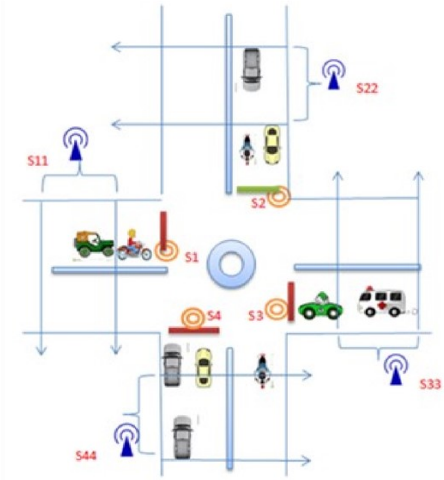
Source: Nguyen, Tran and Huynh (2019)

Aligned, sensors (P) and laser light (L) create a virtual connection, represented in Figure 15 by the red line. These connections enable the detection of vehicles and motorcycles, as well as determine the traffic situation: from normal traffic with no established connections to extremely congested traffic, when the connections have been set up to P3-L3.

Palsa et al. (2019) bring to the fore the growing expansion of technology and the different opportunities it can offer for traffic light controls, with different ways of detecting vehicles carried out at intersections using cameras and sensors, through GPS and laser radars. Moreover, they evidence the alternative of enhancing the results obtained when used in conjunction with pedestrians and vehicles, exchanging information. The authors highlight the availability of various types of sensors that can be used to increase pedestrian safety, detection, and alert of irregular traffic flow. In contrast, Guerrero, Zeadally and Contreras (2018) point out that, despite the good operational results obtained with the implementation of the sensors, these bring as a disadvantage the high cost of installation, maintenance and regulation.

Manasi, Nishitha, Pratyusha and Ramesh (2020) present a solution that analyzes whether the time it takes for a vehicle to cross a predetermined region exceeds the previously defined limit, to then change the green time of the crossing. For that purpose, each section of the road, prior to the crossing, is monitored by a pair of image sensors, represented in Figure 15 by S11-S1, S22-S2, S33-S3 and S44-S4. These sensors capture photos of vehicles in their field of view in order to calculate the travel time.

Figure 15: Spatial arrangement model of an intersection considered in the study



Source: Manasi, Nishitha, Pratyusha and Ramesh (2020)

This takes into account the entry times (ET), when the vehicle is detected by the first sensor (for example S11), and the exit time (EXT), when the vehicle is detected by the second sensor (S1), as shown by El Hassak and Addaim (2019). The difference in these times is compared with the limit stipulated for that stretch of road and, if exceeded, the traffic controller changes the signal to green on the road whose vehicles took longer to travel the distance between the pair of sensors.

Additionally, when passing through the first sensor, there is a check for the vehicle identification. Should the vehicle be identified as an emergency vehicle, the controller gives priority to cross the intersection.

Alaidi, Aljazaery, Alrikabi, Mahmood and Abed (2020) proposed a system based on the detection of vehicles in a certain position of the road, in this case 30 meters from the intersection, enough space to be occupied by a number of vehicles that justify the activation of the green light at the traffic light. For this purpose, two infrared sensors were used, one on each side of the road, which, connected to a microcomputer, indicate that the specified limit of vehicles has been reached, thereby triggering the alteration of the green light of the traffic light and allowing the passage of vehicles in that direction of the road. In addition, the intersection has a camera that allows obtaining and processing vehicle images in the event of accidents and problems.

Conclusions

The aim of this study was to enhance the understanding of smart vehicle traffic light control systems as an alternative to issues related to sustainable urban mobility. With the development of emerging technologies and the availability of relevant data volumes for decision-making arising from the IoT, these solutions play an important role in urban development and are proveing to be a fundamental ally in public policy planning.

However, their presence in metropolises is still incipient considering the benefits it can bring. As a result, this systematic literature review is relevant to make the selected studies visible to the competent bodies and assist them in identifying the strategies that most meet their needs.

The systematic literature review identified various fields of study and technologies that can be implemented using different components in the solution composition, such as sensors, cameras, image processing, IoT and mobile computing. Based on the data captured on the roads, these Technologies, associated with algorithms that seek efficiency in traffic management, have great potential to reduce the undesirable impacts in the environmental, economic and social spheres caused by the restriction of urban mobility.

The solutions were focused on different actors in order to meet the pressing needs of urban regions, among which: studies that seek to increase the safety of pedestrians, identifying their interest in crossing a road, reducing waiting time; traffic light controllers that speed up the passage of priority vehicles, aware of the importance of speeding up their movement; sensors that meet the demand of motorcycles, seen as the main mode of transportaton in some cities and devices using mobile communication, whether among vehicles, in infrastructures or in networks, enabling the implementation of virtual traffic lights to replace physical traffic lights. It is known that all solutions are not suitable for all situations, so the studies draw a panorama that allows expanding the range of evaluations.

There are important challenges to overcome related to this theme, such as improving data security and communication speed for mobile computing solutions and autonomous driving, in addition to the search for economically viable implementation and maintenance alternatives. Moreover, other limitations were identified in this work, insofar as various studies used simulations as an evaluation strategy, thereby restricting the scope of the analysis to isolated traffic lights.

Hence, an in-depth analysis of these solutions is suggested for further study to assess their feasibility in network environments, which reproduce the reality of cities with several traffic light groups working in coordination with each other.

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