

AUTONOMOUS DELIBERATIVE TRAFFIC LIGHTS

In practice, regulating road traffic by means of a traffic light consists of using a central device called an intersection controller. The latter acts on the states of the green light as well as on the activation duration of each state. Most controllers allocate the activation times of each state either in a static way: cyclically and in a definitive manner, or in a dynamic way: by adopting a preconfigured traffic light plan according to the day and time. These techniques are not adaptive and do not take into account the real traffic condition. Consequently, traffic regulation is not perfect and often requires the intervention of police officers in traffic jam situations.

In order to render traffic light mastering adaptive according to the real traffic condition, a measurement device must be used which allows to assess the presence of vehicles in each direction. The intersection controller will then implement an algorithm having said measurements as inputs and will act accordingly on allocating the activation times for each state. In this case the management is said to be adaptive.

Several measurement devices are known which allow the presence of vehicles in each direction of an intersection to be evaluated. Among these measurement devices are:

- inductive loops encased in the roadway, able to sense the presence of a vehicle metal mass thereabove,
- pneumatic pipes to be fixed on the roadway perpendicular to the traffic flow axial direction and making it possible to detect a vehicle passing, by detecting the pressure generated at the time of crushing said pipe,
- the piezoelectric sensors making it possible to detect the presence of a vehicle thanks to the electrical signal generated by the piezoelectric material at the moment the vehicle passes,
- radars and ultrasonic sensors making it possible to detect the a vehicle passing thanks to the reflection of the signal emitted by these sensors on the surface of the vehicle,
- magnetic sensors making it possible to detect the presence of a vehicle thanks to the earth magnetic field variation induced by the vehicle passing,
- video sensors which analyze the variation in lighting caused by the vehicle passing (US 5444442),
- etc.

These measurement devices suffer from a number of drawbacks, namely:

- the implementation cost
- the cost of road and civil engineering works,
- the high probability of resorting to interrupting traffic for several hours,

- the intervention of specialized companies,
- the very strict constraints on the installation location,
- the complexity of a large-scale implementation,
- the measurement being blind,
- the inability to assess the ground occupancy of vehicles,
- and the inability to assess the waiting line length.

Measurement devices are known that allow to detect the Bluetooth and/or Wi-Fi signals radiating from vehicles, which allows to count the number of vehicles passing through a terminal and thus to evaluate the ground occupancy of the vehicles. This technique is not very reliable because it presupposes that all vehicles are equipped with a Bluetooth and/or Wi-Fi system and that the latter is activated in a visible mode.

Measurement devices are known that are based on cameras as an information source combined with a centralized processing unit (EP 0454166, EP 0479698). The latter allows to analyze and extract useful information contained in the video stream, and thus to use it in order to effectively master the traffic light. Over this method, the techniques used for image processing are based either on automatic learning techniques (Machine Learning) (WO 8806326, DE 4105809), or deep learning techniques (Deep Learning) (CN 110556000A).

However, the following drawbacks are observed:

The system rests upon a centralized architecture where all streams are routed to a processing unit. Providing interfaces to ensure the necessary throughput to transfer the streams in raw format (in the case of industrial cameras) risks making the system very expensive. Moreover, the use of standard cameras integrating an image compression mechanism decreases the image quality and integrates therein compression information which alters the quality of predictions. Consequently, several applications are no longer possible, namely the identification of vehicle registration numbers as well as the recognition of certain vehicle classes.

In addition, installing the cameras and the passageway for power and data transmission cables require the intervention of specialized companies, which is likely to disrupt traffic for several hours, or even several days.

These solutions require installing a centralized cabinet which will house the calculation unit intended to analyze the video streams, in the case of a localized architecture, and to then master the traffic lights through an automated device. In the case of a decentralized architecture (cloud), the video streams are routed to remote servers to be analyzed, the results are exploited to master traffic lights in the same way. Whether localized or decentralized, these solutions require a cabinet to be installed at each intersection, which generates additional costs and work. Moreover, in the case of the delocalized architecture, a high-speed communication medium linking the intersection

and the processing servers proves to be inevitable in order to take account of the real-time constraints, which is likely to considerably increase the cost of the solution.

With reference to **Error! Reference source not found.**, the purpose of the device and method of the invention is the automation of traffic light management in a completely autonomous and smart manner through a road traffic regulation system mainly characterized in that it is completely distributed and autonomous requiring no centralized management or installation, in particular an intersection controller, and in that it operates in wireless mode.

The device and method of the invention can be implemented in a smart road traffic regulation device installable on the poles of traffic lights.

It can be implemented in a smart light head for road traffic regulation.

It can also be implemented in a smart (optical) light module (3), for road traffic regulation, which can be plugged into existing light heads (1) as a replacement for conventional light modules.

In the following description, the device and method of the invention will be implemented in a light module referred to as a “*smart light module*”.

Requiring only a power source, these smart traffic light modules allow to take control of the intersection by adopting dynamic and adaptive regulation plans based on the traffic reality.

A smart traffic light module installed in a traffic light head allows to analyze road traffic entering the intersection therethrough. It also allows to take control of all the (traffic, special or pedestrian) light modules installed in the same lane, and possibly those installed in the adjacent lanes extending in the same traffic direction. So a four-branch intersection, for example, will require at least four smart light modules, to be preferably installed in the main traffic light of each branch.

Calculating the regulation plans is mainly based on the analysis of spatio-temporal information (ground occupancy of the vehicles over time) collected in real time by the smart light modules.

The various smart light modules communicate and exchange traffic reports wirelessly, which makes the installation of these modules less restrictive by eliminating the civil engineering work associated with the passageways for communication cables in the case of a wired solution.

Thanks to the distributed program shared by all the smart traffic modules, the latter collaborate and synchronize in a completely autonomous manner by adopting the plan relating to the best regulation strategy with respect to the traffic reality.

This device and method of the invention will also serve as a control and monitoring tool. Indeed, the smart light modules (2) can automatically detect red traffic light running while reading the license plates of the pertaining vehicles. As such, they can have access to information necessary for ticketing the offender. This ability to read license plates can also serve for monitoring purposes. Smart light modules can be equipped with other communication media to allow remote monitoring and control if necessary.

The smart traffic light modules can be installed on the base of an existing installation (1, 2) without being obliged to replace the existing traffic lights and junction controller. Smart traffic light modules are compatible with the majority of existing traffic light heads. The intersection controller can be disabled and serve as a redundancy solution if required. This behavior can be automated via the hardware watchdog (13) of the smart traffic light module by interfacing it with the intersection controller.

Indeed, the smart light modules are capable of interfacing with other external systems or measurement sensors as needed using wired or wireless communication interfaces. The system can integrate this information as decisional measures.

In addition to these advantages, the present invention aims to remedy the drawbacks mentioned at the beginning in relation to currently existing devices.

A smart light module (3) is mainly consisting of:

- a power supply module (7),
- a LED lighting system (8) (green, yellow, or red),
- an orientatable image and video capture module (5) allowing to capture images of road traffic,
- an embedded system equipped with hardware acceleration (9) in order to ensure processing of video streams by means of artificial intelligence mechanisms,
- a cooling system (10,11),
- a wireless communication system (4) allowing communication with the rest of the smart light modules,
- a command system (12) allows to control the other light modules,
- and a hardware watchdog (13).

The power supply module (7) allows to adapt the mains power supply to the power supply of the various electronic and electrical components of the smart light module.

The LED illumination system (8) constitutes the lamp of the light module. A smart light module can have a red, yellow or green lamp. Other colors or illuminated shapes can be implemented if needed.

The image capture module (5) provides wide-angle vision with night vision capable of reaching a rate of at least 30 FPS. This module is connected to the embedded module by means of a high-speed link (14), namely the CSI. This link allows to transfer images in raw format in order to allow better recognition through artificial intelligence mechanisms.

This image capture module is located at the bottom of the domed lens (6) of the smart light module, which grants thereto a degree of downward inclination allowing it to be oriented naturally towards the road.

Considering that the orientation mechanism is not obligatory, the image capture module can be electrically oriented through a configuration application in order to cover the area of interest in a more precise and flexible way. It can be dynamically reoriented by the artificial intelligence program while in use in order to better assess the traffic by covering the dead zones.

The embedded system (9) is consisting of a single board computer, equipped with hardware acceleration such as the GPU or the TPU. Thanks to the latter, the system will be able to run recognition, classification and object detection models in real time using deep learning techniques. It is cooled and kept at normal operating temperature by means of two distinct mechanisms:

- Ventilated cooling system installed on board the embedded system (10)
- Galvanized metal layer (11) covering the interior of the smart light module used as a heat exchanger for the embedded system.

The embedded system executes a distributed artificial intelligence program allowing to calculate the plan corresponding to the best regulation strategy.

Indeed, thanks to the pre-trained recognition model implemented in the embedded system, the latter is capable of classifying vehicles according to different criteria, including type, category, range, etc. and to integrate this information as decisional measures.

The embedded system can execute several pre-trained visual recognition models and exploit this information in order to offer a better regulation strategy.

Depending on the need, recognition models allowing to detect road accidents, fires, certain behaviors of drivers, or certain traffic anomalies can be implemented at the level of the embedded system. The latter will then be able to integrate this information as decisional measures.

Similarly, recognition models allowing to detect and recognize pedestrians, cyclists or any alternative transportation mode (scooter, segway, motorized unicycle, etc.) can be implemented in the embedded system. The latter can then integrate this information as decisional measures.

Models for recognizing and reading vehicle license plates can be implemented at the level of the embedded system in order to be able to identify them. This information can be used in red light running detection scenarios, or for safety purposes.

The embedded system can implement a right of way prioritization logic for a certain class of vehicles, in particular vehicles of general interest having priority (ambulances, public transportation vehicles, etc.). For example, if an ambulance is recognized on a lane in the course of a red cycle of the light, passage will be immediately given thereto by interrupting the current cycle and by switching to the green cycle.

The system could implement a right of way prioritization logic for individual vehicles based on license plate identification or a wireless identification mechanism. This right of way prioritization

can be granted by a selection of smart light modules, which would be used to delimit a route, and/or during a predefined time frame.

This prioritization logic can give rise to a new monetization paradigm for smart cities by offering a right of way service at traffic light intersections.

The wireless communication system (4) is the communication medium of the smart light modules. It allows to exchange the traffic reports and synchronization information between smart light modules. It implements data encryption and security mechanisms guaranteeing the required security level.

This wireless communication system makes installing these smart light modules less constraining by eliminating the civil engineering work associated with the passageways for communication cables in the case of a wired solution.

The regulation of road traffic can be done on the scale of intersections. In such case, the smart light modules of the same intersection establish point-to-point communications in order to set up the regulation strategy of the programmed logic (15).

With a sufficiently high uptake of smart traffic modules at the intersections of a road network, the wireless communication systems of these modules will be able to implement a mesh network (Mesh Network) which will reread them all. This meshed network can be exploited to set up regulation on the scale of the entire road network. This will allow to avoid congestion situations by implementing global regulation strategies.

Depending on the need, the mesh network constituted by the smart light modules can be exploited for purposes other than those related to road traffic regulation.

The command system (12) of a smart light module allows to control the other light modules (traffic, special or pedestrian lights) installed in its lane by mastering them according to the regulation plan calculated by the programmed logic.

The command system is provided with a relay board having essentially four channels:

- a channel for operating (turning on or off) the green light modules,
- a channel for operating the yellow light modules,
- a channel for operating the red light modules,
- and a channel for operating the pedestrian modules,

Other channels for activating other special modules can be integrated.

The hardware watchdog (13) allows to monitor the proper operation of the various modules and systems of the smart light module, namely the embedded system, the image capture module, the command system, and the wireless communication system. If an anomaly is detected on one of these elements, the hardware watchdog takes control by adopting the best resiliency behavior depending on the element that has failed.

Resilience behaviors can range from applying a predefined static regulation plan, to handing over control to the intersection controller provided the intersection is equipped with one beforehand. Other behaviors aimed at shutting down the entire system and notifying users by flashing the yellow light, for example, are also possible.

Alongside the applied resiliency mechanism, the hardware watchdog attempts to initialize the system in anticipation of potential reinstatement.

The smart light module can be equipped with other interfaces and modules according to the need in order to be exploited at best. A cellular communication module, for example, can connect it to a remote control and monitoring platform.

With reference to **Error! Reference source not found.**, the smart light modules starts by launching the synchronization process.

The synchronization process is a process that runs alongside the programmed logic throughout its life cycle. The purpose thereof is to keep the various smart light modules in a connected and synchronized state. If a connection or synchronization problem occurs, the process notifies the hardware watchdog so as to trigger the appropriate resilience mechanism.

After the synchronization process has been launched, the smart light modules load the initial regulation plan. The latter contains the parameters of an initial cycle predefined by the user during configuration.

During the initial cycle, the smart light modules analyze the road traffic according to predefined decisional measures, namely the ground occupancy ratio of the vehicles, the waiting file length, the number of pedestrians, etc.

If the right of way is integrated as a decisional measure, the initial cycle can be interrupted at any time based on the right of way, thus marking the end thereof.

Before the end of the initial cycle, the smart modules archive their analyzes in the format of traffic reports and share them with each other.

After receiving the traffic reports from the other smart traffic modules, each smart traffic module calculates a correction coefficient with respect to the parameters of the initial cycle in order to adapt it to the traffic reality.

The smart light modules trigger the new calculated cycle and continue analyzing road traffic for the next cycle.

The smart traffic modules can decide to extend the current cycle if the traffic parameters are favorable. For example, at an intersection with four branches, in the case where there is no traffic on a branch and its continuation which are in a stop state (red) at the end of the cycle, it is advisable to extend the red phase on these branches, and the green phase on the others.

CLAIMS

1. System for regulating road traffic for a traffic light, characterized in that it is entirely embedded at the level of a traffic light head, in that it is distributed and autonomous, requiring no centralized management or installation, in particular an intersection controller, in that it operates wirelessly and in that it includes:
 - At least one image and video capture module (5), characterized in that it is integrated into the lens (6) of a light module. Integrating the image capture module at the level of a light module lens allows to always orientate it towards the road in the case of domed lenses. This module enables high definition capture of road traffic passing by the road.
 - An embedded processing system connected to the image capture module, within the same device, using a high-speed connection and including:
 - A hardware accelerator allowing to run visual recognition models on captured images and videos. These recognition models are based on artificial intelligence and allow to calculate decisional metrics such as the number of vehicles, the vehicle ground occupancy ratio, the waiting file length, vehicle categories, etc.
 - A set of inputs/outputs allowing the system to be interfaced with other modules.

The fact that the embedded system is linked to the image capture module within the same device allows a transfer in raw format of the images by means of the high-speed connection without the need for special equipment for the same transfer in the case of a long-distance connection.
- A cooling system ensuring the embedded processing system operation at normal temperature.
- A wireless communication module connected to the embedded system through its inputs/outputs allowing secure short and long range communications. This module allows to exchange regulation parameters such as decision metrics, synchronization data, regulation plans, etc. This module allows to eliminate civil engineering work related to feeding communication cables in the case of wired solutions.
- A light command module connected to the embedded system through the inputs/outputs thereof allowing mastering traffic, pedestrian or special light modules of the same lane according to the regulation calculated by the programmed logic. This module allows to do without the intersection controller.
- A hardware watchdog connected to the embedded processing system making it possible to ensure proper operation of all the aforementioned elements and to take control of the command module, if necessary.

The system allows to calculate, from its decisional metrics and the decisional metrics received from the other systems, regulation plans adapted to the traffic reality and to master traffic, pedestrian or special light modules following these plans.

2 - System for regulating road traffic for a traffic light, according to claim 1, characterized in that said image and video capture module has an orientation mechanism. The latter provides thereto a degree of freedom allowing it to orientate it effectively over the area of interest, and to cover the dead areas when it is exploited.

3 - System for regulating road traffic for a traffic light, according to claim 1 or 2, characterized in that it is entirely embedded at the level of a traffic light head module (3). This allows it to be plugged into an existing traffic light head as a replacement for one of its conventional modules. This system makes maintenance easier by allowing easy replacement thereof in the event of a failure.

4 - System for regulating road traffic for a traffic light, according to claims 1 to 3, characterized in that it is capable of detecting and reading vehicle license plates. This allows the use thereof for control and monitoring purposes.

5 - System for regulating road traffic for a traffic light, according to claim 4, characterized in that it is capable of detecting vehicles crossing the red light and identifying them by their registration numbers.

6 - System for regulating road traffic for a traffic light, according to claims 1 to 3, characterized in that it is capable of interfacing with another independent external system through its wired inputs/outputs or through its wireless communication module. This interfacing allows new uses such as road traffic monitoring and analysis, setting up a display system, etc.

7 - System for regulating road traffic for a traffic light, according to claims 1 to 3, characterized in that it is capable of classifying vehicles according to several criteria, in particular the type, category, etc. and of integrating this information as decisional measures.

8 - System for regulating road traffic for a traffic light, according to claims 1 to 3, characterized in that it is capable of detecting and recognizing traffic accidents, fires, certain behaviors of drivers and certain traffic anomalies and of integrating this information as decisional measures.

9 - System for regulating road traffic for a traffic light, according to claims 1 to 3, characterized in that it is able of detecting and recognizing pedestrians, cyclists or any alternative transportation mode and of integrating this information as decisional measures.

10 - System for regulating road traffic for a traffic light, according to claims 1 to 3, characterized in that it is capable of detecting and recognizing any object or action whose recognition model is implemented in its embedded system, and of integrating this information as decisional measures.

11 - System for regulating road traffic for a traffic light, according to claims 1 to 3, characterized in that it is capable of interfacing with measurement sensors, and of integrating this information as decisional measures.

12 - System for regulating road traffic for a traffic light, according to claims 1 to 3, characterized in that it is capable of interfacing with other communication media.

13 - System for regulating road traffic for a traffic light, according to claims 1 to 3, characterized in that it implements a right of way prioritization logic based on the detection of the vehicle categories, license plate identifications or vehicle identifications through a wireless identification mechanism.

14 - Method for regulating road traffic at an intersection having traffic lights, characterized in that at least one light of each branch of an intersection comprises the system claimed according to one of claims 1 to 13.

15 - Method for regulating road traffic for an intersection provided with traffic lights, according to claim 14, characterized in that the right of way generates a monetization paradigm by offering a chargeable right of way service at traffic light intersections.

16 - Method for regulating road traffic for an intersection provided with traffic lights, according to claim 14, characterized in that it includes the following steps:

- a) The systems, according to one of claims 1 to 13, launch the synchronization process
- b) The systems, according to one of claims 1 to 13, load a preconfigured regulation plan and trigger the initial regulation plan
- c) During the loaded regulation plan:
 - Each system of the intersection, according to one of claims 1 to 13, analyzes road traffic according to various parameters, namely the vehicle ground occupancy ratio, the waiting line length, the number of passing or stationary vehicles, etc.
 - At 90% completion of the current regulation plan, the systems, according to one of claims 1 to 13, exchange the calculated parameters.
 - Each system, according to one of claims 1 to 13, uses these parameters to calculate a cycle correction coefficient.
 - Each system, according to one of claims 1 to 13, calculates the next cycle based on the current cycle and the calculated correction coefficient.
- d) At the end of the current regulation plan, each system, according to one of claims 1 to 13, triggers the newly calculated regulation plan.
- e) Each system according, to one of claims 1 to 13, repeats from step (c)

The synchronization process is a process that runs alongside the programmed logic throughout its life cycle. Its objective is to maintain the various systems, according to one of claims 1 to 13, in a connection and synchronization state. If a connection or synchronization problem occurs, this process notifies the hardware watchdog so as to trigger an appropriate resilience mechanism.

17 - Method for a global regulation of road traffic at an intersection having traffic lights characterized in that at least two intersections of a road network include the method according to claim 14, and in that the decision metrics of each intersection are shared with at least one other intersection comprising the process according to claim 14. In this way, the intersections coordinate together, through the mesh network developed by the systems, according to claims 1 to 13, in order to adopt the best regulation strategy on the global scale of the network.

18 - Method for a global regulation of road traffic at an intersection having traffic lights characterized in that at least two intersections of a road network include the method according to claim 14, and in that the mesh network constituted by the systems, according to claims 1 to 13, can be exploited for purposes other than those related to road traffic regulation.

19 - Light head characterized in that it includes the system claimed according to one of claims 1 to 13.

20 - Light head module characterized in that it includes the system claimed according to one of claims 1 to 13.