**Title:** SIGNALING SYSTEM FOR OPTIMIZING THE FUEL CONSUMPTION OF A VEHICLE TRAVELLING ON A ROAD WITH TRAFFIC LIGHTS

**Abstract:** The present invention relates to a signalling system (1) for optimizing the fuel consumption of a vehicle (6a, 6b) travelling on a road (2) consisting of a plurality of road stretches (4, 4a, 4b) connected by traffic light controlled intersections (3a, 3b), the signalling system (1) comprising: signalling means (5) associated with each one of the road stretches (4, 4a, 4b) and adapted to provide a visual signalling representing an optimized pacing speed for the vehicle (6a, 6b) in each one of the road stretches (4, 4a, 4b); at least one control unit configured for generating the visual signalling according to a plurality of optimized speed profiles, each one concerning the whole ride through the road (2). The optimized speed profiles are predetermined and representative of optimized speed sub-profiles in each one of the road stretches (4, 4a, 4b), such profiles being different from each other for different time intervals in a same road stretch, and being compatible with each other for composing each one of the optimized speed profiles.

**FIG. 1**
SIGNALING SYSTEM FOR OPTIMIZING THE FUEL CONSUMPTION OF A VEHICLE TRAVELLING ON A ROAD WITH TRAFFIC LIGHTS

DESCRIPTION

[FIELD OF THE INVENTION]
The present invention relates to a signalling system for optimizing the fuel consumption of vehicles.

In particular, the present invention relates to optimization of the fuel consumption of a vehicle travelling on a road with traffic light controlled intersections, through the use of visual signalling means installed on the road.

[PRIOR ART]
Systems are currently known which are aimed at reducing the fuel consumption of a vehicle travelling on a road. Systems are also known which are aimed at reducing the time necessary for travelling through a road, so as to reduce road traffic.

For example, document DE1 02004024259 provides for a system for determining an optimized driving strategy that reduces a vehicle's fuel consumption; such strategy is calculated in real time on the basis of cartographic route information, which takes into account the road being driven on and the detected or estimated traffic on the same road.

Document WO201 1074369 relates to a system for evaluating the cost of a path by means of a program that calculates the lowest-cost path for driving through the selected road stretch. Such systems have the drawback that they are not accurate, in that they are based on information that is difficult to verify and costly to acquire. Moreover, such systems are not effective in reducing the fuel consumption of a vehicle, in that the actual fuel consumption is mostly dependent on the driver's driving style, and only to a lesser extent on the route.

Other systems are also known which are aimed at improving the transit of a vehicle along a traffic light controlled road.

For example, document JPH08329384 proposes to calculate an optimized speed range in which a vehicle can cross a next traffic light in the green condition, on the basis of the vehicle's position measured by means of a GPS system.

For example, document JPH05 128399 proposes to reduce the stops of vehicles at traffic lights, by receiving a vehicle position signal from roadside mounted sensors and adjusting the traffic lights accordingly.
Document CN103021 191 relates to a system for intelligent traffic control, wherein a plurality of LED lamps produce the red, green and yellow light of the traffic light, and are controlled in real time on the basis of the detected traffic flow.

Document US2010145600A1 relates to a system for reducing the fuel consumption of a vehicle, which avoids rapid accelerations of the vehicle in the presence of road intersections. Said document US2010145600A1 proposes the use of sensors for detecting the instant at which a vehicle goes through a road intersection, as well as the speed thereof. According to such a system, an optimized speed is calculated in real time which takes into account the distance to be covered in order to reach the next intersection, the condition of the traffic light at the next intersection, and information about the vehicle's fuel consumption and speed. An output unit then indicates the speed calculated for the vehicle.

The above-mentioned solutions suffer from the drawback that they require sensors to be installed aboard the vehicle, or at least on the road for detecting the traffic flow. In addition, the above-mentioned solutions compute optimal speeds for the vehicle in real time, thus requiring high computational power to cope with the requests generated by all vehicles passing by.

However, it often turns out to be unfeasible to calculate the optimal speeds for each vehicle, due to the complexity of the variables that need to be taken into account for determining, instant by instant, the optimal speed.

[OBJECTS AND SUMMARY OF THE INVENTION]

It is one object of the present invention to provide a signalling system aimed at optimizing the fuel consumption of a generic vehicle travelling on a road, which is more effective than prior-art systems.

In particular, it is one object of the present invention to provide a signalling system for optimizing the fuel consumption of a vehicle, which does not require the execution of exacting real-time optimization calculations. In particular, it is one object of the present invention to provide a signalling system that requires no real-time interventions on the timing and priority of traffic lights installed at road intersections.

It is another object of the present invention to provide a signalling system having a simpler architecture, for easier on-road implementation thereof. In particular, it is one object of the present invention to provide a signalling system that requires no on-vehicle sensors to be then connected to the information signalling infrastructure. It is a further object of the present
invention to provide a signalling system that does not require the use of sensors located along
the road for traffic recognition and for detecting the number of vehicles, their speed, etc.
It is yet another object of the present invention to provide a system for signalling an optimized
travelling speed, which is advantageously available to all road users.

These and other objects of the present invention are achieved through a signalling system
incorporating the features set out in the appended claims, which are intended to be an integral
part of the present description.

A general idea at the basis of the present invention is to provide a signalling system for
optimizing the fuel consumption of a vehicle travelling on a road comprising a plurality of
road stretches connected by traffic light controlled intersections. It is envisaged to equip said
system with signalling means associated with the road stretches and adapted to provide a
visual signalling representing an optimized pacing speed in each one of the road stretches. It
is also envisaged to equip the system with at least one control unit configured for generating
the visual signalling according to a plurality of optimized speed profiles. Such optimized
speed profiles concern the whole ride through the road, are predetermined, and are
representative of optimized speed sub-profiles in each one of the road stretches; such
optimized speed sub-profiles are different from each other for different time intervals in a
same road stretch, and are compatible with each other for composing each one of the
optimized speed profiles.

This signalling system allows reducing the fuel consumption and polluting gas emissions of
the vehicles travelling on the road, by signalling an optimized speed profile that the vehicle
can adhere to. Such optimized speed profile is predetermined by an algorithm capable of
computing lowest-consumption road paths. Such paths, composed of optimized speed sub-
profiles for the various road stretches, are recommended by the signalling system to the
drivers of the vehicles entering the road.

The present invention uses a substantially "open-loop" approach, wherein the optimized speed
profiles are predetermined. This approach is more versatile and practically effective than a
"closed-loop" solution involving, in the speed profile calculations, every vehicle that travels
on the road stretch.

Furthermore, the determination of the optimized speed profiles requires neither direct control
of each vehicle nor any on-board or roadside sensors.

By adopting predetermined speed profiles signalled by the signalling means, it is possible to
cyclically reproduce visual signals without any real-time calculations being required.
Preferably, the control unit is further configured for interfacing with a calculation system adapted to provide optimized speed profiles, by computing them based on available road information, in particular information which is available a priori, which comprises: number, length and sequence of the road stretches; patterns of the traffic lights' cycles of the traffic light controlled intersections. Advantageously, such road information allow optimizing the speed profiles on the basis of objective information about the problem.

Preferably, the optimized speed profiles are further calculated based on vehicles' entries into the road that are hypothesized, in particular a priori, and hence predetermined, and also on a predetermined final driving time on the road. In this manner, periodic signalling of the optimized speed profiles is allowed, and a predetermined final driving time is ensured.

More preferably, the final driving time is calculated as a standard time for driving through the road based on: number, length and sequence of the road stretches; and based on: patterns of the traffic lights' cycles of the traffic light controlled intersections. In this manner, a final driving time is determined which is only slightly different, or not at all, from a vehicle's average driving time in the absence of the signalling system; thus, the average driving time on the road will not get worse, while however improving the vehicle's fuel consumption.

Preferably, vehicles' entries into the road are hypothesized as occurring at regular time intervals, in particular as a function of the day and time of entry, for which average traffic conditions can be reasonably estimated.

Preferably, the optimized speed profiles are calculated by means of a constrained optimization process, which determines the time instants wherein a variation of a control variable representative of the speed of the vehicle is provided, for each one of the optimized speed sub-profiles.

More in particular, the calculation system preferably exploits an optimization process for calculating the optimized speed profiles, by minimizing a figure of merit representing the total motor energy spent by the vehicle for travelling along the road. Advantageously, the present invention tackles the problem of speed profile optimization, focusing the analysis on the vehicle's energy consumption, which can be correlated in a known manner to fuel consumption and polluting emissions. In fact, the present invention deals with the problem of driving vehicles through traffic light controlled road stretches not only from a traffic viewpoint (e.g. reducing the vehicles' average wait times or the average length of queues at traffic lights), since it is also focused on fuel consumption reduction and improved driving efficiency, resulting in advantages in terms of urban pollution and traffic.
Preferably, the calculation system is configured for calculating the optimized speed sub-profiles such that the vehicle can go through traffic light controlled intersections without having to stop.

Preferably, the calculation system is configured for calculating the optimized speed sub-profiles such that, at the interface between adjacent stretches at the traffic light controlled intersections, they will have a locally compatible speed profile.

Preferably, the calculation system is configured for calculating the optimized speed sub-profiles such that a speed limit set for the road stretches is never exceeded.

Preferably, the calculation system is configured for calculating the optimized speed sub-profiles so as not to cause any collisions between vehicles following different optimized speed profiles being signalled at the same time.

In one embodiment of the present invention, the signalling system uses signalling means comprising a plurality of optical indicators arranged along the road and configured for reproducing a visual flow which is mobile in space, in accordance with the plurality of optimized speed profiles.

Preferably, the optical indicators comprise LED markers that may be directly arranged on the road surface, preferably along each lane, or at the side of the road, preferably proximal to the roadway and at a raised level from the road surface.

Further objects and advantages of the present invention will become more apparent from the following detailed description.

[BRIEF DESCRIPTION OF THE DRAWINGS]

Some preferred and advantageous examples of embodiment of the present invention will now be described by way of non-limiting example with reference to the annexed drawings, wherein the same reference numerals are used to designate similar components, materials or functions, and wherein:

- Figure 1 schematically shows a signalling system according to the present invention.
- Figure 2 exemplifies the operation of a signalling system according to the present invention.
- Figure 3 exemplifies the operation of a calculation system associated with the signalling system according to the present invention.
- Figure 4 exemplifies the calculation of a first optimized speed sub-profile.
- Figure 5 exemplifies the calculation of a second optimized speed sub-profile.
- Figure 6 shows a comparison between an optimized speed profile and a standard speed profile.
- Figure 7 shows a plurality of optimized speed profiles for the same road, evolving over time.

[DETAILED DESCRIPTION OF THE INVENTION]

The present invention relates to a signalling system that allows optimizing the fuel consumption of a generic vehicle travelling on a road.

The transport sector is responsible for 27% of CO2 emissions in the atmosphere and 22% of primary energy consumption throughout the world; of these, 87% is due to road transport.

In order to reduce a vehicle's fuel consumption, it is necessary to optimize at least one of the following aspects:

- Well-to-tank efficiency: new fuels, extraction and refining techniques.
- Tank-to-wheel efficiency: new vehicle typologies, such as electric, hybrid, etc., or new control systems.
- Wheel-to-miles efficiency: influenced by vehicle's parameters (mass, area, etc.) and by human factors.

In particular, the human factor that mostly affects a vehicle's fuel consumption is the driving style, meaning the speed and acceleration imposed on the vehicle by its driver. The driver's driving style is strongly influenced by traffic congestion, which is also related to urban planning efficiency.

Figure 1 schematically shows a signalling system 1 for optimizing the fuel consumption of a vehicle, designed to act upon the user's behaviour so as to optimize his/her driving style and reduce the vehicle's fuel consumption.

The signalling system 1 is installed on a road 2, whereon traffic light infrastructures 3a, 3b are present at the intersections. The intersections define an interface between respective road stretches 4, 4a and 4b that are contiguous to each other.

The signalling system 1 comprises signalling means associated with each one of the road stretches 4, 4a and 4b. Such signalling means preferably comprise a sequence of optical indicators 5, such as LED markers. Such optical indicators 5 can be turned on or off, or in general can have different luminous intensities.

The optical indicators 5 are arranged along the road and are configured for reproducing a visual flow advancing in space at a certain speed. For example, the optical indicators are configured for sequentially going on and off. The vehicles 6a and 6b can thus follow the
luminous flows 7a and 7b, respectively, which will guide them by means of a visual signalling representative of an optimized driving speed.

The LED indicators 5 may be directly arranged on the road surface, preferably along each lane, following the centre line as shown in Figure 1.

Alternatively, the indicators 5 may be located at the side of the road, preferably proximal to the roadway and at a raised level from the road surface. For example, the indicators 5 may be positioned on the curb alongside the roadway.

As will be apparent below, the signalling system will show further signals 7 also on road stretches where there are no vehicles following them at the moment.

The signalling system 1 further comprises at least one control unit (not shown), which is configured for controlling the signalling means 5 and generating a visual signalling according to optimized speed profiles, i.e. flows of mobile light that can be followed by a vehicle.

The speed profiles correspond to different timings and starting instants of the luminous flow along the road, so that when a vehicle "hooks" to a luminous flow, it will follow the visual signalling up to a turn or the end of the road, and at the end of the path it will have consumed less fuel (and hence it will have emitted less polluting substances, whether directly or indirectly), the time taken being equal.

The signalling system 1 thus signals optimized speed profiles concerning the whole ride through the road 2 involved, which are predetermined and represent optimized speed sub-profiles in each one of the stretches 4, 4a and 4b, as will be illustrated in more detail below.

In this manner, the signalling system contributes to optimizing the fuel consumption of those vehicles that, while travelling on the road 2, stick to the signalling.

As will be described more in detail below, the optimized speed sub-profiles are different from one another, even within the same road stretch, for different time instants. In fact, the calculation of the optimized sub-profiles takes into account the different signalling of traffic lights, which varies instant by instant.

For signalling the speed profiles, the signalling system 1 makes use of a calculation system (not shown) that provides optimized speed profiles in suitable manners. In particular, the signalling system 1 can be interfaced with a computer system comprising one or more computers, receiving as input a base of information about the road, available apriori.

In particular, it is envisaged to provide the calculation system with at least information about the number of road stretches 4, 4a and 4b, their length and sequence, and the time pattern of the signalling variation of the traffic light controlled systems 3a and 3b for each intersection.
Once such information representing the characteristics of the road 2 have been set, an
algorithm calculates, by utilizing suitable constraints, the optimized speed profiles that the
vehicles entering the road will have to follow in order to minimize their fuel consumption.
Advantageously, the calculation system can operate off-line, i.e. a continuous connection to
the signalling system is not required, and the speed profile calculations need not be made in
real time. In fact, the information about the road 2 in question and the constraints to be used
by the algorithm are known a priori, and therefore the optimized speed calculation procedure
is carried out off-line and una tantum.

Nevertheless, a vehicle 6a or 6b sticking to the signalled speed profile will run through the
road 2 in a reasonable time, preferably without any stops, while also improving its fuel
consumption compared to a standard driver.

Figure 2 exemplifies the operation of a signalling system according to the present invention,
in particular by describing the calculation of the optimized speed profiles.

The calculation system is adapted to provide optimized speed profiles, such that the road will
be covered with reduced or minimal fuel consumption. For this calculation it is assumed that
some road information is known about the road 2, but no information updated in real time is
needed (number of vehicles, speed, etc.).

The calculation system 201 requires the entry of information 202 about the road, such as: road
length, number of traffic lights, duration of green/yellow/red, etc.

The calculation system 201 then requires the definition of a suitable energetic figure of merit
203 to be minimized.

The calculation system 201 then requires the definition of the constraints 204 that the
optimized speed profiles will have to comply with, such as: speed limits, acceleration and
deceleration limits, absence of collisions or local incompatibilities, etc.

Furthermore, the calculation system 201 requires a vector 205 for the vehicles entering the
road over time, which are hypothesized a priori. For example, the entries of vehicles into the
road may be hypothesized as being at regular intervals, preferably for a given date and time,
or may be obtained from statistical analyses or in other manners.

The calculation system 201 is then adapted to define a plurality of optimized speed profiles
that minimize the chosen figure of merit, such as the energy consumption necessary for going
through the traffic light controlled road by a generic vehicle taken as a reference.

Figure 3 exemplifies the algorithm according to which the calculation system 201 operates, in
a preferred and advantageous embodiment thereof.
In order to calculate and estimate the optimized speed profiles, which minimize the energy consumption when driving through the road, it is envisaged to use an energy-oriented model that describes the longitudinal dynamics of the generic vehicle.

The optimization procedure assumes that the following road information is known *apriori*: length and sequence of the road stretches taken into consideration; number of traffic lights (traffic light controlled intersections); patterns of the traffic lights' cycles (duration of the green, yellow and red cycles for each traffic light controlled intersection).

The optimization procedure also envisages the definition of a few constraints: maximum accelerations and decelerations allowed for the generic vehicle; maximum speed limit that can be reached in the various road stretches; reference time for driving through the whole road; admissibility constraints for the speed profiles (e.g. traffic light observance: not jumping a red light)

The above information required by the algorithm is known *apriori* or may be hypothesized, so that it is not necessary to use sensors in real time for obtaining additional information (such vehicle speed, number of vehicles, etc.). This makes it possible to calculate optimized speed profiles *apriori*, i.e. only once for the road under examination.

At step 301 the reference speed profile is calculated, to be associated with a standard time for driving through the road, representing the predetermined standard.

The reference speed profile, called "standard driver", modellizes the behaviour of a driver observing traffic lights and speed limits, but it is calculated with an approach aimed at minimizing the time necessary for driving through the road stretch being travelled on (i.e. also dependent on the current state of a traffic light possibly in view), without paying attention to global driving time and fuel consumption. This reference speed profile is calculated on the basis of the number, length and sequence of said road stretches and of the patterns of the traffic lights' cycles of said traffic light controlled intersections, i.e. the road information.

As an alternative, at step 301 it would be possible to hypothesize *apriori* a final driving time based on statistical or experimental considerations.

At step 302 the algorithm identifies the admissible time intervals for going through the traffic lights.

In fact, only a part of all time intervals for which the vehicle would find a green light are compatible with the assigned final driving time of the road. Step 302 is preferably solved in a recursive manner, for determining the times for crossing the traffic light controlled intersections.
Inadmissible intervals are discarded, such as, for example, time instants that cannot be reached due to constraints in terms of maximum allowable acceleration/deceleration/speed or covered space.

At step 303 the algorithm solves the problem through a constrained optimization process, which determines the time instants at which vehicle driving variations need to occur, as will be better described with reference to Figures 5 and 6.

In particular, step 303 defines some possible speed sub-profiles for driving through the road stretches, which are compatible with the constraints.

At step 303 the following unknowns are assumed: traffic light crossing times; traffic light crossing speeds; intermediate times when a variation of the control variable representing the vehicle speed occurs.

At step 303 the following constraints are assumed: time sequence, traffic light observance; speed limit observance; acceleration and deceleration limits; traffic light crossing; final conditions (arrival at the end of the road and arrival speed); compliance with motion and continuity link equations (so that the optimized speed sub-profiles are locally compatible at the interface between adjacent road stretches).

At step 304 the speed sub-profiles are selected for constituting an optimized speed profile for driving through the road. Preferably, the selection criterion is to minimize the vehicle's fuel consumption, the time taken for driving through the whole road being equal.

In particular, it is envisaged to use a vehicle dynamics model that takes into account motive power, braking force and resistance forces. Therefore, the figure of merit is representative of the energy spent for driving through the whole road, i.e. motive power by speed, integrated into the driving time.

The procedure described with reference to steps 301, 302, 303 and 304 is iteratively repeated, for different instants of entry into the road (established apriori), necessarily corresponding to different configurations of the (predetermined) traffic lights' cycles.

In this manner, a plurality of optimized speed profiles are determined for multiples vehicle entries, assumed to be known apriori.

At step 305, once a plurality of optimized speed profiles have been calculated for driving through the road for multiple entries, any conflicts between speed profiles are removed. In particular, it is envisaged to calculate optimized speed profiles for which no collisions will occur between vehicles following different optimized speed profiles being signalled at the same time by the signalling system.
At the end of the algorithm, optimized speed profiles will be calculated, according to which the previously described signalling system will be controlled in a predetermined manner. It must be pointed out that, whether an optimal or sub-optimal solution is found, the calculated optimized speed profiles will ensure reduced fuel consumption and polluting emissions.

Figure 4 exemplifies the calculation of a first optimized speed sub-profile. Said optimized speed sub-profile refers to a road stretch comprised between two traffic light controlled intersections, designated by references "A" and "B".

The vehicle enters the road stretch at a speed $v_A$, as exemplified in Figure 4 at point 401. As aforementioned, the traffic light crossing times ($t_A$ and $t_B$), the traffic light crossing speeds ($v_A$ and $v_B$) are unknowns of the problem.

Also unknown are the intermediate times when a variation of the control variable representing the vehicle speed occurs, as will be described below.

As shown in Figure 4, for example, the algorithm can determine three different types of admissible profiles.

A first admissible profile envisages a maximum acceleration from point 401, up to the speed $v_{\text{MAX}}$ at point 402. At the time instant associated with point 402, a variation of the control variable associated with vehicle speed is made to occur, which speed remains constant at $v_{\text{MAX}}$ up to point 403. The speed $v_{\text{MAX}}$ is, in fact, a constraint of the problem, since it is the legally allowable maximum speed on the road stretch in question. It is clear that the speed sub-profile represented in Figure 4 is merely exemplificative in its feature wherein it equals the maximum speed $v_{\text{MAX}}$; in fact, a generic optimized speed sub-profile will not necessarily always reach the maximum speed $v_{\text{MAX}}$ allowed on the road stretch (in this regard, see the following description of Figure 5). In particular, for generic speed sub-profiles, any speed lower than or equal to the maximum speed $v_{\text{MAX}}$ will be admissible.

From point 403 to point 404, the vehicle decelerates to the exit speed $v_B$. In the example of Figure 4, the speed $v_A$ of entry into the road stretch is therefore higher than the speed $v_B$ of exit from the road stretch.

A second admissible profile envisages an initial deceleration from point 401, down to a lower intermediate speed associated with point 405. At the time instant associated with point 405, a different variation of the control variable associated with the vehicle speed is made to occur, which will thus remain constant up to point 406. From point 406 to point 404 the vehicle will decelerate again to the exit speed $v_B$. 

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A third admissible profile envisages an initial deceleration from point 401 to an even lower intermediate speed associated with point 407. At the time instant associated with point 407, a variation of the control variable associated with the vehicle speed is also made to occur, which will thus remain constant up to point 408. From point 408 to point 404 the vehicle will accelerate constantly up to the exit speed $v_B$.

Figure 5 exemplifies the calculation of a second optimized speed sub-profile. This different optimized speed profile refers to a road stretch comprised between two traffic light controlled intersections, designated by references "B" and "C", wherein the traffic light controlled intersection "B" is the same as that of the road stretch discussed with reference to Figure 4. The vehicle enters the road stretch at a speed $v_B$, as exemplified in Figure 5 at point 501. The entry speed $v_B$ is imposed, and is the same as the exit speed calculated for the optimized speed sub-profile of Figure 4; in this manner, the optimized speed sub-profiles will be locally compatible at the interface between adjacent road stretches, without requiring instantaneous speed variations that might be unfeasible.

As aforementioned, the time $t_c$ when the traffic light "C" is crossed and the crossing speed $v_C$ are unknowns of the problem. Also unknown remain the intermediate times when a variation of the control variable representing the vehicle speed occurs, as will be described below. Also in the case of Figure 5, for example, the algorithm can determine three different types of admissible profiles.

A first admissible profile envisages a maximum acceleration from point 501 to the speed of point 502. At the time instant associated with point 502, a variation of the control variable associated with the vehicle speed is made to occur, which will thus remain constant up to point 503. From point 503 to point 504 the vehicle will decelerate to the exit speed $v_C$. In the example of Figure 5, the speed $v_B$ of entry into the road stretch is therefore lower than the speed $v_C$ of exit from the road stretch.

A second admissible profile envisages an initial acceleration from point 501, up to a higher speed associated with point 505. At the time instant associated with point 505, a different variation of the control variable associated with the vehicle speed is made to occur, which will thus remain constant up to point 506. From point 506 to point 504 the vehicle will accelerate again up to the exit speed $v_C$.

A third admissible profile envisages an initial deceleration from point 501 to a lower speed associated with point 507. At the time instant associated with point 507, a variation of the control variable associated with the vehicle speed is also made to occur, which will thus
remain constant up to point 508. From point 508 to point 504 the vehicle will accelerate
constantly up to the exit speed \( v_c \).
As exemplified in Figures 4 and 5, the algorithm calculates a plurality of admissible speed
sub-profiles by imposing: time sequence, traffic light observance, speed limit observance,
traffic light crossing, final conditions for driving through the road stretch. This plurality of
speed sub-profiles, for all road stretches, are compatible with each other and contribute to
defining optimized speed profiles for the whole road.
It should also be pointed out that the optimized speed sub-profiles are different from each
other, even within the same road stretch, for different time instants. In fact, the different
signalling of the traffic lights is taken into account, which varies instant by instant.
Among the plurality of compatible sub-profiles, or among the plurality of optimized speed
profiles, speed sub-profiles are selected based on a suitable selection criterion;
advantageously, this selection criterion minimizes a figure of merit representing the motor
energy spent, the time taken being equal, for driving through the whole road; as aforesaid, it is
thus possible to optimize the vehicle's fuel consumption while travelling on the road.
Figure 6 shows a comparison between an optimized speed profile 601 and a standard speed
profile 602 calculated for a "standard driver", as described above.
In sub-figure 6(a), which shows the ride through the road over time according to the different
speed profiles 601 and 602, it can be appreciated that the final driving time on the road
remains unchanged. In fact, the ride ends at the same time instant with both the optimized
speed profile 601 and the standard speed profile 602.
As better visible in sub-figure 6(b), which shows the speed over time according to the
different speed profiles 601 and 602, the standard speed profile 602 implies some stop periods
(horizontal sections in sub-figure 6(a), sections with \( v = 0 \text{ m/s} \) in sub-figure 6(b)); these stop
periods correspond to stops at traffic light controlled intersections, wherein the vehicle stops
at a red light for a given time interval.
On the contrary, the optimized speed profile 601 implies no stops at traffic light controlled
intersections, since it has been calculated appropriately. Furthermore, the optimized speed
profile 601 requires less speed variations over time, since it requires a constant pace resulting
in less energy spent, and hence lower fuel consumption.
It is therefore apparent that the invention allows optimizing a vehicle's fuel consumption and
polluting emissions when travelling on a road with traffic light controlled intersections.
The signalling system allows vehicle drivers, in fact, to follow a visual signalling representing an optimized speed profile for the road being driven on, through which they will be able to consume less fuel while driving through the whole road in the same time.

Advantageously, the signalling system envisages to signal optimized speed profiles calculated by means of an effective and structured algorithm, which considers the road driving problem from the energy consumption viewpoint and directly optimizes an energetic figure of merit. Figure 7 shows a plurality of optimized speed profiles, according to which the signalling system will be able to signal to a plurality of vehicles travelling on the road what speed they will have to keep, stretch by stretch and instant by instant.

As can be appreciated in Figure 7, at least one optimized speed profile corresponds to entries into the road at arbitrary time instants \((s = 0 \text{ m})\), which profile the driver can "hook" to at will by either "following" the signalling "in front" of him/her or "waiting" for the signalling "behind" him/her, as also shown in Figure 1.

It can also be appreciated that, after a certain part of the road, the optimized speed profiles tend to lead to a common pace that minimizes the vehicle's energy consumption. Therefore, after having covered a certain portion of the road, the vehicles will come to follow signalling that will "travel" at the same speed, possibly in parallel. In this manner, all vehicles will be able to adjust their pace to an optimal speed, which will also allow them to reach the end of the road in a time that will not be longer than if they did not observe the signalling and tried to "overtake" it.

In addition to improving some traffic congestion aspects, the signalling system especially presents the drivers with a signalling that will allow optimized rides. Advantageously, the calculation of the optimized speed profiles takes place off-line and \(una tantum\); only afterwards the optimized speed profiles are signalled to the drivers, without requiring complex real-time systems for controlling the traffic lights' timings and priorities, nor any vehicle-infrastructure cooperative systems.

It is apparent that many changes may be made to the present invention by those skilled in the art without departing from the protection scope thereof as stated in the appended claims.

For example, several alternatives may be conceived as regards the visual signalling means, which may be based on various technologies and visualization modalities, possibly also including signalling systems to be installed aboard vehicles.
CLAIMS

1. A signalling system (1) for optimizing the fuel consumption of a vehicle (6a, 6b) travelling on a road (2), said road (2) comprising a plurality of road stretches (4, 4a, 4b) connected by traffic light controlled intersections (3a, 3b), said signalling system (1) comprising: signalling means (5) associated with each one of said road stretches (4, 4a, 4b) and adapted to provide a visual signalling (7, 7a, 7b) representing an optimized pacing speed for said vehicle (6a, 6b) in each one of said road stretches (4, 4a, 4b), characterized in that it further comprises at least one control unit configured for generating said visual signalling according to a plurality of optimized speed profiles, each one of said optimized speed profiles concerning the whole ride through said road (2), said optimized speed profiles being predetermined and representing optimized speed sub-profiles in each one of said road stretches (4, 4a, 4b), said optimized speed sub-profiles being different from each other for different time intervals in a same one of said road stretches, and being compatible with each other for composing each one of said optimized speed profiles.

2. A signalling system according to claim 1, wherein said at least one control unit is further configured for interfacing with a calculation system (201) adapted to provide said optimized speed profiles, wherein said calculation system is configured for calculating said optimized speed profiles based on information (202) which is available about said road, said information about said road comprising: number, length and sequence of said road stretches (4, 4a, 4b); patterns of the traffic lights' cycles of said traffic light controlled intersections (3a, 3b).

3. A signalling system according to claim 2, wherein said optimized speed profiles are further calculated based on vehicles' entries (205) into said road (2) that are hypothesized and predetermined, and wherein said optimized speed profiles are further calculated based on a final driving time of said vehicle (6a, 6b) on said road (2), which is predetermined (301).

4. A signalling system according to claim 3, wherein said final driving time is predetermined by calculating it (301) as a standard time for driving through said road (2) based on said information (202) about said road.

5. A signalling system according to claim 3 or 4, wherein said vehicles' entries into said road are hypothesized as being at regular time intervals.

6. A signalling system according to any one of claims 2 to 5, wherein said calculation system (201) is further configured for calculating said optimized speed profiles through a constrained optimization process, which determines the time instants (401, 402, 403, 404, 405, 406, 407, 408, 501, 502, 503, 504, 505, 506, 507, 508) wherein a variation of a control variable
representing the speed of said vehicle (6a, 5b) is provided, for each one of said optimized speed sub-profiles.

7. A signalling system according to claim 6, wherein said constrained optimization process is adapted to calculate said optimized speed profiles by minimizing (304) a figure of merit (203) representing the motor energy spent by said vehicle (6a, 6b) for travelling along said road (2).

8. A signalling system according to any one of claims 2 to 7, wherein said calculation system (201) is further configured for calculating said optimized speed sub-profiles such that (204), in each one of said road stretches, said vehicle can go through said traffic light controlled intersections without having to stop.

9. A signalling system according to claim 8, wherein said calculation system (201) is further configured for calculating said optimized speed sub-profiles such that (204), at the interface between adjacent stretches of said road stretches at said traffic light controlled intersections (3a, 3b), each one of said optimized speed profiles has a locally compatible speed profile.

10. A signalling system according to claim 8 or 9, wherein said calculation system (201) is further configured for calculating said optimized speed sub-profiles such that (204) a speed limit set for said road stretches (4, 4a, 4b) is never exceeded.

11. A signalling system according to any one of claims 8 to 10, wherein said calculation system (201) is further configured for calculating said optimized speed sub-profiles (305) so as not to cause collisions between vehicles following different optimized speed profiles being signalled at the same time.

12. A signalling system according to any one of claims 1 to 11, wherein said signalling means (5) comprise a plurality of optical indicators arranged along said road and configured for reproducing a visual flow which is mobile in space, in accordance with said plurality of optimized speed profiles.

13. A signalling system according to claim 12, wherein said optical indicators comprise LED markers.

14. A signalling system according to claim 12 or 13, wherein said optical indicators are directly arranged on the road surface of said road, preferably along each lane.

15. A signalling system according to claim 12 or 13, wherein said optical indicators are located at the side of said road, preferably proximal to the roadway and at a raised level from the road surface of said road.
FIG. 6

FIG. 7
International application No
PCT/IB2015/053920

A. CLASSIFICATION OF SUBJECT MATTER
INV. G08G1/Q7 G08G1/095

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G08G

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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<tr>
<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
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Further documents are listed in the continuation of Box C. X See patent family annex.

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Date of the actual completion of the international search
8 October 2015

Date of mailing of the international search report
16/10/2015

Name and mailing address of the ISA/
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016

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