TITAN : NEW TRAFFIC MEASUREMENTS BY IMAGE PROCESSING

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Abstract. TITAN is a traffic sensor based on image processing techniques. The analyzed scenes consist in 100 to 300 meters long stretches of motorway by day and night. Various traffic measurements are obtained such as speeds, concentrations, flows, lane changes and queue lengths. An automatic initialization module makes possible the use of remote controlled cameras. Using Mathematical Morphology, vehicle features are extracted for each image independently. They are the lights by night, the roofs, hoods and front shadows by day. A dedicated machine has been developed in order to process 4 images per second. The features are aggregated into individual cars and lorries. In case of congestion, queues are obtained in the upper part of the image. Finally, a tracking module is used for calculating dynamical measurements and reducing the rate of false detections.

Keywords. Traffic measurements ; Video sensor ; Vehicle detection ; Image processing ; Mathematical morphology ; Pattern recognition.

INTRODUCTION

The two first applications of image processing to the road traffic measurements were japanese (ONOE, 1973 [1]) and american (HILBERT, 1978 [2]) . Since then, numerous systems have been under development but yet, only one has been commercialized (DEVLONICS [3]). Because of the great diversity of the information brought by an image, research approaches are different, so as measurement potentialities.

One class of research approaches deals with rather vertical views of small stretches of the road. In these conditions the vehicles tend to be separate and the classical measurements provided by traditional sensors can be extracted from the image processing. Some researchers use algorithms that process the whole image (HOUGHTON [4] and HOOSE [5]) ; others restrict the computing effort to small zones crossed by vehicles (DICKINSON [6], DODS [7], MICHALOPOULOS [8], DEVLONICS,...).

Another class of research is dealing with wider views (100 - 500 m of motorway). In this case also, different sizes of the area of interest are considered : longitudinal lines close to the axis of each lane are monitored in the ABRAMCZUK approach [9], while the whole lanes are considered by UCL [10] and INRETS [11][12].

Although presenting more difficulties and therefore demanding more computing power than the first application case, the last one offers more in measurement capability. Classical measurements (volume, speed, time occupancy) are still possible to perform. Furthermore, the spatial ones, such as concentration and queue length, impossible to provide at the moment with classical sensors, can also be performed. Hence improvements in traffic measurements can be expected from these new sensors, especially during non homogeneous flows which occur in congestion or incident conditions.

TECHNICAL SPECIFICATIONS OF THE SENSOR

The application conditions of the presented algorithms are obtained with nearly frontal or rear views of multi-lane motorways, the camera pole being placed in the middle of the carriage-way or on the side near the shoulder lane. Depending on the height of the camera (15 - 30 m) medium long stretches of motorway (100 - 300 m) can be monitored. Because we want to make measurements having a physical sense for the traffic engineers, cars need to appear separate in the image foreground.

Image sensors may be remote controlled cameras. This means that an initialization procedure can be used to automatically restart the measurement process when an operator has moved the camera for incident detection for example.

During free flow the vehicles are usually separate on the whole image, all the microscopic measurements derived from individual trajectories can be performed. Obviously, macroscopic variables, classical or not, can also be calculated. Hence, concentrations, volumes, speeds, lane changes and size classification are provided.

During high concentration, queues are detected in the background, so that measurements necessitating the separation of the vehicles are made on the foreground. Only queue lengths and other estimated parameters can be performed in the background.

SCENE CHARACTERISTICS

There are at least three characteristics of the scene that strongly influence the sensor algorithms :

the luminosity ,
the traffic conditions,
the geometrical situation.

The main luminosity changes are due to the day/night alternation. Some specific situations as, for instance, the day/night transition, rainy and foggy days, sunrise and sunset with lateral shadows, must also be considered carefully.

The traffic conditions vary from extremely fluid to congestions. This last case is the most difficult since some parts of the vehicles can be hidden by others (occlusion).

The geometrical situation is a key information :

- the first problem concerns cases of front and rear views of vehicles ;
- furthermore, the perspective distorsion plays a very important role : the same object surface appears with different aspects in upper and lower parts of the camera scope (long and short distances). It must be pointed out that this distorsion effect depends on the surface altitude and orientation.

SENSOR ALGORITHMS

The sensor algorithms can be divided into four main parts :

a) automatic initialization ;
b) vehicle feature detection ;
c) feature aggregation into vehicles or queues ;
d) tracking.

Each part is influenced by some of the previous three scene characteristics.

a) Automatic initialization

The goal of this module is to determine the geometrical characteristics. As the camera is allowed to be moved and zoomed by operators in the traffic control center, all geometrical parameters must be re-calculated periodically.

By observing image histograms, a rather simple module discriminates night from day. Afterwards, some algorithms are used for a rough estimation of the geometrical parameters, namely the position of the road in the image, the focal length (F) and the angle (a) between the camera axis and the ground (see Fig. 1).

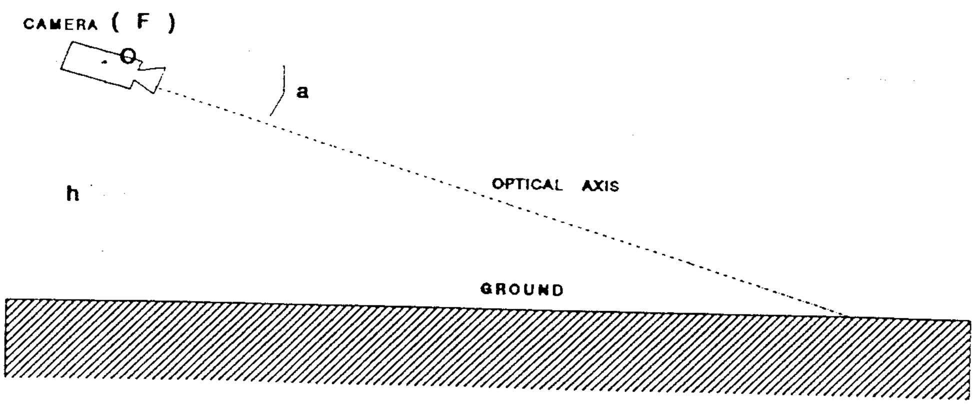

Fig. 1. Definition of some geometrical parameters

These calculations are based on the fact that the moving objects in the scene are mainly vehicles. Zones of motion are detected (difference image technique) (see Fig. 2) and aggregated, so that the mask of the road is obtained (see Fig. 3). Then, the geometrical parameters are derived by observing the linear relation between the lane width in pixels(w) and the screen line(l) ($w = A * l + B$), provided that the altitude of the camera (h) is known ; the following equations are used :

$$\cos(a) = (h * A) / W$$

$$F = (B * h) / (\sin(a) * W)$$

where W is the real lane width (3.50 meters in France).

Fig. 2. Partial detection of the lanes

b) Feature detection

There are several vehicle feature detection algorithms depending on the luminosity (especially day and night algorithms) and some geometrical aspects (front or rear views).
Each algorithm must intensively use the size of the vehicles on the camera scope, which is determined by the initialization step. They are based on Mathematical Morphology techniques and can be described as an image processing step.
As they need a lot of calculations, a dedicated machine has been developed to allow a real time treatment (4 images are analyzed every second).

Various strategies were investigated for extracting the vehicle features. One could concentrate on the motion by comparing successive images or, instead, analyze each image independently.
This last solution has been adopted, since it allows to detect the stopped vehicles. However, the motion information is not neglected as it is used afterwards to reduce the rate of false detections (see the step "tracking").
The features to be detected were selected carefully since they had to be as robust as possible. They are different for day and night scenes, as also the detection algorithms.

By daylight, a frontal or rear frontal view of a vehicle appears as a collection of dark and clear horizontal zones, one or two meters wide (see Fig. 4).

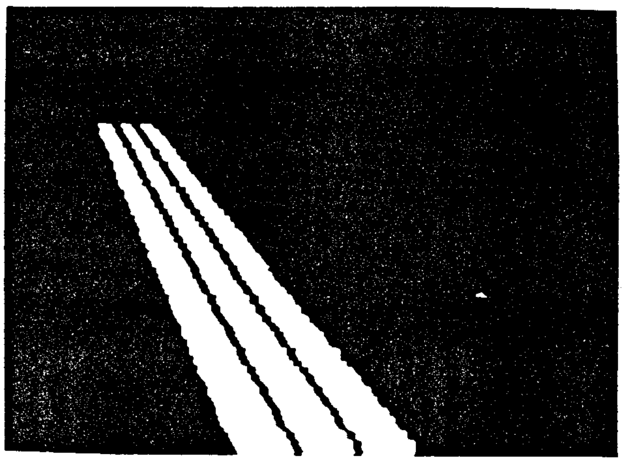

Fig. 3. Final mask of the interesting lanes

Fig. 4. Day : original image

The clear zones are roofs and hoods (see Fig. 5) while the dark ones correspond to windscreens, radiator grils and front shadows (see Fig. 6). These shadows are often the most robust and easily detectable parts, and are usually sufficient to find all the vehicles.
For very specific luminosity conditions, these shadows may not appear in the image ; therefore, the algorithm also detects the clear parts. This clear/dark duality ensures a good robustness for detecting vehicles and give valuable information to the aggregation module (especially it allows to discriminate trucks from cars).
The dark zones are extracted by detecting the gray level local minima which are sufficiently deep and wide.
The clear zones are usually less constrasted than the dark ones ; the detection process is very similar, but a gradient-based method is added.

By night, the features of the vehicles which enable to identify them are their lights. Front and rear views have been studied (see Fig. 7 and 8). In the latter, lights appear as small luminous blobs, compared to the headlights, whose luminosity is much higher and which vary in form and intensity. In both cases the noise consists essentially in :

- motionless objects (lighting, artefacts,...) ;
- reflections on the vehicles ;
- reflections on the road : in the rear views they only appear by specific meteorological conditions (such as rain for instance) ; on the contrary they always perturb the front views, where they appear as diffuse and inhomogeneous blobs.

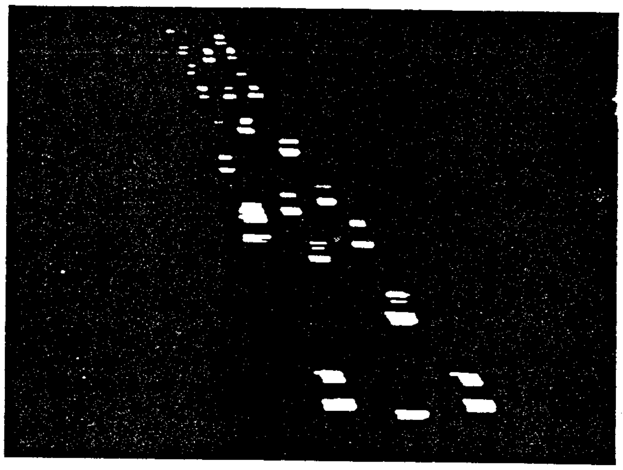

Fig. 5. Day : clear features

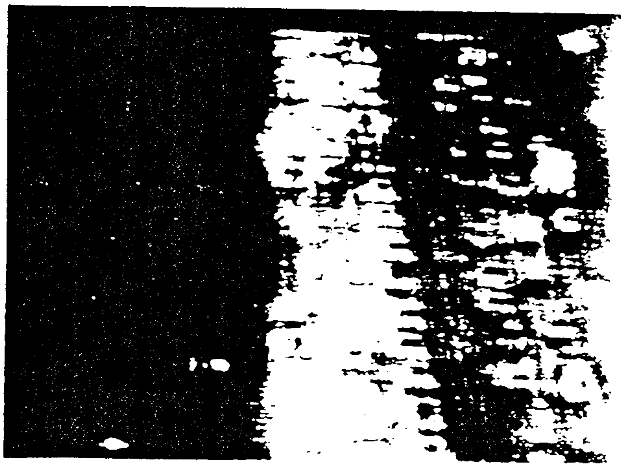

Fig. 7. Night : front view

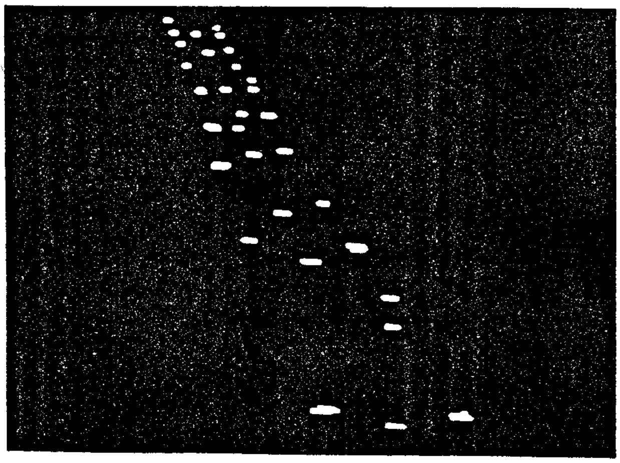

Fig. 6. Day : dark features

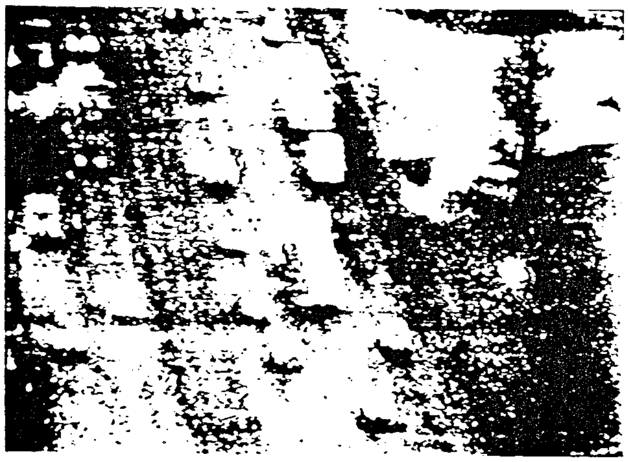

Fig. 8. Night : rear view

Most of the time this noise can generate false detections and so must be eliminated.

The first step of identification of the lights consists in calculating the local maxima of the image, using adapted thresholdings (see Fig. 9 and 10).
As a result, all lights are obtained but some noisy points are also retained. In order to eliminate the many reflections on big vehicles (lorries for instance), large homogeneous areas are identified as their roofs and the local maxima in these regions are considered to be false detections.
A last transform leads to an image of local maxima only containing points (1 pixel) ; aggregates of pixels have been replaced by one of them.

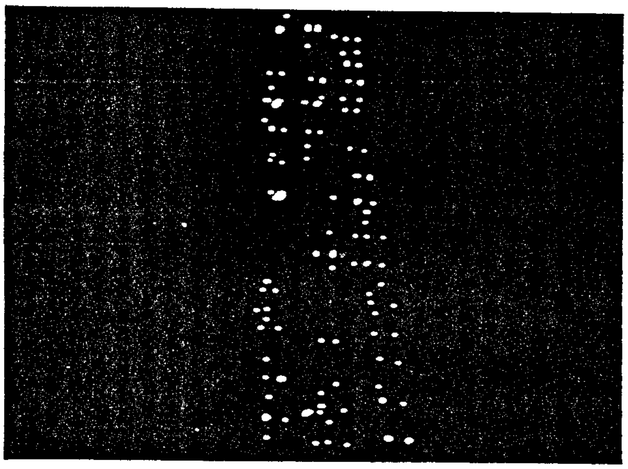

Fig. 9. Night : image of the local maxima (front view)

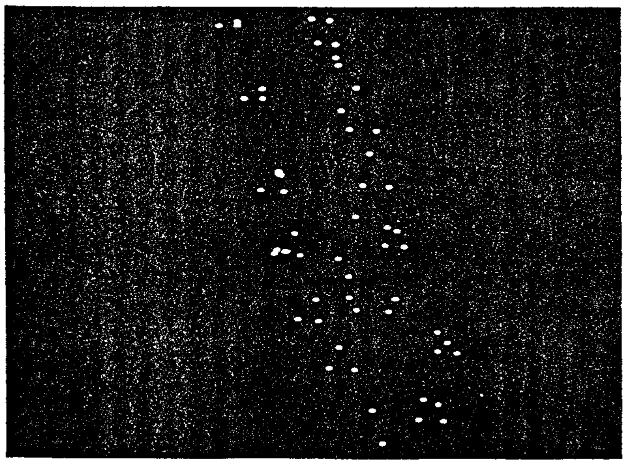

Fig. 10. Night : image of the local maxima (rear view)

In the case of the front views, two other steps are added in order to reduce the false detections due to the many reflections on the road. A gradient is used for separating the headlights from these reflections ; the following method consists in merging the headlights and their reflections on the road with an adapted dilation (morphologic operation) ; the local maxima of reflections whose intensities are lower than those of headlights, tend to disappear after this transform (see Fig. 11).

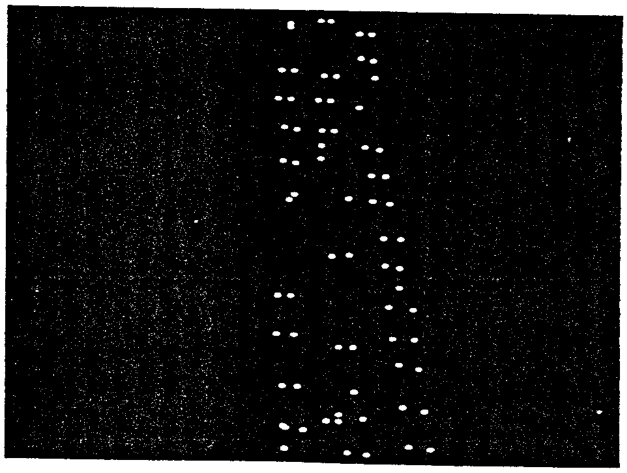

Fig. 11. Night : image of the local maxima after removing reflections (front view)

c) Feature aggregation

The aggregation step handles the features previously detected in order to find the vehicles themselves or the vehicle queues (in case of congestion).
The amount of information having been tremendously reduced (usually, a few tens of features, each of them being described by a dozen of parameters, compared with the 256x256 initial image), the calculations can be fastly performed by a non dedicated machine.
The features are aggregated in respect to the vehicle geometrical aspect under the current luminosity and geometrical characteristics. Therefore, this operation is a pattern recognition step.

In case of daylight scenes, the positions of the detected features in the image are converted into real distances along the road axis. This calculation requires an assumption concerning the altitudes ; for instance, clear features are supposed to be 1.3 m, 2 m or 4 m higher than the road itself according to their length (roofs of light vehicles, vans and trucks). Afterwards, the aggregation process consists, for each lane, in grouping the features that are closed enough, starting from the dark features which usually correspond to the beginning of a

The aggregation rules are rather simple and robust, due to the position of the camera on the side of the road (the vehicles are seen frontly or nearly, never by their side). The main problem is related to the presence of trucks, that can have many different structures (tank trucks, trailers, caravans...). When the traffic is rather fluid, the aggregation module produces a good detection of each vehicle, even if it is more than 100 meters far away. Due to the length of their roof, most of the trucks are well treated. Therefore, both the position and the category (light/heavy) of the vehicles are obtained. In case of congestion, it tends to be very difficult to detect each and every vehicle because of occlusion problems, especially for far distances (more than 70 meters from the camera). Therefore, the sensor does not detect all the vehicles along the road but, instead, <u>the vehicle queues</u>. In order to deal with both situations, two algorithms are run : the first one (1) tends to detect individual vehicles, while the second (2) concentrates on queues. The results are finally compared as follows :

- if a queue obtained by (2) corresponds exactly to a vehicle detected by (1), it is considered to be one vehicle,

- if a queue corresponds to more than one vehicle, it is considered to be a queue.

Finally one obtains, for each image, a number of individual vehicles and queues. In case of fluid traffic, only the individual vehicles remain (see Fig. 12).

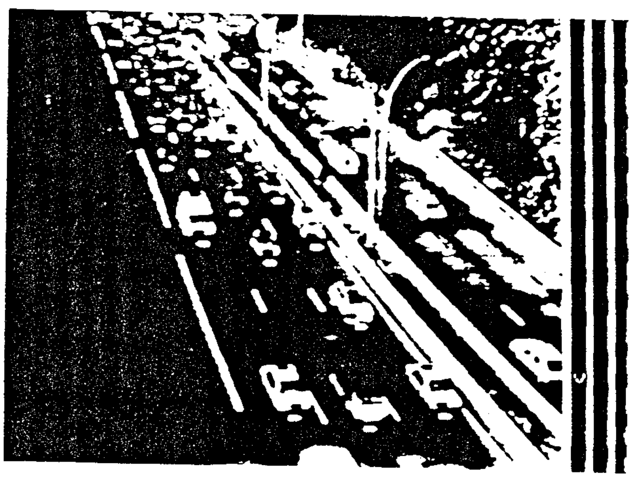

Fig. 12. Day : final detection image in case of fluid traffic ; all vehicles are individualized (right side : vertical view of the lanes ; V stands for van)

In case of congestion, queues appear in the upper part of the image (far from the camera), while vehicles are individualized in the lower part (see Fig. 13).

Fig. 13. Day : final detection image in case of congestion : queues appear in the upper part (right side : vertical view of the lanes ; Q and T stand for queue and truck)

<u>By night</u>, the image of the local maxima after treatment is used to match the lights of a same vehicle. The size of a created pair (horizontal distance between the two lights) is taken into account to determine the type of the vehicle, that is car or truck. Therefore, a single marker can be attributed to each vehicle except those which appear with only one of their lights. Most of the remaining reflections can not be matched together because of size criteria and are eliminated. The aim of the next step is to eliminate eventual false markers by considering distances between them (distances along the road axis). The minimal space between two consecutive markers is the average of a vehicle length. The final results are shown in Fig. 14 and 15.

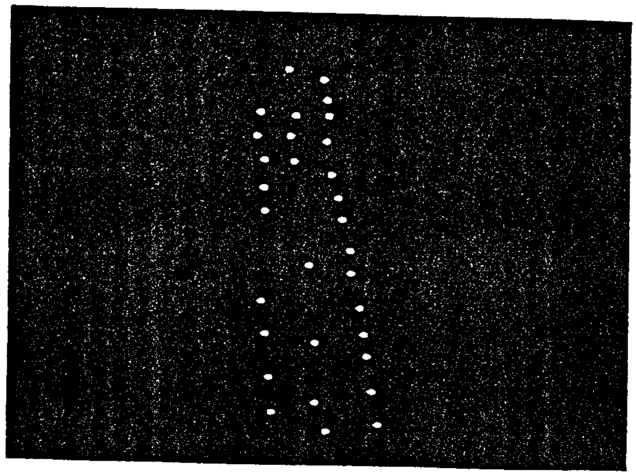

Fig. 14. Night : final detection image (front view)

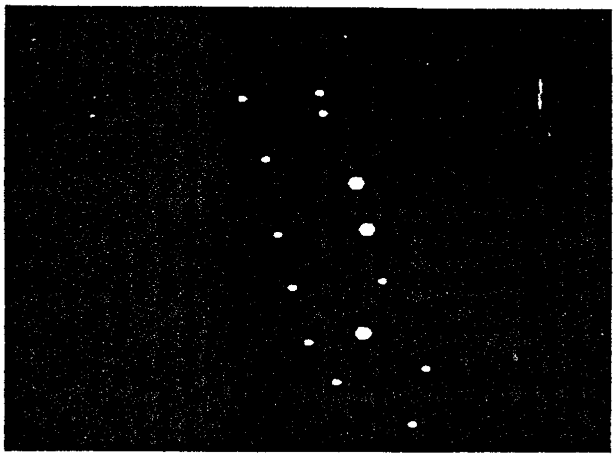

Fig. 15. Night : final detection image (rear view) . Big spots stand for trucks

d) Tracking

The tracking step is the final module of the sensor ; it has two main objectives :

- by following the vehicles in time it can remediate to instantaneous errors of detection (lack of detection of vehicle in t, though it was detected in (t - 1) and (t + 1)) ;

- the calculation of vehicle speed, which is a major parameter for both traffic control and automatic incident detection (see Fig. 16).

It is rather easy to track vehicles, because of the image treatment frequency (4 images per second).

The problem of queue tracking must be considered carefully since queue detection may be rather non stable during the time. No decision has been taken about this until now.

Fig. 16. Trajectories of vehicles across 40 images detection . Instantaneous speed is noticed

GLOBAL PROCESS

As emphasized before, all the algorithms are strongly dependant upon luminosity and geometrical aspects. The role of the initialization module is to calculate roughly the geometrical parameters. However, these should be refined and updated permanently, as also the luminosity characteristics (day/night) :

- luminosity must be checked periodically,

- the vehicle detection leads to a more precise calculation of the geometrical parameters : for instance, the size and position of the detected vehicles can be used to improve the calculation of perspective distorsion effects as well as the localization of the lanes in the image.

The whole process is schemed in Fig. 17. In order to avoid a deviation of geometrical parameters due to the feed-back, the initialization module is activated periodically.

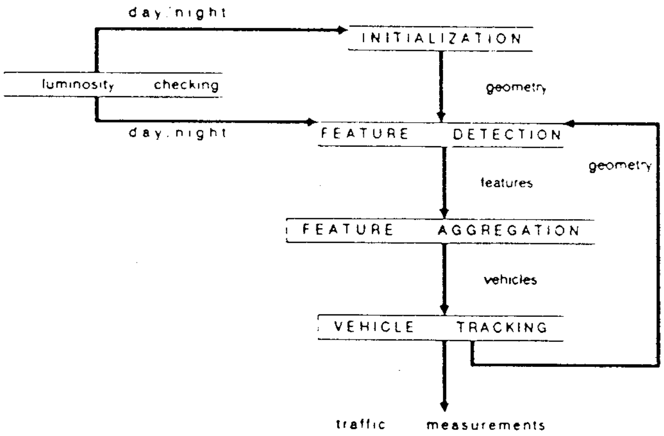

Fig. 17. Global process

CONCLUSION

The night and day detection algorithms have been tested over many representative scenes of motorway traffic and have proved to give good results.

The type of the vehicles can also be identified and the characteristics of the traffic determined (concentration, speed, flow, lane changes, occupancy rates...).

A dedicated hardware, which has been developed, will be able to test in real time these processing algorithms and also offer the means to develop completely new modelling of traffic behaviour (shock waves propagation, weaving section behaviour...).

Twilight scenes must still be treated ; they are transition states which night and day detection algorithms can't be applied to ; an automatic transition must also be operational to connect continuously the successive periods.

By night the initialization step and the treatment of congestion scenes have still to be considered.

Although some trials have been made, all the meteorological conditions must also be extensively studied in order to complete the algorithms, and namely :

- sunny scenes where large shadows appear on the road and may be identified as dark parts of vehicles, thus generating false detections ;
- foggy scenes ; this situation is very particular since vehicles have their lights switched on during the day ;
- rainy scenes by night ; there are a lot of reflections on the road, which look like lights in form and intensity;
- snowy scenes because the luminance is very specific.

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