Stefan JACKOWSKI, Małgorzata GÓRSKA

RETINA – A SURVEILLANCE TOOL FOR ROAD TRAFFIC

Abstract

Retina is a conceptual system combining modules for telecommunication, visual data acquisition, data processing and decision making. The goal is the study of options for the monitoring of motion trajectories of selected objects – driver/vehicle units – without support from the observed car or truck by means of GPS, RFID or other onboard units such as are used e.g. for toll collection. In the paper, the state of the art of the technical components is evaluated along with a proof of concept of the whole system by means of a computer simulation.

INTRODUCTION

Monitoring of road traffic is a dynamically evolving field of Telematics. In this paper, the real-time surveillance of chosen vehicles – selected by given criteria – is analysed on the basis of pure visual methods.

In the given ecological and political situation, a possible goal may be the tracking of stolen cars or other illegal activities, bringing support to the Police and other authorities in the fight against organized crime.

A continuous flow of information between authorities, the system's operators (*OC – Op-Centre*) and local observation units is the backbone of such a system. On the one hand, a list of wanted objects is sent to RETINA and regularly updated. On the other hand, registered sightings of vehicles, together with predictions of their future courses up to possible interceptions is transferred to the officials.

The main point of the conceived system is the tracking of all vehicles on a given list, or all vehicles fulfilling given criteria, possessing certain features. Analysis of acquired pictures, extracted data transmitted in suitable formats, will serve to create motion trajectories of past movements and – to a certain degree – extrapolate the future progress of each given driver/car unit.

It is natural to subdivide a RETINA type system into three components: the telecommunications network as the physical basis, the local observation points as the data source, and the Op-Centre as the central processing and assessing all collected information and interchanging orders and results with the entitled users of the system.

For a computer simulation of the system, beyond its own components, also a road net and a fleet of vehicles needs to be modelled and animated.

Systems of the considered features – optical vehicle tracing without electronic signals from the mobile objects like GPS, RFID etc., are already active in the US and other countries. Some aspects of their operation are discussed in recent scientific publications. For obvious reasons, most details are confidential, a thorough scientific analysis of the whole concept is missing.

In Fig. 1, the architecture of the information flow in Retina is sketched.

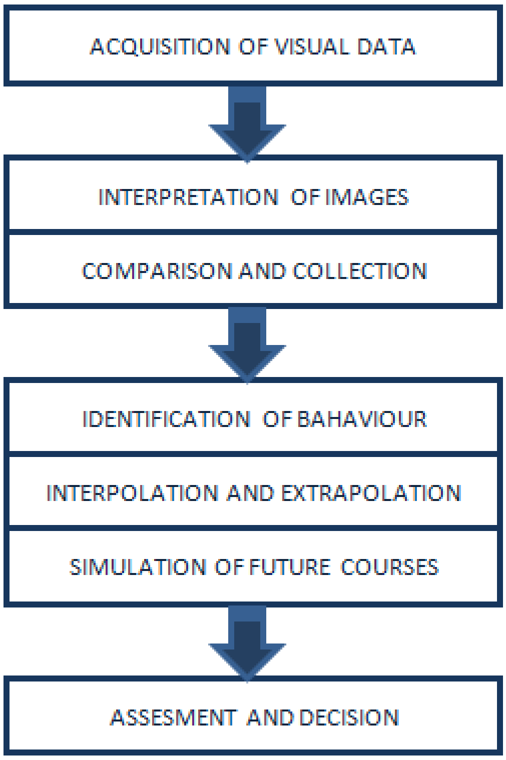

***Fig. 1.** General scheme of Retina's functionality*

In this paper, some methods for the analysis of past trajectories and the reasoning allowing to draw conclusions as to future positions are presented. The quality of predictions decreases dramatically with time, hence quick transmission and calculation of probable courses is of the essence. Important tools are optimization methods, which will be illustrated on some examples. Also the other two components of Retina, i.e. the heterogeneous telecommunications network and the data acquisition equipment, together with present standards and parameters, will be discussed.

1. REQUIREMENTS

The usefulness of a RETINA type system depends on several minimum requirements as to the quality of the acquired picture raw material, the accuracy of the identification of the wanted vehicles, the speed of the information flow and deduction of conclusions as to further actions. Hence it is assumed that the optical resolution of the observers, e.g. traffic cams, is sufficient for number plate identification. A certain error rate, problems with bad weather, reduced visuality, dirt on number plates, foreign character sets etc. have to be introduced, nonetheless. State of the art LTE wireless data transfer should be fast enough for the system's needs, however, fourth generation networks are not accessible on the whole of the covered territory, and the amount of data is huge. So this topic will need to be discussed later in some detail. The pure mathematical operations of interpolating and extrapolation the position data are the least time critical steps, however, their results are very sensitive if only few sightings are available.

In this paper, two types of observation points are taken into account. The first one is denotes as an *I2CU* (*Intelligent Interconnected Camera Unit*), which is assumed to be equipped in a way that it may make its own decisions. An I2CU has local computation power to interpret taken pictures, extract a vehicles identity, compare it to a wanted-list and decide whether to send the information of the sighting to the Op-Center, or to store and/or send a picture – or destroy the record. This solution is easy on telecommunications and heavy on local data processing – it leads to minimal data transfer.

The extreme alternative is a *LC2U* (*Low Cost Camera Unit*) which sends all data to the Op-Center – where the whole load of image analysis for all observers is concentrated. This concept, allows, as in general in Cloud Computing, to work with a high number of local clients, but it has high requirements when it comes to data transmission. For the proper operation of the whole of Retina, an optimal mixture of both types of components seems appropriate, given that the telecommunication network is heterogeneous.

The design of the whole network – given the topography of the territory, the locations of existing phot radars and other cameras, the placement of antennas and the telecommunication equipment and demands of other customers – is a complicated optimization problem. In particular, positions and type of observer units may be adjusted to the situation in such a way, that the overall performance of the Retina system will be maximized.

1.1. Analysis of hardware requirements

Vehicle identification takes place on the basis of visual data, therefore significant components like cameras are used for this purpose. In the paper [1], an analysis of currently available hardware is conducted, which is essential for testing the mobile variant of observation points (*LC2U*). Also some experimental research was carried out, based on test drives using a vehicle equipped with a car-DVR (car *Digital Video Recorder*). The chosen type belongs to the market's upper segment, what was shown in table 1 in [1]. It is characterized by the following parameters: resolution Full HD 1920x1080, codec/format H.264/mov, viewing angle 130^0 , screen size 2,4", recording speed 30fps, SDHC 32GB card support, integrated GPS module, [25].

Fig. 2. *Dash cam used for field test*

An extensive video material was recorded (more than 1435 km, 1434 min of total recording time), typical for the following situations: driving on national roads, highways, day and night driving conditions (i.e. good and bad visibility). In the next part of the article, the results of this empirical studies are presented.

1.2. Requirements for telecommunication gear

Within the system described in the works [7], [8], [9], [10] and [11], the input data comes from observation points distributed over a large area such as province or whole country. Thus one of the system's most important elements is a heterogeneous wireless network, which processes and transmits data from visual units to the computing center or observation center, thus allowing authorized intervention forces access to the observation.

The information transfer (after pre-selection) is caused by the registration of any object, which is seen by a camera being part of the sensor network. The main features necessary to identify a given object are the registration plate information, and/or other distinctive indicators of vehicle or driver. A detailed discussion of this matter was presented in [2].

There are many more or less effective solutions to this problem, such as e.g. the ARTR system, some of which have been used commercially for years, cf. [14].

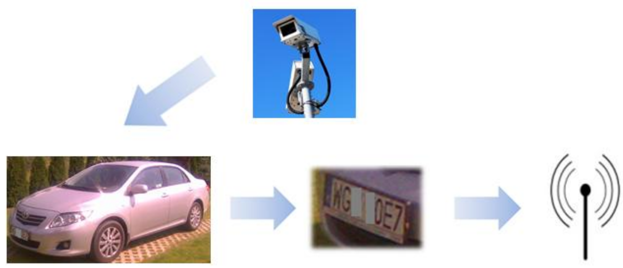

Fig. 3. *Scheme of visual identification (read out of registration tags)*

In each observation point, the camera is activated by a motion sensor. Next, a photo of the vehicle or only the information about it, is transmitted to the main server. At the same time, if necessary, the photo could be used as documentation in case of interventional procedures. Also, video packets can be sent. Bearing this in mind, the essential requirements which every telecommunication network must meet are:

– speed and quality of transmitted data;
– links reliability;
– information transmission safety;
– flexibility of the network's architecture;
– resistance to interference;
– ease of hardware implementation;
– specified capacity.

The use of existing systems is imperative, and assuming appropriate configuration and modification also possible. Therefore it should be considered as obvious, that the telecommunications network used for RETONA is heterogeneous.

Depending on the chosen observation point, in case of sending only text data, a sufficient system that meets the requirements is already GSM, GSM-EDGE. For video streaming, however, it is required to use newer communication techniques. At present, the best system, which meets all conditions required, is UMTS, mainly because of its wide coverage. In the near future, also the LTE technic (Long Term Evolution) can be taken under consideration. It transmits multiple data packets at the same time on orthogonal carrier frequencies. LTE uses OFDM modulation, which significantly increases the resistance to inter-symbol interference, [13, 15, 22]. The maximum speed of LTE transmissions in Poland reaches 150Mb/s, and is hence large enough to allow good quality video streaming in real time. Consequently, the use of the present system is justified. However, the current coverage of LTE is insufficient to meet the demands of the designed system. Furthermore, network overload – because of smartphones, tablets, new mobile services like mobile television - is another reason why the real-time transmissions be slower than specified or delayed.

After the preliminary analysis of existing telecommunication systems, it can be observed that the structure of the observation network should be optimized according to operation stability in real conditions. To do so it is best to prefer intelligent observation units, previously denoted as I2CU, where the pre-processing begins with the data reduction (locally on the observation site), which minimizes the need to transmit videos or graphic files. In this variant, only small data packets containing selected information are sent through the net.

2. EMPIRICAL STUDY OF *LC2Us*

Simulation tests, the results of which are shown in [3, 4, 10], are based on the assumption of error-free and 100 percent effective observation. Empirical studies have to verify this assumption. Further, an assessment of the new possibilities provided by equipment now commonly available of the type of car-DVR in Retina the system is needed. The principles of integrating mobile observers into the surveillance are described in [5, 10].

Fig. 4. *Experimental setup [1]*

In the manner presented in Fig. 4, there was recorded more than 30 GB of *.mov format files with data on vehicle location (GPS coordinates in *.nmea). *.Mov files were processed with the aim to isolate individual movie frames, which were then assessed for their suitability for the extraction of alphanumeric data.

A series of frames, taken from the recorded video files, shows clearly that there are limits to their usefulness for the exploration road vehicles according to selected distinctive features, which in most cases is number plate.

The total observation time was 1,434 minutes = 86040 seconds. Data presented in Table 1 in the article [1] and [12] shows that the average speed of car-DVR recording is 30 fps (fps - frames per second). So more than 2.5 million movie frames had to be analyzed. Of this total only approximately 20 thousand were suitable to read out an exact registration from a vehicles number plate. Thus, the present study shows that the movie frames with clear registration is amounts to less than 1%. Thus one comes to the obvious conclusion that the straightforward use of car-DVRs as mobile sources of information in the Retina system does not give good results. The reason for this is that the number of frames useful for the system is not satisfactory. This creates a heavy burden on the telecommunications network, with an unacceptably low effectiveness in reading out number plates. However, car-DVR in connection with some reasonable preprocessing in the still is a viable option for the future.

Thus, for now, the ability to install stationary observers (I*2CU*) to generate images / movies exactly when optimum visibility is given – e.g. with support from radar or an induction loop, is the option of choice. Only this way the burden on the telecommunications network can be kept to a reasonable minimum, guaranteeing at the same time the efficiency of the system.

The advantage of a system based on stationary observer units is the high quality of the obtained picture material. The disadvantage of such an installation is, on the other hand, that for wanted vehicles it is comparably easy to avoid the known camera sites. This is, in the case of a set of diffused mobile observation points, not possible, or at least much harder. Further, a major drawback of currently prevalent car-DVRs is their too small resolution and hence too small number of pixels representing the number plates area.

The conclusion is that there is still the need to develop further the concept of stationary observation units, while at the same time monitoring the changes taking place in the parameters of the newest car-DVRs and their ability for post-processing data. .

3. ROAD NETS

Graph theory is one of the most important tools in modelling of road traffic. The key concepts are those of nodes or vertices and edges – which represent road segments. All points on a map, representing cities or crossroads or sites as highway exits, fuel stations of parking lots are abstractly represented as vertices. All line segments, however, are edges in the graph used for simulations.

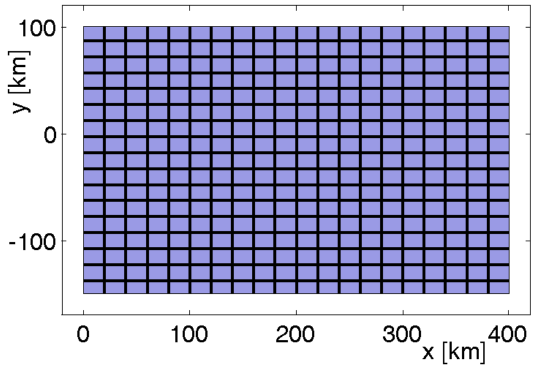

Fig. 5. *Domain Ω with rectangular grid*

A classical example of the simulation of motion used a rectangular grid, reminding the streets and avenues on Manhattan. In Fig.5 such a hypothetical domain Ω, constructed for scientific analysis, is given. This rectangular net of 15 (vertical) times 20 (horizontal) lines was already used in [7]. It was assumed, that in very regular distances of each other, e.g. 20km and 15km, respectively, roads were built – all parallel to the coordinate axes. Roads as well as trajectories of vehicles are now interwoven sequences of vertices and edges. The latter connect neighbouring nodes, while roads may reach across the whole extend of the domain.

Formally, a graph is defined as an ordered pair of to sets, cf. [9]:

$$\mathrm{G} = (V, E) \qquad (1)$$

where *V* is the set of all vertices, $V = \{v_1, v_2, \ldots, v_m\}$, and *E* is the collection of edges connecting the vertices or nodes.

By writing $(v_1, v_2) \in E$ the fact is expressed that v_1 and v_2 are directly connected by a road segment, without need to pass through other nodes underway. The incidence matrix *I* is defined by:

$$I_{\{ij\}} = 1 \Leftrightarrow (v_1, v_2) \in E \qquad (2)$$

One of the most cited sources in modeling of car traffic – mostly in the context of simulating traffic jams on highways – is the papers [18] by Nagel and Schreckenberg. Models of the NaSCH type consist of 23.947.347 vertices and 58.333.334 edges in the case of the USA. A model of New York City takes 264.345 nodes and 733.846 segments into consideration, where only the island of Manhattan features 12.000 points, see [23].

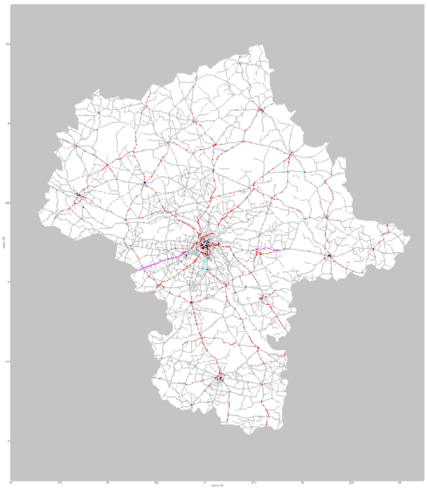

Fig. 6. *Graph representing the roads of Masovia*

For the current research at its present stage, a much smaller resolution is sufficient, the map in Fig.6. contains just a few thousands of nodes and segments. For a proof of concepts of the systems under investigation, this seems to be a reasonable compromise between resolution and efficiency. Larger grids might lead to excessive computation times, while the goal here was to perform lots of simulation in order to gather material for a statistical evaluation of Retina's performance.

The graph in Fig.6. contains only higher priority roads, all segments are bi-directional. More advanced modelling distinguishes between segments from v_1 to v_2, and from v_2 to v_1. In fact, on a finer resolution, e.g. in the case of a city map – as in Fig.7 – lanes in different directions have to be treated individually.

Fig. 7 depicts data extracted from OpenStreetMap (*OSM*), which is an open source project collecting geographical information from different sources, among others geo-tracking results volunteered by private users. There exist several tools for the handling of OSM data, here Quantum GIS (*QGIS*) [24] was used to read out the coordinates, which were next plotted by a Matlab script. Tests on larger territories suggested that the amount of data is too big to handle in the simulation environment chosen for this project. Hence, the data depicted in Fig.6 was taken as basis for all further analysis.

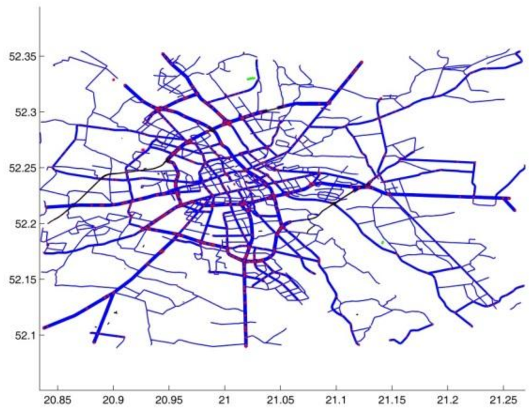

Fig. 7. *Map of main roads in the Warsaw region, from OSM using QGIS*

This means in particular, that no concept of bi-directional routes was taken into account, as is the case in oriented graphs, [16]. In such a case, E a set of ordered pairs (v_1, v_2), where one distinguishes (v_1, v_2) from (v_2, v_1), while in the case of two-element sets it holds $\{v_1, v_2\} = \{v_2, v_1\}$. Analogously as in (1), an oriented graph is given by (3) as a pair:

$$\vec{G} = (V, \vec{E}) \tag{3}$$

where the arrow stands for the orientation.

It is worthwhile to mention that in such a model also egdes of the type (v_1, v_1) may exist, which denote loops, e.g. in the case of a round-about or loop.

Next, we define the order of a node. Let $\mathrm{G} = (V, E)$ be a graph describing a road map, and $v \in V$ is a vertex of this graph. Then the number of segments in E exiting from v is called the order of v. In the case of oriented graphs $\vec{G} = (V, \vec{E})$, there are separate orders for entries and exits – which in general may be different, cf. [20].

It has to be said that the mathematical definition of a graph is pretty abstract, however, it is very useful for a study of general properties as for instance the connectivity of a road map. On the other hand, for most studies of traffic flows it is necessary to know localizations of vertices and lengths of road segments – which are not provided in (1) or in (3). Additional data like coordinates or distances may be assigned in the form of so-called weights – which define properties of nodes and edges. For details of such an approach the book [17] may serve as a reference.

4. SIMULATION OF THE SYSTEM

One major ingredient of the system is the method by which observation data are extrapolated into the near future, i.e. the algorithm used for predicting the course of a given vehicle. As a first approach, a linear interpolation of past position is proposed. This works in three steps. First, the acquired position data of the vehicle under observation is put into a table, next the entries are approximated by a least squares regression line, and finally, this curve is prolonged and projected to the road map. A more detailed description of the procedure was given in [6], more test results and a refined version will be published in [21]. In particular the fact that a prolonged regression curve is unlikely to hit a node or edge of the assumed road net requires some extra consideration. It turns out to be necessary to find the closest reachable point on a road, in other words: the calculated linear extrapolation is projected in the sense of shortest distance. Obviously, this type of prediction may be inaccurate in the case of densely urbanized territories, since there is always the possibility of a vehicle leaving the considered roads net into lower priority streets.

As an alternative, a decision tree may be used. The progress of the vehicle is traced from node to node in the general direction of its motion so far. At each intersection, the next exit is chosen according to a given probability distribution, obtained from general traffic counts. This can be shown on the example of the Rondo Narodowych Sił Zbrojnych in Radom, denoted in Fig.8 by the symbol *O*. The example was previously discussed in [5]. Possible bifurcations at this node are the edges in the road graph denoted by *W* – Warszawa, *K* – Kraków, *R* – Rzeszów (and at the same time to downtown Radom) and *L* – Lublin.

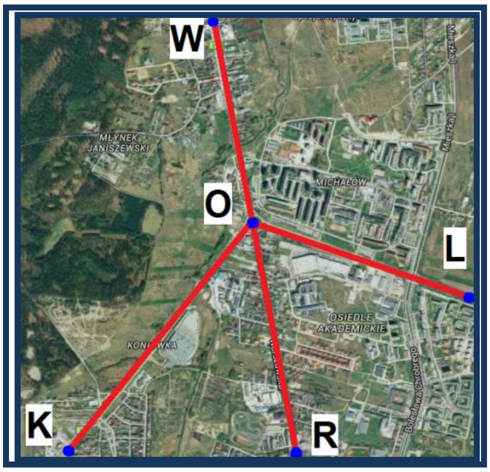

Fig. 8. *Site of empirical study – Rondo Narodowych Sił Zbrojnych in Radom*

A low budget empirical study was undertaken to obtain some statistical evidence as basis for a simulation of the system. For other nodes, however, for the lack of suitable data, theoretical distributions were assumed. In a real world application, the dependence of the time of day, day of week, holydays, and other traffic regulations like [26].

By empirical observation (traffic count by hand, on a weak day in 2014, late morning) for one of the main cross roads of Radom, traffic intensities were estimated. Cars from and to the four directions K (Kraków), R (Radom), L (Lublin) and W (Warszawa) were registered, the counts are represented in Figs. 9 to 11.

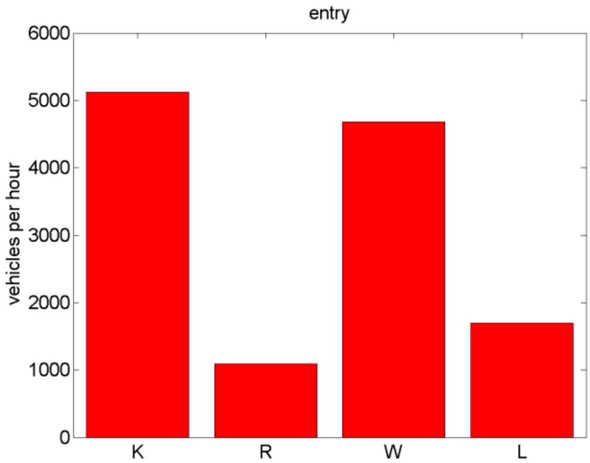

Fig. 9. *Traffic into Rondo Narodowych Sił Zbrojnych*

The traffic intensity, in terms of vehicles per hour, was counted for each of the entries and for each of the exits, independently. The results are plotted in Figs 9 and 10, for entries and exits, correspondingly.

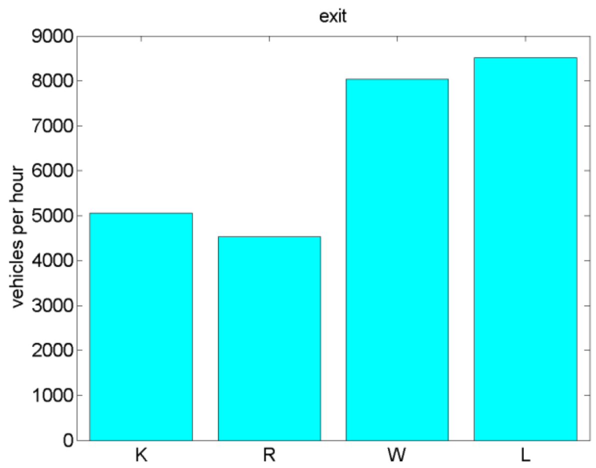

Fig. 10. Traffic per exit from Rondo Narodowych Sił Zbrojnych

The shares of vehicles from and to the four possible directions form a square matrix, which conveniently if represented by a bar diagram, (Fig. 11).

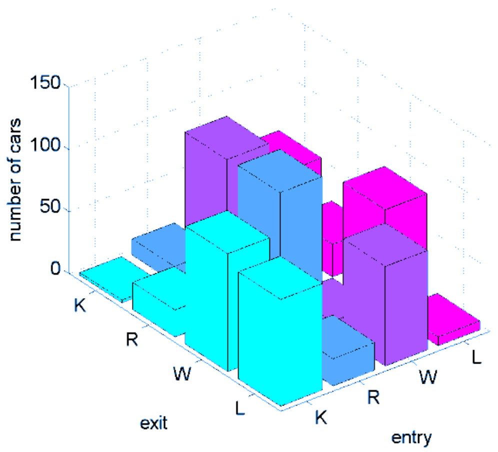

Fig. 11. Split of the total by entry and exit

If the statistics of the traffic at a given node is known, then the most likely trajectory of an average vehicle can be easily calculated, as well as some more and more unlikely alternatives. Of course, the probability of reaching other nodes will undergo a very quick diffusion. After a small number of intersections, the region of possible future positions will be too large to provide guidance in an attempt to intercept the tracked object. Moreover, it has to be taken into account, that the selected kind of driver/car units differs significantly from the average user of the given road or intersection.

In the simulation study undertaken for this article, the nonlocal roads of Masovia, as presented on Fig. 12 and Fig. 6, was chosen as the scene of the surveillance action.

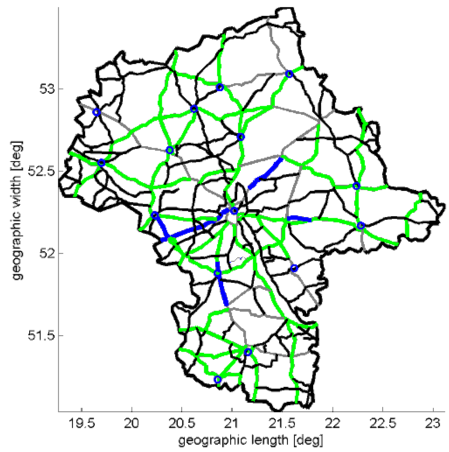

Fig. 12. Main routes in Masovia

A total of ten thousands of cars were sent on a virtual ride from randomly selected initial points to such destinations [14]. An example of a single car's route is constructed in Fig. 13 and 14. Here it is assumed that each car and or its driver is aware of the optimal route – in terms of time or distance or cost – to his destination. However, there is a chance of deviating from this route, due to choice or human error. The optimal routes are calculated by back propagation (Dijkstra's algorithm), cf. Fig. 13, [19] later modified at random, Fig. 14., so that different instances of the same pair origin-destination may lead to different realizations of courses (coloured trajectories in Fig. 14).

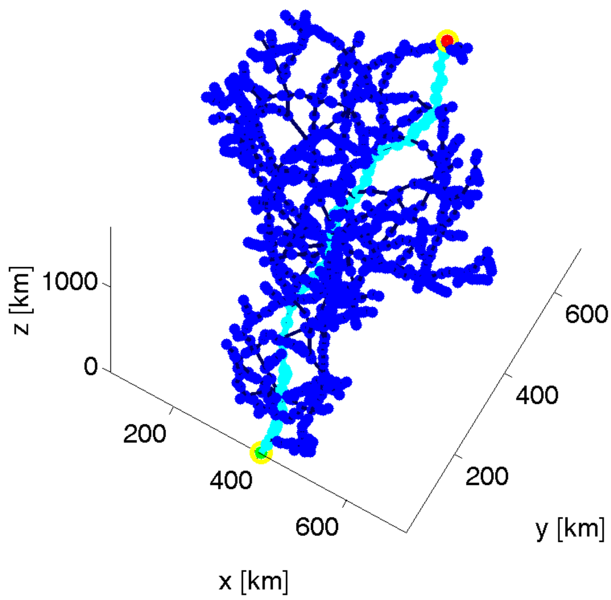

Fig. 13. Routing by minimization of remaining distance

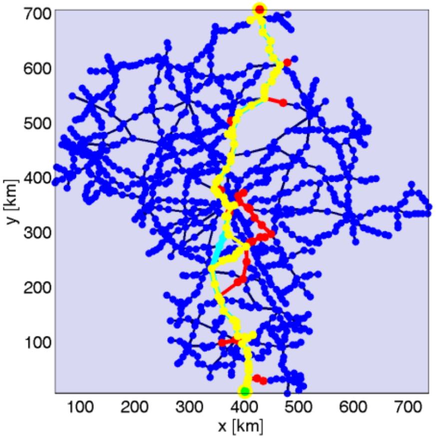

Fig. 14. *Simulated motion trajectories on the chosen road map*

Now, given positions of observers, at a given probability, vehicles are spotted when passing underneath a camera, and this information is transferred, with a random delay, to Op-Centre. There, sightings are registered, and when there are enough of them accumulated for the same object, a course prediction is attempted. Successes – predictions in accordance with the true course – are counted and taken as basis for the evaluation of the system in its current state.

CONCLUSIONS

At present, all technological conditions for implementing a Retina type system in real life are fulfilled. Initially, photo radars, traffic monitoring cameras and toll collecting systems may serve as data sources, the main problem for researchers being the access to the corresponding streams. Hence, a rudimentary version might be set up in short time. Obviously, the quality of reconstructed trajectories and the accuracy of predictions will depend on the density of the picture material and the speed and reliability of data transmission. A further important factor is the processing power, locally at observation points and globally in the Op-Centre. The choice of localizations of observers, the coordination of processing and transfer in a heterogeneous network are topics of ongoing research in Telematics of Transport.

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RETINA JAKO NARZĘDZIE NADZORU DRÓG PUBLICZNYCH

Streszczenie

Retina jest koncepcją systemu składającego się z komponentów telekomunikacyjnego, akwizycji danych wizualnych, przetwarzania danych oraz podejmowania decyzji. Celem całości jest badanie możliwości monito-

rowania trajektorii ruchu wybranych obiektów – jednostek kierowca/pojazd – bez wsparcia ze strony monitorowanego auta osobowego czy TIRa sygnałami przykładowo wbudowanych modułów GPS, RFID lub innych tzw. „onboard units" służących do poboru opłat. W artykule ocenia się stan obecny w rozwoju technicznych elementów składowych oraz aktualną sprawność działania koncypowanego systemu drogą symulacji komputerowej.

Autorzy:

prof. dr hab. inż. **Stefan Jackowski** – Uniwersytet Technologiczno-Humanistyczny im. Kazimierza Pułaskiego w Radomiu, Wydział Transportu i Elektrotechniki

mgr inż. **Małgorzata Górska** – Uniwersytet Technologiczno-Humanistyczny im. Kazimierza Pułaskiego w Radomiu, Wydział Transportu i Elektrotechniki