Syntactic Method for Vehicles Movement Description and Analysis

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Abstract

The syntactic primitives and the description language can be used for assignment and analysis of vehicles movement. The paper introduces a method that allows spotting vehicles' manoeuvres on and between traffic lanes, observing images, registered by a video camera. The analysis algorithms of the vehicles' movement trajectories were considered in this paper as well.

Keywords. Syntactic primitives, vehicles' trajectories, description language, manoeuvres of moving cars.

1. Introduction

The video-camera usage, for a traffic data real time registration and analysis, needs various simplifications for obtaining results of the computing process in a reasonable time. First of all, the data registration then the traffic controlling algorithms have to be executed in very limited real time, assigned by a speed of this passing vehicles. Additional restrictions concern several items defined by a traffic safety regulations.

The digital cameras (available on a market today) are clocking the image stream 25 times per second, recording each car; driving 50 km/h at a 100 m road passage, 182 times [11]. This clock rate produces immense set of the data that is much bigger than it is needed for this slow process description.

From the other hand, the manoeuvres of passing cars, on or between traffic lanes, have to be caught in sampling intervals that cannot be longer than the cars need to do these movements.

Taking into account the time, which the controller needs for the data set analysis, several factors of the elaborated algorithms have to be optimised.

First, the grid of the controlling intervals must be chosen. It has to be related to a number of traffic attendees and distances between vehicles, for keeping the traffic safety. The computing tasks, the assumed time for calculations and the available computer power have to be considered in analysis of the algorithms eligible complexity.

The indicated above demands of the transportation model description, were already discussed in several works; among them [2, 4].

Due to reduce the computing processes in analysis of the vehicle's movement trajectories, some simplifications of their descriptions were provided. Instead of using the pixels bitmap descriptors, the vehicle's route was divided into smaller, elementary units. These descriptors allow assigning the vehicle's route in a satisfactory manner. The vehicles movement trajectories are described by several elementary graphical symbols, as: straight lines and curves. The trajectories example is introducing the solution called road junction (in Fig.1), on an output from a main road into a sub-way.
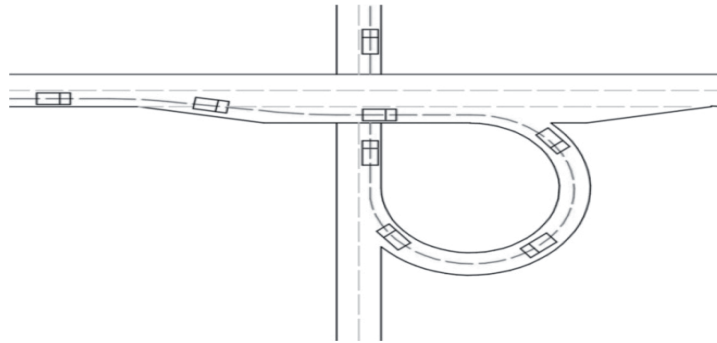
Figure 1. The vehicles' movement on a road junction example trajectory

At the road junction entrance, the vehicle is changing the traffic lane - first, assigned by two curves and one strait line in between. After that, the vehicle enters the curve-shape road of the junction. The end part of the route is also a straight line. These trajectories assign the vehicle's movement on the junction, using several curves and straight lines.

These simplifications of the description are not loosing the description preciseness, as the trajectories are defined by connections of the vehicle's layout discrete indicators; on every cell of the video image. However the needed memory size and the computing power of the traffic controller is reduced remarkable.

2.   The syntactic descriptors of the trajectories

In Fig.2 the movement trajectory primitives are indicated. The trajectory is divided into elementary units, showing the object's localisation, along the traffic lane [13].

The traffic route recognition means identification of the vehicle's primitive descriptors, used for the object's assignment [14, 9],
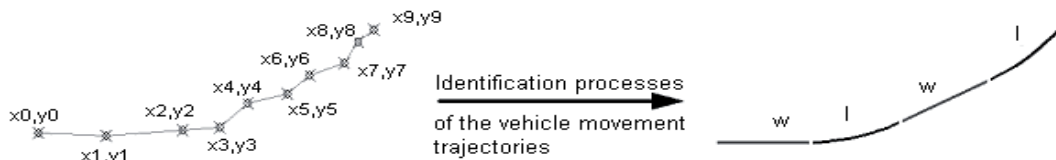

Figure 2. The syntactic primitives assignment

On a left side of the figure a geometrical coordinates were assigned. On the right side, the syntactic symbols are introduced. The trajectory description area is limited into the camera observation field size and its projection onto a road surface (the trajectory part under analysis). The distinguished shapes of the trajectory elementary units allow us assigning the vehicle's movement by several syntactic symbols.

The analysis algorithm distinguishes the not eligible movements on the road, observed in a specified road area. They are indicated by an evidence of traffic law, defining so called traffic incidents [6].
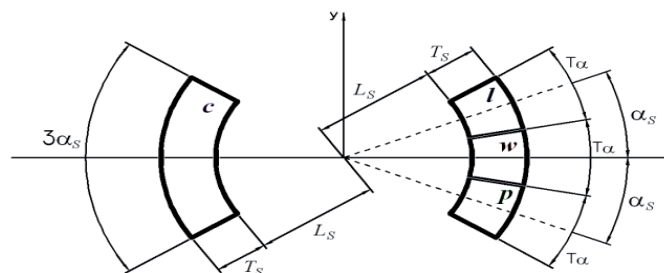

Figure 3. The syntactic symbols geometrical assignment

In Fig. 3 the geometrical assignment of main four description symbols was established, namely: driving ahead - „w", turning to the left - „l", turning to the right - „p" and reverse driving - „c" [11], [9]. Their parameters are provided by an angle coordinates (Table 1) [11], [9].

	L_S	T_L	α_S	T_α
Driving ahead: w	1,8	0,4	0	0,16
Turning left: l	1,8	0,4	0,16	0,16
Turning right: p	1,8	0,4	- 0,16	0,16
Reverse: c	1,8	0,4	π	0,16

Table 1. The syntactic descriptors example values

The vehicle's movement description primitives indicate present coordinates of its location. In case the current coordinate of the description unit is close to parameters of any symbol (of the description language), the subsequent part of the vehicle's trajectory is indicated (Fig.4). In the analysed video sequence, the vehicle's direction and placement was appointed by x.
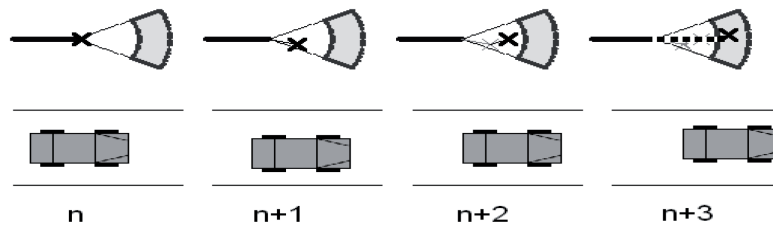

Figure 4. The vehicle's trajectory assignment in an image sequence

When the location vectors are close to any primitives of the language, the dotted line indicates the replacement of the vehicle - the movement trajectory (Fig.4).

The illustration for the directions symbols, as: driving straight-on, turning left and right or changing the vehicle's placement, on subsequent video frames (for v=60km/h), was introduced in Fig.5.
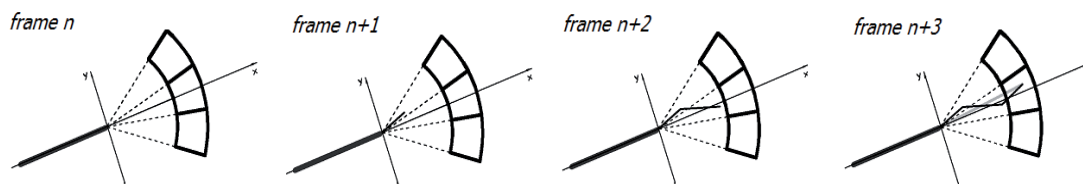

Figure 5. The vehicle's movement trajectory assignment

Majority of recently developed fast real time controlling machines, apply gate-level technologies (PLA, FPGA, GAL, etc.). They provide the user with the fastest processing units. Although this technology is satisfactory fast the data size need not to be larger then it is necessary, as the processor's number of gates is limited.

When the vehicle's movement description preciseness increases, the algorithms complexity (and processing time) is also increasing. Simplifying the vehicles trajectories tracking procedures we reduce remarkable the calculations complexity.

In traffic lanes junctions one can observe remarkable changes of vehicles speed and driving directions.

The high ways measurement sites are indicating in majority cases the over-speeding vehicles. In towns or in parking places, the vehicles movement analysis methods concern different and more complex tasks.

The syntactic symbols identifiers allow us not only reduce the data set size, but also reduce the scale of object characteristics recognition. Combining a data sampling rate with the vehicles' localisation one can find their speed and the driving (accidents) history.

Analysing this data samples the vehicles' dynamic characteristics can be assigned as well. The recorded number of vehicles placement (in the video sequence) indicates accelerations, slowing down or braking of the vehicle.

The movement trajectories, observed on the traffic lane background, allow us indicate all illegible manoeuvres of vehicles, as well.

3.   The trajectories description language

The discussed above primitives, of the vehicles traffic, assign the description alphabet Σ, for this specific language. The language grammar allows us modelling the transportation network structure. The language, using the alphabet Σ, understands any combination and subset of these symbols [5]. They produce words and sentences, of the language. The undefined or unrecognised movement is not classified by the algorithm formulas.

The fundamental task of the syntactic assignment method supports the vehicle's movement and localisation recognition, using the video data. The vehicle's movement description (and recognition) mechanisms are encoded by the language grammar, with several combination of these elementary symbols.

The definitions of the language grammar [6] are expressed by several relations of:

$$G = \left(\Sigma_N, \Sigma_T, P, S \right) \tag{1}$$

where:

Σ_N -   defines a set of non-terminals,

Σ_T -   set of terminals,

P -   is a finite set of rules or productions,

S -   is the starting symbol $S \in \Sigma_N$.

The alphabet Σ calls the limited set of symbols: $\Sigma = \Sigma_N \cup \Sigma_T$ and $\Sigma_N \cap \Sigma_T = 0$. The set of terminal Σ_T contains the defined {w, l, p, c} of the trajectories assignment. The non-terminals Σ_N consists of variables, used in words construction of the language body, then the production set P is used for the words construction by operations:

$$\eta \rightarrow \gamma \tag{2}$$

where: η, γ indicate symbols' sequences of products P.

According to boundaries, given by means of these productions [8], four grammar types were distinguished: unrestricted, context-sensitive, context-free and regular. The description of the road traffic manoeuvre, the context-sensitive grammar uses productions, expressed by following relations:

$$\eta_1 A \eta_2 \rightarrow \eta_1 \gamma \eta_2 \tag{3}$$

where: $\eta_1, \eta_2 \in \Sigma^*$ -   set of all symbols combinations in the alphabet
                        (with an empty word λ)

$\Sigma^* = \Sigma^+ \cup \{\lambda\}, \gamma \in \Sigma^+$ - sequence of not empty symbols:

$$\Sigma^+ = \{a, b, ab, aa, bb, ...\}, A \in \Sigma_N,$$

The symbol A can be replaced by the sequence of symbols γ, when A appears in context of symbols η_1 and η_2.

4. The traffic description by context-sensitive grammar

The context-sensitive grammar defines the rules of membership, within an advanced level of words formation of transportation objects free modelling.

It allows describing the manoeuvres as: a vehicle's lane turnover, overtaking and U-turning (back).

The turning manoeuvre, for the grammar construction of the turning radius, is observed in a range of 5 to 25 meters. It concerns identification process of the manoeuvre on crossroads in cities.

The grammar expression for the manoeuvre of the vehicles turning - left or right is expressed as:

$$G_{turn\_left} = \left(\sum_N, \sum_T, P, S \right)_{turn\_left} \qquad (4)$$

where:

$\sum_N = \{S, A, B, C\}, \sum_T = \{l, w\},$

$P = :$

0. $S \rightarrow All$
1. $All \rightarrow lBl$
2. $Al \rightarrow Awl$
3. $Awl \rightarrow wwlB$
4. $Awl \rightarrow wlB$
5. $lBl \rightarrow llC$
6. $Bl \rightarrow Bwl$
7. $Bwl \rightarrow wwlC$
8. $Bwl \rightarrow wlC$
9. $lC \rightarrow lwC$
10. $lwC \rightarrow lwwC$
11. $C \rightarrow l$

By the defined rules of membership of P, 27 words of the alphabet $\sum$ were obtained. The largest lock radius contains the lock primitives l of the vehicle, separated by two primitives of driving ahead movement w.

A graphical interpretation of this analysis, concerning the grammar words of the lock G_{turn_left}, has been presented in Fig. 6. The lock symbol visible in the figure, has a radius $R=5m$.

The grammar constructions of the vehicle's turn to the left and to the right, look the same; as in grammar G_{turn_left}.

Figure 6.   A grammar G_{turn_left}, for radius R=5m - graphical illustration

The traffic lane change is also an important manoeuvre, needed for the transportation network state complete description. The words definition of the manoeuvres' grammar, with the necessary set of the vehicle's movement symbols, has to be assigned as well.

The description language structure contains units for: driving ahead and the vehicle's locks. The sequence of symbols for the traffic-lane change description, consists of the vehicle's lock primitives combinations.

For avoiding mistakes in manoeuvres description (of the traffic lanes changes) the driving direction descriptors were provided as well (Fig. 5).
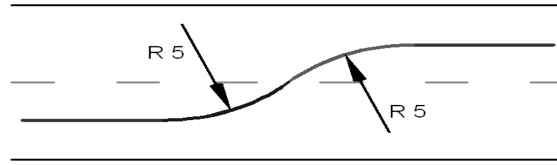

Figure 7.   The traffic lanes change manoeuvres; for radius R=5m

The grammar of the traffic lane turning to the left manoeuvre, contains the following symbols:

$$G_{change\_left} = \left(\sum\nolimits_N, \sum\nolimits_T, P, S \right)_{change\_left} \tag{5}$$

where:

$\sum_N = \{S, A\}, \quad \sum_T = \{l, w, p\},$

$P = :$

0. $S \rightarrow wwlApwww$
1. $Apw \rightarrow Appw$
2. $Ap \rightarrow Awp$
3. $Awp \rightarrow Awwp$
4. $Awwp \rightarrow Awwwp$
5. $lA \rightarrow Al$
6. $Alw \rightarrow Allw$
7. $Alp \rightarrow Allp$
8. $Al \rightarrow wl$

The belonging rules P, for the traffic lane changes, allow us finding up to 16 words of these states description, using the alphabet $\sum$. The vehicle's manoeuvre shape, on the traffic lane was illustrated in Fig 6.

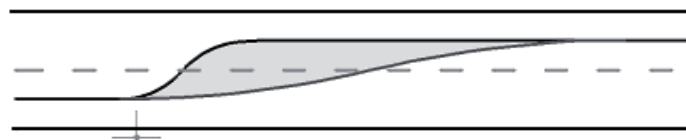The grey area shows an example of an eligible change zone (surface) on the traffic lane: G_{change_left}.

Figure 8. The traffic lane change illustration (G_{change_left})

The grammar constructions for traffic lane change descriptors were defined similarly to the above manoeuvre of turning left definition.

This construction of the manoeuvres' grammar is also used for the description at the parking by a kerb. The driving dynamics analysis is indicating a type of the manoeuvre and its characteristic features.

Two additional movement symbols, in the vehicles manoeuvres description language; for overtaking and turning of the vehicle, were also considered. Their grammar indicators are used for the manoeuvres assignment; with the trajectories' indicators defined in similar way.

The vehicle's overtaking manoeuvre [1] is defined as the traffic lane change; similarly to driving strait-on with overtaking; the barrier with U-turn (back) and the lane change.

The overtaking from the left is assigned by the relations:

$$L_{turnover\_left} = \left\{ \begin{array}{c} L_{change\_left}, w^n, L_{change\_right} : \\ 0 \leq n \leq 4 \end{array} \right\}$$ (6)

where:

L_{change_left} — the traffic change manoeuvre for grammar G_{change_left},

w^n — sequence of primitives; in the form of: $\{ \lambda, w, ww, www, wwww \}$,

L_{change_right} — the manoeuvre for traffic lane change, defined by a grammar G_{change_right}

The construction $L_{turnover\_left}$ of the language gives us 1280 words, of the manoeuvre for overtaking description, as a combination: the lane change – forward – the lane change.

The right-sided manoeuvre of overtaking was defined analogously to the left-sided manoeuvre, with different order of its components:

$$L_{turnover\_right} = \left\{ \begin{array}{c} L_{change\_right}, w^n, L_{change\_left} : \\ 0 \leq n \leq 4 \end{array} \right\}$$ (7)

The vehicle's U-turning manoeuvre, in the syntactic description method of the movement, uses combination of the early defined language units. The offered solutions allow us identify the direct U-turn of the vehicle, often with U-turn manoeuvre.

The language of U-turn manoeuvre description has been defined by:

$$L_{U\_turn} = \left\{ \begin{array}{c} L_{turn\_left}, c^n, L_{turn\_left} : \\ 0 \leq n \leq 4 \end{array} \right\}$$ (8)

where:

L_{turn_left} — the vehicle turn - manoeuvre was described by the grammar G_{turn_left}.

c^n — primitives sequence: $\{ \lambda, c, cc, ccc, cccc \}$,

Number of the language words, assigning the turning back manoeuvre, contains 3645 sequences, with their syntactic symbols.

5. The automaton for vehicle's movement trajectories description recognition

The automaton for the description words, accepting [3] the trajectory description language, allows us identify the observed scenery; by a Turing machine and its versions, as: a finite-state automaton, push-down automaton and linearly-bounded automaton [7].

This way the language description units are indicated. The machine is counting the function values for the given arguments [7]. The fundamental Turing machine model is assigned by the system [1]:

$$M = \left(Q, \Sigma, \Gamma, \delta, q_0, B, F \right)$$ (9)

where:

Q — is finite set of states,

Σ — an input variables set,

$\Sigma \subset \Gamma - \{B\}$ — (the input variables alphabet),

Γ — finite set of eligible bend symbols (the bend alphabet),

δ – the transition function,

q_0 – the starting state, $q_0 \in Q$,

B – blank symbol, $B \in \Gamma$,

F – the accepted states set, $F \subseteq Q$.

5.1. Linearly-bounded automata for states description

The linearly-bounded automata were defined by the Turing machine. It is restricted to modifications of the machine, doing calculations for a part of the bend, where an input status was recorded.

The linearly bounded automaton is called single-bend Turing machine, with a stop mode. Its alphabet contains two special symbols: starting and ending delimiters that define direct cells with the input data.

The presented work introduces the programming implementation of the automata theory, constructed as a parser, corresponding to the procedures of the syntactic assignment, of traffic accidents in the transportation network.

The linearly-bounded automaton defines a not deterministic model. The parser constructions identifying the network states, can be expressed by the following states:

$$P = (Q, \Sigma, \delta, q_0, F) \tag{10}$$

where:

Q – finite, not empty set of states,

Σ – finite inputs alphabet,

δ – the transition function (for mapping),

q_0 – starting delimiter,

F – ending delimiter.

The defined parsers of the road incidents identifiers [11] concern manoeuvres: turning the vehicle, traffic lane change, overtaking and U-turn of the vehicle. The parser construction for the turn left manoeuvres is assigned by the expressions:

$$P_{turn\_left} = (Q, \Sigma, \delta, q_0, F)_{turn\_left} \tag{11}$$

where:

Q – { q0, q1, q2, q3, q4, q5, q6, q7, q8},

Σ – { w, l },

δ – is defined by graph 1 (fig.9),
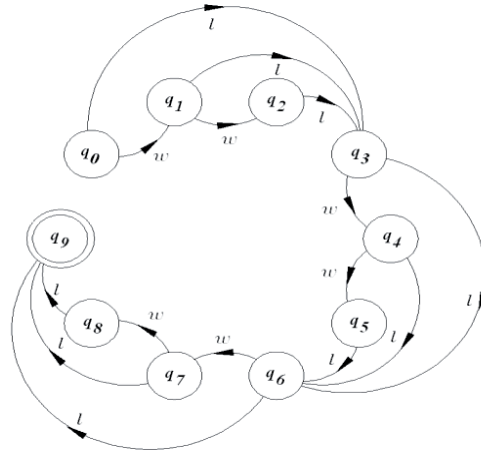
q_0 – {q0},

F – {q9}.

Figure 9. The parser states graph P_{turn_left} for assigning vehicles' turning manoeuvres

The linearly-bounded automaton P_{turn_left} allows us finding twenty seven words of the alphabet Σ for vehicles turning manoeuvres.

The parser states graph P_{turn_left} was presented in Fig. 9. The manoeuvre of the traffic lanes changing, for a left sided traffic, will be widening the traffic description symbols and a traffic network assignment.

Its localisation will identify a parser P_{change_left}, as:

$$P_{change\_left} = \left(Q, \Sigma, \delta, q_0, F\right)_{change\_left} \tag{12}$$

where:

$Q - \{q0, q1, q2, q3, q4, q5, q6, q7, q8, q9, q10, q11, q12, 12, q13, q14\}$,

$\Sigma - \{w, p, \text{ and } l\}$,

δ – is defined by graph 2 (fig.10),

$q_0 - \{q0\}$,

$F - \{q14\}$.

The offered construction P_{change_left} allows us accepting all sixteen alphabet words from Σ; the language of the manoeuvres, assigning the movement of vehicles. The parser P_{change_left} of the traffic states was introduced in Fig 10.
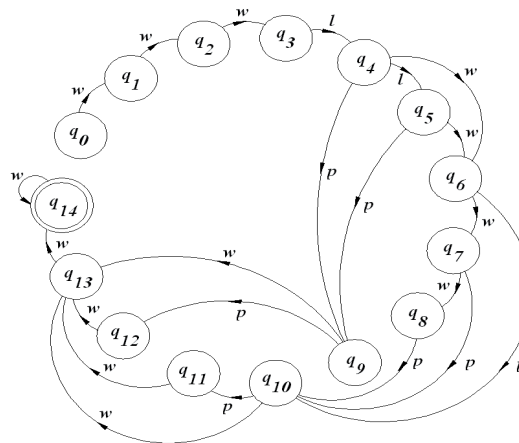

Figure 10. The parser states graph P_{change_left} for vehicles changing manoeuvres

The vehicles overtaking, it is a next manoeuvre that needs to be assigned for a complete vehicles and transportation lanes description. The construction of the parser $P_{turnover\_left}$, accepting this trajectory, has been defined by the expression:

$$P_{turnover\_left} = (Q, \Sigma, \delta, q_0, F)_{turnover\_left} \qquad (13)$$

where:

Q – {q0, q1, q2, q3, q33},

Σ – {w, l, and p},

δ – defined by the graph 3 (in fig.11),
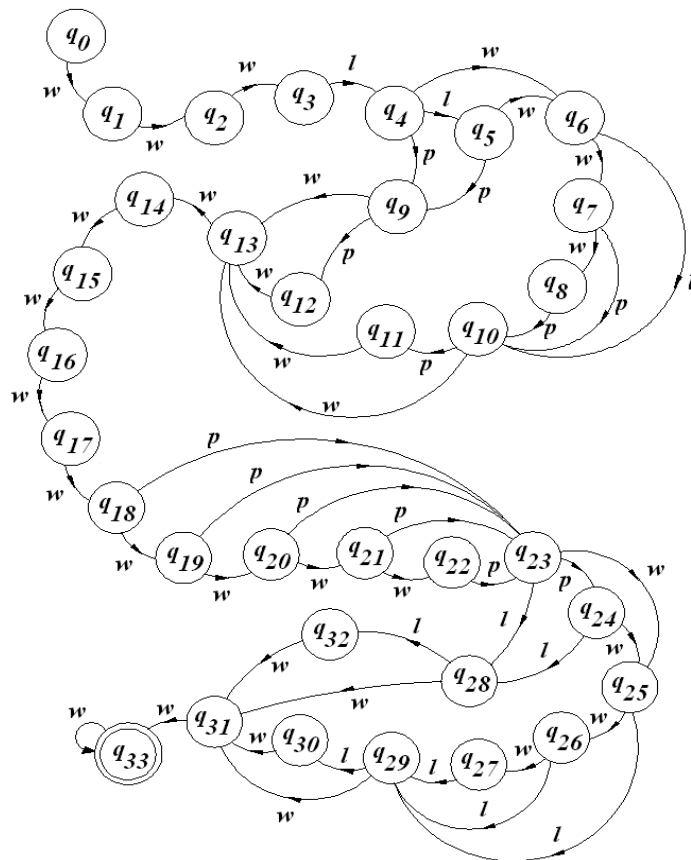
q_0 – {q0},

F – {q33}.

Figure 11. The parser states graph $P_{turnover\_left}$ for the manoeuvres turning-over

A very big number of expressions (1280), defining the complete manoeuvres set for overtaking is a reason that the table, of the accepted words by the parser $P_{turnover\_left}$, was omitted.

The next state on the road (with a complex movement trajectory) concerns the U- turn of the vehicle.

The parser P_{U-turn} uses the early defined automata, for the turn-right and turn-left manoeuvres, like in equation bellow:

$$P_{U-turn} = (Q, \Sigma, \delta, q_0, F)_{U-turn} \qquad (14)$$

where:

Q – {q0, q1, q2, q3, …, q23},

Σ – {w, p, c},

δ – is defined by the graph 4 (in fig.12),

q_0 – {q0},

F – {q23}.

Remarkable big number of words (3645), defining the U-turn manoeuvre, makes it difficult illustrating this operation by a table of words, accepted by the parser P_{U-turn}.

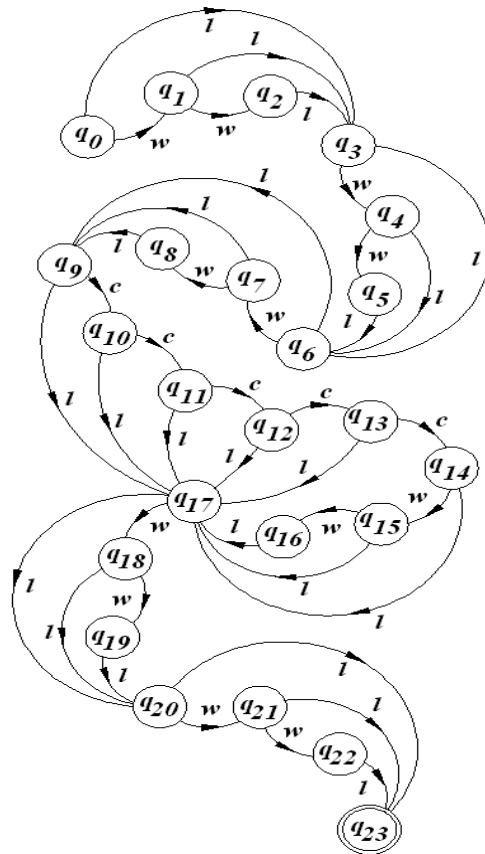
Figure 12. The parser states graph P_{U-turn} for vehicles U-turn manoeuvres

6. Conclusions

The vehicles' movement trajectories description allows us converting, very complex formalisms for states set of the road traffic description, into the language constructions. They convert difficult transportation scenery layout of the traffic, into the sequence of video frames, with simplified syntactic descriptions of this scene. The trajectories symbols define all movements of vehicles at the video sequences.

Today's attention, given the video-cameras on the roads, comes from a very useful data available for various analyses (in these fashionable applications).

They provide the traffic control technologies with unique data sets supporting the traditional data units, as: number of passing vehicles, their characteristics, vehicles' speed, vehicles' classes, specific traffic services indicators, etc.

It is remarkable more then it is available from classical measurements, using inductive loops or photo radars.

The elaborated algorithms allow us not only detect the passing vehicles. The methods identify the vehicles' movement trajectories, with many traffic incidents or accidents, registered by cameras installed on the roads. The available data set allows us to use modern video technologies for traffic identification, description, control and management.

The elaborated methods of the video-image processing were verified empirically in time of the project, for the video technologies transfer into small industry, carried on within the EC funds actions (in years 2006-2008).

The data for analysis were registered by the video real time systems, installed on several crossroads of Katowice city. They are powered by traffic controllers of ZIR-SSR Bytom, leading producer of the road traffic controllers in Poland. All steps of the development works, were verified continuously in time of the project development steps, by a research team in Informatics Systems Department of Transport.

References

[1]   Aho A., V.; Ullman J., D. *The theory of parsing, Translation and Compiling,* Prentice-Hall Series in Automatic Computation, Vol. 1, 1972.

[2]   Beymer D.; McLauchlan P.; Coifman B.; Malik J. *A Real-time Computer Vision System for Measuring Traffic Parameters,* Proc. of Int. Conf. Computer Vision and Pattern Recognition Workshops , p. 495-501, 1997

[3]   Chomsky A. *Syntactic structure*, Published: Walter de Gruyter, Berlin, 2002.

[4]   Deng L.; Tang N.; Lee D.; Wang Ch.; Lu M. *Vision Based Adaptive Traffic Signal Control System Development,* Proc. Of Int. Conf. Parallel and Distributed Systems, Vol.2, p 634 – 638, 2005

[5]   Fu K., S. *Syntactic Methods in Pattern Recognition*, Academic Press, New York, 1974.

[6]   Fu K., S. *Syntactic Pattern Recognition and Applications*, New Jersey, Prentice-Hall, 1982.

[7]   Hopcroft J.; Motwain R.; Ullman J. *Introduction to Automata Theory, Languages and Computation,* Person Education, Second Edition, 2001.

[8]   Kotowski W. *Kodeks drogowy -wprowadzenie,* (in polish), Stan prawny 2002-01-01, Wydawnictwo Infor, Warszawa 2002.

[9]   Piecha J.; Staniek M. *The syntactic alphabet analysis for vehicles simple and fast assignment,* Proc of Int. Conf. on Telematics, Logistics & Transport Safety, Silesian University of Technology, Katowice, 2009.

[10]   Piecha J.; Staniek M. *Formal Language For Vehicle Trajectory Description*, Monograph: "Transactions on Transport Systems Telematics and Safety"; edited by: Piecha J., Węgrzyn T., Silesian University of Technology -Academic Press, Gliwice (2009), chapter 3.4.

[11]   Staniek M.; Piecha J. *A Parser Construction For Identification Of Traffic Events In A Linguistic Description Of Road Traffic Flow*; Monograph: "Transactions on Transport Systems Telematics and Safety"; edited by: Piecha J., Węgrzyn T., Silesian University of Technology -Academic Press, Gliwice (2009), chapter 2.2.

[12]   Piecha J.; Staniek M. *Vehicles Trajectories Movement Description by Means of Syntatic Method*, Transport Problems Scientific Journal, Silesian University of Technology (2009), vol. 4/4, pp. 53-60.

[13]   Roess R.; McShane W.; Prassas E. *Traffic Engineering*, New York, Prentice-Hall, 2004.

[14]   Staniek M. *Metoda syntaktycznego opisu trajektorii ruchu pojazdów w sieci transportowej*, PhD work (in polish), Gliwice 2009.