Jan PIECHA, Marcin STANIEK*
Faculty of Transport, Silesian University of Technology
ul. Krasińskiego 8, 40-019 Katowice, Poland
**Corresponding author's e-mail:marcin.staniek@polsl.pl*

VEHICLES TRAJECTORIES MOVEMENT DESCRIPTION BY MEANS OF SYNTACTIC METHOD

Summary. The paper introduces an approach that allows the user spotting by video camera moving cars between traffic lanes. The syntactic primitives and the description language were defined. The algorithms of the vehicles trajectories movement recognition are also under consideration in this paper.

METODA SYNTAKTYCZNA OPISU TRAJEKTORII PRZEMIESZCZANIA POJAZDÓW

Streszczenie. Praca przedstawia metodę śledzenia, za pomocą kamery wideo, przemieszczania się pojazdów miedzy pasami ruchu. Zdefiniowane zostały również elementy opisu trajektorii ruchu pojazdów oraz język tego opisu. W pracy przedstawiono ponadto zasadnicze składowe algorytmów opracowanych do rozpoznania trajektorii ruchu na podstawie elementów zastosowanego języka opisu.

1. INTRODUCTION

Analysing the vehicle trajectories movement some simplifications of real trajectories descriptions were assumed. The vehicle route was divided into smaller elementary parts that allows assigning the vehicle's route, instead of pixels bitmap description. The vehicle's shape and its trajectory movement can be assigned by elementary graphical symbols, like: straight lines and curves.

The example of the so called vehicles trajectories movement was introduced in Fig.1. There was presented an output from a main road into a sub-way, by a road solution called road junction.

At the entrance of this road junction the vehicle is changing lane, assigned by two curves and one straight line in between. After that the vehicle enters the road junction, where the route has a curve-shape. The end part of the route becomes a straight line.

In this trajectories description some simplifications were used. They concern the junction of the curve and the straight line descriptors as they make the algorithms more complex not giving better quality of the trajectories description. What's more the trajectories are defined by connections of the vehicle's layout discrete indicators from every cell of the video image.

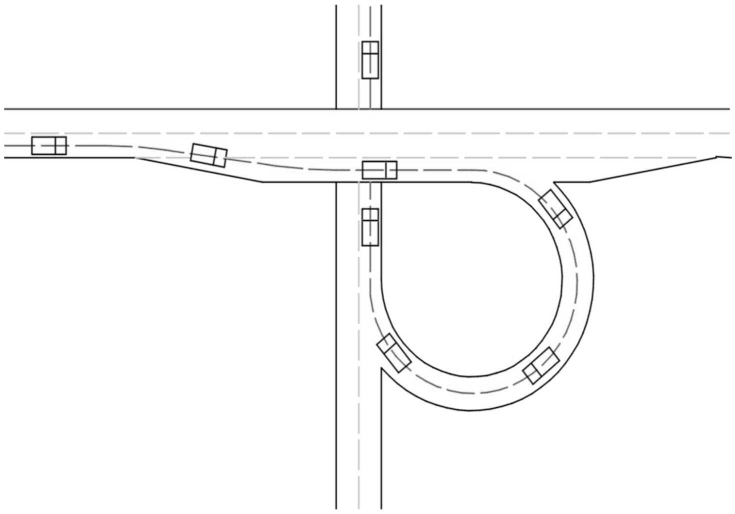

Fig. 1. The example trajectory of the vehicle movement (straight line – curve)
Rys. 1. Przykład trajektorii ruchu pojazdu (uogólnienie prosta - łuk)

2. SYNTACTIC SYMBOLS OF THE VEHICLE MOVEMENT TRAJECTORIES ASSIGNMENT

The traffic route recognition was defined by identification processes of the vehicle's primitive descriptors, used for the assignment of the analysed objects [1, 2]. They are analysed using the description rules, of the description language.

In Fig.2 the illustration of the trajectory primitives was introduced. The trajectory is divided into units indicating the vehicle's localisation during its journey along a traffic lane [3].

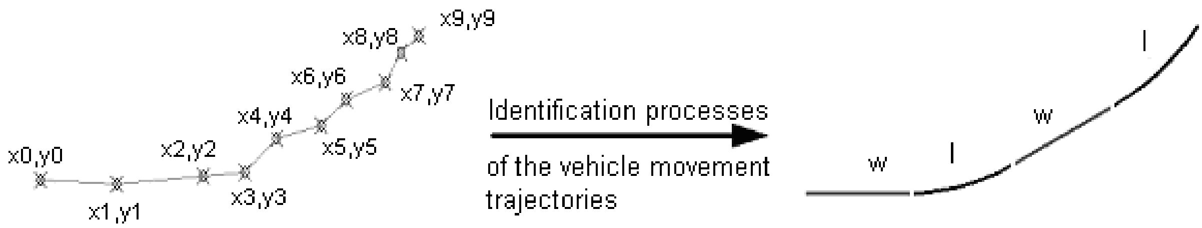

Fig. 2. Syntactic primitives illustration
Rys. 2. Ilustracja prymitywów opisu syntaktycznego

On a left part of the figure a geometrical coordinates were indicated. On the right part syntactic symbols were defined. The trajectory description was limited by the camera observation field size and projection on a road surface of the observed trajectory fragment. The distinguished shapes of the trajectory elementary units allow assigning the vehicle's movement by these syntactic units.

The analysis is needed for fast algorithms development, used for recognition of not eligible movements of the vehicle on the road. The operation has to be executed in a real time mode, of the traffic control system. This analysis indicates the traffic law, defining the so called traffic incidents [4].

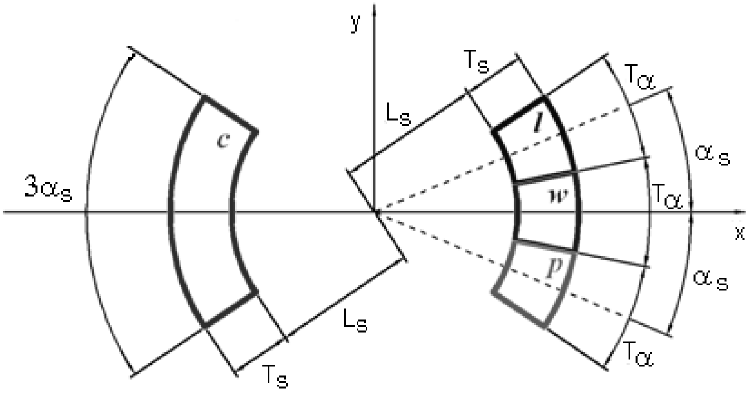

Fig .3. Geometrical assignment of the syntactic symbols
Rys. 3. Opis geometryczny symboli syntaktycznych

In Fig 3 geometrical assignment of main four symbols was established: driving ahead „w”, turning to the left „l”, turning to the right „p” and driving back „c”. These symbols were used for vehicle’s movement trajectory description [1], [2]. These three parameters are provided by an angle coordinates, like [1], [2]:

- 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),
- driving back: c (1.8, 0.4, π, 0.16).

3. THE TRAJECTORIES DESCRIPTION LANGUAGE

The discussed above symbols (primitives) for vehicles traffic description define the description alphabet $\sum$, for new introduced language, used for the traffic network assignment and modelling. The language using the alphabet $\sum$ understands any combinations and subsets of these symbols [5] – they produce words and sentences of the language.

The symbols define in driving sequences the passing vehicle’s trajectories. The undefined or unrecognised movement is not classified by this recognition algorithm. The fundamental task of the syntactic assignment method concerns the vehicle’s movement and localisation recognition at the video sequence. The vehicle’s movement recognition mechanism is encoded using the language grammar and generated by the grammar combination of these elementary symbols.

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

$$G = \left(\sum_N, \sum_T, P, S\right)$$

where: $\sum_N$ - defines set of nonterminals, $\sum_T$ - set of terminals, P - is a finite set of rules or productions, S - the starting symbol $S \in \sum_N$.

The alphabet $\sum$ calls the limited set of symbols, as: $\sum = \sum_N \cup \sum_T$ and $\sum_N \cap \sum_T = 0$. The set of terminal $\sum_T$ contains the defined {w, l, p, c} of the trajectories assignment.

The nonterminals $\sum_N$ consists of variables used in words construction of the language body, then the production set P is used for the words construction by operations:

$$\eta \rightarrow \gamma \tag{1}$$

According to boundaries given by means of the productions [7], 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:

$$\eta_1 A \eta_2 \rightarrow \eta_1 \gamma \eta_2 \tag{2}$$

where: $\eta_1, \eta_2 \in \sum^*$, $\gamma \in \sum^+$, $A \in \sum_N$,

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

4. THE CONTEXT-SENSITIVE GRAMMAR FOR THE TRAFFIC MOVEMENT DESCRIPTION

The context-sensitive grammar defines the rules of membership defining an advanced level of words formation of transportation objects free modelling. It allows describing the manoeuvres as: a vehicle's lane turnover, overtaking and 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:

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

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

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

Using the defined rules of membership in P it allows us getting 27 words of the alphabet $\sum$. The largest lock radius contains the lock primitives l of vehicle, separated by two primitives of a direct movement w. A graphical interpretation of this analysis that concerns the grammar words of the lock G_{turn_left} has been presented in Fig. 4. The lock symbols l indicated in the figure concerns 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}.

The traffic lane change (replacement) is a next important manoeuvre, for the transportation network state description. Due to definition of the word generation manoeuvre grammar the necessary set of the vehicle's movement symbols has to be defined. The description language construction contains units for: driving ahead and the vehicle lock. The sequence of symbols for the traffic lane change consists of contrary primitives of the vehicle's lock.

Fig 4. Graphical interpretation of a grammar G_{turn_left}, for radius R=5m
Rys. 4. Interpretacja graficzna wywodu słów gramatyki $G_{turn\_left,}$ dla promienia R=5m

For avoiding mistakes in manoeuvres description in the traffic lanes change, the driving direction descriptors were provided (Fig. 5).

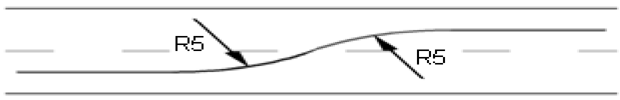

Fig 5. The graphical illustration of manoeuvres for radius R=5m
Rys. 5. Interpretacja graficzna manewru zmiany pasa dla promienia R=5m

The grammar of the traffic lane manoeuvre into the left:

$$G_{change\_left} = \left(\sum_N, \sum_T, P, S\right)_{change\_left} \tag{5}$$

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

P = :

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

The belonging rules P for the traffic lane change allow us finding up to 16 words of the state description, by the alphabet $\sum$.

The manoeuvre shape of the traffic lane change illustrates Fig 6. The dashed area defines a surface of an eligible change of the traffic lane change: G_{change_left}.

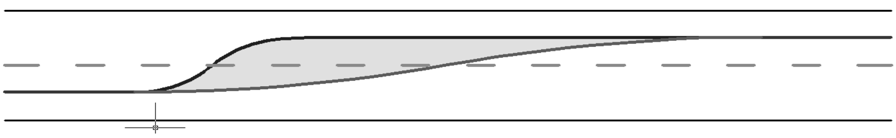

Fig. 6. The illustration of the traffic lane change according to the grammar G_{change_left}
Rys. 6. Interpretacja graficzna obszaru zmiany pasa wg gramatyki G_{change_left}

The grammar constructions for traffic lane change were defined similarly to the turning left. The differences concern symbols, assigning the vehicle turn left manoeuvre. This constructions of the manoeuvres grammar is used for description at the parking by a kerb as well. The driving dynamic analysis is indicating a type of the manoeuvre.

Next two vehicle movement symbols of the language for overtaking and turning of the vehicle were considered. Their grammar construction was used earlier as elements for the vehicles' manoeuvres assignment. The trajectories of these kinds of manoeuvres can also be defined similarly.

The vehicle's overtaking manoeuvre [8] is defined by the traffic lane manoeuvre change, similarly to driving straight on with overtaking of a barrier with turning back and a lane change. The overtaking from the left is defined by:

$$L_{turnover\_left} = \left\{ L_{change\_left}, w^n, L_{change\_right} : \qquad 0 \le n \le 4 \right\} \tag{6}$$

where: L_{change_left} – the traffic change manoeuvre for grammar G_{change_left}, w^n– sequence of primitives; in the form of: { λ, w, ww, www, wwww}, L_{change_righ} – 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 of overtaking description (the lane change – forward driving – the lane change).

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

$$L_{\text{turnover\_right}} = \left\{ L_{change\_right}, w^n, L_{change\_left} : \qquad 0 \le n \le 4 \right\} \tag{7}$$

The vehicle's turn back manoeuvre, in the syntactic description method of movement uses the early defined language units. The offered solution allows us identify the direct turn back of the vehicle, often with driving back manoeuvre.

The language of turning back manoeuvre description has been defined as follows:

$$L_{turn\_back} = \left\{ L_{turn\_left}, c^n, L_{turn\_left} : \qquad 0 \le n \le 4 \right\} \tag{8}$$

where: L_{turn_left} – the vehicle turn manoeuvre was described by the grammar $G_{turn\_left,}$ C – primitives sequence: { λ, c, cc, ccc, cccc},

Number of the language words assigning the turning back manoeuvre contains 3645 sequences with the syntactic symbols of the method (lock – moving-back – lock: $27 \cdot 5 \cdot 27$).

5. THE AUTOMATA FOR VEHICLE'S MOVEMENT TRAJECTORIES DESRIPTION RECOGNITION

The automata for the description words accepting [6] in the trajectory description language, allows us to identify the observed scenery; by a Turing machine and its versions, as: a finite-state automata, push-down automata and linear-bounded automata [9]. This way the language description units are recognised. The machine is counting the function values for the given arguments [9].

The fundamental Turing machine model is assigned by the system [8]:

$$M = (Q, \Sigma, \Gamma, \delta, q_0, B, F) \tag{9}$$

where: Q - is finite set of states, $\sum$ - an input variables set, $\sum \subset \Gamma - \{B\}$ (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 transportation network states description

The linearly-bounded automata defines the Turing machine, restricted to modifications of the machine for doing calculations for a part of the bend, where was recorded an input word. The linearly bounded automata is called single-bend Turing machine with a stop mode. Its alphabet contains two special symbols – ending delimiters that reduce direct entrance into the cells with an input data.

The work introduces the programming implementation of the automata, constructed as a parser that corresponds with the procedure of the syntactic assignment of traffic accidents in the transportation network.

The linear-bounded automata define a not deterministic model. The parser constructions for identifying the network states can be expressed by an equation:

$$P = (Q, \Sigma, \delta, q_0, F)$$

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. Q - is the finite set of states, Σ - is the finite set of input symbols, δ - is a mapping function, q_0 - is an initial state, $q_0 \in Q$, F - is a set of final states $F \subseteq Q$.

The defined parsers of the road incidents identifiers [1] concern manoeuvres: turn of vehicle, traffic lane change, overtaking and turning back the vehicle.

The parser construction for a turn left manoeuvres is assigned by the expression:

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

where: Q - { q0, q1, q2, q3, q4, q5, q6, q7, q8}, Σ - { w, l }, δ - is defined by graph 1, q_0 - { q0 }, F - { q9 }.

The linearly-bounded automata 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. 7.

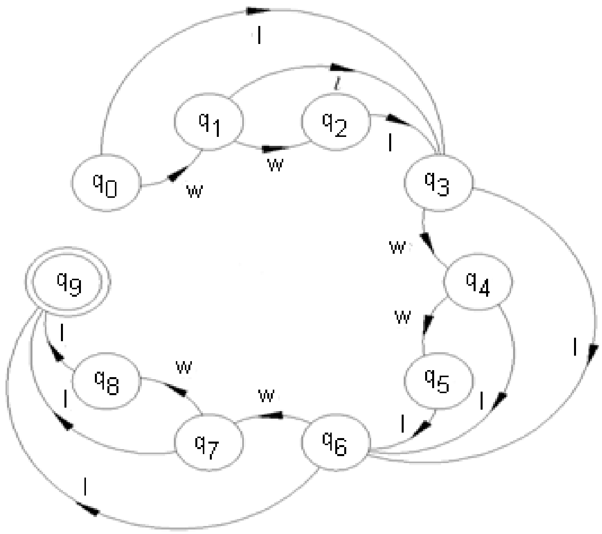

Fig. 7. The parser states graph P_{turn_left} for vehicles turning manoeuvres

Rys. 7. Graf stanów parsera P_{turn_left} akceptacji manewru skrętu pojazdu

Because of very complex transition functions δ of vehicles manoeuvres description for: the lanes changing, overtaking and the vehicles turning back, the parsers' functions were not introduced. In a work [1] the needed details of these manoeuvres identification are available.

6. CONCLUSIONS

The vehicles movement trajectories description allows us converting, very complex formalisms for states set of the road traffic. They convert a very difficult transportation scenery layout into the sequence of video frames, with simplified syntactic description of this scene. The trajectories symbols define all movements of vehicles at the video current record. Today's attention given the video-recorders comes from very attractive data (fashionable applied), available for various analysis. They provide the traffic control technologies with unique data sets supporting the traditional data units; as number of passing vehicles with their characteristics (speed, vehicles class, specific traffic services). It is more remarkable than it was provided by classical measurements with inductive loops or photo radars. The elaborated, by the contribution's authors, algorithms allows us not only detect the passing vehicles. The method identifies the vehicles movement and traffic accidents, visible in objective of the camera. This way very advanced traffic control algorithms can be defined and executed.

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

The data for analysis is recorded by video real time systems installed on several crossroads of the city of Katowice; powered by traffic controllers of ZIR-SSR Bytom, a leading producer of the road traffic controllers in Poland.

All step of the development works were verified continuously in time of the project development stages, by a research team in Informatics Systems Department of Transport, Faculty of Transport.

The introduced methods can be extended into further incidents of the road traffic description. What is more the available data set allows us to use modern video technologies for traffic identification, description, control and management; recorded by a single video-camera unit or by remarkable limited number of the cameras, watching the traffic scene of big cities.

References

1. Staniek M.: *Metoda syntaktycznego opisu trajektorii ruchu pojazdów w sieci transportowej*, PhD work (in polish), Gliwice, 2009.
2. 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, p.51-57
3. Roess R., McShane W., Prassas E.: *Traffic Engineering*, New York, Prentice-Hall, 2004.
4. Fu K.S.: *Syntactic Pattern Recognition and Applications*, New Jersey, Prentice-Hall, 1982.
5. Fu K.S.: *Syntactic Methods in Pattern Recognition,* Academic Press, New York, 1974.
6. Chomsky A.: *Syntactic structure*, Published: Walter de Gruyter, Berlin, 2002.
7. Kotowski W.: *Kodeks drogowy -wprowadzenie*, (in polish), Stan prawny 2002-01-01, Wydawnictwo Infor, Warszawa, 2002.
8. Aho A., V., Ullman J., D.: *The theory of parsing, Translation and Compiling*, Prentice-Hall Series in Automatic Computation, Vol. 1, 1972.
9. Hopcroft J., Motwain R., Ullman J.: *Introduction to Automata Theory, Languages and Computation,* Person Education, Second Edition, 2001.

Received 25.04.2009; accepted in revised form 16.12.2009