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# Mapping of city traffic network from digital aerial images

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ABSTRACT: High resolution aerial imagery provide an excellent basis of deriving information for a city traffic information system. The data capture procedure requires a suitable data model, which can be developed on lane level. The junction models can be quite complex on this level of details. The manual evaluation of the images can take these models into consideration, but is slow and expensive. Automation in data capture can apply the achievements of digital image processing, machine vision, artificial intelligence or their combination. The database of the traffic information system consists not only of geometric, but attribute information, too. These data can be derived partly from the imagery, but also importing from other sources is also required. The combination of imaging technologies with GPS vehicle navigation is a verification tool and an attribute data capturing method is realized.

## 1 INTRODUCTION

Traffic in cities nowadays has increased enormously, so that in some cities serious problems have arisen. In order to manage the traffic, other cities also need to have exact maps, in order to make the right decisions and to introduce efficient tools, like traffic lights, loop sensors or similar.

One excellent possibility in these efforts is to apply imaging techniques: remote sensing and photogrammetry. These sciences dealing with images taken from satellites or airplanes have enough geometric, radiometric and spectral resolution to bring the required information in the mapping procedure. The coupling information processing disciplines, like digital images processing, data base management, object modelling and last but not least geoinformatics bring further tools, which make the derived information much more useful.

The digital aerial images about Budapest, which were used in the experiments, have a field resolution of about 40 and 60 cm. This geometric resolution makes possible to detect most traffic objects including cars, road furniture and the lane marks. The last mentioned is therefore applicable to produce maps, which contain not only the roads and streets, but also their lanes, too.

Having the objective to create a traffic information system, we must design the system itself, develop an adequate data collection method with a suitable data model, then perform analyses and finally make products, partly for non-experts.

This paper will present the steps, which were executed independently, in order to be able to analyze them, of course with the hope to bring them together in the near future.

## 2 DATA MODELLING

The first step in the establishment of a traffic information system after the investigation of the hardware is to choose a base environment. Because the data to be handled are mostly referenced to a point with co-ordinates, a geographic information system (GIS) needs to be set up. The traffic management is dealing with streets, roads, junctions, so the GIS must have a toolkit for managing these features. The suggested data modelling philosophy is therefore the vector representation. The vector data model contains points, edges (sometimes called arcs) and polygons. The last one is uninteresting for building up a traffic system. The goal system must therefore handle these two basic elements. The next step is to develop a more detailed data model, which makes possible the later queries and analyses.

The detailed data model is based on directed graphs (digraphs). These graphs have edges, starting from a node point going through intermediate points (vertex points) and ending in another node point. The simple edge has only a starting and an endpoint, furthermore a connection between these points. The described element is usable for a street segment or in a higher detail level for a lane.

The traffic network has not only these straight segments, but also several crossings, junctions. The development of a crossing needs more design efforts. Taking only the road segments as basic system elements, a simple 4-arm crossing will have the model as presented in Figure 1.

If we refine the model to express not only the corresponding streets, but also the lanes, the model is getting complicated (Figure 2). This modelling has the advantage, that experts can take the turning restrictions also into consideration.

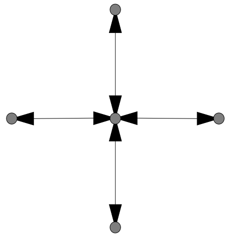

Figure 1. Simple 4-arm junction model with streets

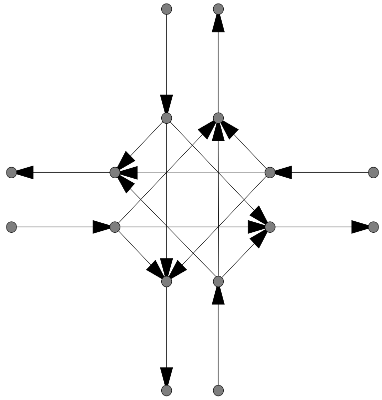

Figure 2. A lane-level model for the above 4-arm junction without turning back option

The drafted junction description is well suitable also for the data capturing procedure. When a colour aerial image has to be used, the model can be derived by overlaying the data model segments with the image. Figure 3, 4 and 5 are illustrating different junctions with their lane-level data model. The graph segments are drawn in blue (dark lines), where the nodes are in orange (thick dots).

Figure 3. A 3-arm junction overlaid with the lane level model

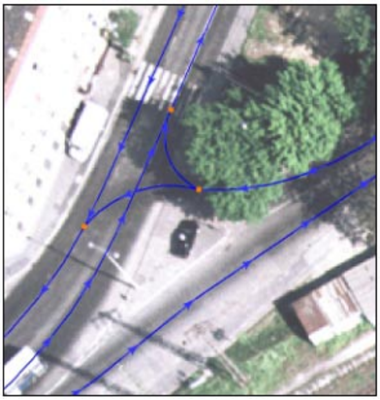

Figure 4. A constrained 3-arm junction with overlaying data model

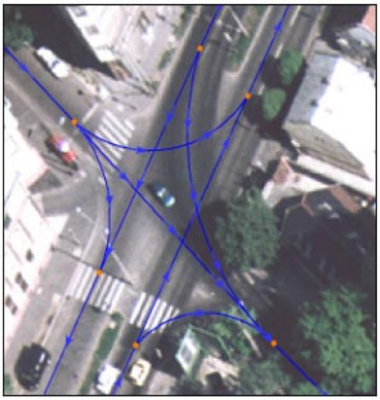

Figure 5. An asymmetric 4-arm junction overlaid by the lane-level data model

A disadvantage of the technique is the increasing complexity, which requires much experience. The use of efficient expert systems can help in the future in this modelling task in a (semi) automatic way. At this point it is also imaginable, that existing registration maps can be the input to the junction modelling. Such map works (Figure 6) contain not only lane marks, but traffic signs, which increase the readability; also allowing to handle those additional information in a perfect way. Artificial intelligence has quite efficient approaches to solve the problem.

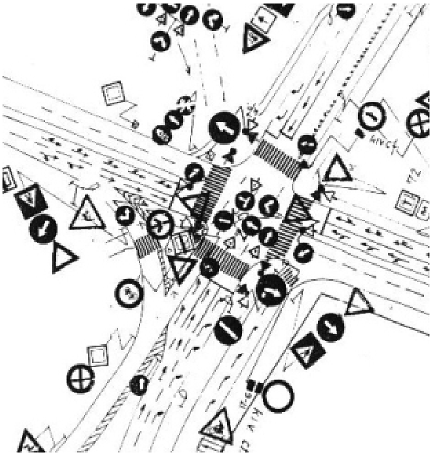

Figure 6. Subset of a registration map with all lane marks and traffic signs

## 3 DATABASE BUILT-UP

The traffic information system cannot be realized just with pure geometric data. Beside the street and lane geometry several attributes are also fed in. The later queries and analyses are also using this information so a deep consideration to design is required. The current GIS environments are working with powerful database management systems (DBMS), mostly with relational DBMS (RDBMS), which have superb possibilities to store, update and query these data. In the design phase must be decided, which offices can (must) serve with such information. Possible attributes for streets can be followings:

- name
- category
- type of surface
- speed limit
- average speed by day
- average speed by night
- strength
- maximal height
- maximal width
- maximal length
- noise level by day
- noise level by night
- CO, $NO_x$ concentration by day
- CO, $NO_x$ concentration by night
- dust level
- other restrictions.

The database built-up procedure contains also the data capture. The data capture can be split into two phases: geometric and attribute data capture. The first is easily executable by evaluating the digital aerial images. For this purpose softcopy photogrammetry software or a digital photogrammetric workstation is required. The manual data collection is a hard job, which needs skilled staff. Modern efforts in the automation apply also naturally to digital photogrammetry. More possibilities are discussed in chapter 4.

The attribute data collection required different methods. Direct field measurements (traffic counts, noise or chemical measurements), digitizing tabular data (strength, speed limits, restrictions), converting existing database (maximal height, width or length data) contents are all possible ways.

The mentioned attribute data can be used also in a more refined way: the time resolution can be increased with e.g. on-line registration (air pollution, traffic size etc.). The new systems can accept data via Internet (upload), also quite automatically. For public purposes other types of data can be managed as well, for example web cam images.

After storing all the required data, the analyzing functionality can serve with value added products: these outputs can be used by the traffic control, traffic planning, but can be offered also for moving vehicles and pedestrians. The different GIS systems offer nice analyzing functions together with adequate visualization. Traffic restriction maps, average traffic speed map, suggested routes for extreme loadings are just some examples of these. Figure 7 shows a drive through speed map. It is noticeable that the junctions are quite critical. With an automatic traffic count (by e.g. built-in loop sensors) one can produce a critical junction list for traffic messages.

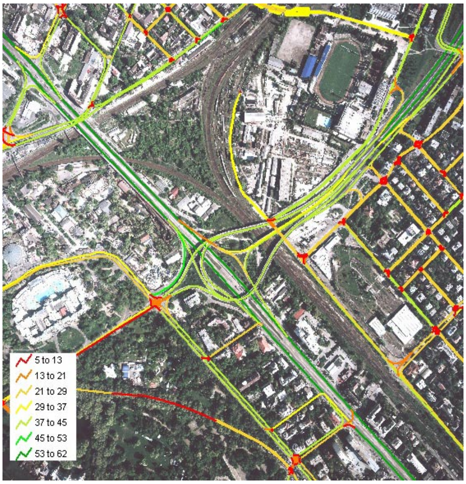


Figure 7. Speed map for a loaded junction and its neighborhood

## 4 DIGITAL IMAGE PROCESSING

Digital photogrammetry uses many tools for image processing and computer vision. The different filtering methods (like edge detection, sharpening, noise suppression) can support manual data collection, but there is also a power to develop an almost automatic data capturing strategy. The several supervised and unsupervised classification techniques produce a raster image containing only the interesting objects.

There were many experiments executed with supervised classifiers. Their base can be:

- image features: e.g. hyperbox and minimum distance (MD) methods
- statistics: Mahalanobis, maximum likehood (ML) or Bayes-classifier
- artificial neural networks: perceptrons, backpropagation networks
- hybrid solutions: MD+ML, ML with automatic splitting into subclasses etc.

Unsupervised methods can serve also as applicable techniques:

- statistical methods: K-means or ISODATA
- graph theoretical methods: minimum spanning trees
- artificial neural networks: competitive nets, SOM
- fuzzy logic: c-means method etc.

In the classification task several features could be used as input: from the raw pixel intensities to the different indices (vegetation, soil etc.), transformed intensities, neighborhood and texture, moments or even interest operators (e.g. Moravec, Förstner). The combination of the inputs could increase the classification accuracy in quite difficult situations. Figure 8 demonstrates a combined classification for a junction image, where raw pixel intensities of visible RGB channels, as well as texture measures (standard deviations, mask averages) were taken into consideration.

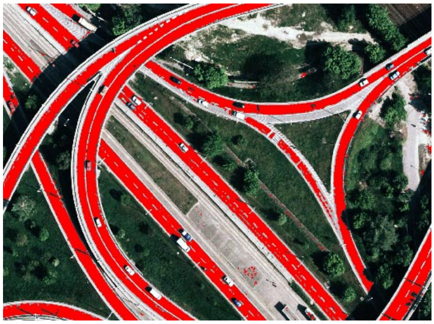

Figure 8. Supervised classification for a junction with pixel intensity and texture parameters (background image: color orthophoto)

By a possibly connecting conversion this classified image can be transformed into vector elements (edges). During the conversion special filters and vision operators can refine the classification result: majority filter, LIFE-filter, modus-filter, erosion, dilation, opening, closing and so on. These post-processing steps can remove the disturbing "pixel singles" or smaller pixel groups; they smooth the resulting raster images. The conversion itself can be any vectorizing procedure, e.g. skeletonizing. In Figure 9 a detail of the further processed junction image is presented. The figure shows the road edges, markers, so even the lanes.

Figure 9. Lane limits (red lines) derived from the above junction classification

By the higher level imaging algorithms, as by the grouping functions it can be reach, the computer recognizes the road objects, then creates a most likely network. By the grouping the smaller edge segments are to be connected. During this procedure the real network elements are built: we can speak about streets and no more about image edges!

The network creation step can expand the usage: the segments are compiled together, then even failing segments can be detected and eventually determined.

Using special road models and the corresponding extraction methods, the traffic network can be described. The description means a road graph, which is directly an input for traffic information systems. This description isn't limited of course for the geometry, but a group of attributes can be determined simultaneously. Attributes, like width, number of lanes, type of surface can be derived from the images. The use of colour imagery is suggested in this phase.

## 5 GPS APPLICATION

The traffic network mapping procedure can be extended by other approaches. One of the most convenient techniques is the use of the Global Positioning System (GPS). Putting the antenna on the car's roof, switching on the receiver and the test vehicle can start. During the trip, the equipment automatically registers the positions and other required data. The registered route can be overlaid with a digital orthoimage, so the imaging technique can be controlled in an independent way. Beside this control the route mapping data can be fusion with the derived data: the on-surface physical measurement with the measurement by remotely sensed data. In Figure 10 a test drive path is shown on a colour digital orthophoto.

Figure 10. A navigational trip path on a color orthophoto

After the read-out several very important traffic measurements can be calculated:

- *speed*: concerning the average traffic speed (of course with special conditions: the driver just follows the traffic, does not want to overtake all others!)
- *acceleration*: important is the negative acceleration, which means quick breakings. From this dangerous places could be detected.
- *side acceleration*: again the mapping of potential dangers, accidents.

These measurements are attributes, which must be stored in the database of the traffic information system. The later analyses and queries are based on these and the geometry. The next illustration shows a side acceleration analysis, where path segments of critical values are coloured and were visualized against the color orthoimage.

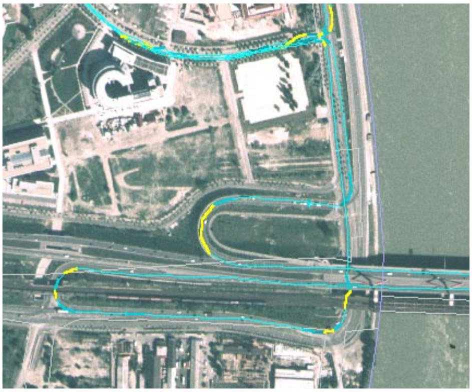

Figure 11. Critical side accelerations are coming up in curves

## 6 CONCLUSIONS

The paper integrates the research efforts in the direction of creating a GIS based traffic information system. Digital photogrammetry and remote sensing extended with several adequate information management disciplines can be an efficient data capturing technology. In order to use all the possibilities, high-resolution imagery have to be used, then even lane based information system can be achieved. After developing a suitable data model, the database can be filled up by manual or (semi) automatic image evaluation steps.

The executed tests and analyses concerning the manual data capture, as well as the current results of the application of higher level image processing techniques are illustrated.

The individual developments in the fields of photogrammetry, remote sensing, GIS, database management, object modelling or artificial intelligence can increase the automation level of the processing. The results of these disciplines can be integrated into a user-friendly traffic information system. Coupled with built-in sensors, the developed system can serve for 24 hour monitoring, too. The control instructions can be automated also having real time database. The build-up of this database can be realized by the mentioned imaging technologies.

The data modeling described has to be developed further in the near future. The automatic junction description could bring a convenient way to have model fulfilling the navigation requirements. Once the model is realized, the different imaging technologies can be applied to fill up the database concerning the model. The model building procedure can be extended by the demonstrated existing registration map using different techniques.

The new approaches in the automatic object recognition are also worth integrating in the system. The object recognition must concentrate on processing aerial imagery for extracting road and junction objects. The current statistical, machine vision and AI-based techniques have the potential to revolutionize the data capture, which is the basis of traffic management. After the creation and first database fill-up the next task is the change detection. From time to time the high resolution imagery taken can be applied to verify the data set, further the processing of the new images can correct it. In the situation the first phase will concentrate on the raw control having time resolution of days or week, but in the later phases more frequent checks could be performed, so the traffic detection is also reachable by remote sensing techniques. Other valuable remote sensing technologies, which are producing terrain height data (among others: SAR, Lidar), could be coupled to the data processing flowchart.

The integration of built-in sensors (e.g. loop sensors) is a kind of data fusion, where the results of these independent measurements will increase the usability of the information system. As built-in sensors we are planning to apply junction control cameras, so the data processing will be extended by machine vision solution on terrestrial imagery.

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## REFERENCES

Agouris, P. & Stefanidis, A. (Eds.) 1999. *Integrated Spatial Databases – Digital Images and GIS*. Springer, Berlin

Albertz, J. 1991. *Grundlagen der Interpretation von Luft- und Satellitenbildern – Eine Einführung in die Fernerkundung*. Wissenschaftliche Buchgesellschaft, Darmstadt

Bakos, G. 2002. *Realizing a vehicle navigation system in geoinformatical environment*. Thesis work. Budapest

Baltsavias, E.P., Grün, A. & Gool, L.V. (Eds.) *2001. Automatic Extraction of Man-Made Objects from Aerial and Space Images III*. Alkema Publishers, Lisse

Bähr, H.P. & Vögtle, T. 1991. *Digitale Bildverarbeitung*. Wichmann, Karlsruhe

Barsi, A., Detrekői, A. & et al. 1995. *Tutorial on Basic Concepts of GIS*. ISPRS Workshop, Budapest

Colwell, R.M. 1983. *Manual of Remote Sensing*. Sheridan Press, Falls Church

Duda, R.O., Hart, P.E. & Stork, D.G. 2001. *Pattern Classification*. Wiley, New York

Fórián, Z. 2002. *Using geoinformatical system in Internet-based environment*. Thesis work. Budapest

Jähne, B. 1991. *Digitale Bildverarbeitung*. Springer, Berlin

Kraus, K. 1990. *Fernerkundung – Band 2: Auswertung photographischer und digitaler Bilder*. Dümmler, Bonn

Laurini, R. & Thompson, D. 1999. *Fundamentals of Spatial Information Systems*. Academic Press, London

Li, H. 1997. *Semi-automatic Road Extraction from Satellite and Aerial Images*. Dissertation, Zürich

Longley, P.A., Goodchild, M., Maguire, D.J., Rhind, D.W. & Lobley, J. 2001. *Geographic Information Systems and Science*. Wiley, Chichester

Lovas, T., Barsi, A. & Eppel, G. 2001. *Processing of GPS measurements for navigational GIS*. IAG Symposium, Budapest

Lovas, T., Barsi, A. & Eppel, G. 2002. *GPS, GIS and vehicle navigation* [in Hungarian], Terinformatika, Budapest

Niemann, H. 1990. *Pattern Analysis and Understanding*. Springer, Berlin

Openshaw, S. & Openshaw, C. 1997. *Artificial Intelligence in Geography*. Wiley, Chichester

Russel, S.J. & Norvig, P. 1994. *Artificial Intelligence: A Modern Approach*. Prentice Hall, London

Swain, P.H. & Davis, S.M. 1978. *Remote Sensing: The Quantitative Approach*. McGraw Hill, London