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GPS Positioning and Digital Map Processing in 2D and 3D Terrain Environment

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One of the worlds most advanced and in the last few years most popular positioning system, that allows real global positioning and navigation, is Global Positioning System (GPS), also known as NAVSTAR GPS. Quick, precise and effective positioning in any territory can be achieved by using GPS system and computerized maps obtained by image processing technologies merged with application dependent overhead. The most persuading way of GPS data visualization is visualization on computerized maps or digital terrain model (DTM). Sometimes scanning errors have great influence on the quality and geometry of digital maps. These errors may be reduced or neglected with the use of some image processing techniques. In the paper we present a prototype of a system that is able to model terrain in the 2D space. It uses the information of the GPS system, passes it to a computer that contains an electronic map of large dimensions and visualizes the position of the receiver in real time on digital maps.

The further research is oriented in three-dimensional space using digital terrain models for positioning and for real-time movement through them.

1. Introduction

The NAVSTAR/GPS is actually the most accurate positioning service compared with traditional radio navigation systems. It provides satisfactory accuracy for many civil applications. The accuracy of the Standard Positioning Service (C/A code), that is available to civil users, is under degradation of Selective Availability (SA) which contribution is the greatest among GPS errors (ionosphere, troposphere, satellite clock, ephemeris, multipath, receiver's noise, etc.). SA can be bypassed with the use of Differential GPS (DGPS) [4]. The information provided to user by a GPS receiver contains many data that tell only a little to an inexperienced user. Therefore these data must be user-friendly represented and clearly visualised to be useful to anyone. Probably the most persuading way of GPS data visualisation is visualisation on computerised maps. To gain good results, maps must be prepared with special care [6]. Because the majority of maps exist as yet only as hard-copies, they must be first input into computer through the scanning device. The scanning process depends on the type of a certain map. Sometimes scanning errors have a great influence on the quality and geometry of digital maps. These errors may be reduced or neglected with some image processing techniques. These techniques are specific to a map type. On colour images some colour reduction and edge enhancement filters can be used to clear the picture and to reduce the noise. On grey scale images some other filters should be used [9]. If black-and-white maps are concerned appropriate thresholding technique should be chosen to obtain the best result. Another significant error caused by the scanning device is a geometric distortion. This distortion is also a consequence of paper contraction and extension. Some mathematical transformation can be applied to compensate such a distortion. After image processing digital maps should be stored in a way to occupy as little space as possible and at the same time the decompression time should not exceed reasonable limits. The JPEG algorithm was found to have been very convenient, because of its ability to change the ratio between a compression factor and a restoration quality. Depending on what geographic or geodetic projection the hard-copy map was drawn in, the digitised map must be adjoined into the appropriate co-ordinate system in which the incoming GPS data must be transformed too. Maps prepared in such a way can be a good base for a CAD program that is used to visualise GPS data and can offer a wide range of applications [6].

2. GPS system overview

GPS was introduced in 1973 by US Department of Defence. Two programs of satellite navigation, TIMATION that was being developed by US Navy and PROGRAM 621B that was being developed by Air Forces, were joint into a common project NAVSTAR GPS. The system was very good planed. Main characteristics were settled in the beginning and were not changed until now. It was planed to put 21 primary space vehicles and 3 spares into 6 twelve hours, 63^o inclination orbits. Later the number was reduced to 21 space vehicles because of financial troubles. The inclination was also changed to 55^o that causes some troubles with reception in Mediterranean. Today there are 19 satellites launched in 6 orbit planes at height 20 231 km. 2 - D navigation was first possible in October 1978 and 3-D was made possible in December 1978, both only a few hours a day [8]. Today 2-D coverage is provided 24 hours a day and 3-D navigation is possible for about 21 hours a day. The system is expected to be declared fully operational in 1995 with guaranty of US government not to charge direct users' fees for ten years from that point. GPS provides precise military service, using P-Code signals with accuracy under 1m, and civil service, using C/A code with accuracy of 100 m. Besides GPS there are also other satellite positioning services, like GLONASS (Russia), Navsat and Granas (Europe).

2.1. Principles

Space vehicles transmit spread spectrum signals on two bi-phase right-circular modulated carriers, denoted as L1 = 1575,42 MHz and L2 = 1227,60 MHz. Both frequencies are an integer multiple of atomic standard, present on each satellite. L1 carrier is modulated by both a 10.23 MHz clock rate *P-signal* and a 1.023 MHz *C/A-signal*. The L2 carrier is normally modulated by a P-signal identical to that on L1, but it can also be modulated by the C/A-signal to support special testing applications [12]. On L1, the C/A signal has twice the power of P code signal. The period of the P-code is 267 days. Each space vehicle contributes 7 day period code. This way 36 satellites can transmit its position simultaneously and receiver can detect the code from each satellite unambiguously. The period of C/A code is 1 ms and contains so called Handover word that is used by P code receiver to synchronise itself to the very long P-code. To civil users only C/A code is available. Satellite sends its position, status, information of other space vehicles in the system, time base correction and some other data, 16 all together to the receiver. Receiver calculates so called pseudo range to each space vehicle by estimating time that signal used to travel from satellite to receiver. This range is composed of real range and error ranges due to difference between satellites and receiver's time base and ionosphere delay (equation 1).

$$\begin{aligned}\rho_k &= t_k c \qquad (1)\\ &= \sqrt{(x-x_k)^2+(y-y_k)^2+(z-z_k)^2}+cdt\end{aligned}$$

Receiver knows (from received data) the position of a certain space vehicle (x_k, y_k, z_k). It must calculate its own position (x, y, z) and time difference (dt) due to ionosphere delay and time base difference. These are four unknowns and therefore it needs to know at least pseudo ranges to four space vehicles to find out 3-D information. If it doesn't "see" four satellites, only 2-D information is available or if the number is less than 3 it can not estimate accurate position at all. How to avoid such an outage is one of the problems in using GPS data for positioning and navigation.

2.2. Differential GPS

To increase accuracy of GPS position determination an approach called differential GPS should be used. A reference receiver on known location calculates corrections for satellite data and passes them to user receivers through radio or other data link. User receivers make corrections of position calculated by satellite data. As stated in [3] Accuracy 3-5 m can be reached this way. The problem is that user receivers should receive the same constellation of satellites as reference one. The area that is "covered" by one reference receiver is limited. To cover large distances a network of reference receivers must be used.

2.3. Error sources

The main error sources that affect GPS accuracy are [11] :

- *Selective availability (SA):* The Department of Defence of the USA corrupts GPS when using C/A mode. The characteristics of this degradation are classified, but it is known that SA involves a combination of signal "dithering" and ephemeris data manipulation. In the first case SA introduces a slowly varying delay into the time of satellite signal transmission. The gross features of this dithering can be approximated by a second order Markov process. In the second case, SA introduces a bias error into satellite ephemeris data. All this results in 100 m error for single user and about 0.8-2 m error if differential corrections are used.
- *Troposphere:* Troposphere can introduce a delay at very low satellite elevation angles (below 10^o). This can result in 2-3 m error for a single user and less than 1 m for differential GPS.
- *Ionosphere:* Ionosphere error depends on sun activity. P code receiver can simply correct this problem using data from satellites. C/A receiver can use a model to reduce the error, which is about 30 m in worst case for a single user and 2-3 m for differential GPS.
- *GPS receiver:* Error consists from background noise, thermal noise, multiple access interference, measurement quantisation error and code tracking loop noise. All together contributes to 1 m error, which can not be reduced using differential corrections.
- *Multipath:* Multipath error is usually less than a meter. It increases in concentrated cities, mountains...
- *Satellite clock:* Unpreciseness of satellite clock can result in about 1 m error.
- *Bad geometry* of space vehicles that are "seen" by the receiver can result in so called dilution of precision (DOP). The position range accuracy can be calculated through DOP by multiplying pseudo range accuracy by DOP.

3. Map Digitalisation

There exist many different types of maps. In general they can be classified by different criteria. One can be measuring scale (1:50000, 1:5000, etc.), the other can be purpose (tourist, geodetic,...). From the digitalisation and computerisation point of view, maps can be divided by the technique they were drawn:

- Black-and-white maps (cadastral maps, land register maps, simple line maps usually sparse)
- Grey-level maps (geodetic, military and tourist maps, usually very dense with a lot of information)
- Colour maps (geographic (atlas) or tourist maps with a lot of information)

The first decision that should be made when hard-copy maps are digitised is how they should appear in a computer. When simple black-and-white maps are concerned there is usually only one possibility. It should appear as a black-and-white digital map. Usually it does not make sense to produce coloured or grey level map out of black-and-white one, even if it is quite possible to achieve. The same applies to colour and grey level images. The informational contents should only stay the same or be reduced. If this is taken under the consideration six possible transformations can be done:

hard-copy map	**digital map**
black-and-white	black-and-white
grey-level	black-and-white
grey-level	grey-level
colour	black-and-white
colour	grey-level
colour	colour

There are two possible ways to achieve particular transformation. It can be done by

- scanning mode
- image processing

The first depends almost only on scanning device being used. After digitalisation some image processing can also be done to improve image quality and to reduce noise. This way images are scanned in the mode as the final image should look like. If the hard-copy map is grey-level or colour and the result should be a binary (black-and-white) image, the scanning mode should be black-and-white. The binarisation is done by a scanner and the user has only a small influence on quality. The second way offers much more control over the process flow. Scanning is done in the same or one degree higher mode regarding informational rate as the final image should be. This results in these relations:

hard-copy map	**bitmap image**	**scanning mode**
hard-copy map	bitmap image	scanning mode
black-and-white	black-and-white	grey-level
grey-level	black-and-white	grey-level
grey-level	grey-level	grey-level
colour	black-and-white	colour
colour	grey-level	colour
colour	colour	colour

The most important step here is pre-processing of scanned images. The user can choose various image processing techniques to gain the result that satisfies his demands [5]. In our case two particular cases from above were taken into investigation. The first was preparation of cadastral maps for a CAD program that can semi-automaticly do raster-to-vector conversion [2] and can visualise GPS data in real time. The second was preparation of colour geographic maps for some geographic information system (GIS) applications, including GPS tracking.

3.1. Cadastral maps

Cadastral maps are black-and-white maps, containing usually only polygons and some text. The result of map pre-processing should be low-noise one bit raster image, that represents the original as accurately as possible. The distribution of black signal pixels and black noisy pixels on hard copy is very spatial dependant. The experiment with black-and-white scanning mode showed that the scanner made bad thresholding and the result was noisy bitmap image, which would be hardly improved by additional image processing. A good binary image was needed because of an easier implementation of semi-automatic raster-to-vector conversion algorithm. Therefore the maps were scanned with a dynamic range of 256 grey levels and a resolution of 200 dpi. After that each pixel was classified in one of two classes using dynamic

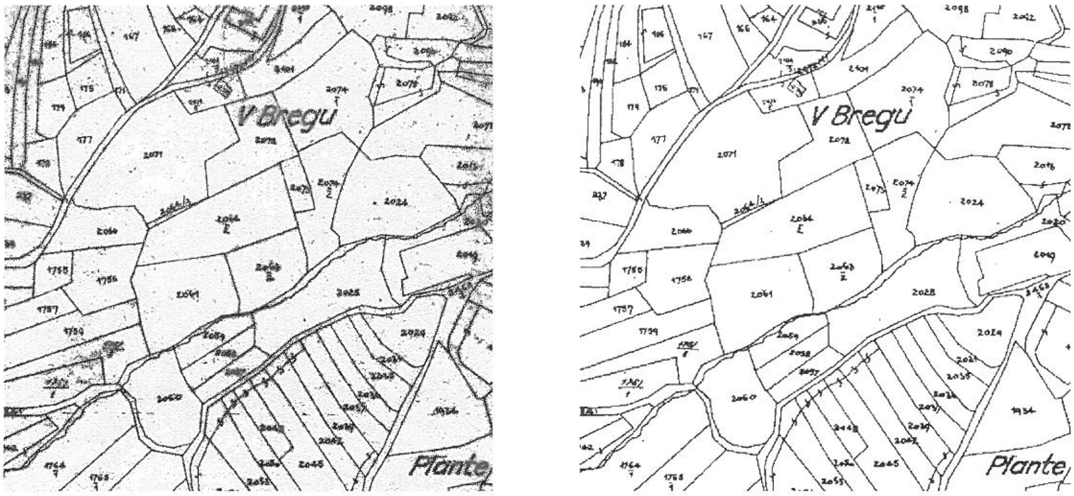

Figure 1: The cadaster map scanned in 256 grey-levels before and after threshholding

Figure 2: Block diagram of a despecle filter

thresholding, which gave better results as local and much better results as global thresholding. Some methods of dynamic threshold were tested [10] , resulting in a modified algorithm for dynamic threshold determination. The results were tested with calculating two coefficients: the shape measure and the uniformity.

The threshold in every pixel of the grey level image was determined using the formula:

$$T(x,y) = C(x,y)\sigma_{x,y} + \mu_{x,y} \qquad (2)$$

where:
$C_{x,y}$ is so called threshold coefficient, defined as
$C_{x,y} = \frac{kH_n}{N.}$
H_n is the number of pixels in the whole image having the same grey level as pixel itself
N is the number of all pixels in the image
k is determined experimentally and lies between 0.65 and 1
$\sigma_{x,y}$ is the standard deviation of the pixel (x,y) and eight adjacent pixels
$\mu_{x,y}$ is the mean value of nine pixels

3.2. Colour maps

Colour maps were digitised to be used in a GIS application, permitting real-time GPS positioning. Because of the amount of data and the nature of application, grey level digital maps were chosen as satisfying. Scanning was made in a colour mode, using 256 colours.

Then colour was removed and despecle filter was applied [5]. Resulting grey level image was then processed by a sharpen filter twice. This results in a clear 8 bit grey-level image, suitable for zooming and unzooming with all text clearly visible and readable.

3.3. Geometry correction

The scanner and paper errors result in a geometric distortion of a rectangle to a general quadrangular. This was compensated on a digital image using special geometric transformation that

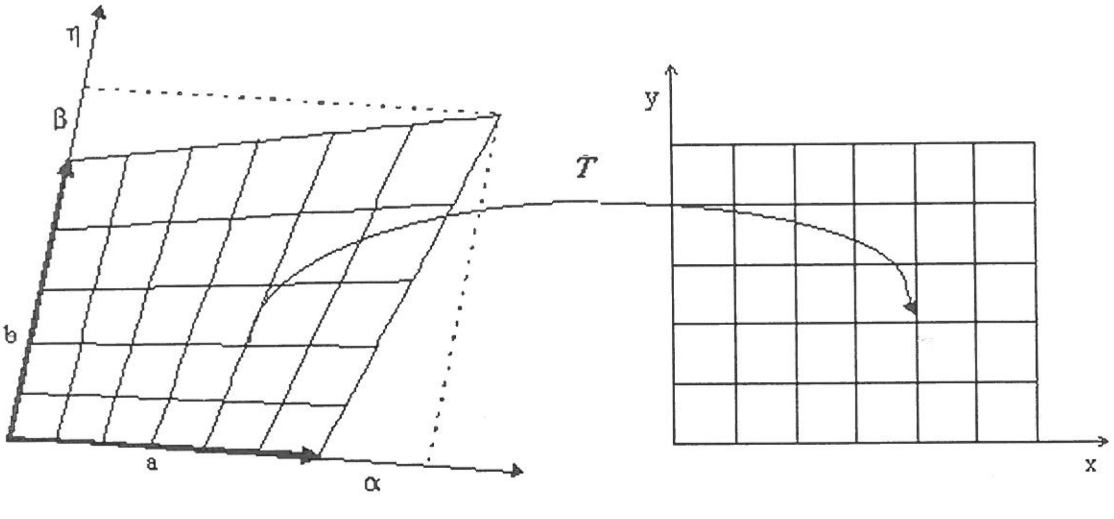

Figure 3: Transforming of a general quadrangular to a regular rectangle

needs only four map's corner points determining general quadrangular as an input and four points of a resulting rectangle. The transformation T from coordinate system into coordinate system (x,y) is expressed in equations 3, 4.

$$x = \frac{1}{2\beta}(-1 + \beta\xi - \alpha\eta + |\sqrt{D}|) \quad (3)$$

$$y = \frac{1}{2\alpha}(-1 - \beta\xi - \alpha\eta + |\sqrt{D}|) \quad (4)$$

where D is a discriminant:

$$D = (1 + \beta x + \alpha y)^2$$

3.4. Image compression

Digitised maps of large dimensions request also a lot of data space on hard disk. The need of data compression arises if many maps should be stored on a computer hard disk, being available to a certain CAD program to display them and use them in an application. On cadastral maps run length encoding is already good enough compression. It was applied on image segments to make possible their fast redrawing and almost smooth moving across the image. Grey level images demands much more storage space as black-and-white. The RLE (Runa Length Encoding) for every bitplane separately is not good enough. We found the JPEG algorithm [13] very suitable to compress 8 bit grey level images. The compression ratio depends on a demanded image restoration quality. Because the input images were quite good, the quality of 40and the compression ratio of approximate 10 was achieved. All the maps of Slovenia in measuring scale 1:50000, 256 grey levels were compressed into 80 MB this way. The speed of JPEG software compression and decompression depends on a computer speed

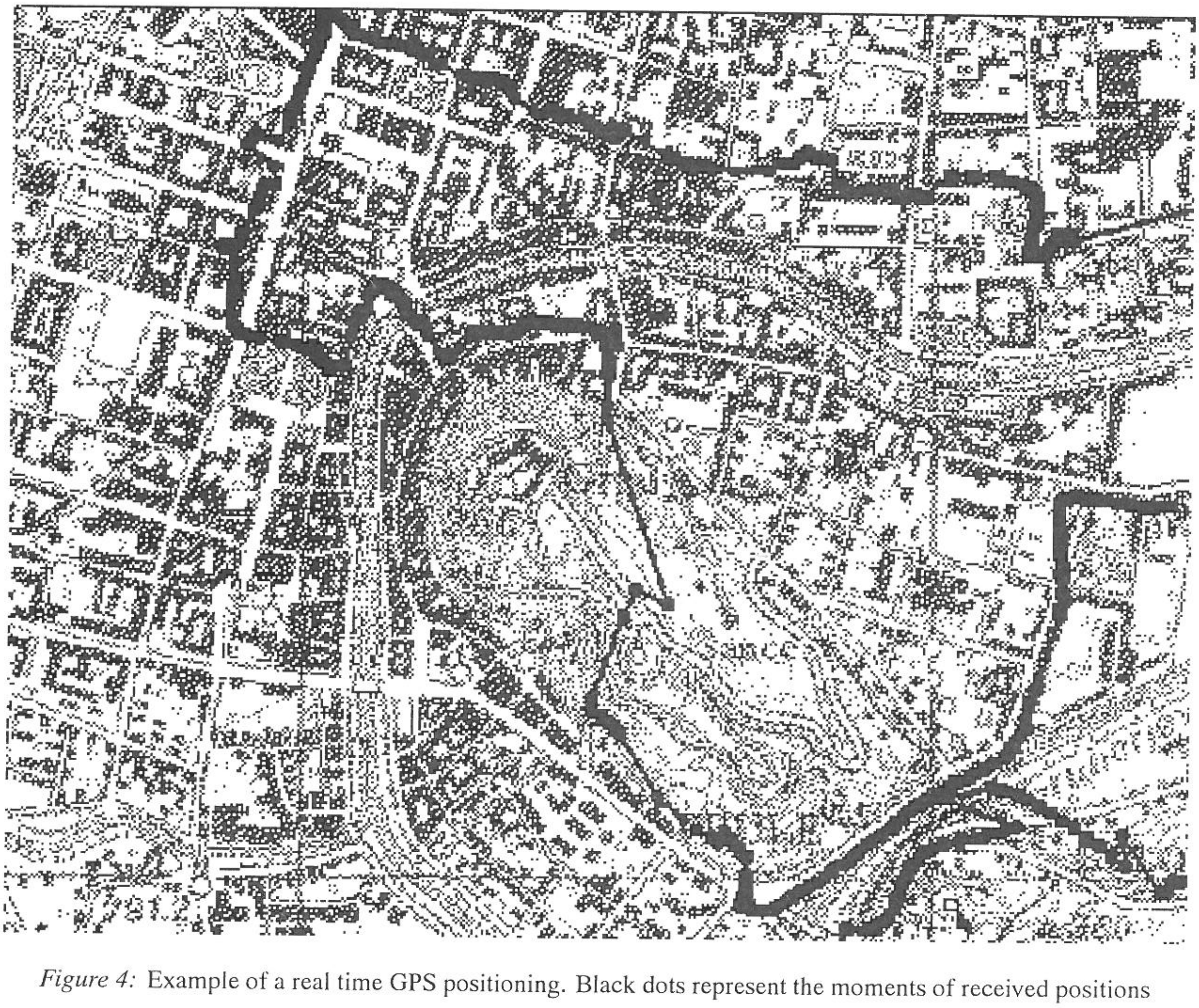

Figure 4: Example of a real time GPS positioning. Black dots represent the moments of received positions

and available memory. This can be eliminated with hardware implementation of an algorithm, which is already. commercially available.

4. Experimental results in 2D positioning

Both types of maps described so far were used in a GPS application where GPS data were visualised in real time. First maps were digitised and properly adjoined into coordinate system. Position from GPS receiver, which has a period of 1 second, was on-line transformed into the same coordinate system. GPS receiver provides position usually in geographic coordinates i.e, geographic latitude and longitude. Slovene cadastral maps are plotted in transverse mercator projection (TM) also called Gauss-Krüger projection. Transformation is done through mathematical series, where the number of taken terms, defines the precision. After the transformation a certain fixed error, that exceeded all known GPS errors together including SA, was observed. It was found out that this error was due to a digression of Slovenian geodetic net to world net. This fixed error was observed across the time and an average was estimated. Every incoming position was than first corrected by this average estimation. The same solution was applied to grey-level maps, plotted in geographic coordinates.

Some pre-processing of position data, including Kalman filtering was done to improve precision of position visualisation in dynamic applications like vehicle tracking. Besides the position it is necessary to visualise some other data from GPS (time, speed,...). Cadastral maps are usually sparse enough to permit writing some text near the position marks not covering important map data. Grey-level maps are much more sensitive to writing text over them. A layer based approach was implemented to overcome such

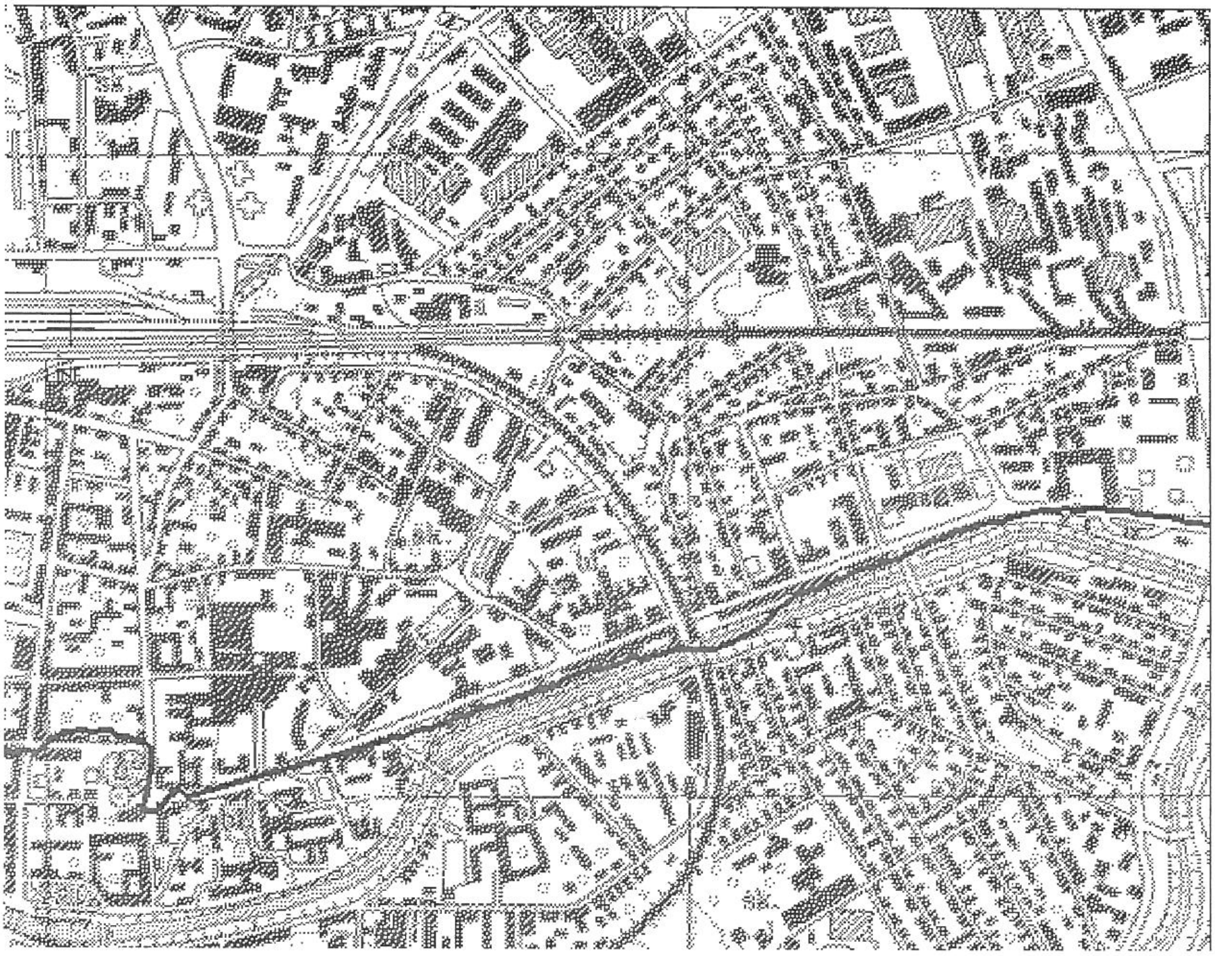

Figure 5: Another example of a real time GPS positioning (car tracking) using digital grey-level map - city drive

Figure 6: Delaunay triangulation correction using 2D map information

troubles and to admit GPS data being incorporated in GIS environment.

5. 3D terrain representation

Terrain can be represented in several ways. One of them is using Digital Elevation Model (DEM) which consists of equally spaced 3D points. These points should be somehow conected to give the impression of the terrain. If fast manipulation or redrawing is needed the Delaunay triangulation is very suitable. The triangles can be corrected (redivided) using 2D map information [7]. The real-time movement through 3D environment is also made posible.

Since the visual impression of such triangles sometimes does not remind on a certain part of terrain, some other way should be chosen to present valleys and hills more plasticly. The net connecting the DEM points or 3D surface is somehow more suitable than a triangulation.

An interesting research point is also matching DEM and aerial photos. 3D information must be extracted from a single image and matched with 3D terrain model or several projections of DEM in 2D plane must be compared with a photo.

Connecting the above mentioned terrain manipulations with 3D positioning using GPS can offer an interesting spectrum of applications. The third coordinate (the height) is in C/A mode of GPS less precise than other two. The reason is connetcted with bad fitting of an ellepsoid used as the earth model to real environment. To obtain an useful 3D information GPS must be used in P code, differential or codeless mode. Otherwise some other source for height information must be selected.

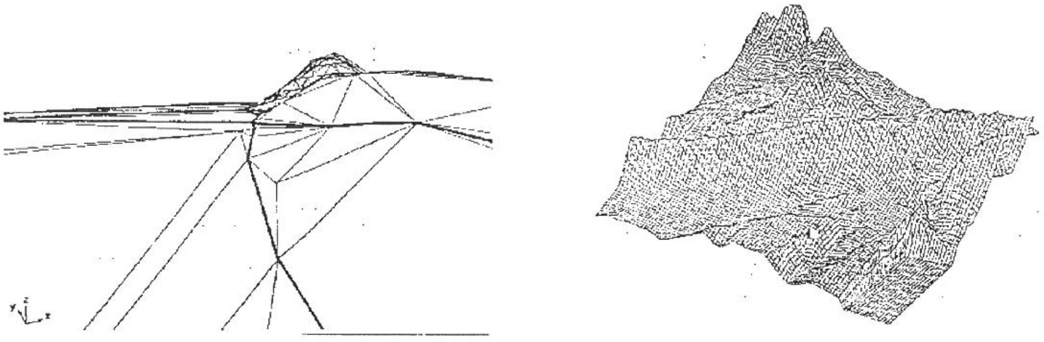

Figure 7: Terrain representation with triangulation and net

6. Conclusion

GPS system can provide satisfactory position estimation for use in 2–D environment. Accuracy generally depends on price of GPS equipment. Low-cost receivers with almost no additional pre- and post-processing software can provide 100 m accuracy. This can be greatly improved with the use of differencial GPS system (under 5 m).

If digital maps are correctly prepared and organised, real time positioning can be easily achieved, even with portable PC compatible computers. This fact can offer wide area of applications in traffic monitoring, tourism, etc. Additionally a ground communication system can be used to pass many GPS positions to the same place (communication center) which can keep track and pass feedback information to GPS receivers.

Using GPS information in 3–D terrain environment is a bit more difficult because of the problems with accuracy of height data. Rendering 3D terrain data in real time also demands powerful hardware. 3D applications are therefore much more expensive requiring accurate DEM data and fast redrawing algorithms.

Future research will be oriented in simplifying and price reducing of 3D real-time GPS positioning with emphasis on 3D terrain data processing and rendering.

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