SENSING GEO-INFORMATION

Inaugural address

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Sensing Geo-Information

Dear Rector of ITC, members of the board, professors, staff and students of ITC, distinguished guests, dear friends,

Up-to-date and reliable geo-information is indispensable for managing our planet. ITC is developing and transferring knowledge in the field of geo-information and earth observation for a wide variety of management problems such as water management and the management of natural resources and urban areas.

While several departments at ITC are applying geo-information and earth observation technology to provide solutions to those problems, the role of the department of Earth Observation Science is in the development and transfer of methods for the acquisition and quality analysis of geo-information. In what we call the knowledge node "Topographic Mapping" we focus on the acquisition of large scale geo-information in support of applications like you will find them in cadastres, urban planning and management, navigation, and disaster management.

As listed in a recent study by the Netherlands Geodetic Commission this type of geo-information is now rapidly moving away from traditional maps to sheet-less and scale-less topographic databases, from two-dimensional to three-dimensional representations and from static to dynamic. Just as an example I show a view of the web application Google Earth that was launched recently (figure 1). Here 3D building models are combined with high-resolution satellite imagery and used for the purpose of navigation in a virtual reality like environment.

Figure 1:
Screen shot of Google Earth

Like the geo-information itself, the acquisition of geo-information has also been subject to many developments over the past few years. And many more are to come. All these developments will clearly impact the way in which we will acquire geo-information in future. In this inaugural address I would like to give you a short overview on several developments with respect to sensors, platforms and data processing methods and then present what I would see as the prospects for automating geo-information extraction with sensor systems.

Sensor developments

Digital aerial camera's

Aerial images are a very important source for acquiring large scale geo-information. Although digital photogrammetry has gradually been introduced into practice since 1980, the first digital aerial cameras that can compete with the conventional film cameras are only available since around 2000. The reason for this slow development is that it is technically very difficult to produce CCD-chips with a size of some 10.000 by 10.000 sensor elements. Yet such a size would be required to approximate the geometric resolution of aerial film cameras. Some years ago camera manufacturers decided not to wait any longer for advancements in CCD-chip technology but to adopt work-arounds. This resulted in two different types of digital aerial cameras: the three-line cameras and the multi-frame cameras. The three-line cameras are using the well-known push broom technology. Three linear array CCD-sensors sharing the same lens system are providing forward, nadir and backward looking views. GPS/INS-technology is required to determine the orientation of all recorded scan lines.

Multi-frame camera's on the other hand use multiple frame CCD-sensors that all have their own optical system. By combining either convergent or time-delayed recordings of these frame sensors, large digital images of up to 8000 by 14000 pixels are composed.

The advantages of both types of digital aerial cameras are evident: problems with image deformation should be history, the radiometric resolution is much better than that of film cameras (allowing better measurements in shadow regions) and the digital cameras can provide larger forward overlaps between the images. The last aspect is of importance for automation in the photogrammetric processing. I'll return to that topic later.

Laser scanners

Another important sensor development of the last decade is the advent of airborne laser scanning. In the Western world laser scanning has rapidly become the preferred way of acquiring digital elevation models. Laser scanning is currently conquering the world wide markets and has already been applied in ITC clientele countries like Honduras, Brazil, Egypt, Algeria, India and Thailand.

It is clear that airborne laser scanning is gaining more and more importance for the acquisition of geo-information. This is witnessed by the increasing number of companies providing laser scanning services and the increasing number of articles published on laser scanning at international conferences. It was also witnessed by the good attendance of the laser scanning workshop that was held at ITC from Monday till Wednesday this week.

The Netherlands has probably been the first country to use laser scanning for the acquisition of a detailed nation wide digital elevation model. The laser scanning surveys for this so-called AHN started in 1996. The first version was completed in 2004.

The point density of 1 point / 16 m^2 of the AHN was chosen based on the system specifications of the laser scanners in the mid 90-ies. Since then laser scanning technology developed much further. Instead of 2000 measured points per second the latest laser scanners now operate with frequencies of 100.000 points per second. With these measurement frequencies very detailed surface models can be acquired of up to 10 points per square meter. With helicopters, even more detailed surface models can be acquired. Although digital elevation models remain the most important product of laser scanning, the high point densities open opportunities for a much wider range of applications. And, very important, they also enable a much higher level of automated processing.

Another improvement is the storage of multiple reflecting pulses. Laser scanners emit very short light pulses. Such a pulse reflects on the object it encounters and the laser scanner measures the elapsed time. The footprints of laser beams have a width of some 20-50 cm. Within a single beam some of the energy of a pulse may reflect from the top of trees whereas another part may reflect from the ground that is visible in between the leaves. A single emitted pulse may therefore result in multiple reflected pulses. Modern laser scanners are now capable of recording up to 4 or 5 of such pulses.

This enables to capture both the top surfaces as the bottom surfaces in one survey. On the left hand side of figure 2 you see the shaded height image of all pulses that reflected first, e.g. reflected on the highest object in the terrain. On the right hand side the lowest recorded surface is shown. Note that on the right side of the building, you now suddenly see cars that were parked under the trees.

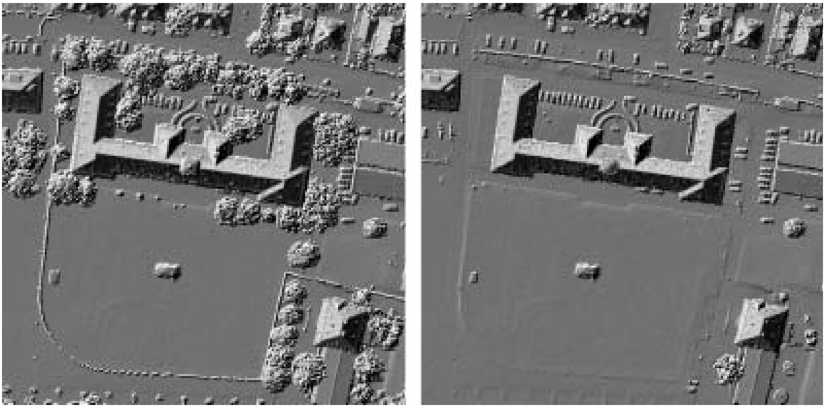

Figure 2: **First and last pulse recording with a laser scanner (images created by TopoSys)[1]**

The latest development in this field is the recording of full waveforms. If a laser beam hits a tree part of the energy reflects from the various leaves and branches of the tree and a part reflects from the terrain. Instead of storing the positions of the peaks in the returned signal, several scanners now have the option to digitize and store the complete waveform. This improves opportunities for studies in forestry but may also lead to better means for determining terrain heights.

[1] **See** *http://www.toposys.com/* **for more information**

Multi-sensor systems

While both the optical as well the laser ranging sensors are further improving, it is commonly agreed that the future of airborne surveys will be in the integration of both sensors. Laser scanners excel in the efficient determination of surfaces. Optical data, however, remains indispensable for the accurate outlining of objects as is required for most mapping projects. Imagery and point clouds are thus complementary data sources for the production of geo-information. Already now, most providers of laser scanner surveys offer the simultaneous acquisition of optical data. The combination of such data enables much better classifications than from a single data source only.

High-resolution satellites

Another development that caught quite some attention is the advent of high-resolution satellites. The image resolutions of these satellites are still expected to improve to about 40 cm in two years from now. For mapping projects on a mid-size scale satellite imagery may become a good alternative for aerial photographs. For large scale mapping, however, the resolution remains insufficient.

Clearly there are several other interesting sensor developments, like those on global navigation satellite systems (in particular Galileo) and hyperspectral and radar sensors. For the purpose of large scale mapping, optical and laser ranging sensors will be the most important. In this address I restrict the sensors development overview to these sensors.

Platform developments

Let me then now continue with some developments on the platforms that can be used to acquire sensor data. When ITC was founded 55 years ago, it was called the International Training Centre for Aerial Survey. At that time, aeroplanes were the only suitable platform for data acquisition over large areas. Later, recognising that information was now also gathered from satellites, ITC changed its name to the International Institute for Aerospace Survey and Earth Sciences. Aeroplanes, helicopters and satellites now have been the platforms for aerospace surveys for a long time. In the next few years new platforms will be introduced that may have a large impact on the availability of geo-information.

Unmanned airborne vehicles

In June this year the Flemish government signed a contract for the production of a so-called high altitude long endurance unmanned airborne vehicle. This UAV will be powered by solar energy and fly on an altitude between 12 and 20 kilometres. Test flights will commence next year and in 2007 the UAV should be operational with a multispectral camera. The first UAV with a laser scanner is planned for 2008, followed by a radar and thermal camera UAV in 2009. The properties of a UAV are very attractive. They are somewhere in between or a mixture of those of aeroplanes and satellites. Like satellites, UAV's are flying continuously. Well, that is, for eight months per year. Only in the winter months the solar energy is insufficient for operation. At an altitude of 12 km images will be recorded with a resolution of 12 cm, which is close to the resolution of aerial photography. UAV's seem to be a very suitable platform for monitoring events with a high frequency and are therefore heavily promoted for the European Union's programme on Global Monitoring for Environment and Security (GMES).

Model aircrafts

The usage of UAV's for data acquisition has been made possible by the miniaturisation of sensors. The advent of low weight pocket size cameras and videos for the consumer market is now even enabling their usage in model aircrafts and model helicopters. Figure 3 shows the acquisition of large scale imagery with a video system mounted on a model helicopter. The helicopter as well as the direction of the camera head can be radio controlled. Data was recorded over an area near Phuket, shortly after the tsunami. Model aircrafts are very portable and low cost platforms. They may be in particular useful for immediate response actions like damage assessment, albeit that their application will be restricted to relatively small areas.

Figure 3: Video frame captured from a model helicopter

Processing developments

While all these sensor and platform developments are important for obtaining data, the most time consuming and costly phase is the extraction of information out of this data. Before assessing the chances of automation in this field, I first like to mention a few developments related to data processing.

Image understanding

In the eighties and nineties of the last century much research efforts have been put into computer understanding of aerial imagery. It has proven to be extremely difficult, if not impossible, to get anywhere near the quality of results produced by human photogrammetric operators. In particular, modelling of knowledge required for image understanding remains unsolved. Clearly, quite some progress has been made on modelling and using knowledge in frames and semantic networks. Roads in rural areas and buildings with simple shapes can be reconstructed with a moderate level of success. However, more complex situations, in particular urban areas, can not be dealt with automatically. And, unfortunately, most mapping needs to be done in urban areas! Even though modelling of knowledge will remain a problem for a long time, the availability of high resolution height data may now very well change the chances of successful automation.

Point cloud processing

Let me therefore first elaborate on the importance of high resolution for automated processing of laser scanner data. Probably the most important task in processing point clouds is the separation between points on the terrain and points on buildings, trees and other objects. This is commonly referred to as filtering. If I would give you the sampling of a height profile (top profile of figure 4) and tell you that the point spacing is about 10 meter, it is difficult, if not impossible, to tell which points are terrain points. If I would increase the point density (middle profile), the picture starts to become much clearer and one would be able to make a classification. With the same original points at 10 m intervals, a higher point density data set could, however, also have looked like the bottom profile of figure 4. Now your classification would be different. High point density is very important for automated classification of point clouds. I would therefore expect that for future laser scanning surveys, the optimal point density will not be determined by the required accuracy of a digital elevation model. It will be determined by the interpretability of the point cloud. In fact, this is very similar to the issue of choosing the right photo scale of aerial photographs for large scale mapping: the most critical factor for determining the optimal photo scale is the interpretability of the photograph, and not, as one may think, the required map accuracy.

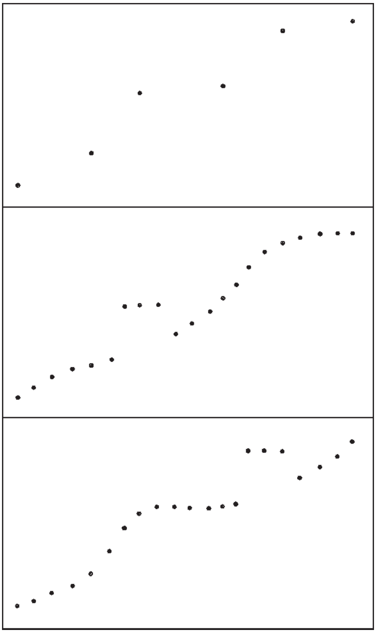

Figure 4: **Top: Profile sampled at 10 m intervals. Middle and bottom: two possible profiles of the same area at higher point density.**

With the higher point densities it becomes feasible to group points into meaningful segments. Segment-wise classifications and processing algorithms are now being developed. I expect they will replace the current point-wise classifications. In remote sensing we have seen a similar transition. In the early days all classification algorithms were pixel-based. Nowadays, the focus is more on segment- or object-based image classifications.

On the left hand side of figure 5 you see points that are grouped based on proximity only. Already this simple operation allows one to select large patches of terrain points and roof points. On the right hand side the point cloud has been segmented into planar regions. This result can be used as the basis for three-dimensional building modelling. The high point densities result in highly redundant and therefore reliable estimations of surface parameters.

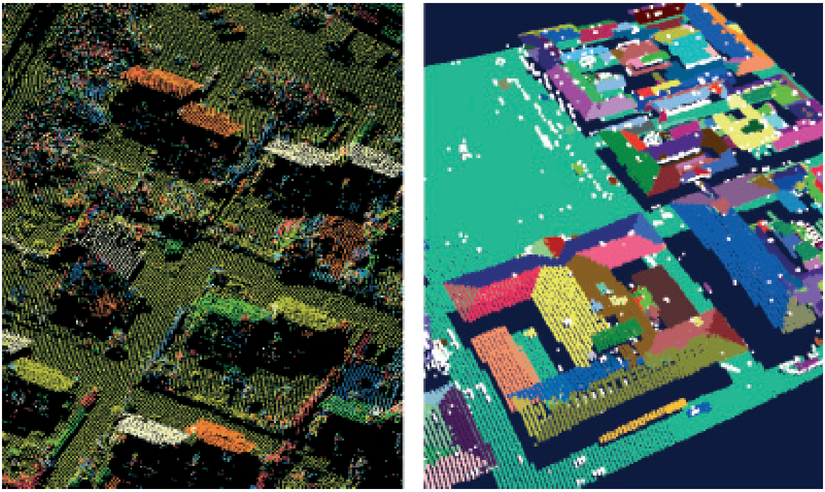

Figure 5: Segmented point clouds.

Video processing

Redundancy is also the keyword for automated processing of video data. With 25 images per second, the differences in perspective and contents of two successive images is usually very small. This makes it relatively easy to automatically track distinct features from image to image. Tracking of features through time can be used for various purposes. It enables automated robust estimation of the camera motion as well as the recorded object surfaces. More recently it has also been used to improve image segmentation. I would like to show you examples of the last two applications.

Figure 6 shows a terrain surface that was reconstructed from a video sequence. The video was taken from a model helicopter over a rather remote pre-Inkaic settlement in Peru by colleagues from the ETH Zürich[2]. By matching the terrain texture from image to image, many corresponding points can be determined that allow to reconstruct the object surface. The video data is also used to create an orthophoto that is projected onto the reconstructed surface shown here in a frame of a simulated fly-through.

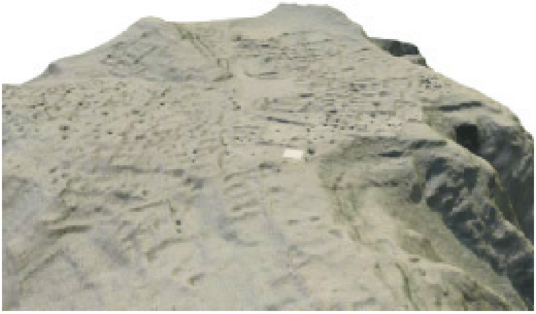

Figure 6: Terrain surface reconstructed from video imagery.

The second example is from recent research at the University of Washington in Seattle[3]. It shows how to exploit the redundancy in a stack of video images to improve the image segmentation. Here this technique is used for converting a video into a cartoon animation (figure 7).

Figure 7: Segmented video image making use of redundancy between successive frames.

We expect that similar techniques may also proof useful for the interactive extraction of geo-information from video data.

[2] See *http://www.photogrammetry.ethz.ch/research/pinchango/home.htm* for more info

[3] See *http://students.washington.edu/juew/* for more information

Prospects for automating geo-information extraction with sensor systems

I have sketched you now several developments with respect to sensors, platforms and data processing methods. With all these recent and expected changes, what can we expect of automatic extraction of geo-information with sensor systems? I would like to review these prospects for digital elevation modelling, mapping, change detection and 3D city modelling.

Digital elevation modelling

Digital elevation models will remain an important type of geo-information that is required for many applications. Like no other sensor, laser scanners are capable of recording high quality and high resolution height data. In many countries laser scanning replaced other methods for the acquisition of digital elevation models. It will be a matter of time, maybe a few years, until this technology is available to most of ITC's clientele countries.

By that time I expect that the problem of extracting digital elevation models from the sensor data, i.e. the point clouds, will be largely solved. Nowadays, companies need to spend much time on quality control and editing of the elevation models that are produced by filter algorithms. Discontinuities in the landscape and the sometimes low point densities cause the filter algorithms to break down and make manual editing necessary. This is time-consuming and costly. With the advent of segmentation-based filter approaches and the higher point densities of modern laser scanners a much higher amount of automation seem to be within reach.

Mapping

Some progress, but clearly to a lesser extent, can also be expected for automation in mapping. Nowadays, mapping is primarily performed using digital photogrammetric workstations. Based on decades of experience, these workstations are highly optimised for manual mapping in aerial photographs. To take advantage of information that can easily be extracted from laser scanner data, the producers of photogrammetric workstations should make immediate efforts to extend their software with tools for processing point clouds, or even better, with tools that allow simultaneous mapping in images and point clouds.

Within such environments it seems feasible to automate the mapping of some important features. Experiments on combined imagery and laser scanner data with a point spacing of 1.4 m already yielded accuracies of 95% for classifications of buildings and vegetation. With densities of 10-20 points/m^2 and making use of imagery to refine feature outlines, I expect that a large percentage of buildings can be mapped automatically in future.

This will, however, not be the case for all topographic features. The mapping of roads, fences, and many other features will still require the intelligence of the human photogrammetric operator. For the manual mapping, the high spectral resolution of images of the new digital aerial cameras may proof useful. For automatic extraction of features, however, it will have little impact.

Change detection

When topographic databases need to be updated the detection of changes becomes part of the mapping process. This part is becoming more and more important. The need for up-to-date geo-information forces the providers of geo-information to shorten their revision cycles. Now, if revision cycles get very short, only a small part of the database objects will need to be modified. And this implies that the amount of time that is required just to check whether objects need to be updated becomes a substantial part of the revision process. It is therefore interesting to assess to what extent the change detection process can be automated.

Luckily, change detection is less demanding than change mapping. For change detection a computer algorithm does not need to fully understand the new situation or to outline the changed objects. The only purpose of the change detection is to flag a database object. A human operator could then perform the actual mapping of the changes for that object.

For this task I again expect that the availability of high resolution height data could enable automation to a large extent. In multi-temporal datasets all construction activities result in a changed surface description. For buildings this is quite obvious, but also road construction works or forest cuts will immediately show up in multi-temporal height data. In future such data could well be acquired by sensors on board of UAVs that are constantly monitoring the Earth's surface.

3D city modelling

For the more advanced three-dimensional modelling of cities I expect that building models can be reconstructed automatically for some 90 to 95 percent. The remaining 5-10 percent will require some amount of operator interaction. This does not imply that those buildings need to be measured completely manual. Large parts of those buildings may still be correct. What would be required are tools for editing the results of automatic reconstruction. Such tools are not yet available and will need to be developed and incorporated in photogrammetric workstations.

In two projects subsidised by the BSIK programme Space for Geo-Information, ITC will further develop methods for automated and semi-automated extraction of building models from laser scanner data and imagery.

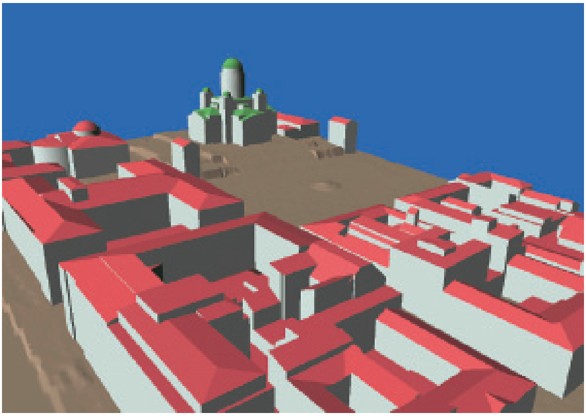

Figure 8: City model of Helsinki, interactively reconstructed from a segmented laser scanner point cloud.

For small modelling projects, like urban renewal projects, the usage of video data may be very cost effective. Video data can be recorded either from model helicopters or just hand-held for street level views. The latter recordings are important for façade details as well as for texture projection. Because of the high redundancy in video data, the extraction of texture to be pasted onto building models will most likely be automated completely.

Conclusions

In conclusion, I dare say that the prospects for automated extraction of large scale geo-information improved considerably. Ten years ago research groups were struggling with the very hard problems of automated image understanding. Although these problems are still unsolved, I'm now much more optimistic that in the near future computer algorithms can be used to extract various types of geo-information largely automatically. The current developments of sensors, platforms and processing methods potentially enable a cheaper and more frequent provision of geo-information. And with that we will be able to better tackle the wide range of management problems that require geo-information.

I therefore consider it a privilege and a pleasure to be working in this field right now. I'm looking forward to further develop and transfer knowledge on geo-information extraction at ITC and in cooperation with ITC's world-wide partners. I would like to thank the board and directorate for giving me this opportunity.

Ladies and gentlemen, I thank you for your attention.
Dear Rector, I have spoken.