Geodata and Information Systems – a Vision for the Next Century

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1. Need for Mapping and Geoinformation

The state of the world is characterized by the anticipated doubling of the world population in the next 50 years, particularly in the developing continents.

1.1 This will cause increasing demands for agricultural production and for water resources. Because of limited resources of land and forests and their degradation, because of the growing impact of disasters and because of urbanization sustainable development, as it has been defined 1992 at the Rio UNCED Conference, is in need.

1.2 There is a need to monitor the environment to be able to protect the natural resources.

2. Progress in Mapping

The monitoring of the environment is not possible without geospatial data.

2.1 This is an issue of scale. Global monitoring needs small scale data sets. Regional or national monitoring needs medium scale data, and local issues require large scale data sets.

2.2 The United Nations have made an official enquiry in 1990 as to the current status of mapping in the world at medium and small scales. The result is that mapping of the land area of the globe is nearly complete at 1:200 000, that 2/3 of this area is completed by 1:50 000 maps, and 1/3 by 1:25 000 maps. No statistics are available on large scale data sets, except to note, that these are generally lacking behind requirements.

2.3 But the updating of these maps is far from satisfactory. It is 3.5 % (or every 30 years) for 1:200 000 maps, 2 % (or every 50 years) for 1:50 000 maps and 5 % (or every 20 years) for 1:25 000 maps. Only Europe with about 7.5 % (every 15 years) has a much better update rate.

2.4 The situation can only be improved by a new data acquisition technology such as by mapping from satellites. Current satellite technology (with 1 m pixels from Iconos-2) is capable to produce 1:10 000 mapping.

3. Geoinformation Systems

While satellite images can be acquired the management of the information and its analysis must be done efficiently in geographic information systems.

3.1 Historically geographic information systems were in the 1960's pioneered by individuals from the Harvard Laboratory of Computer Graphics or from the Canadian Government. Then government agencies took the development over in the 1970's to find that industrial development dominated in the 1980's. In the 1990's the technical problems are greatly solved due to computer developments, so that the specific user dominates the scene.

3.2 A GIS consists of 3 major components:

- hardware
- software
- data.

There are currently over 300 vendors producing hard- and software for GIS uses.

With the growth of computing power the tendency of hardware and software systems is to accommodate data of the following types:

3.3 A GIS must serve a particular purpose for which it is necessary:

- to select pertinent information
- to set the necessary and cost efficient accuracy standards
- to design cost-effective updating schemes to keep the information valid
- to analyze the data for relevant purposes, designing pertinent analysis models
- to utilize the analyzed data for planning implementations, for administrative uses, for public information, and for monitoring the natural and social environment.

While the hardware and software provision is the task of the GIS vendors, the definition of uses and the needed customization of the GIS for its purposes is the task of the users.

The provision of the data is considered the most expensive part of a GIS.

3.4 The early GIS developments have concentrated on one-purpose projects with the difficulty to prevent the costly data from use by others because of different data definitions, data structures, and data formats and because of different accuracy an timeliness standards. It has become evident that good cost-benefit ratios could only be achieved by a GIS design permitting data integration including the updating capability.

3.5 Because no agency was in the position to collect and to update all relevant information contained in a GIS this has led to the tendency of data sharing in which each administration responsible for a particular data sector could exchange data according to predefined standards for common analysis in a GIS center. With the advent of networked systems and the Internet or Intranet this networking concept is growing in importance.

3.6 Currently 25 % of all GIS uses are in the area of facilities management by utility companies and 19 % on land information as the largest users with other applications to follow in smaller percentages (business applications 13 %, environmental applications 11 %, basic cartography 9 %).
All users concentrated in the first 5 years of operation n creating an inventory, followed in the next 5 years on the analysis of data finally leading to the management of data.

3.7 Much of the existing information cannot be cost-effectively integrated into a GIS structure. Therefore the creation of meta-data bases, locating other non-structured information is part of the task.

4. Mapping and GIS

4.1 It has been realized, however, that all geo-referenced data require a base map to be commonly used and maintained. Thus basic mapping is at the core of GIS data provision.

4.2 To the base map thematic layers may be attached.

4.3 Base maps and thematic maps can generate links to non-graphic attribute data on various applications.

4.4 Base mapping has been the prime interest of the Surveys and Mapping profession, which in the past had divided and very specialized interests:
- Control was provided by the geodesist or the surveyor.
- The photogrammetrist provided the map manuscripts.
- The specialist provided thematic content.
- The cartographer created the map layout and was responsible for the printing and the distribution of maps.

4.5 New surveying and mapping tools, such as
- total stations
- GPS
- orthophoto mapping
- digital plotting
- satellite remote sensing

have totally changed the old concept. It is no longer necessary to produce maps alone. Photo maps and the GIS screen output have become new media of presentation.

4.6 A reengineering of the Surveys and Mapping Profession into Geoinformatics is required because of such new tools as
- GPS
- digital remote sensing and digital photogrammetry
- GIS

Application of these tools is no longer the task of a specialized group within the Surveying and Mapping profession. They can interchangeably be used by anyone calling himself a geoinformatics professional.

The proper choice of tools becomes more and more a decision on efficiency and cost rather than the use of a particular technology.

The current advances in these new tools can be summarized as follows:

5. Reference Systems and GPS

Control has in the past been based on local reference systems, defined by monuments, established by astronomic positioning and triangulation.

The existence of GPS and in particular DGPS has not only made control surveys by orders of magnitude more accurate but also by orders of magnitude more efficient.

5.1 ITRF

The U.S. military Navstar GPS-System has made accessible to high precision civilian surveys by differential observation techniques in which the International Terrestrial Reference Frame is created. A number of permanent GPS observation stations situated around the globe has permitted to track movements of the earth crust to a few centimeters, adding a time dimension in form of an epoch to the coordinates of a point.

5.2 EUREf

This ITRF network has been densified over certain continents such as Europe, creating the European reference frame EUREF permitting to track crustal movements in the centimeter range.

5.3 SAPOS

A number of countries such as Germany have made use of EUREF for further densifications of GPS reference stations.

In Germany permanent reference stations have been established every 50 km. They permit to transmit correction signals to local observations, so that near real time point determinations can be measured with one suitable GPS receiver to an accuracy of ± 5 cm. If the distance to the reference station is closer than 10 km then an accuracy of ± 1 cm can be reached. Therefore the state survey administrations intend to create a network of permanent reference stations with radio transmission of corrections at distances 10 km apart.

It is possible to commercially utilize provision of this information as shown in table 1.

Table 1: GPS-Positioning Service SAPOS in Germany

Service	Operation	Accuracy	Band	Format	Cost
EPS	real time	± 1-3 m	2 m band	RTCM 2.0	300 DM once
HEPS	real time	± 1-5 cm	2 m band GSM	RTCM-ADV RTCM 2.1	0.20 DM/min 0.40 DM/min
GPPS	post proc.	± 1 cm every 1-15 sec	2 m band GSM	RTCM-ADV Rinex 2.0	0.40 DM/min 0,80 DM/min
GHPS	post proc.	< 1 sec	2 m band GSM	RTCM-ADV Rinex 2.0	0.80 DM/min 1.60 DM/min

The result of this change in technology is that every cadastral survey party is now equipped with a GPS receiver cutting survey costs down from at least half to 20 %.

5.4 GPS and IMU technology for positioning and for orientation

Recently it has become possible to use real time reception of DGPS signals in aircraft to measure the location of exposure stations of imagery to ± 10 cm when the exposure time can be matched or interpolated to the time when the DGPS signals are received.

When linked to inertial measuring units the sensor orientation parameters can be more precisely interpolated for the images in an orientation procedure combined with bundle block adjustment.

It is furthermore possible to use positions and sensor orientations for the rectification of scanner imagery.

6. Digital Maps as GIS Base Information

The provision of digital map data at the various mapping scales has started not only in North America and Australia, but in every European country. The developing continents of the world follow this development closely.

6.1 The DCW

The U.S. Military has issued the digital chart of the world at the scale 1:1 million, which is sold for only a few hundred dollars. By the year 2002 a more homogenized and geometrically corrected digital map 1:200 000 may be generally available.

6.2 MEGRIN

The Comité des Responsables de la Cartographie Oficielle (CERCO) has initiated to homogenize and to geometrically fit European digital maps at national scale coverages.

6.3 ATKIS

Germany is now covered by a digital map coverage derived from the digitization of 1:5000 analog maps. Its object oriented structure portrays 90 object categories. It serves the automatic generation of 1:25000 maps and can be used for map outputs at the scale 1:10000 as a base GIS.

6.4 ALKIS

Large parts of Germany have attempted to convert the cadastral map series 1:1000 with GPS surveyed boundary points into a large scale information system on the land parcel level. N the year 2007 the whole of Germany will utilize these land parcel data for cadastral, rural, and urban planning operations.

Both ATKIS and ALKIS will permit generalization for the preparation of traditional maps at various scales by digital means.

Again, the state administrations recover costs of the updated base data, which are offered in various forms such as

- ATKIS and ALKIS vector data
- digital elevation models
- raster map data.

Current costs for these products are shown in table 2.

Table 2: Digital base map products available from the German Survey Administrations

Vector Data:	**ATKIS-DLM** Digitized from maps 1:5000, Accuracy ± 3 m Corresponding to Maps 1:10 000 or 1:25 000 < 5000 km² DM 30,-/km² 5000 – 25 000 km² DM 15,-/km² > 25 000 km² DM 5,-/km²
Digital Elevation Models:	**DEM 5** Accuracy ± 0.5 m (in forest ± 1.5 m) 12.5 m grid with structure DM 100,-/km² without structure DM 60,-/km² **DEM 50** Accuracy ± 3 m (in forest ± 10 m) 50 m grid < 5000 m² DM 3,-/km² 5000 – 25 000 km2 DM 2,-/km² > 25 000 km² DM 1,-/km²
Raster Data:	**Maps** 1:5000 DGK 5 DM 128,-/sheet 200 L/cm 4 km² DM 64,-/sheet 100 L/cm 4 km² 1:25 000 TK 25 1:50 000 TK 50 1:100 000 TK 100 DM 320,-/sheet 200 L/cm DM 160,-/sheet 100 L/cm 1:200 000 ÜKN200 DM 315,-/sheet 200 L/cm DM 157.50/sheet 100 L/cm
Digital Orthophotos:	24 µm, 30 cm on the ground < 5000 m² DM 15,-/km² 5000 – 25 000 km2 DM 10,-/km² > 25 000 km² DM 4,-/km²
CD-ROM:	TK 50 all of Lower Saxony in raster form DM 98,-

7. Digital Mapping

The technology for new mapping and for its updating has greatly changed from analog to analytical to digital during the past 50 years.

7.1 Digital Elevation Models

In the analog era elevations in mapping have been determined as contours supplemented by occasional spot heights.

In the analytical era elevations were determined in regular grids on analytical plotters supplemented by breaklines. If contours were desired, they could be interpolated by a variety of interpolation methods (weighted averages, Delaunay triangles or least squares) from the measured primary data.

In the digital era image matching algorithms have gained increasing significance (calculation of optimal correlation coefficients, feature based matching of selected points with optimal symmetric contrast, feature based matching of linear elements or least squares matching taking into account the inclination of the surface). To avoid losses of correlation image pyramids were introduced, which permitted a zoomed-in correlation approach in case correlation was lost due to weak local contrasts.

These techniques could equally be utilized for point transfer between images along and across the strips of a photogrammetric block.

Recently even non-classical DEM acquisition methods such as laser scanning, and airborne or satellite radar interferometry have been added to the possibilities.

It becomes a decision as to which method meets the particular accuracy requirements and as to which method is the most cost-effective under local conditions.

An accuracy-cost comparison for the various methods to derive DEM's is contained in table 3.

Table 3: Accuracy-Cost Comparison for various DEM generation methods

Method	Accuracy	Cost per km_2
large scale aerial photography	± 0.2 m	1000 DM
laser scanning	± 0.2 m	500 DM
small scale aerial photography	± 1 m	500 DM
airborne interfero-metric radar	± 1 m	100 DM
SPOT satellite images	± 10 m	10 DM
satellite radar interferometry	± 20 m	5 DM

7.2 Digital Orthophotos

Based on the digital elevation models created by these methods the positions and exposure orientations of the imagery may be used in collinearity equations for photographs and scanners to derive differentially rectified geo-coded image products in the form of ortho-photos and stereo partners.

This technology has proved itself applicable for orthoimages at the scale 1:5000 or smaller, while buildings and other high objects (vegetation, posts and towers) have presented rectification of urban images at larger scales.

Attempts to create socalled "true orthophotos" at these scales for the roof tops of buildings have not been very successful for aerial photographic imagery because of concealed, not imaged parts of the photos.

A relief is, however, in sight with the use of stereo-scanners (3 line scanners, forward, vertical and aft) which cover objects completely in the direction of a strip. When flown with a lateral strip overlap of over 50 % this technique promises a breakthrough to create true orthophotos in the future even at large scales.

7.3 On-Screen Digitizing

Orthophotos at scales 1:5000 or smaller, and "true orthophotos" at larger scales permit a more cost-effective on-screen 2D-digitizing procedure to obtain interpreted vector data for maps.

7.4 Stereo Restitution

Analytical plotters and digital stereo-work-stations permit vectorization of interpreted objects in the traditional manner.

On screen digitizing or stereo-restitution will therefore be the prime resource for the up-dating of topography unless GPS surveys (static or on the fly) can be used more effectively in a local situation.

7.5 Progress in Lower Saxony

For the State of Lower Saxony in Germany, covering about 30 000 km^2, digital elevation models at 0.5 m accuracy are available in a 12.5 m grid over more than 80 % of the territory. For more than 30 % of the state area digital orthophotos are available for the scale 1:5000 with 0.5 m pixels on the ground.

DEM's may be utilized for oblique views draping vector information or thematic image content (generated by interpretation or by automatic classification of multispectral imagery) over the DEM grid.

This is an ideal tool for the design of road or railway projects and for other earth work.

Even though large scale orthophotos at scales 1:1000 do not meet accuracy specifications for rooftops they are an ideal tool for up-dating of cadastral and building information when superimposed with the cadastral map.

For the Emirate of Dubai with a fast changing topography due to intense building activity the superimposition of digital orthophotos at 10 cm ground pixels to a topographic vector map 1:1000 has proved extremely useful and cost-effective.

Research is under way to update a limited number of features in an automated fashion by knowledge based methods. The non-updated GIS provides the opportunity to select existing feature classes of interest. New imagery is subjected to verify whether the spectral and the spatial characteristics for the selected features are still valid. Grey level or color checks, edge detection checks and context checks permit this verification in a rule based system. Promise has been shown for the updating of roads and vegetation boundaries.

8. 2D-GIS Applications

8.1 Cadastre

A major GIS application is in the area of the cadastre. A cadastre consists principally of a geometric identification of all land parcels through a unique identifier and a non-graphic attribute table for each identified parcel containing the name and identification of the owner, the use of the land, the ownership rights, and the associated administrative data.

The land parcel is an ideal basis to links buildings and socio-economic data to persons living or working in these buildings.

The accuracy by which the geometry of a parcel is to be established, determines the method by which cadastral surveys or its updates need to be carried out.

A graphical cadastre with position accuracy in the meter range is sufficient, if each parcel is defined by accurate ground measurements for the benefit of the owner shown in a (scanned) certificate. A graphical cadastre can be established by the use of orthophotos, while the dimensions of the parcel, not of public interest, are an issue for the owner. Otherwise the coarse boundaries to be identified in the orthophoto can be established by a photo-adjudication process.

A numerical cadastre tries to incorporate precise locations of boundary points by ground measurements (total stations, GPS). Often the boundaries cannot be made visible in the orthophotos, thus the establishment and maintenance of a numerical cadastre cannot be accomplished by photogrammetry.

Cadastral information systems are an important asset in the economy of a country in the real estate market, the planning activities and the collection of property taxes.

8.2 Utility Locations and Facilities Management

Another important GIS application is in the mapping of utility networks. In large scale aerial photographs the manholes and other utility objects on the ground may be identified and measured at decimeter accuracy. When combined with data collected on the ground this may lead to the geocoded location of utility networks and the mapping of relative positions between various utility types.

While the identification of utility features on photographs is not always possible, a combination with ground survey methods may lead to a cost-optimized solution.

Utility providers are often less interested in the geometric position of the utility lines, but in the linkages of the utility networks and the type, the age, the capacity and the depth of the utility lines (cables, pipes).

The traditional way has been to provide this information in schematic drawings showing individual cables and pipes with their connections or with the slope of the drainage pipes.

The principal aim of documenting utility networks in form of a GIS has been to enable facilities management devoted to modelling the capacity of the network, to identify bottlenecks and to use the result of the analysis for expansion and the maintenance of the networks. On the basis of the linked informationit has even become possible to charge customers connected with identiied utility lines for their energy or water consumption or for their discharge contribution.

Nevertheless the relative location of different utility networks in a GIS is a great advantage for planning and construction activities.

8.3 Valuation

Land valuation for the purpose of taxation or for the fair assessment of real estate prices in the real estate market and in mortgaging depends on land use, the zoning regulations, the general geographic location of the object, its access and the risks to which it is subjected. Also valuation of buildings may be included.

In Germany land valuation maps are prepared on the basis of a cadastral information system as a public service in order to counteract land speculation.

The land values are derived for the statistical averages of actually recorded sales for a particular zone which may easily be identified in a land parcel based GIS.

8.4 Land Cover – Land Use

Planning decisions in the management of renewable resources are based on land cover – land use information. On the basis of land cover other surveys of economical significance can be made, for example in the survey of agricultural statistics. Crop inventories permit to predict yield and to determine subsidies to the farmers.

Agricultural statistics can be compiled on the basis of a land parcel based cadastre by ground inspection or by an enquiry to the farmers. Multispectral remote sensing offers another possibility to monitor or to verify the information.

Ground based surveys with the help of photographic base data for identification, or photographic interpretation are the most reliable, but also the most expensive.

Multispectral classification in a non-supervised or in a supervised manner (minimum distance, maximum likelihood, neural networks) can be applied as a more economical procedure with Landsat images. However, in temperature climates it will rarely be possible to time the imagery at critical points of the growing season because of cloud cover.

A multitemporal approach using radar images has the advantage, that the imaging may be more correctly timed, but the spectral response discrimination in optical systems is superior to multitemporal radar backscatter differences for land cover classifications.

Regional crop forecasts for cereals have proved rather successful, when conducted with low resolution NOAA satellites. In a time sequence of 10 days it is generally possible to obtain a cloud free image from the 4 daily overpasses of two such satellites at 1 km resolution. Forecasts have shown a correlation of at least 90 % with actual yields on a district basis.

If Landsat or radar images may be obtained for the critical time periods the cost will be higher due to the acquisition price of the imagery. But the surveys may be extended up to the parcel level.

8.5 Environment

There exists a wide range of environmental surveys from the measurement of trace gases at selected gauges several kilometers apart and the bio-chemical sampling techniques in waters of rivers and lakes to the probing of noise and the hydrocarbon content of air along traffic arteries up to the survey of contaminants on an individual parcel basis.
Interpolation of the measured data or the customized visualization of the collected information in a GIS provides many value added opportunities for GIS applications.
How such customization can be of value has been demonstrated by the visualization of attributes on a parcel basis showing the type of soil, the ground water capacity, the air quality and the chemical contamination carried out by the Institute of Photogrammetry.

8.6 Disasters

One of the applications for disaster prevention was the customization of GIS base data for fire brigade access by the Institute for Photogrammetry and Engineering Surveys of the University of Hannover. The base data did not show hydrants needed for water supply. They also did not show trees, which would limit the access of fire trucks. These data were provided by local ground surveys and by superimposition of recent orthophotos showing the extent of tree crowns.
Disasters caused by flooding can be easily monitored by radar images superimposed over GIS base data or orthophotos. Flood prediction, on the other hand, depends on modelling of combined remote sensing and GIS data. A drainage basin is defined from DEM data. The catchment characteristics are determined from land cover and soil characteristics. Combined with precipitation data the progression of floods is modelled.
In snow covered mountain regions avalanche endangered zones can be determined from slopes derived from a DEM, combined with information on vegetation and aspect.

8.7 Transportation

A road network data base can easily be customized for linking and displaying road conditions or traffic densities. Road network data are a principal input for car navigation and optimal traffic routing systems.

8.8 Urban Planning

The base data can be augmented to include zoning data showing urban planning information (intended land use, permitted height of buildings, traffic restrictions). They are well suited to plan public transport.

The delimitation of buildings or blocks to collect population statistics (places of residence, income, places of work, use of vehicles, gender, age groups) is a very important customization product.

9. Digital Mapping

The traditional GIS base data are two-dimensional. They are supplemented by a digital elevation model to construct a three-dimensional surface for oblique views. Combination of these data is useful at small and medium scales, but it fails for 3D-representation of discontinuous objects, as they appear in a large scale scene.

A 3D-modelling approach with other data combinations or with other software therefore has to be applied for those applications.

9.1 City Models

City models are required for visualization o a city landscape. Mobile telephone networks also require the locations and the heights of individual buildings to be able to predict the performance of specific antenna locations and to plan them in an optimal manner.

The details to be included in such a representation (roof structure, views of facades) greatly depend upon the acquisition cost to include such details.

In the most primitive, but least costly way the buildings are taken as square blocks which are constructed above the terrain given by the DEM on the basis of a single roof top height. In reality these are 2 1/2 D-GIS models.

For about 40 German cities such models satisfying the needs of the mobile telephone industry have been constructed. This can be done by extracting the building outlines from a 2D-GIS and by masking the non-building areas. Stereo image data can be matched over the building areas to generate a roof top model for the city.

For visualization purposes it is imperative that detailed roof structures and images of the facades are included. This requires imaging of the same object from different view angles in order to avoid hidden areas. One possibility for obtaining such imagery is by triple line scanner when flown with more than 50 % lateral overlap. Forward and aft images will image both facades along the flight strip and the adjacent flight strips will cover the hidden areas in the cross strip direction. Overlapping aerial photography with sufficient longitudinal and lateral overlap can be used in a similar way, even though this requires additional organizational effort.

9.2 Cultural Heritage Objects

The technique of using many photographs to cover hidden surfaces has been demonstrated in various projects documenting cultural heritage. This requires first the construction of a 3D-wire frame model onto which the specific image portions of the surfaces imaged can be draped.

9.3 Construction Objects

The described techniques are likewise applicable to document large construction sites and to include into them views of virtual objects, which are planned for construction.

10. Geoinformatics

The great variety of tools for acquisition, management, archival and visualization of GIS data at varying accuracy and cost requirements leads to the conclusion that geoinformatics is a professional field for which a special education is a key activity.

10.1 Geoinformatics Education

Worldwide there are many curricula with specializations in surveying and mapping, geography, environmental science or in other disciplines trying to adapt the geoinformatics content into their field with varying degree of success.

The generation of a geoinformatics core curriculum is therefore a prime necessity for creating, maintaining and utilizing GIS systems.

10.2 Geoinformatics Problem Areas

The problem areas of geoinformatics do not lie in the technology which is now available for use, and which can be enhanced by the growing technological capabilities, but in the management of spatial data. Decisions must be reached within a spatial data infrastructure as to:

- who is responsible for the collection of which data
- who is responsible for the maintenance of the data
- to what spatial and temporal accuracy standards the data need to be acquired and maintained
- to what feature or object classification the data are to be extended
- to what formats and procedures are required for the exchange of data

- to what level of data sharing and at which cost the data are to be made available to whom

The future of GIS could therefore be threatened by

- lack of vision
- lack of support of decision makers
- lack of expertise
- lack of data access
- lack of data analysis and
- lack of a long term development plan.

11. Conclusions

In conclusion it can be said:

11.1 New GIS technologies are available. They are used in competition, and often the decision for their use is not in the hands of those who understand the subject matter.

11.2 There are many members of the young generation who understand the technology, but have no possibility to apply it due to lack of vision of the management to secure financing for programs needed for sustainable development.

11.3 The competing technical methods are interchangeable, but prices and performance under local conditions should play a role in their application.

11.4 There is need for GIS professionals to manage geodata.

11.5 It is now required to bridge the gap between research and application for the benefit of our future.