MAP REVISION AND NEW TECHNOLOGIES: A GENERAL FRAMEWORK AND TWO PROOF OF CONCEPT TESTS

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Abstract

A framework for revision of topographic maps is presented. This framework answers questions such as: Why and how does terrain change? How are these changes related to time? How do these changes affect existing topographic maps? How might modern technologies, such as a mobile mapping system (specifically, the GPSVan™ developed by The Ohio State University Center for Mapping), be integrated with other technologies for use in local revision of topographic maps? This framework has been developed as part of on-going research in spatially referenced data.

1. Introduction

A great deal of effort has been dedicated to the conversion and generation of spatially referenced digital data. The extensive use of Geographic Information Systems (GIS) has created a great demand for these data that will continue for years to come. The kind of data needed in a GIS must be in digital format, as free of errors as possible and up-to-date, but errors in these data will affect representation, analysis and decision-making. Out-of-date data will have the same effects. Spatially referenced digital data is generated from existing maps or collected from the terrain in digital form. Therefore, the problems of data errors and outdated data must also be considered in the framework of digital mapping.

Digital data quality is a complicated topic, but significant research gains have been made in this area. The topic of topographic map revision, on the other hand, is considered an extension of map production, resulting in very little independent research. Topographic map production is agency-dependent, and no universally accepted set of norms exists for this activity. The same is true for map updating. Map updating, in general, is done by re-compiling part or all the map using the same approach as in map production. This approach is costly and time-consuming.

Many current updating practices also create inconsistencies in the representation of the terrain. For example, in the case of the United States Geological Survey 7.5' quadrangles, revision of the road system sometimes does not include revision of the contour lines, which creates inconsistencies in the spatially referenced digital data. Digital maps support better map revision solutions because the nature of the media makes it possible to explore different approaches. This paper, which is an expansion of another paper by Ramirez (1995-a), addresses the problems of topographic map revision as separate from map production issues.

A framework for topographic map revision (planimetric and hypsographic features) is presented. This paper starts with a review of conventional methods of map revision and is followed by a discussion of the mobile mapping systems developed by the Center for Mapping and alternative data collection and processing methods for map revision. Finally, the conceptual framework is presented.

2. Map Revision: Current Status

Map revision is defined as "updating, improving and correcting map content for publication in the same series" (Thompson, 1987). In other words, the purpose of map revision is to update the information of a map from a time t1 in the past to a time t2 in the present. As indicated earlier, no universally accepted map revision method exists.

For the purpose of providing an example, a brief description of the U.S. Geological Survey topographic map revision method is given next. Following Thompson (1987) and others, map revision is divided into four major tasks: total revision, partial revision, photorevision and photoinspection. Total revision is the "correction of all deficiencies in planimetry and relief features." Partial revision is the "correction of specified map deficiencies." Photorevision is the "updating of maps from aerial photographs and other available sources to reflect planimetric changes." Photoinspection is the process of "comparing the latest published map to recent aerial photographs to determine both the need for revision and the extent of the changes." Contour revision usually is undertaken only as part of the total revision task, which creates inconsistencies for the other types of revision.

Map revision, conventionally, requires the use of current aerial photographs and manual compiling of all the changes on the terrain. Today, with the increasing use of computer-based methods, partial revision is possible. This requires obtaining current aerial photos, forming photogrammetric models, manually identifying areas where changes have occurred, manually removing out-of-date data, re-compiling and merging the new with the old data. This is very time consuming and costly.

Are there any other alternatives for map revision? The next sections, which present brief discussions of the Center for Mapping mobile mapping system, will direct us to alternative solutions.

3. The Center for Mapping Mobile Mapping System

The Ohio State University Center for Mapping with the support of eight private companies, 38 state transportation agencies, the transportation department of Alberta and the Federal Highway Administration has designed and developed a mobile mapping system: the GPSVan™. A detailed description of the GPSVan™ is given by the Center for Mapping (1991), Bossler et al. (1991), Novak (1991), He (1995) and Dedes (1995) among others. A brief description of the GPSVan™, based on these publications, is presented next.

The GPSVan™ has been designed to efficiently collect highway information in a dynamic mode. The information collected are geographic locations, digital images and textual attributes. The major hardware components are two GPS receivers (one used as a base-station and the other one, mounted in the van, as a rover station), an inertial system, a magnetic wheel sensor, a stereo-vision system, a computer, and input and storage devices.

The GPS receivers provide absolute positioning, which are complemented by the inertial system and the wheel sensor in those cases where satellite signals are blocked. The stereo-vision system is formed by two CCD cameras, a fast digital interface, a signal processing system, a SCSI channel and a storage device (a 8 mm tape). This stereo-vision system provides images of the road and its vicinity (with respect to the front or the back of the GPSVan™) and allows the extraction of metric information by photogrammetric means. The computer is used to store data, and synchronize and manage the different components of the GPSVan™ system. Input devices allow the inter-active collection of road attributes. The major software components are: synchronization and management, stereo-vision system calibration. GPS post-processing. line generation and automatic extraction of features.

The Center for Mapping tested a prototype GPSVan™ in 1991. and since then, a new generation GPSVan™ has been built with major improvements. Current positional accuracy of the GPSVan™ is of the order of 0.05 to 0.10 meters horizontally and 0.10 to 0.15 meters vertically for base lines of 50 kilometers (assuming continuous satellite tracking) and 0.40 to 0.50 meters horizontally and 0.50 to 0.60 meters vertically (without satellite tracking for a complete minute). GPS positions are determined by a double differencing of pseudo-ranges relative to the base station. Positions from the stereo-vision system. computed by photogrammetric triangulation. can be transformed from a local coordinate system into an absolute topo-centric or geo-centric system.

Thus far, the GPSVan™ has been used primarily for inventorying transportation systems such as roads. railroads. airports. The high rate of data collection along the traveled path. together with the large amount of information collected by the stereo-vision system.make this and similar systems highly competitive with conventional methods of spatial data collection. The whole potential of the GPSVan™ and similar systems is. however. still unknown. It is clear that the system will become even more cost-efficient as the number of application of this technology increase. This is the idea behind this paper: to explore the use of GPSVan™ data for map revision.

4. Understanding Map Revision and its Causes

The obvious reason why spatially referenced information (or maps) are revised is because they represent a dynamic surface: the surface of the earth. The surface of the earth is subject to the action of natural forces and man-made actions. Both produce changes on the surface of the earth. Only the subset of changes in elements traditionally represented in topographic maps (including the relief) are of interest here.

Natural forces. in general. generate two types of changes: systematic changes and abrupt changes. Systematic changes are those continuous changes on the surface of the earth generated by the gravity force. wind. life-cycle and others. Systematic changes include the change in the course of a river. in the coast line. in sand dunes. in vegetation. etc. Some of these changes are very slow and only can be appreciated after long time periods: others can be appreciated sooner. but all of them are predictable and require a time interval $t_2 - t_1$ to alter the currency of the spatial data representation.

Abrupt changes caused by the forces of nature immediately affect the currency of spatial data. Examples of these changes are those caused by earthquakes. flooding. forest fires. land slides and so forth. Minimal changes are of no interest in spatial data revision. and they will not be considered in this discussion. Abrupt changes are not predictable. and in a very short interval of time $t_4 - t_3$. they affect the currency of the spatial data representation.

Human actions modify the surface of the earth in two ways: by predictable and unpredictable changes. Again. only those changes that affect the currency of spatial digital data are considered here. Predictable changes are those whose outcome will be known in advance and are evident by a time t_5: construction of roads. shopping malls. sport fields. parks and so forth. Unpredictable changes are those whose outcome is unknown at time t_6 and are only evident later. at time t_7: open-field mining. logging and so forth.

All the above changes are local in nature. They alter a specific geographic zone, and, in most cases, the relief and the representation of the features on the terrain. Features of interest here are those contained in topographic maps. These features can be classified in a set of layers or coverages. There is not a universal classification for map features; however, a typical example of classification is the one used by the U.S. Geological Survey. In this classification, features are grouped in 9 layers:

(1) Boundaries
(2) Hydrography
(3) Hypsography
(4) Geodetic control
(5) Miscellaneous cultural features
(6) Non-vegetative features
(7) Public Land Survey System
(8) Transportation system
(9) Vegetation.

In some cases, changes in one layer do not affect other layers. For example, changes in boundaries, vegetation, or geodetic control layers generally do not affect other layers. In other instances, changes in a layer may result in changes in other layer(s). For example, generally a change in the transportation layer, such as the construction of a new road, will result in changes in the hypsographic layer. Changes in the relief following an earthquake may result, for example, in changes in the hydrographic and transportation layers.

Changes in most topographic layers are caused by natural forces or by human actions. Systematic changes due to natural forces are apparent, in general, only over long periods of time. It is important to recognize, for example, that for hypsography these changes become significant only when they reach the magnitude of about a half of the contour interval of the map. Abrupt changes are impossible to predict, and, generally, they affect the terrain representation and are significant right away. They have the potential of changing the terrain representation in the most radical way. But, on the other hand, it may be a long time between abrupt terrain changes.

Terrain changes due to human actions are the most common, especially predictable changes. Terrain is constantly changing due to new constructions, especially of transportation features (all kind of roads, airports, etc.) and miscellaneous cultural features (buildings, shopping malls and so forth). Unpredictable changes because of human actions also affect the terrain representation -- perhaps more radically but usually less frequently. Some unpredictable changes are only temporal (at least in the USA). For example, open field mining changes the relief in a substantial fashion. But, once mining is completed, the relief must be reconstructed to its original shape. Based on this discussion, the need for terrain revision could be classified and summarized as shown in Table 1.

Table 1
Topographic Map Revision: Change Factors

Origin	Frequency	Magnitude
Systematic	Constant	Small
Abrupt	Low	Large
Predictable	High	Large
Unpredictable	Medium	Medium

Table 1 can be used to gain some insight into map revision. Changes due to predictable human actions are those that occur more frequently and greatly alter the terrain representation. Unpredictable changes due to human actions and abrupt changes due to natural forces affect the terrain in perhaps equivalent fashion (medium frequency/medium magnitude vs. low frequency/large magnitude). Finally, changes due to the systematic action of natural forces affect the terrain the least. These basic ideas will be used in the next sections as the basis of a framework for map revision .

5. Alternative Data Collection Methods for Topographic Map Revision

Topographic map revision requires the collection of representative data on the changes in terrain and their processing, replacing and merging with existing terrain representation. We will assumed here that local terrain changes have been identified in some way, and in this section we only discuss the problem of data collection. If only predictable changes due to human actions modify the terrain, the data reflecting these changes can be collected along the new roads, shopping malls, airports, sport fields and so forth. Generally, they could be collected by a mobile mapping system such as the GPSVan™ (assuming the accuracy of the spatial data from such a system is appropriate). The basic justification for this approach is that these changes in the relief are caused only by the type of terrain features a mobile mapping system collects best.

This approach has several advantages. A mobile mapping system, such as the GPSVan™, has been designed to collect spatial data at highway speed. Therefore, collection speed is a major advantage. The data collected by the GPSVan™ are in the form of GPS positions (latitude, longitude, ellipsoidal height), digital images and text attributes. From the viewpoint of elevations, the GPSVan™ collects geocentric distances from the origin of the 3-D coordinate system (center of the WGS84 ellipsoid) to the ground beneath the GPS receiver in the GPSVan™. From these distances, the ellipsoidal heights are computed. These values allow us to compute orthometric heights (in conjunction with geoidal heights or undulations).

In agreement with Milbert (1991), the best possible results will be obtained today if the GEOID90 Geoid height model is used. In this case, the accuracy of the orthometric heights obtainied by the GPSVan™ is between 0.50 and 1.0 meter for distances of 100 km. Therefore, 3-D coordinates of a consistent accuracy (σ_x= ±0.05 meters, σ_y= ±0.05 meters , σ_H= ±0.50 meters under the best possible circumstances) will be collected with continuous satellite lock. Because these data can be collected at almost any rate, it will be possible to use as much or as little positional information as needed almost with no additional collection cost. The only additional cost will be related to storage space. Using photogrammetric techniques, it is possible to extract additional elevation information for features such as road edges, tops of bridges and overpasses, etc. from the digital images. This data could be used as part of the hypsographic revision.

Data reflecting unpredictable changes could be partially collected by the GPSVan™ (for example, in open field mining), but in many other cases, collection may not be possible. This latter situation is similar to the collection of abrupt changes due to nature's forces. In these cases, a different approach should be used to collect the necessary data: digital photogrammetry could be used to generate a DEM of these areas, because, generally, hypsography is the only layer modified for these changes. There are several advantages in such a collection approach: first, it is highly automated, and second, it can be limited to very specific terrain areas.

Finally, data for systematic changes due to natural forces will be needed occasionally. Perhaps the most obvious changes to be collected are those due to hydrographic features. In this case, the

GPSVan™ technology mounted in a boat could be used to survey respective water lines to collect data. This collection mode offers the same advantages indicated above for regular changes.

6. Processing Topographic Map Revision Data

The previous paragraphs describe how data reflecting changes in the terrain can be collected. This section discusses how these data could be processed to produce a revised terrain representation. There is an additional data set to be considered: the digital representation of the existing terrain. For the purpose of this discussion, it will be assumed that there is such a data set. Otherwise, it can be generated by well-established conversion methods. See Ramirez (1995-b) for a description of one of those methods.

As a first step, vertical data will be transformed to a common reference datum: the Geoid. In order to accomplish this step, the GPS ellipsoidal heights will be corrected for local and global undulations to generate orthometric heights. Planimetric data also will be transformed to a common system: in the case of the USGS, the Universal Transverse Mercator (UTM). Then, the data set of the current terrain representation will be compared against the collected data sets (GPSVan™ and DEM), and a search for coincident horizontal data will be conducted.

Comparing spatial data sets is not an easy task. At the Center for Mapping, we have been developing efficient tools for such comparison. The approach is based on the Center for Mapping Database Format (Ramirez et al., 1991). Basically, a grid representation of the vector data for both data sets is generated, and artificial points are introduced at the grid edges for any line going across more than one grid. A cell key table keeps track of the grid representation of every line, and a cell table keeps track of all line elements in a particular cell. These tables allow for efficient comparison between the modified vector data sets. Once the data sets are compared, horizontal coincident data will be eliminated from the current terrain representation. Their elevations will be then compared against the elevations of the new data, and if differences are found, then the correspondent elevations will be removed from the current relief representation data.

After differences in elevations are found, a DTM program will be used to process all these data sets and generate a new set of contour lines. Different weights will be assigned to different data sets. For example, GPS data will usually have a higher weight than DEM data, and DEM data will have a higher weight than current relief representation data. Fundamentally, GPS data will be used as break lines. The result will be the updated representation of the relief.

Horizontal data will be integrated by a conflation program. Map conflation is the technology that allows us to take two data sets D_1 and D_2 representing elements of the same geographic area and generates a new data set D_3, which contains a unique representation of all elements in the two data sets. Combination of these two data sets is done based on a set of cartographic and geometric rules. Map conflation has been in use by the Bureau of the Census of the U.S. Department of Commerce for several years, and several commercial programs are available. In our case, the two data sets to be considered are the digital data set representing the out-of-date planimetric representation (with the modifications indicated earlier) and the data set representing the collected GPSVan™ data (land and water data). The resulting planimetric data set is constrained by the relief representation.

7. Conceptual Framework for Map Revision

In this section, the different pieces discussed in sections 3, 4, 5 and 6 will be integrated. We will start by assuming that changes in the terrain are systematic, abrupt, predictable and unpredictable as it was presented in Section 4. and that changes in a map have been detected by some means. After that, the following sequence of steps will be followed:

1. Collect data for regular changes
2. Collect data for irregular and abrupt changes
3. Collect data for systematic changes
4. Obtain data for current relief representation
5. Generate grid tables to compare data sets
6. Search for coincident horizontal data

From the viewpoint of Hypsography, computations will proceed as follows:

7. Compute orthometric heights (from ellipsoidal heights)
8. Compare elevations and remove elevations of coincident data
9. Assign weights to the different data sets
10. Process data sets through DTM software and generate new relief representation

From the viewpoint of planimetric features, computations will proceed as follows:

7'. Generate cartographic representation for non coincident features (if needed)
8'. Remove horizontal data from new data for coincident planimetric features
9'. Assign weights to different data sets
10'. Process data sets through conflation program and generate new planimetric representation

8 Proof of Concept

The Ohio State University Center for Mapping conducted two separate tests to demonstrate the concept behind the hypsographic and the planimetric revision approaches described in this paper. In the first test, portions of roads in the Laurelville 7.5' quadrangle in Ohio were surveyed by the first generation GPSVan™. In this vehicle, the positional accuracy was between 2 and 5 meters: the ellipsoidal heights were computed with respect to the GPS antenna (not the ground) and the software wasn't fully developed. No DEM or water lines were collected. The current relief representation was converted to digital form (DLG-3) from the corresponding 7.5' quadrangle by Center for Mapping personnel.

The DTM program SCOPE from the University of Vienna was used to process these two data sets. The original data set from the current relief had more than 350,000 points and could not be processed by SCOPE. Contour lines in the data set were filtered using a generalization algorithm based on distance and azimuth. A new data set of about 250,000 points was generated and used to generate the new relief representation. Only steps 1, 4, 6, 7, 9 and 10 of Section 7 were applied. In step 5, only global undulations corrections were applied.

Results of the test were encouraging from the viewpoint of showing the feasibility of the proposed method. On the other hand, the quality of the new relief representation was only fair due to the limitations and problems with the data and the software used. Figure 1 shows samples from the original and resulting relief.

In the second test, all public roads in Clark County, Ohio, were surveyed by the second generation GPSVan™. The existing fourteen road maps from 7.5' quadrangles were converted to USGS DLG-3

(Digital Line Graphic-3) format by Center for Mapping staff. Both data sets were graphically compared using ESRI's ArcInfo.

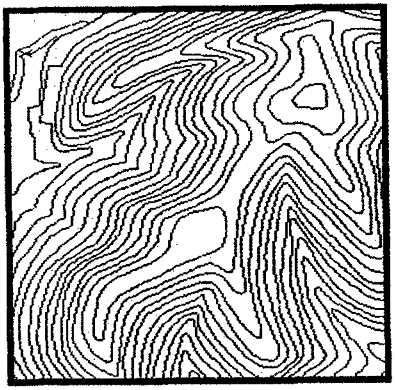
In order to do that, all fourteen maps were joined into a single Arc/Info coverage. This was the first data set to be used. The second one was the UTM data computed from the GPSVan™ data. Because comparing two line coverages is difficult in Arc/Info, polygon coverages were created by buffering the lines and comparing buffers. The process was time consuming and inefficient and shows the need for specialized tools. In this test only steps 1, 5, 6, 7' and a variation of 10' of Section 7 were used. The test, on the other hand, proved that road updating as described here is possible. Figure 2 shows samples of the existing and surveyed road data.

9. Conclusions

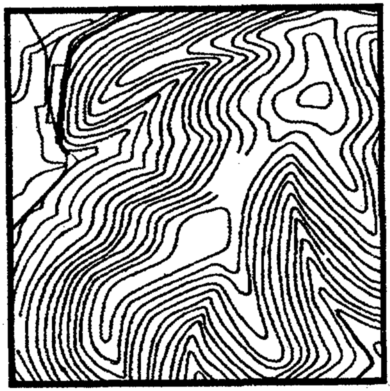
The framework presented for topographic map revision uses the GPSVan™ technology as the basic collection tool. Therefore, it is an additional application of this technology. This framework supports the generation of up-to-date hypsography by a new approach and the updating of planimetric features by direct surveying and modern computational techniques.

In the case of the U.S. Geological Survey, where 57,000 maps at 1:24,000 scale need to be revised, this solution may be the most cost-efficient because it is local and does not require manual compiling. It also uses a very efficient data collection system. The current accuracy of the GPSVan™ system exceeds the accuracy required for these maps (Light, 1995) and could be used for the revision of larger map scales (up to 5 feet contour interval).

The framework presented here may still be incomplete and additional research may be needed. Specifically, software integrating steps 5 to 9 and new software for steps 7' to 10' of Section 7 should be developed. It is our intent to pursue this work as an alternative to current map revision methodologies.



Original Relief



Generated Relief

Figure 1.

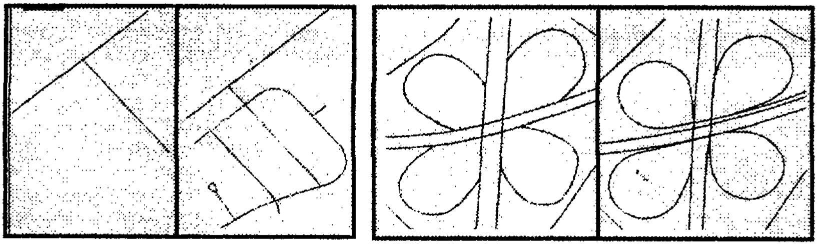


Figure 2.

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