SPATIAL DATA REVISION: TOWARD AN INTEGRATED SOLUTION USING NEW TECHNOLOGIES

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ABSTRACT:

Geographic Information System (GIS) is one of the fastest growing technologies in the world. Its ability to analyze and provide answers to many spatial problems is impressive. Spatial data are the backbone of GIS analysis, but only current and accurate spatial data can provide the appropriate framework for successful use of GIS technology. Out-of-date and/or inaccurate spatial data could contaminate GIS results. Therefore, there is a great need for cost-efficient spatial data revision and quality control methods.

The Center for Mapping is involved in a large spatial data conversion effort, the Generating Information from Scanning Ohio Maps (GISOM) project. The GISOM project is converting to computer-readable form all 793 7.5-minute quadrangle maps produced by the U.S. Geological Survey (USGS) covering the State of Ohio. The average age of these maps is twenty years. The Center recognizes the capital importance of revising these data in order to have the base needed by the State of Ohio to make full use of GIS technology.

The Center for Mapping is developing a conceptual framework for spatial data collection (including conversion) and revision and investigating how to integrate local collection and revision of spatial data with modern technologies such as: mobile mapping systems, spatial data conflation, digital photogrammetry, digital terrain models, etc. This paper presents a summary of the conceptual framework of spatial data collection and revision and describes the GISOM project and the latest results of our spatial data revision research. Finally, future research directions are discussed.

1. INTRODUCTION

Geographic Information System (GIS) is a growing technology. More and more users are finding its capability to analyze and query geographic information of incredible help in understanding the environment and making better decisions. Today, the major limitation to the use of GIS technology is the limited availability of digital spatial data. As an example, in 1991, less than 5% of the maps of the United States of America at scale 1:24,000 (the primary topographic map series) had computer-compatible representation.

Collection of computer-compatible spatial data in vector format is a costly and time-consuming process. The two major approaches are: (1) digital spatial data collection from the terrain (using remote sensing or mobile mapping systems techniques or a combined approach) and (2) conversion of existing maps into digital representations. Both approaches are operator-intensive. Mobile mapping systems currently offer the highest degree of automation and accuracy for the collection of road and railroad data. However, the collection of all the data included in a general purpose spatial database requires a lot of human intervention.

It took almost forty years and hundreds million of dollars for the USGS to complete the analog coverage of the United States at scale 1:24,000. It can be argued that a country the size of the United States is impossible to remap (in digital form) in entirety because of cost and time constraints. The most cost-efficient solution to generate the digital spatial data needed by GIS in a country the size of the United States is, perhaps, a combination of remapping selected areas, conversion of existing analog maps, and revision of digital spatial data. This paper introduces the topic of spatial data collection and revision, describes briefly the map conversion effort at the Center for Mapping, describes the status of our research in this area, and finally, discusses future research directions.

2. SPATIAL DATA REVISION

Spatial data revision is defined by Ramirez (1996) as correcting, updating, and improving the content of existing data to obtain a current representation of the terrain, in agreement with a predefined purpose. The revision effort at the Center for Mapping is directed toward the DLG-3 files generated by the GISOM project.

Conventionally, spatial data revision requires the use of current aerial photographs and manual identification and compiling of all the changes on the terrain. With the increasing use of computer-based methods, partial revisions are possible today.

There is not a universally accepted spatial data revision method. In general, spatial data revision is agency dependent. For the purpose of providing an example of revision, a brief description of the USGS's method follows. In agreement with Thompson (1987) and others, map revision is divided into four major tasks: total revision, partial revision, photorevision, and photo-inspection. Total revision is the "correction of all deficiencies in planimetry and relief features" and it is the only type of revision that keeps a consistent terrain representation. Photo-inspection 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."

For the past few years, the USGS has been experimenting with digital revision methods. The first DLG-3 revision software was introduced by the USGS in 1995: the RevPG product. RevPG is the Arc/Info-based Revision and Product Generation program developed by the USGS in cooperation with the Environmental Systems Research Institute (ESRI) as part of a Cooperative Research and Development Agreement (CRADA). RevPG has been developed for the revision of DLG files using digital orthophoto quarter-quadrangles (DOQQ) as the source material. As indicated by Decker (1986), "the DOQQ is treated as the ground truth and the DLG is updated to match the features identified on the DOQQ."

Revision with RevPG is a highly interactive process. The operator displays a digital orthophoto quarter-quadrangle and visually compares the DLG-3 features with the terrain shown in the raster image. Changes in the geometric centerline or the centerline of new features are collected by a heads-up digitizing process. Appropriate attributes are attached to each geometric centerline. Besides the interactive tools, RevPG provides some automatic tools. For example, it checks for consistency between two layers of the same quadrangle (for example, hydrography and hypsography).

Besides RevPG, the USGS has developed some additional products and tools for the revision process. The Digital Raster Graphics (DRG) files is one of these products. DRGs are color raster images of analog 7.5-minute quadrangles. DRGs can be merged with DOQQs in order to generate an image with the existing features in the DLG data and the most current terrain representation. A program developed by the USGS: DRG_DOQ MERGE performs this operation. These computer-based tools are being tested by the USGS and by a few other agencies and universities; their efficiency and performance are still unknown.

3. THE GISOM PROJECT AND SPATIAL DATA REVISION

3.1 Background

The Ohio State University Center for Mapping started a study of analog-to-digital map conversion technique in 1991. This effort turned into the GISOM project. The GISOM project started in October 1993, with two goals: (1) developing a cost-efficient methodology for conversion of 7.5-minute USGS quadrangles into Digital Line Graphic-3 (DLG-3) files (the USGS digital format), and (2) testing this methodology by converting all 793 7.5-minute quadrangles covering the state of Ohio. The GISOM project will last four years, with an expenditure of five million dollars. The GISOM project is in its third year and has completed the conversion of 500 quadrangles. All the DLG files generated need revision and we are developing such capability.

The GISOM project is a cooperative effort among the federal government (USGS), the state government (Ohio Departments of Administrative Services, Development, Natural Resources, and Transportation, the Ohio Environmental Protection Agency, and the Ohio Geographically Referenced Program), the university (The Ohio State University Center for Mapping), and the private sector (independent contractors).

3.2 Technical Aspects

As part of the GISOM project, five of the nine cartographic layers of the 7.5-minute quadrangles are converted into seven DLG-3 files: boundaries, hydrography, hypsography, public land survey system (PLSS), and transportation (three files: roads, railroads, and miscellaneous transportation).

Conversion includes the collection of the geometric centerline of the elements of each cartographic layer and the corresponding attributes. The geometric centerline is expressed by four topological elements: nodes, lines, degenerated lines (points), and areas. Attributes are classified as major attributes (common for a given layer) and minor attributes (with specific meaning to describe the characteristics of the elements of a layer). A maximum of one major and ten minor attributes can be attached to a topological element.

Conversion is done by a combination of heads-up digitizing and interactive and automatic line following. A commercial program has been used with reasonable results for automatic vectorizing. Software developed by the Center for Mapping is used for attribute collection, heads-up digitizing and/or interactive line following digitizing. The heads-up software was modeled after the USGS heads-down digitizing software.

After the attributing and digitizing is completed, files are checked by a quality control program (PROSYS) developed by the USGS. This program evaluates the internal consistency of these files. After that, interactive quality control for geometric accuracy, attribute consistency, and completeness is performed by Center for Mapping staff, and then, files are automatically transferred to the USGS mainframe via FTP.

4. SPATIAL DATA REVISION AT THE CENTER FOR MAPPING

4.1 Background

The Ohio State University Center for Mapping has been researching the topic of spatial data collection and revision (especially DLG files) for the last five years. This is part of a project on analytical study of spatial data and spatial data representation (Ramirez, 1989, 1991; Ramirez and Lee, 1991; Ramirez and Fernandez-Falcon, 1992). A major topic of research has been the development of a conceptual framework for spatial data collection and revision.

The Center for Mapping is interested in the "total revision" approach as defined by the USGS. GIS analysis and the computer-based design of man-made features (bridges, highways, shopping malls, reservoirs, etc.) is better served by a consistent, accurate, and up-to-date terrain representation. Therefore, our research of revision includes the revision of spatial data representing the relief as well as "planimetric" features (natural and man-made).

4.2 Understanding Changes on the Surface of the Earth

The discussion in this section is based on Ramirez (1995a, 1995b, 1996). The obvious reason why spatially referenced data (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 earth's surface. Only the subset of changes in elements traditionally represented in topographic maps (including relief) are of interest here.

Natural forces, in general, generate two types of changes: systematic and abrupt. Systematic changes are those continuous changes on the surface of the earth generated by the forces of gravity, wind, life-cycle, and others. Systematic changes are predictable (we know that they will happen and affect the surface of the earth) 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, and landslides. Abrupt changes are unpredictable, and affect the currency of the spatial data representation in a very short time interval (t_4 - t_3).

Human actions also 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). Examples of these include construction of roads, shopping malls, sport fields, and parks. Unpredictable changes are those changes, such as open-field mining and logging, whose outcome is unknown at time (t_6) and are evident only later at time (t_7).

All of 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 conventional 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 USGS (see Table No. 1). In this classification, features are grouped in nine layers.

Table No. 1
Cartographic Elements: Major Coverages

Boundaries
Geodetic Control
Hydrography
Hypsography
Miscellaneous Cultural Features
Non-Vegetative Features
Public Land Survey System
Transportation System
Vegetation

Systematic changes due to natural forces are apparent only over long periods of time. For example, hypsographic changes become significant only when they reach the magnitude of about half the contour interval of the cartographic product. Abrupt changes are impossible to predict and can affect the terrain representation immediately. They have the potential of changing the terrain representation in the most radical way; however, it may be a long time between abrupt terrain changes.

Terrain changes due to human actions, especially predictable changes, are the most common. The terrain is constantly changing, due to new constructions, particularly of transportation features (all kinds 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 substantially. However, once mining is completed, by law, 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 No. 2.

Table No. 2
Topographic Map Revision: Change Factors

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

4.3 The Cartographic Language

The analytical study of spatial data (maps) provides another part of the framework for spatial data revision. As part of the study of spatial data, Ramirez (1991) has identified a cartographic language to represent spatial features. The cartographic language is composed of the alphabet and grammar. The alphabet is the set of primitive signs from which all spatial features (cartographic elements) can be generated. It is equivalent to the alphabet of any natural language (for example, a, b, c, d, etc., for the English language). The grammar is the set of operations, rules, and writing mechanisms that allows (and constrains) the generation of spatial features from the cartographic alphabet. In this context, spatial features or cartographic elements are the terrain features represented on a spatial database or map (for example, the outline of a house). In the next paragraphs, a brief description of the cartographic alphabet and grammar are given.

The Ramirez alphabet is composed of four signs: point, line, curve, and blank space. Point is the sign that occupies no area and has no length. The alphabetic sign point is different from the cartographic point which occupies an area (for example, the cartographic point representing an individual tree). As a matter of fact, the alphabetic sign point is the skeletal representation of cartographic points. It carries positional and representational information. The alphabetic sign line has length but occupies no area. It joins two points on the plane or in the space (the shortest distance). It is different from the cartographic line, which has length and occupies an area (for example, the cartographic line representing a street in a map). The alphabetic sign line is part of the skeletal representation of cartographic lines, areas, polygons, cartographic elements, and so forth. It carries positional and representational information. The alphabetic sign curve has a nonlinear functional representation, has length, and occupies no area. It joins at least three points on the plane or the space. It is part of the skeletal representation of areas, cartographic elements, and so forth. It carries positional and representational information. The alphabetic sign blank space carries only positional information and has no visible representation.

There are four cartographic operations: (1) concatenation, (2) image construction, (3) coordinate transformation, and (4) addition. Concatenation is the operation which allows the connection of two alphabetic signs to create a more complex sign, two complex signs, or a complex sign and an alphabetic sign to create even more complex signs.

Image construction is the operation that adds to the skeletal representation some or all of the Bertin (1983) visual variables: size, value, pattern, color, orientation, and shape, to create a cartographic element at the original scale.

Coordinate transformation is the operation that takes the cartographic element (at the original size) and modifies it to reduce it to the map size, location, and orientation.

Addition is the algebraic operation which allows insertion/ removal of cartographic elements (or a portion of them) to/from a spatial database or a map. In this operation, the graphic representation of a spatial database or a map are considered, at the beginning, as a blank space (SP_i) filled only with positional information. Then, Sp_i is modified by the addition operation by adding (or removing) cartographic elements carrying locational information, resulting in a new version of the space (SP_{i+1}).

Cartographic rules are the regulations for constructing cartographic elements. There are three different sources of cartographic rules: (1) product planning and design, (2) element priority, and (3) element representation.

Product planning and design is the process of selecting all of the general and particular characteristics of spatial data (for example, an individual map or map series). Characteristics such as components, scale, projection, surface of reference, units, specific graphic symbols to be used, and characteristics of those symbols are set during this process.

Element priority is the order of placement of cartographic elements on the graphic representation of the terrain. Features with higher priority are placed before features with lower priority. This priority is related to each particular application and is generally related to the level of importance and permanency of terrain features.

Element representation is how terrain features are represented graphically, and the interrelation of these representations. For example, on most topographic maps, relief is represented by contour lines.

Cartographic rules can be grouped as general, layer-related, and priority rules. General rules apply to complete spatial data bases (topographic map series) as a whole. For example, the following rule applies to the 7.5-minute series (1:24,000 scale) of the USGS:

Every 7.5-minute map should have a legend and a title block as part of the map heading. The title block must include the following information: Quadrangle and state or states' names, county name, map series ID, and agency. The legend must show the road classification and route signs and must be placed on the lower-right margin of the map.

Layer-related rules apply to each coverage of cartographic elements, in particular, and to intercoverage relations. There are rules for each one of these coverages. For example, the following rule applies to hydrography and hypsography, respectively:

Two natural flowing water features cannot cross each other.

Contour lines of the same type should not cross each other.

The following interfamily rule applies to hydrography and hypsography:

A standing water body cannot be crossed by contours.

There are more than seventy general, coverage-related, and interfamily cartographic rules at this time (Ramirez, 1988), and as the analytical study of maps progresses, more rules are expected to be found.

Priority rules are purpose dependent. Two major criteria are used in their establishment: importance and permanency. The most important cartographic features are those that will remain unchanged on a graphic representation (such as a map) in those situations where some features must be altered (for example, in overcrowded areas). If two features are of equal importance, then the most permanent is the one that will remain unchanged. Permanency is related to the longevity of terrain features. The longer a terrain feature stays without undergoing any change, the more permanent its cartographic representation.

The writing mechanism of the cartographic language is the Universal Mapping Command (UMC) (Ramirez, 1991). The general expression of a UMC is:

$$UMC = +(@(K((\{c\,A\,\hat{}\,\}\,\hat{}\,[\{c_1\,B\}]\,\hat{}\ldots)(<U><V><U_1><V_1>)))). \qquad (1)$$

A UMC is a formula-like expression that allows analytical representation of any graphic element of a spatial product (such as a topographic map). UMCs make use of the cartographic alphabet and cartographic operations, plus some additional operators (**K, c, c_1**) to express cartographic elements.

K is the cartographic element restriction which is one or more constraints imposed over the whole cartographic element. Topology and layer and feature constraints can be defined through **K**. **c** and $\mathbf{c}_1$ are the alphabetic character restrictions. Alphabetic character restrictions are constraints imposed over individual and/or consecutive alphabetic characters in a cartographic element. For example, two consecutive line segments are perpendicular to each other.

In the general UMC expression (Formula 1), **A** and **B** are alphabetic characters from the cartographic alphabet, or text, or numerical expressions. **U** and $\mathbf{U}_1$ are space dimensions (coordinate values such as X, Y, and Z) and **V** and $\mathbf{V}_1$ are image construction operators.

4.4 A Model for Representing Spatial Data

The cartographic language provides an efficient mechanism to collect and modify (consistently and systematically) individual features of a spatial database or a map, but it is not enough to handle simultaneously all of the information presented in a spatial database or maps. This is accomplished by a cartographic model. A cartographic model for the representation of spatial data is defined by Ramirez and Lee (1991) as "a simplified representation of the surface of the earth or any celestial body that can be expressed in analytical form." A cartographic model is only a generalization or idealization of reality.

Major problems in the process of automating the collection of spatial data are: (1) producers do not yet understand the nature of these data or the mental process followed to collect them, (2) production is operator-intensive and (3) computers are only used to accelerate manual operations and simulate analog production methods. A possible solution to this is to rethink the concept of mapping and simplify the cartographic collection process to a well-defined set of steps. This is the idea behind the cartographic model. Ideally, terrain elements could be expressed by known functions of the type,

$$\text{Element} = F(\text{Parameters}), \qquad (2)$$

from which a cartographic product could be generated in a consistent and efficient manner. Conceptually, the model will encompass all of the rules employed by cartographic products today.

The cartographic form to be presented here was developed by Ramirez and Lee (1991). It resembles the Bakus-Naur Form (BNF) (1960) used in the definition of Algol; for this reason it is called the Bakus-Naur Cartographic Form (BNCF). The BNCF is composed of five basic symbols. This symbols are shown in Table No. 3.

Table No. 3
Bakus-Naur Cartographic Form Symbols

:=	Consists of
< >	Single occurrence of an abstraction
[ ]	Optional occurrence of an abstraction
{ }	Multiple occurrence of an abstraction
( )	Always occurs together

The context-free syntax of the language is given in the form of production rules of the type, <A> := <B> , where <A> is one of the members of the production rule which is called the left-hand side (LHS) of the production rule and <B> is the other member which is called the right-hand side (RHS). They are always separated by the symbol ":=". The LHS is always of the type < > and it is a nonterminal sign. Nonterminal signs are those abstractions which can be expressed in terms of other terminal and nonterminal signs. Terminal signs are known values, such as color, line weight, line style, and coordinate values. The RHS could be of the type < >, [ ], { }, ( ), any combination of them, and/or terminal signs. A derivation is a set of production rules which enable the LHS to be fully expressed by terminal signs.

Spatial data (topographic cartographic products) can be written in terms of the BNCF. In order to do that, the cartographic components of spatial data must be used. They are given in Table No. 4. Using the above terminology, Ramirez and Lee (1991) found that any topographic cartographic product can be expressed in BNCF by the derivation given in Table No. 5.

Table No.1, the cartographic language (alphabet, operations, rules, and writing mechanism), and the cartographic model provide part of the conceptual framework needed for spatial data collection and revision. Table No.1 and the corresponding discussion tell us how the terrain and its features change, the cartographic rules tell us how features (new and old) behave, the writing mechanism provides us with a systematic way to express individual features, and the cartographic model allows expression of the entire spatial database (or map) in a systematic and formula-like fashion for collection or revision of spatial data.

Table No. 4
Cartographic Elements

CI	contour interval specification	QD	quality of data sources
CN	credits and notes	RF	positional reference frame
HD	heading	RS	representational signs
LG	heading-legend	SF	surface of reference
MP	cartographic projection	SR	scale representation
NA	north arrow	TB	heading-title block
PD	positional diagram		
AS	area sign	PA	patterning
AP	area patterning	PO	point
BS	blank space	PS	point sign
CO	color	SA	sentences
CU	curve	SD	spatial dimension
LA	label	SG	graphic sign
LB	line symbol	SH	shape
LI	line	SI	size
LN	label number	SL	natural language sign
LS	line sign	SN	numerical language sign
LT	line width	SS	symbol size
LY	line style	ST	structural grammar
NM	name	TS	terminal sign
NN	name number	VA	value
OR	orientation	VV	visual variable

5 DATA INTEGRATION FOR SPATIAL DATA REVISION: CURRENT AND FUTURE RESEARCH AT THE CENTER FOR MAPPING

Operationally, the problem of spatial data revision can be divided in three steps: (1) identification of local changes, (2) collection of data reflecting the changes, and (3) processing, removing, and/or merging of new data with unchanged old data (consistently) to generate up-to-date terrain representation.

Table No. 5
Cartographic Product Derivation

<map> := {RS}[HD][RF][SF][MP][NA][SR][CI][PD][QD][CN]	
<RS> := {[SG][SL][SN]} <RF> := {[SG][SL][SN]} <MP> := {[SL][SN]} <NA> := {[SG][SL][SN]} <PD> := {[SG][SL][SN]} <CN> := {[SL][SN]}	<HD> := [TB][LG] <SR> := {[SL][SN]} <SR> := {[SG][SL][SN]} <CI> := {[SG][SL][SN]} <QD> := {[SG][SL][SN]}
<TB> := {[SG][SL][SN]}	<LG> := {[SG][SL][SN]}
<SG> := {[AS][LS][PS]} <SN> := {[NN][LN]}	<SL> := {[NM][LA][SA]}
<AS> := {[PO][LI][CU][BS]} <PS> := {[PO][LI][CU][BS]} <LA> := <ST> <NN> := TS	<LS> := {[PO][LI][CU][BS]} <NM> := <ST> <SA> := <ST> <LN> := TS
<PO> := <SD>[VV] <CU> := <SD>[VV] <ST> := TS	<LI> := <SD>[VV] <BS> := <SD>
<SD> := ({X}{Y}[{Z}]) <VV> := [SI][VA][PA][CO][OR][SH]	
<X> := TS <Z> := TS <VA> := TS <CO> := TS <SH> := TS	<Y> := TS <SI> := [LT][SS] <PA> := [LY][LB][AP] <OR> := TS
<LT> := TS <LY> := TS <AP> := TS	<SS> := TS <LB> := TS

To identify local changes, we are exploring the use of new raster images (for example, digital orthophotos) and vector data representing the old terrain (such as DLG-3 files) to develop a means to automate the detection of local changes. The idea is to use the information (spatial position and attributes) of the vector data and the cartographic rules to learn about the nature of the image representation. For example, unchanged elements of the road network will provide information about how these roads are portrayed on the raster images. This, together with the rules about the road network (for example, a new road is connected to an existing road), is being used to develop a partial or highly automated solution for new road detection.

Once changes are detected, representative data needs to be collected. We propose to study different data and collection options such as conventional photogrammetric data, digital orthophotos and orthophoto quads, digital elevation models, satellite multispectral data, mobile mapping systems, and classical GPS. Currently, we have been studying digital orthophotos and the mobile mapping system developed by the Center for Mapping (GPSVan™). Figure No. 1 is an example of integration of these two datasets.

We have found that these data sources complement each other well. Figure No. 1 shows a new road which does not appear in the digital orthophoto-image used to review the corresponding DLG data. In such a case, the most cost-efficient collection approach may be the GPSVan™.

We also found that digital orthophoto data, generally, are not enough for revision of all the spatial data carried by digital spatial databases or topographic maps (the nine coverages of Table No. 1). We are currently investigating, besides the mobile mapping systems data, the use of DEM, color, and black and white photographic images as complementary data sources. This specific research just started and no finding can be reported yet.

The last operational step is to process, remove, and/or merge, in a consistent fashion, the new and the unchanged old data to generate a new terrain representation.

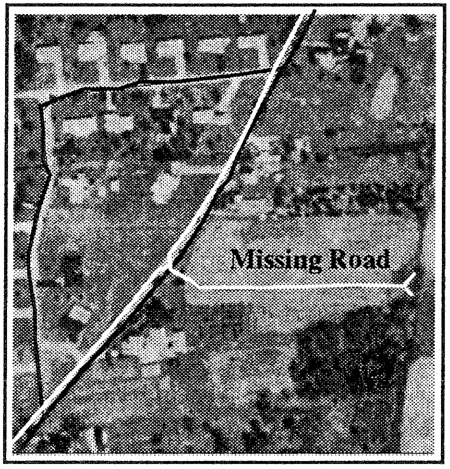

Figure 1. GPSVan™ (white), Digital Orthophoto, and DLG data (black)

As a first step of processing, removing, and/or merging the datasets, data will be transformed into a common reference datum and a common coordinate system. Then the dataset of the current terrain representation will be compared against the collected datasets, and a search for coincidental data (and differences) will be conducted.

After differences are found, a spatial conflation program (to be developed) will be used to process all these datasets and generate a new, consistent dataset. Spatial conflation is the technology that allows us to take two datasets (D_1 and D_2) representing elements of the same geographic area and generate a new dataset (D_3), which contains a unique representation of all elements in the two datasets. Combination of these two datasets 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 datasets to be considered are the digital dataset representing the out-of-date terrain and the dataset representing the changes on the terrain (collected from digital orthophotos, GPSVan™, and other sources). This portion of the research has just begun.

Finally, we have found that automation tools must be developed to make the revision process cost-efficient. We are developing some of these automation tools on PCs.

6. CONCLUSION

Spatial data revision is a field of great importance for GIS. It offers many challenging problems that need to be understood and solved in a cost-efficient fashion. The Center for Mapping is committed to their study and is making major progress in their understanding and solution.

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