GIS FOR A SMALL CITY USING GPS & PHOTOGRAMMETRY

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Abstract

This article will highlight the procedures used in one approach to create an automated GIS for a small city to include development of the base map. The paper will show the efficiency in using GPS surveying to establish ground control as well as the integral role photogrammetry plays in the development of GIS. The significant amount of time to build the nongraphical attribute data base will be pointed out as well as suggestions to shorten the time involved in this task. The paper shows an automated GIS can assist in the operation of a small city as well as a larger city.

Key Words: Geographic Information Systems, Surface State Plane Coordinates,
Global Positioning System

Introduction

A Geographic Information System (GIS) should be able to provide the graphic display of a location, information on the location, analyze this information, and also relate this information to those of other locations. One very broad definition of a GIS is that it is a facility for preparing, presenting and interpreting facts that pertain to the surface of the earth (2). According to this definition manual or cartographic maps can be classified as a GIS (1). In both automated or manual systems, a base map providing the geographical reference to all information is required. A base map for a city must show spatial information such as utilities, building outlines, property boundaries, contours, etc. and nongraphical attribute data pertaining to the graphics (See fig. 1). In light of this, the essential elements a GIS must have (1):

1. the capability to acquire data. This is the process of identifying and gathering data pertaining to the application.
2. the capability to preprocess data. This is the process of putting all data into a format for entry into the GIS.
3. capability to manage data. This is the process of creating and providing access to the data bases while providing for security.
4. capability to manipulate and analyze data, which is a process of creating new data from existing data.
5. capability to generate output products, to produce a soft copy (on screen) or a hard copy in a particular format. (See figure 2.)

Commercial GIS software packages have different capabilities and features. One of the more important and distinguishing features of a software is its spatial data structure. The data structure affects both the storage volume and processing efficiency of the system. The data structure of the software will determine which data base one might import for use in GIS. These are two major categories of spatial data structure: raster and vector. In raster structures, a value for the parameter of interest, land cover type for example, is developed for each picture element (pixel) within the limit of the area of concern (1). A line would be stored as a series of pixels lined up together from the starting to the ending point. Satellite remote sensing data are processed in a raster structure. Vector data structures are based on the locations of basic entities such as points, lines and circles. A circle might be stored as a center point with a radius in a vector structure, whereas in raster structure the circle is stored as a series of pixels that form its perimeter. Some GIS softwares can process both types of data structures.

In the GIS application for cities knowing specific location and lengths of features are important and almost all spacial features of concern are linear or polygons bounded by straight lines. Since UltiMap, a vector data structure software, possesses both characteristics, it is suitable for developing GIS for cities.

One of the primary requirements for developing a GIS for the city is a coordinate base map. When a coordinate base map is developed by digitizing existing city and subdivision maps, many systematic and random errors may result because these maps may themselves be second or third generation maps having errors from previous drawing or reproduction. The paper on which these maps are printed may have contracted or expanded causing further inaccuracies. Other errors may also result when the operator places the cross-hairs of the digitizing puck on the point or from the electronic capabilities of the digitizing hardware. In order to overcome these problems, modern GPS

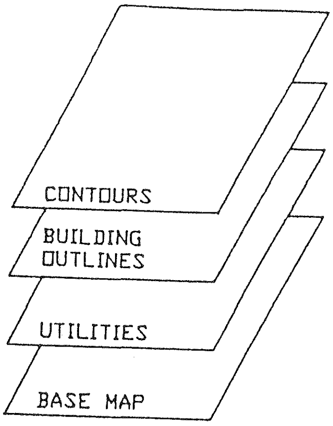

Figure 1. Spatial information layering concept

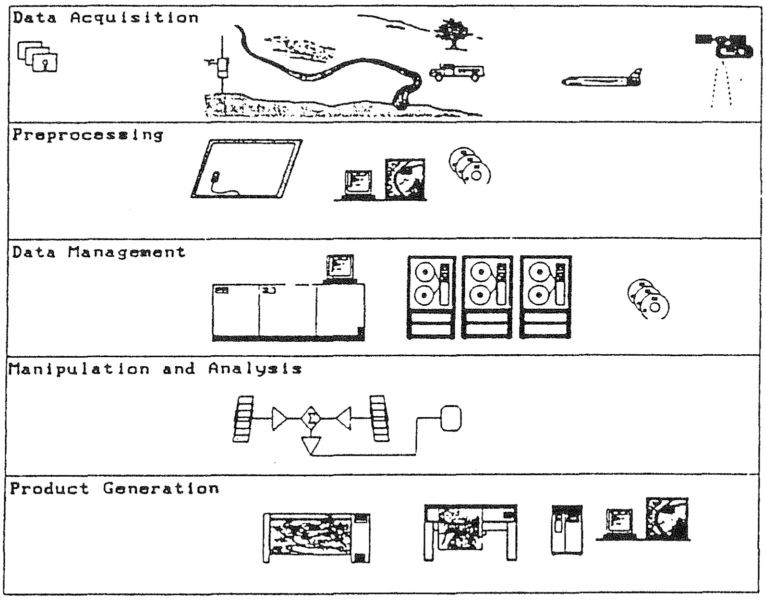

Figure 2. The five elements of a GIS

surveying can be used to develop the coordinate base map. The coordinates of key points on the ground, such as parcel corners, points along centerline of a road are determined by GPS and design maps with dimensions. These coordinates are entered directly into computer graphics file. These points are then connected with lines or arcs to form the base map required in GIS. Unfortunately, subdivision maps and road design maps do not give elevations and the location of buildings. Utility maps are tied to fire hydrants, power and telephone poles, etc; thus, in order to add the utility maps to the coordinate base maps, the location of the fire hydrant, etc. must be determined. Fortunately digital photogrammetry using large scale aerial photography can be used to precisely locate buildings, fire hydrants, telephone posts, power poles and elevations of points on the same base map coordinate system and build the GIS for the city.

Roland, Iowa was selected as the project city for several reasons. With a population of about 1,000 people, Roland is large enough to have a city utility department which provides water, sewer and street maintenance for the town. Roland's corporate boundaries lie directly along lines connecting U.S. Public Land Survey Monuments (See figure 3). All subdivision maps and land parcels are tied to U.S. Public Land Survey Monuments known as section and quarter section corners. Using GPS the locations of survey monuments can be determined precisely on a World Geodetic System (WGS). The dimensions of subdivision, parcel and other design maps are in surface horizontal distances. In U.S.A. State Plane Coordinate systems are used as the projection coordinates at the state level. Universal Transverse Mercator (UTM) is the projection system for the entire country. Thus for a city, it is desirable to have the base map coordinate system in a surface State Plane Coordinate system. The city of Roland had a base map prepared in 1983. They have copies of the subdivision plats, plans and profiles of streets and utilities. Attribute data such as parcel ownership or current assessed values are also available from the Story County assessor. Thus, by definition, Roland has a manual GIS.

The objectives of this paper are to describe the procedures developed in creating a modern automated GIS for Roland, Iowa under the following headings:

(1) GIS Applications for a City
(2) Ultimap GIS Software
(3) Base Map Coordinate System
(4) Development of the Base Map
(5) Data Acquisition Techniques
(6) Building GIS

GIS APPLICATIONS FOR A CITY

A GIS for a city should provide a minimum of two capabilities. First, the capability to store, retrieve and display attribute data pertaining to graphical entities. More specifically, one should be able to view a map of the city, select an entity with the cursor and have the system display attribute data pertaining to that entity. Secondly, the GIS should have the capability to analyze an existing attribute data file and indicate all graphical features which meet a particular attribute description provided by the user.

Two subdivisions, Britson, Second Addition and Ryan, First Addition, which meet all the requirements of a city, are selected as the study area. The specific attributes available for processing differed between the two subdivisions of the project. The information available in Britson's Second Addition would be

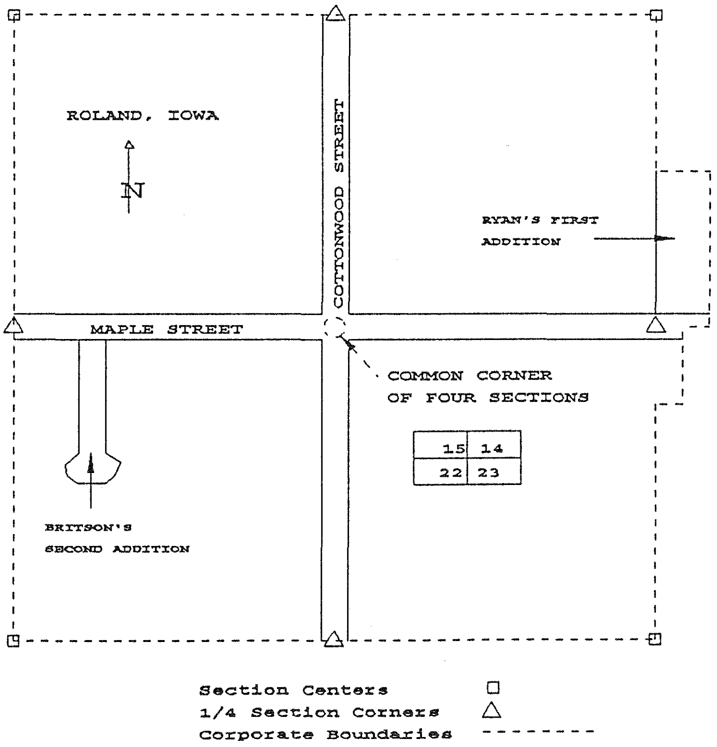

Figure 3. Roland corporate boundaries. (Not to scale)

of primary use to those concerned with boundary location and control, while Ryan's First Addition data provides information useful for more expanded areas of municipal engineering, tax assessment, and property purchasing.

Specific attributes available for processing within Britson's Second Addition are:

(1) owner of each lot in the subdivision.
(2) the street address for each lot.
(3) the area and perimeter of each lot.
(4) the surface and projection state plane coordinates of all lot corners.
(5) the bearing of all lot lines.
(6) the current assessed value of each lot.

The following attributes are available for processing within Ryan's First Addition:

1. the owner of each lot.
2. the street address of each lot.
3. the number of bedrooms in each home.
4. the surface state plane coordinates for fire hydrants and power poles.
5. the type of pipe, diameter of pipe, average percent slope, and minimum depth of coverage for sewer and water pipes.

The attribute data were gathered from several locations. The city's utility department provided a copy of the plat for Britson's Second Addition as well as plan and profile drawings for underground utilities. A copy of the plat for the other subdivision was obtained from the county recorder; the county assessor provided other information.

ULTIMAP GIS SOFTWARE

The UltiMap program meets all software requirements of a GIS to preprocess data, manage data, manipulate and analyze data, and to provide for product generation. The user interface is primarily icon driven with some keyboard entry required.

The program consists of eight modules. Four of these modules are application modules such as Coordinate Geometry (COGO) module and a Road Design System. These modules provide powerful computation capability to produce data for inclusion in GIS or for separate use. The other four are discussed below.

The Interactive Graphics System (IGS) module is the graphics module and is the heart of the system. This module provides a fairly sophisticated level of Computer Assisted Drafting and Design (CADD) capability. Commands within the IGS module are organized under a chapter and page type convention such that every command is entered in an alphanumeric fashion. One major difference between the UltiMap IGS module and a standard CADD program such as AutoCAD is that there are no layers in IGS. Each entity drawn is assigned a specific symbol definition within what is called a symbol dictionary. The visibility of individual symbol definitions is toggled on or off versus layers in AutoCAD. As part of the GIS capability, each entity drawn in IGS is assigned a reference number which can serve as part of a process to tie that particular entity to a record in the data base.

Drawing files created in AutoCAD can be imported into an IGS drawing file by utilizing an UltiMap translator routine. This translation is accomplished using AutoCAD DXF files.

The Revision Control Data Management System (RCDMS) is the data base management module of UltiMap. This module allows the building of a data base through IGS and other modules. RCDMS allows for many people to be working on a project and for the sharing and merging of their respective data. It also provides for project security through user access options. This module also has a time stamping feature which allows for a historical record of a project.

The Topological Access Generator (TAG) module allows for the creation of schemes to relate graphical features to nongraphical attribute data files. The relationship between graphical and nongraphical data is accomplished by linking reference numbers assigned to an entity in IGS with a particular value in an index field of an attribute data file. Figure 4 shows the tagging concept.

Reference Numbers		Index Field	Line Length	Lot No.
100.10	<——————>	LIN01	100	14
100.20	<——————>	LIN02	110	15
100.30	<——————>	LIN03	150	16

Data File

Figure 4. Tag scheme relating reference numbers to values in an index field.

The information to the right of the arrows represents a small data file with the first field being defined as the index field. The remaining fields in the data file represent attribute data pertaining to graphical entities, perhaps lot lines in a subdivision. The reference numbers on the left side of the arrows are the unique reference numbers assigned to three different graphical entities, lot lines in our example.

The user specified how the values in the index field will be linked to a reference number. In Figure 4, reference numbers 100.10, 100.20, and 100.30 are linked with index field values LIN01, LIN02, and LIN03, respectively. When a particular index field value is indicated through different UltiMap processes, all attribute data for the record with that index field value become available for processing.

This linking, or tagging, concept to tie graphical and non-graphical data is a basic concept in all GIS software. Different programs use different procedures.

The Q-Star Fourth Generation Language (Q-Star) module is the primary module used in the development of GIS. Within this module new or existing data files are prepared for processing and the system receives its instructions on what processing is to be done to the available data. Q-Star consists of three major submodules including Q-link Q-join, and Q-view.

Q-link is the submodule used to define the physical layout of a nongraphic data file. New or imported existing files, such as a DIME file, must be defined. This definition tells the system what data are available for processing. Q-join is the module used to manipulate information files for efficient data extraction and file updating. Q-view is the most important submodule of Q-star and is the most important submodule in the creation of GIS.

Within Q-view, the user programs the system as to what data will be processed and what the processing will be. Q-view allows not only for retrieval and display of data, but also analysis of existing data to create new data for management purposes. Q-view allows for combined analysis of graphical and nongraphical data or nongraphical data analysis by itself using spreadsheet type techniques. Within Q-view, the user also specified which device the output of a particular process will be sent to and the output format.

The UltiMap program is sold by the ULTIMAP Corporation of Minneapolis, Minnesota. ULTIMAP provided the software to Iowa State University (ISU) along with the documentation at no charge and provided software and documentation updates as they were developed.

THE BASE MAP COORDINATE SYSTEM

The center of Roland, Iowa is the common corner of Sections 14, 15, 22 and 23 of Township 85 North, Range 23 West of the 5th Principal Meridian (PM) in the United States Public Land Survey System (See figure 3). The 5th PM is one of the many initial points of survey and has a latitude = 34° 38' 45" N and longitude = 91° 3' 37" W.

Roland is in Story County, which is a tract of 24 X 24 miles, whose south-east (SE) corner has a latitude = 41° 51' 47".93 and longitude 93° 13' 55".20. The South East corner is 81 X 6 = 486 miles North and 20 X 6 = 120 miles West of the initial point (See figure 5). Also the Township 85N & R23W, whose SE corner is 84 X 6N = 504 miles N and 22 X 6W = 132 miles west of the initial and 3 X 6N = 18N miles and 2 X 6 = 12 miles West of the SE corner of Story County. The center of Roland is 3 miles North and 2 miles East of the SE corner of Township 85N and Range 23W. Each square is a section which is one mile by one mile. Roland is about, one mile by one mile, being quarter of Sections 14, 15, 22 and 23. According to the U.S. Public Land Survey System every section corner and quarter are monumented. Thus they serve as physical evidence on the ground.

The base map coordinate system to be designed must be acceptable to a city engineer and surveyor. It must also be suitable for a GIS application. Using GPS technology, the

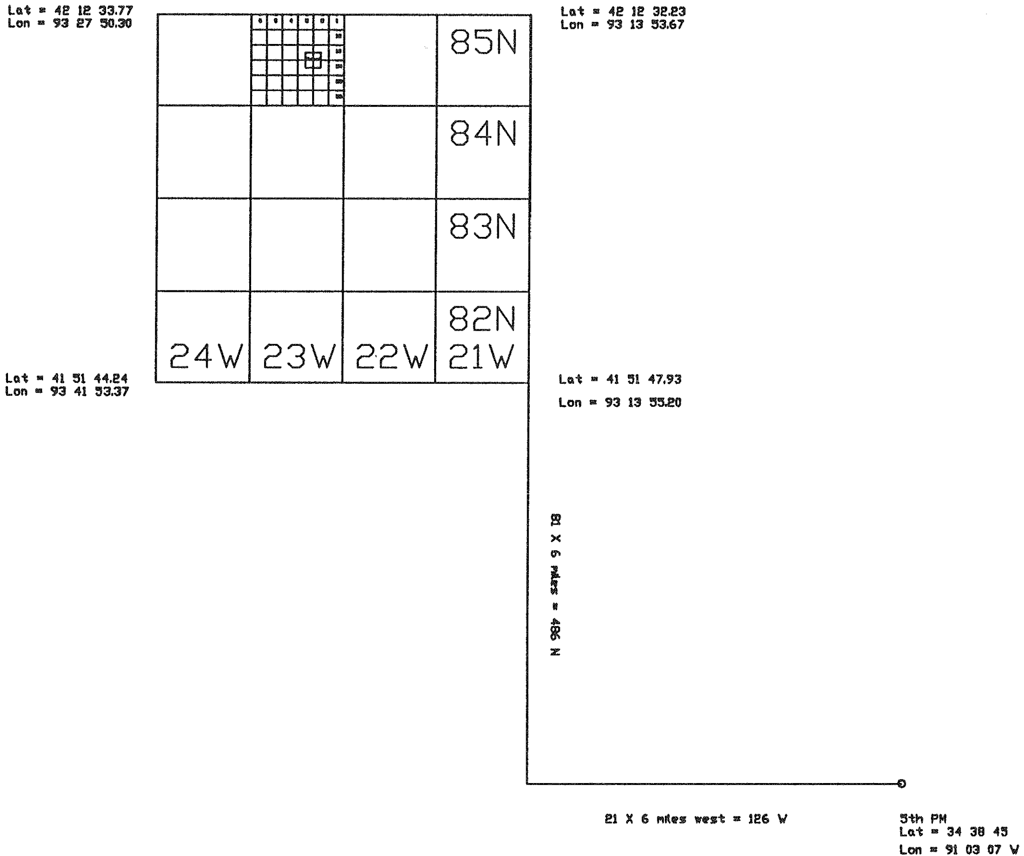

Figure 5. U.S. Public Land Survey System

Geographic coordinates, θ, λ, h on WGS 84 of these monuments can be determined to first order accuracy. For mapping purposes these spherical or 3 dimensional coordinates are converted to plane or 2 dimensional coordinates. In the U.S.A. different states have different plane coordinates known as the State Plane Coordinates. In this system the distances are reduced to the reference surfaces and directions are parallel with central meridian. These projected distances are known as grid distances and directions are known as grid azimuths. In Iowa, the Lambert conformal projection is used for deriving the State Plane Coordinates (X, Y) as

$$X = X_o + R \sin\theta$$
$$Y = R_b - R \cos\theta$$

where θ = convergance angle = f(λ)
= geodetic azimuth - grid azimuth
R = function of latitude
X_o, R_b are the constant of the projection.

These coordinates are convenient for mapping but are not suitable for engineering and surveying application due to distortion in scale. In engineering and surveying one needs surface distance, SD, as opposed to grid distance, GD. The grid distance is related to surface distance by

$$SD = \left(\frac{GD}{K}\right)\left(\frac{r+H}{r}\right) = GD * f$$

where K = scale factor
H = height of point above reference surface
r = radius of the reference surface

$$f = \left(\frac{r + H}{r}\right)\frac{1}{K}$$

Thus a local surface state plan (X_s, Y_s) coordinates is developed such that

$$X_s = X_o + (Y - X_o)\,f$$
$$Y_s = Y_o + (Y - Y_o)\,f$$

where
(X_o, Y_o) - state plane coordinate for a central point in the city

A base map created in surface state plane system can be transformed to state plane which in turn can be transformed to Geographic Coordinate System.

DEVELOPMENT OF THE BASE MAP

A major secondary goal of a GIS project is to develop a coordinate base map for the GIS in the surface state plane coordinate system. The direct entry of coordinate values for key points into a digital drawing file eliminates errors which result when digitizing existing maps. GPS and existing plat maps of the two subdivisions were used to develop the coordinate base map.

In this research the GPS was used to establish the coordinates of the 4 corners of Story County, and about 12 key points in Roland (See figure 6). Figure 6 shows the 12 control points used for the project. All points except 1 and 7 were physically occupied with a GPS antenna. Points 1 and 7 were on the centerline of a busy highway and their positions were established using intersection techniques.

Relative GPS surveying in the static, pseudokinematic, and kinematic modes were used to establish ground control for the base map and photogrammetry. Figure 7 shows the azimuths and distances between key points in the state plane coordinate system. Points 1, 2, 7, 5 are 1/4 section corners on the corporate boundaries of the town and point 4 is the common corner of four sections.

After establishing ground control with GPS, the next step in the development of the base map was to determine coordinate values for lot corners and points along street centerlines in the two subdivisions. Existing plats were used to accomplish this. By transforming the bearing and distance information on the plats from a local coordinate system to the state plane coordinate system, straightforward traverse computations would provide the State Plane Coordinates of the desired points.

The angular rotation between the local system and the state plane system was determined by comparing the local azimuth with the state plane azimuth on a line where both values were known. The difference between the azimuths is applied to all bearings shown on the respective plats to obtain equivalent bearings in the state plane coordinate system.

Surface distances were reduced to the projection in the standard way.

Both subdivisions were tied to public land survey monuments, which are used as control points in the GPS survey so the state plane coordinates were known for these points. From these known points and bearing and distance information between successive points, state plane coordinates for key points in the subdivision were computed.

State Plane Coordinates computed following the above procedures represent locations on the state plane projection surface and are important for precise geodetic surveying applications. To avoid the somewhat lengthy distance reduction procedures and yet maintain an acceptable accuracy for most GIS applications, Surface State Plane Coordinates were developed for key points and these values were actually used to develop the base map. The difference in distances between two points computed in projection State Plane Coordinates and Surface State Plane Coordinates differed by less than 1 part in 15,000. The projection State Plane Coordinates were computed and are available as attribute information for key points.

The Surface State Plane Coordinates for key points in both subdivisions were computed by determining the surface coordinates for control points 1 and 7. Then the same procedure described above to find the projection coordinates were used except that surface

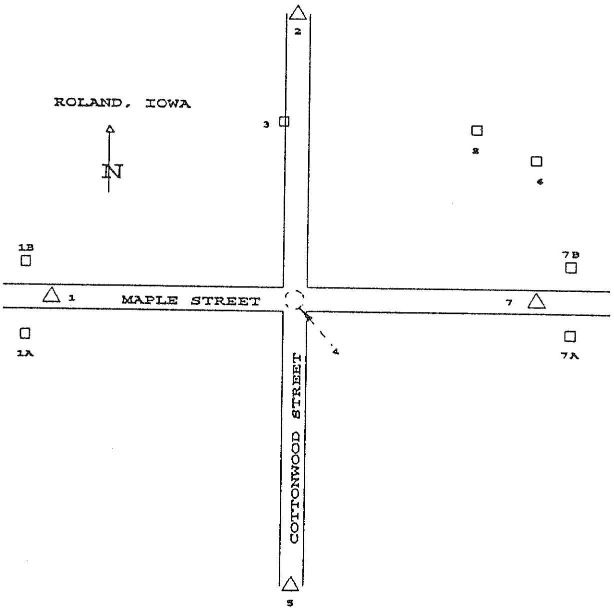

Figure 6. Roland control points.

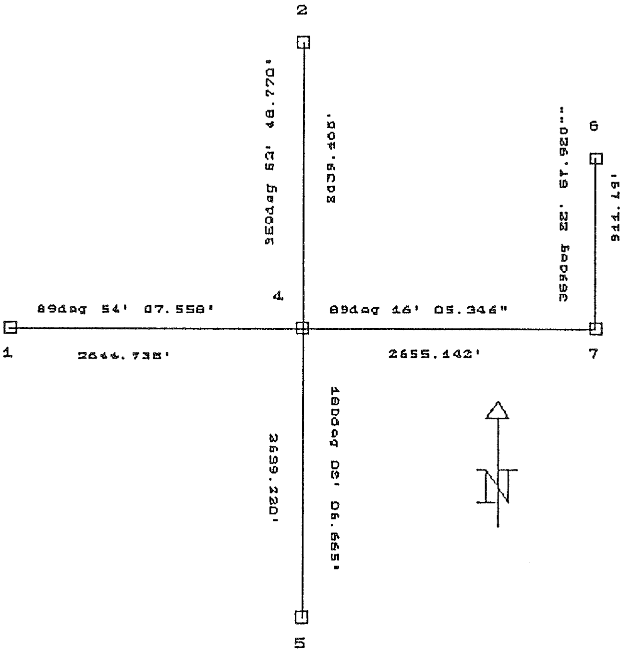

Figure 7. Final azimuths and distances between control points.

distances were not reduced to projection distances. The surface coordinate values for control points 1 and 7 were computed using the projection coordinates for control point 4 as fixed. Next, the differences in the projection X, Y coordinates between point 4 and points 1 and 7 were divided by their respective reduction factors. These adjusted differences were then added or subtracted to the fixed coordinates at point 4 to find the surface state plane coordinates of points 1 and 7.

The AutoCAD CADD program was originally used to create separate base map files for each subdivision which were subsequently translated into the UltiMap program. The Surface State Plane Coordinates for each point were entered into AutoCAD and appropriate lines or arcs were drawn to connect the points to create the map.

DATA ACQUISITION TECHNIQUES

When determining what information should be available in the GIS, it was determined that the location of houses, power poles, fire hydrants, streets, and underground utilities should be included. It was also thought that contour lines should be drawn to represent the topographic relief. Photogrammetry was used to obtain this surface data for Ryan's First Addition.

Existing aerial photography for the project was obtained from a private firm that had photographed the area for an earlier project. A stereomodel including Ryan's First Addition was created on a Kelsh stereoplotter at a scale of 1 inch = 85 feet.

The coordinate values for the ground control points were not available from the private firm we obtained the photography from, forcing us to establish our own ground control. GPS surveying was used to establish combined horizontal and vertical control points in all four corners of the model at points well imaged in the model.

Locations of underground utilities and streets were digitized onto the base map using scaled plan drawings. Profile drawings of the utilities were used to obtain attribute data such as minimum depth of fill, percent slope, diameter, and type of pipe for sewer and water lines.

BUILDING GIS

Once the raw data had been gathered and preprocessed into a computer ready format, it was time to put it all together in UltiMap.

Each subdivision drawing was translated from AutoCAD into UltiMap at a scale of 1 in. = 100 ft. Miscellaneous touch-up work was done at this time, such as adding some street boundaries and text (See figure 8).

The next step was to create the nongraphical attribute data base. A separate data file was built for each entity that attribute data would be tied to. For example, in Ryan's First Addition, one data file was built for attribute data linked to the utilities. Separate files for like type entities were built because common entities share nearly identical attributes. The first field in each file was defined as an index field which would be used in subsequent processes to link each record within the attribute files to the graphical entity it was describing.

At this point, different submodules of the UltiMap program were used to link the graphics with the attribute data base and to instruct the system how to manipulate the graphical and attribute data to achieve the desired applications. Figure 9 shows an example of what attribute data is displayed on the screen or printed to a file regarding any lot in Britson's Second Addition when that lot is selected through different processes. The application to highlight graphical entities which matched a particular attribute description provided by the user was also developed.

CONCLUSIONS

A working GIS was successfully developed. The system accomplished the goal of providing the user with information necessary to make decisions for management purposes. An automated GIS could benefit the city by increasing the efficiency of information processing. The user now has at his fingertips information that was scattered in three different offices in two different towns 13 miles apart. In addition to increased efficiency, an automated GIS would also provide a permanent record of all stored data. This information would be accessible whether or not a key employee was available or if a map or other document was misplaced in the map box on the second floor of city hall.

The single most time consuming portion of the project was developing the attribute data files. When planning the development of a GIS, care should be given not to underestimate the time needed for this task. Designing the format for the files and actual data entry via the keyboard simply takes a long time. Tremendous time can be saved by importing existing digital data files into your system if they are available and match your needs. This approach to acquire data should always be explored.

The use of GPS surveying to assist in the development of the base map as well as establishing ground control for the photogrammetry work was very successful. Ten points were located in the project with centimeter accuracy.

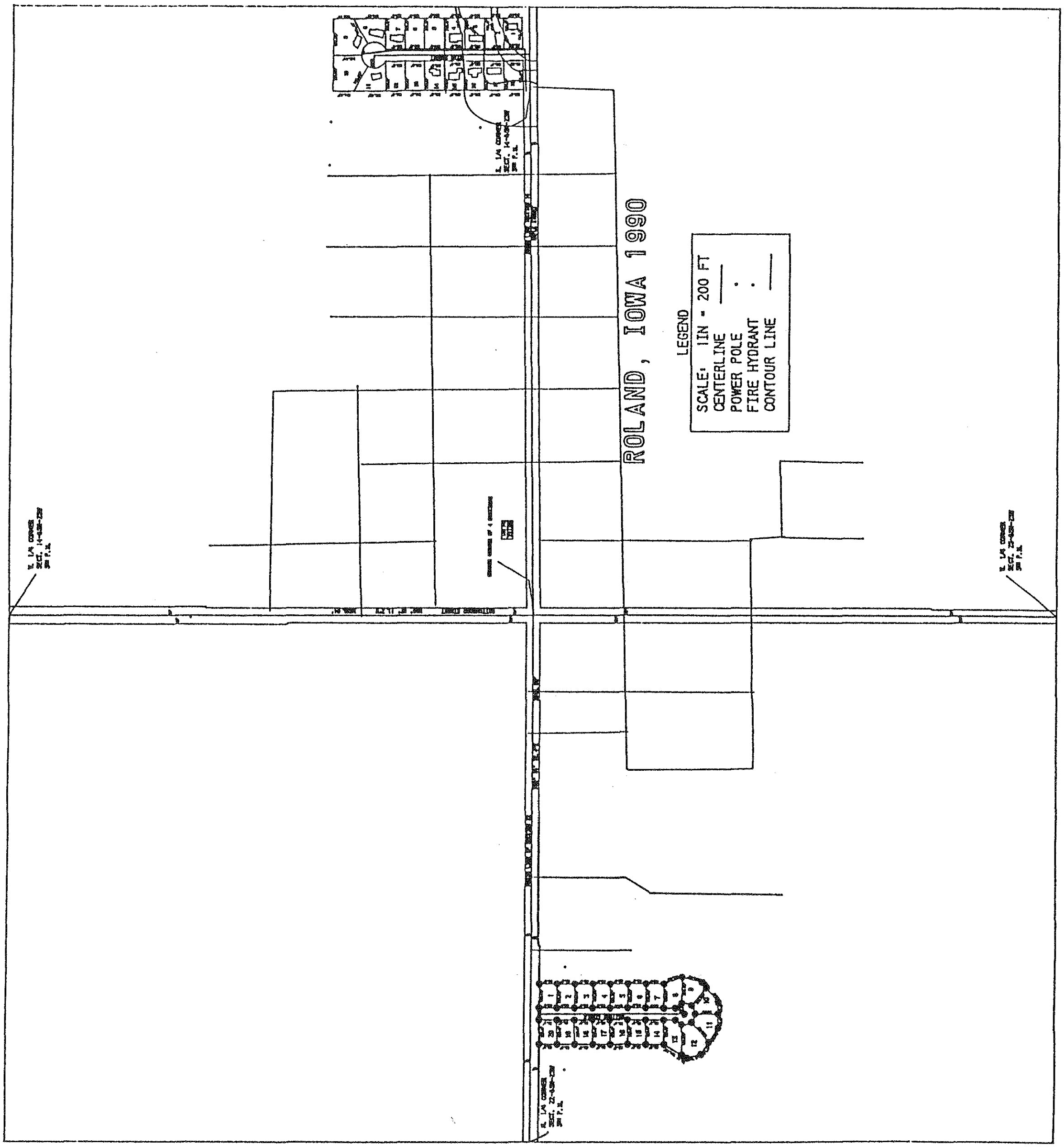

Figure 8. GIS of Roland, Iowa

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    LOT #          SUBDIVISION              OWNER           AREA (SQ. FT.)
   LOTNO02    BRITSON'S 2ND ADDITION     STEVE TWEDT          11034.68


    ADDRESS             CURRENT ASSESSED VALUE              PERIMETER (FT)
   110 BRITSON CIRCLE           54300                           425.22

   SURFACE STATE PLANE COORDINATES OF LOT CORNERS
   STARTING WITH NW CORNER OF LOT AND PROCEEDING CLOCKWISE:

                           CORNER 1        CORNER 2         CORNER 3

     NORTHING (FT)      3523503.023     3523503.205      3523413.205

     EASTING (FT)       4918693.724     4918816.303      4918816.319

                          CORNER 4         CORNER 5         CORNER 6

     NORTHING (FT)      3523413.023       XXXXXX             XXXXX

     EASTING (FT)       4918693.682        XXXXX             XXXXX
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Figure 9. Example attribute output display.

Photogrammetry is an invaluable asset in the development of a GIS with applications similar to this project. It simply provides information that is not available from any other source and generally provides more current information than other sources. When the photography for the area of interest becomes available, the procedures to capture the data and enter it into the GIS are fairly rapid.

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