Development of a land survey system with CAD/GIS interfacing capabilities

Khalid Lotfy Ahmed El-Ashmawy
Civil Eng. Dept., Faculty of Eng., Helwan University, Mataria, Cairo 11718, Egypt

The field of land survey is undergoing tremendous changes attributed to the way data are handled, analyzed and presented. Also, there is a growing demand for digital spatial information, coming primarily from the Geographical Information System (GIS) user community. Such a demand has created a strong development potential for a new land survey software. An overview of the development and capabilities of a land survey software platform based on the Windows system, LandSurMap, is presented. Among its many features, LandSurMap offers great deal of flexibility for networks adjustment, geodetic and plane coordinates transformation, contouring, sectioning, DTM generation, and large scale mapping applications. The system output has compatibility with known CAD/GIS packages to widen its scope of applications. Because the graphic user interface is designed to be user-friendly, LandSurMap is suitable for non-technical users. The system has potential of applications in diverse fields such as engineering, architecture and GIS as well as further academic research. Two applications of LandSurMap, extension of field control and large scale mapping, for the area of the case study are demonstrated.

يهدف هذا البحث إلي ابتكار نظام للمساحة الأرضية يمكن استخدامه في كثير من المجالات مثل ضبط الشبكات الأرضية وتحويل الإحداثيات بين الأنظمة المختلفة وعمل الخرائط الكنتورية وتكوين شكل مجسم للأرض وعمل قطاعات عرضية وطولية للمشاريع المزمع اقامتها و سهولة انتاج الخرائط الطبوغرافية و التفصيلية التي يمكن استخدامها في كثير من المجالات. و من أهم مميزات البرنامج هي إنتاجه للخرائط في صورة رقمية متوافقة تماما مع جميع حزم البرامج المتاحة و الخاصة بالرسم بالحاسب الآلي وبانظمة المعلومات الجغرافية مما يفتح مجالات جديدة لاستخدام البرنامج الذي تم ابتكاره. ويعمل البرنامج مع نظام النوافذ مما يتيح استخدامه بسهولة ولا يحتاج إلي خبرة عالية من المستخدم لتشغيله. ويمكن استخدام البرامج في مجالات متعددة منها التطبيقات الهندسية والمعمارية وأنظمة المعلومات الجغرافية بالإضافة إلى الدراسات والبحوث الأكاديمية. ولتوضيح بعض تطبيقات البرنامج فانه استخدم في ضبط شبكة مضلعات أرضية و إنتاج خرائط مساحية ذات مقياس رسم كبير لكلية الهندسة بالمطرية والمناطق الملاصقة لها.

Keywords: Land survey, LandSurMap system, Network adjustment, Coordinates transformation, Large scale mapping

1. Introduction

The demand for increasingly accurate surveying and mapping methods in areas such as field control extension, large scale mapping, contouring, sectioning, map projection and *GIS* is commonly known among surveyors.

• Densification and extension of field control by ground surveying is an accepted economical practice on most small - and intermediate-sized surveying projects. The generated control points would be used for topographic mapping and other applications. Complete and accurate boundary or cadastral surveys can be performed as a by-product of the generation of control points process. Also, arbitrary targeted points can be located in order to establish their ground positions for further field surveys. Thus, they can form the basis for such projects as highway location, construction surveys, and subdivision layout.

• The growing adoption of up to date geographic information in digital form for planning developmental programmes has put in an increased demand for digital maps, digital data banks and data transference in well-known formats. For the sake of both efficiency and accuracy, it is often desirable to carry out digitisation and editing operations, employing automation techniques, particularly when developing new maps or data bank. Thus the ability to produce automatically digital maps and data banks has gained further importance among surveying firms and their clients.

• Plotting of large scale maps has deliberately been chosen as one of the important application areas as large scale maps are required for all types of engineering planning, construction and maintenance jobs. Since the accuracy of the data required for planning different types of engineering projects such as alignment of roads, railways, pipelines, sewer lines etc. is different, it is essential that this data is plotted on a suitable scale with proper contour intervals. Moreover, large scale maps, in digital form on various layers on a format compatible to *GIS* and other application packages, are therefore required so that resultant *GIS* applications would be easy and dependable for desired end results [1].

Although widespread publication of topographic maps, these have limitations, due to several reasons, thereby reducing the overall efficiency of these maps. The major problem areas, which affect easy availability of topographic maps are:

a. Source of maps: Many of these maps are restricted for security reasons and hence open dissemination of data is often not possible. Also considerable time is required for obtaining clearance for purchase of the restricted maps.

b. Delayed map publication: Copies of the updated maps are not readily available to the public. The maps available on sale are generally those that have taken many years for final publication.

c. Format of maps: The maps are generally available in hardcopy format (paper base) and are likely to have distortions of the stored medium. The methodology to generate topographical databases from these maps (either by digitisation or scanning) is often costly and not of desired accuracy. Further, it is difficult to access the area between adjacent maps and merge it with maps at smaller scales.

d. Unsuitability for engineering projects: The available topographic maps are drawn on a small scale (1:25,000 or smaller) with large contour intervals (10 meters or larger) and hence are not generally suitable for engineering projects. Since the planimetric details of these maps, especially at smaller scales, are subjected to modifications such as map generalisation, the information available from these may not be complete and useful. It is, therefore, important to develop methodology for producing efficient, accurate and flexible topographic maps at desired scale(s) and contour interval(s).

• Projection of ellipsoidal data (latitude, longitude) into map projection coordinates (Eastings, Northings) is necessary both for preparing hard-copy maps and for representing map data digitally in a geographic information system. Eventually *GIS* systems may accommodate latitude and longitude, but at present they generally require Cartesian coordinates. Furthermore, the 2-D coordinate transformation has many applications in surveying mapping and *GIS* activities. It can be applied to compute plane coordinates values for points with known their coordinates from another coordinate system. Also, it can be used to combine maps from different sources when building a *GIS*.

There are several software packages available in the market, which have been developed for meeting the above mentioned needs, but unfortunately they all posses some or all of the following limitations:

- their prices are costly;
- each software individually was developed for a specific task;
- there is no access for users to the mathematical grounds of the software; and
- the output data format may not be suitable for *CAD/GIS* application.

It is thus apparent that there is a need for a system that may have maximum cost effectiveness and minimum limitations.

This paper is concerned with the description and evaluation of a developed system that is called "*LandSurMap*".

LandSurMap is an acronym that the author has coined to specify the utilization of Land Surveying techniques to produce Map(s) for a variety of desired applications. It is a code name given to a package of computer programs that has been developed to solve multi-purpose surveying problems.

2. Concept of LandSurMap

The configuration of *LandSurMap* is realised by the system structure depicted in fig. 1. The structure of *LandSurMap* operations is modular (fig. 2). The main software *LandSurMap* initialises and terminates the operations of five main modules namely *Networking, Coordinates Transformation, Earthwork Applications, Large Scale Mapping,* and *Mathematics*.

The *Networking* module has been developed to perform the computational phases of two-dimensional networks and level networks adjustment for extension of control points. *Coordinates Transformation* module performs the transformation of plane/projected coordinates from one coordinate system to another. *Earthwork Applications* module performs the main tasks of earthwork applications, section ing and *DTM* generation. *Large Scale Mapping* module generates large or small cadastral/ topographic map for the selected area. *Mathematics* module performs some helpful mathematical operations such as matrices processing, least squares technique solution, solution of linear system of equations and curve best fitting.

For automatic processing and representation of the data and results, the system utilises efficient techniques of Data Structuring [2, 3], Random File Access and Dynamic Memory Allocations [4]. The system has been designed to make use of efficient user interfaces (window-driven) for facilitating its execution to the user.

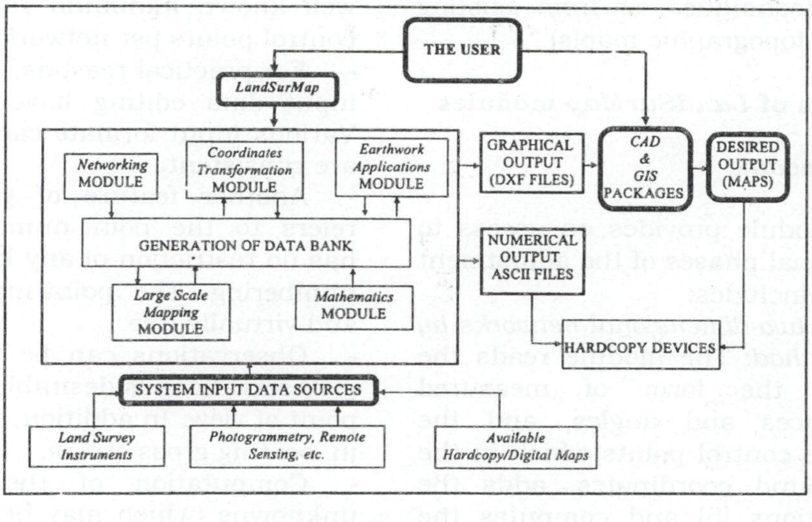

Fig. 1. LandSurMap stucture

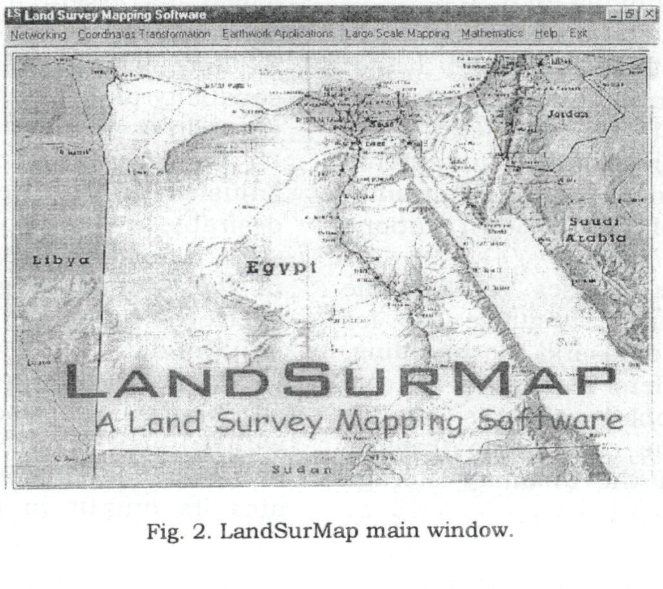

Fig. 2. LandSurMap main window.

3. *LandSurMap* input data sources

The necessary input data for *LandSurMap* is varied according to its modules. Mainly, the software has been designed to process the observations of theodolite, *EDM*, and total station instruments. These observations may include the horizontal and vertical circle readings, horizontal/inclined distances and heights of the used instrument and prism rod. *LandSurMap* has the capability of automatic interfacing of total station instruments (Topcon models) for the utilization of the desired observations.

Moreover, the software accepts the ground coordinates of the points of interest that may be obtained from remote sensing, photogrammetry and *GPS* techniques, or from existing hard copy/digital topographic map(s).

4. Main functions of *LandSurMap* modules

4.1. *Networking module*

Networking module provides an access to major computational phases of the adjustment of networks. This includes:

a. Adjustment of two-dimensional networks by least squares method: The module reads the observations in the form of measured horizontal distances and angles, and the coordinates of the control points which in the form of X,Y ground coordinates, adds the necessary corrections [5] and computes the ground coordinates of unknown stations by using least squares technique [5, 6, 7].

b. Adjustment of level networks by least squares method: In this case, the height differences and distances between stations of the network as well as the known elevations of bench mark(s) (or control point(s)) are entered to a least squares solution for the determination of the elevations of the unknown stations [5, 7].

Networking module utilises random file access in C^{++} computer language [4] for efficient processing of data and file handling. Random file access offers a solution for the major programming problems such as:

- minimising the time required to transfer the data to and from the auxiliary storage device;
- keeping record of the exact location of each data set; and
- saving the storage size by continuously using, updating, the same storage size for different applications.

Furthermore, the *Networking* module uses (i) data structure technique [2, 3] for reducing the *CPU* time of searching for specific data in *LandSurMap* data bank, and (ii) dynamic memory allocation [4] for solving most of the problems resulting from the limited core memory of the personal computers.

Networking module offers a great deal of flexibility for network adjustment that may be summarised as follows:

- Any number of network stations and distribution of control points (other than the well known minimum requirements e.g. two control points per network) are acceptable.
- For practical reasons, the specifications for input data editing have been kept flexible. Various input formats can be accepted if they are consistent.
- Another feature of practical importance refers to the point-numbering. The module has no restriction of any kind about the point-numbering. The point-numbering is natural and virtually free.
- Observations can be weighted. Weighting of observations is desirable from a theoretical point of view. In addition, it helps considerably in locating gross errors.
- Computation of the initial values of unknowns (which may be X,Y ground coordinates, or elevations of unknown stations) which are essential for starting the iterative solution.
- Iterative solution of least squares with the capability of displaying the results of the final iteration or of each iteration.
- Transformation of the coordinates of the adjusted (final) network stations to the desirable system of projection.
- A number of error messages has been built in the various programs of this module to check the working of the module and mistakes in input data.
- The module attains high degree of automation in processing the input data with/without the user interaction.

Networking module automatically generates its output in numerical and graphical forms. The numerical output, in the form of *ASCII* file format, includes variance of unit weight, adjusted ground coordinates of unknown stations and their standard deviations (optional), residuals of observations, corrected observations and their cofactor matrix (optional), and dimensions of the error ellipses (optional). The module has also the capability of automatic generation of its output in data structural format namely point-oriented (which includes for each point elements such as point number, adjusted ground coordinates, standard deviations, etc.). This enables the generated results to be systematically documented for proper storage in data bank and retrieval.

The graphical output, in the form of DXF file format, consists of, if any, plots for the network before and after adjustment and for the adjusted network with error ellipses.

4.2. Coordinates Transformation module

Coordinates Transformation module transforms the coordinates from defined coordinate system to another [5] as follows:

a. From polar coordinates to two-dimensional cartesian coordinates.
b. From three-dimensional polar coordinates to three-dimensional Cartesian coordinates.
c. From two-dimensional Cartesian coordinates to two-dimensional polar coordinates.
d. From two-dimensional Cartesian local coordinates to two-dimensional Cartesian state plane coordinates.

These coordinates transformations are useful for surveying/setting out process, and for converting coordinates in several local systems into one regional framework.

Coordinates Transformation module converts also the coordinates from one projected coordinate system to another [5, 6]; latitude and longitude to northing and easting, and northing and easting to latitude and longitude. Furthermore, the module converts coordinates from Transverse Mercator (TM) to Universal Transverse Mercator (UTM) (and vice versa). This capability enables the users of *GIS* to constitute common database for maps of different organizations.

LandSurMap data bank contains the definitions of the used ellipsoids for map projection in the governmental organizations in Egypt. These are 5 ellipsoids for TM projection and 3 ellipsoids for UTM projection with different zones and central meridians such as Hayford 1910, Hayford 1910 IGN (France), Helmert 1906, Helmert 1906 IGN (France), Clarke 1866 and Clarke 1866 IGN (France). End users refer to coordinates system by pressing buttons. No need to enter long lists of ellipsoid parameters. Thus applications become easy for non-technical personnel to operate reliably.

The results of the module are numerically identical to the appropriate governmental standard.

4.3. Earthwork Applications module

Earthwork Applications module performs the main tasks of earthwork applications such as:

a. Generation of contours: The module generates contours for the selected area using inverse square distance weighted interpolation method [8]. There is no limit on the number of points for generating contours. Contours can be created from thousands of points in just minutes. The module searches for the required points for contour generation from the available data in *LandSurMap* data bank based on the point code. Contour level, interval, index interval (heavy contours), label, color, etc. may be default values or fully specified by the user. The contour plot may be viewed on the screen, output to a plot file, saves as *DXF* file format, and/or send to a hardcopy device.

b. Generation of DTM: Earthwork Applications module searches for the suitable points in *LandSurMap* data bank and creates the surface or *DTM* of the terrain. The projection types, rotation and tilt of the surface, line type, colours, size, etc. have default values or may be specified by the user. The generated *DTM* may send to the screen, printer, or plotter, or save it in *DXF* file format.

c. Utility computations: The module performs several functions for the computation of the earth work quantities such as computation of cuts, fills and net volumes, and surface area above, blow, or at specified level.

d. *Sectioning:* It includes the creation of a profile plot and cross sections at specified intervals for the proposed alignment. There are two ways to specify the extent of the proposed work. The first is to enter the X,Y ground coordinates of a number of points locating on the centre line of the proposed work. The second is to display the contour map and mark the centre line of the proposed work using *AutoCAD* options [9]. Furthermore, the module enables the user to enter the constant intervals and specifications of the cross sections (e.g. the number of points of the cross section and distances between these points).

Finally, the desired horizontal and vertical map scales, map titles, block titles, etc., are entered to the system for generating the desired map in *DXF* file format.

4.4. Large scale mapping module

Plotting of large scale map has deliberately been chosen as one of the important application areas as large scale maps are required for all types of engineering planning, construction and maintenance jobs.

Large scale maps include Cadastral and large scale Topographic maps [10].

a. *Cadastral maps:* They are drawn to scale 1: 10,000 or larger. Because of their large scales, they contain detailed information of buildings, communications and boundaries, with spot heights but no contours. These maps are, thus, useful for local administration and collection of revenue, management of estates, identification of property as legal documents etc.

b. *Topographic maps:* These maps show natural as well as man-made features of an area. They are on scales smaller than the cadastral maps and usually drawn to show lot of natural and man-made features, such as hills, rivers, forests, towns, villages, roads, railways, canals, bridges and telegraph lines, etc. Besides planimetric features, topographic maps also contain spot heights and contours and important control information for plan and height, which can be used directly for some mapping purposes e.g. amplification of existing maps by ground survey or photogrammetry. These maps are very useful to engineers, scientists and geographers for studying the detailed regional geography of an area.

LandSurMap utilises the ground coordinates of specified points of natural and man-made features and its code number [10, 11]. Six digitising modes (options) are programmed to differentiate between features e.g. buildings, roads, spot heights, etc. The feature mode is executed automatically by entering the classification code of the feature and pressing on the suitable button.

To facilitate and make the generation of large scale maps more flexible, the module offers two menus on the screen: *Work sheet* and *Feature-by-feature.*

The Work sheet menu enables the user to enter the map scale, map title, grid interval, contour interval, if any, etc.

Feature-by-feature menu has different options for extracting various features to be plotted. The advantages of generating the map feature by feature are:

i. enabling the user to plot the required feature(s) according to the purpose of the map e.g. plotting thematic map for roads location, and

ii. cutting off unnecessary feature(s) which may be useful for map generalization.

Large scale mapping module offers flexibility in generating the map such as free numbering code of points, free map scale, free contour intervals, and automatic cutting off contours within the planimetric features. The module generates the large scale maps in digital form on various layers in a format compatible with *CAD*, *GIS* and other application packages.

4.5. Mathematics module

Mathematics module performs some mathematical operations which are encountered frequently in surveying and mapping adjustment and computation problems such as [5, 7]:

a. Matrix algebra: such as sum of matrices, multiplication of matrices and finding the inverse of a matrix.

b. Curve fitting: The module selects the function that best approximates to a given collection of points from 25 functions such as straight line, reciprocal of straight line, hyperbola, parabola, etc. The selection is based on statistical criterion such as the method of least squares e.g. choosing the curve that has the least sum of squared deviations between the curve and data. Furthermore, the module draws the best fitting curve with/without the original data points to the desirable interval and scale.

c. Direct and indirect least squares solutions: The module reads the observation or condition equations and performs non-iterative least squares method for getting the adjusted unknowns (parameters or observations) and their cofactor matrix.

d. Solution of a system of linear equations: The module reads the numerical coefficients of the unknowns and constant term of each equation and computes the values of unknowns. The module has no restriction about the number of equations.

5. *LandSurMap* portability and hardware

The system has been implemented using Visual C++ Compiler V6.0 [12] and designed to be flexible and portable to 32-bit Windows platforms (Windows 95, 98, NT 4 and Windows 2000).

LandSurMap requires a minimum of 16 megabytes of memory (*i.e. RAM*) and approximately 40 megabytes of disk space on the hard disk.

The system is released in a compressed format on CD-ROM with a reference manual.

6. Engineering applications of *LandSurMap*

LandSurMap is suitable for all areas in which a land surveying solution to a problem can be applied.

One of the major application areas of *LandSurMap* is the densification and extension of control points that may be used for topographic mapping and other applications as explained earlier.

Since large scale maps are required for a number of development projects in the areas of urban planning, cadastre, microlevel water sheds, municipal services, power generation, coastal zone monitoring, transport, telecommunication, utilities etc., *LandSurMap* system has the capability of its widespread adoption in all types of large scale mapping studies.

The system is capable of generating contours and *DTM* which are widely used for generation of profiles, earthwork calculations, navigation control systems, and engineering and planning.

The system provides an automatic digitised data on various layers rather than manual digitisation in a compatible form with the known *GIS* packages. This makes the potential of *LandSurMap* extendible to various *GIS* applications such as environmental studies, urban and regional planning, agriculture and land use planning, archaeology, transportation, etc.

7. Demonstrating some applications of *LandSurMap*

Some of the above mentioned capabilities of *LandSurMap* have been demonstrated in the following taking the case study of the campus of Matria Faculty of Engineering. Especially the following tasks have been carried out for the case study:

a. Generating the control points; and

b. Generating large scale maps

(Note: The shown maps are for demonstration only and not drawn to scale).

a. Generating the control points: A traverse was carried out inside and outside of the faculty campus. The traverse contained 27 stations. Two stations of the traverse stations were chosen as fixed (control) points. The assumed azimuth between the two fixed stations was measured using magnetic compass. The ground coordinates of one fixed station were assumed while the ground coordinates of the second fixed point were calculated.

The horizontal angles and distances of the traverse were measured using theodolite and *EDM* unit. The observations contained the measurements of 47 horizontal angles and 39 horizontal distances.

The adjustment of the traverse was performed using the capabilities of *Networking* module and the results in numerical and graphical forms, as explained earlier, were obtained. As an example of the graphical output, fig. 3 shows a map for the adjusted traverse.

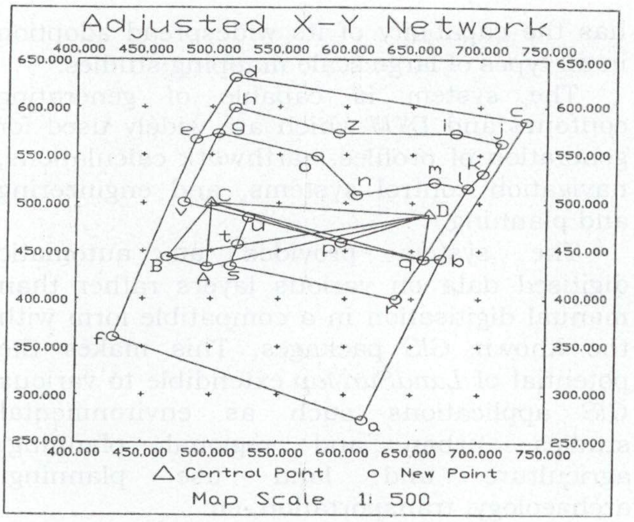

Fig. 3. Adjusted traverse for the case study area.

The levels of traverse stations were determined through level networking procedure [5]. The level of one benchmark was assumed as 10.00m. The differences in the heights of the traverse stations were measured by precise levelling technique. The benchmark level and observed height differences with their weights were entered to *Networking* module by editing data file for getting the adjusted levels of the traverse stations with full statistical results.

b. Generating large scale maps: The polar coordinates, with respect to traverse lines, of the coded points of the man-made and natural features, as explained earlier, were measured using theodolite and *EDM* unit. Computation of the Cartesian ground coordinates (X,Y or X,Y,Z) of the coded points was accomplished using *Coordinates Transformation* module.

The output products of *Large Scale Mapping* module for generating large scale maps are shown in figs. 4 through 6. Large scale topographic map drawn to scale 1:500 with 0.25m contour interval is depicted in fig. 4. Fig. 5 shows a cadastral map of the case study drawn to scale 1:500. Fig. 6 shows the location of buildings of the selected area illustrating the possibility of preparation of thematic maps. Furthermore, *Large Scale Mapping* module generates large scale maps in digital form with user-defined layers as illustrated in fig. 7.

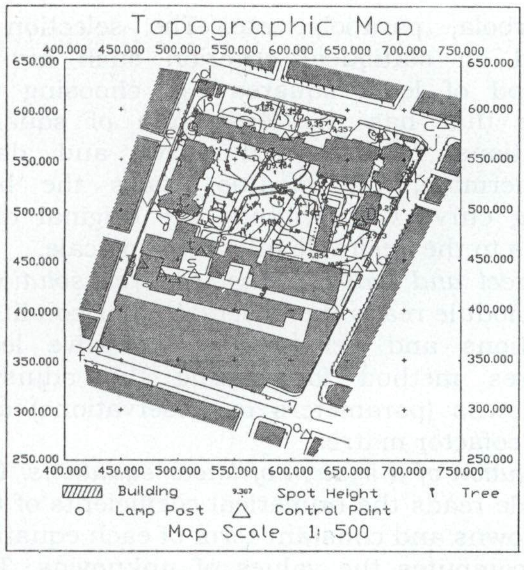

Fig. 4. Topographic Map for the case study area.

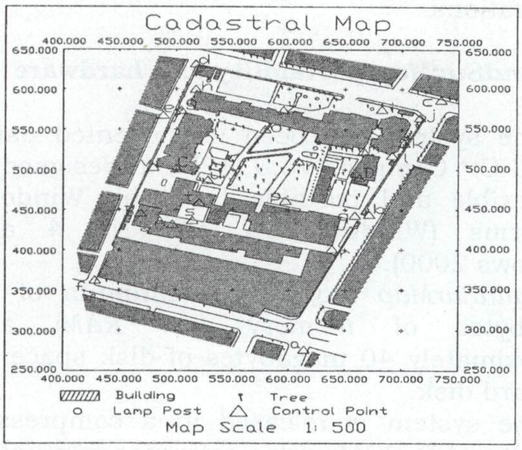

Fig. 5. Cadastral Map for the case study area.

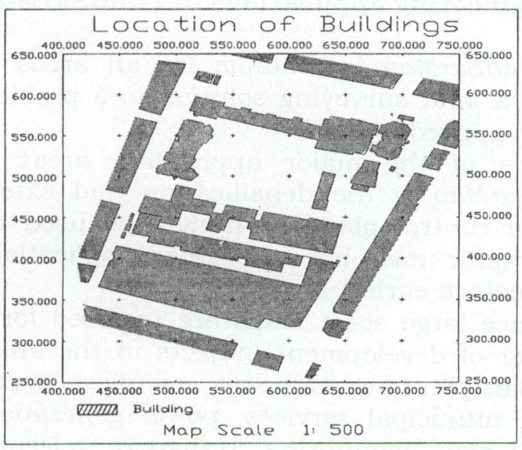

Fig. 6. Location of buildings in the case study area.

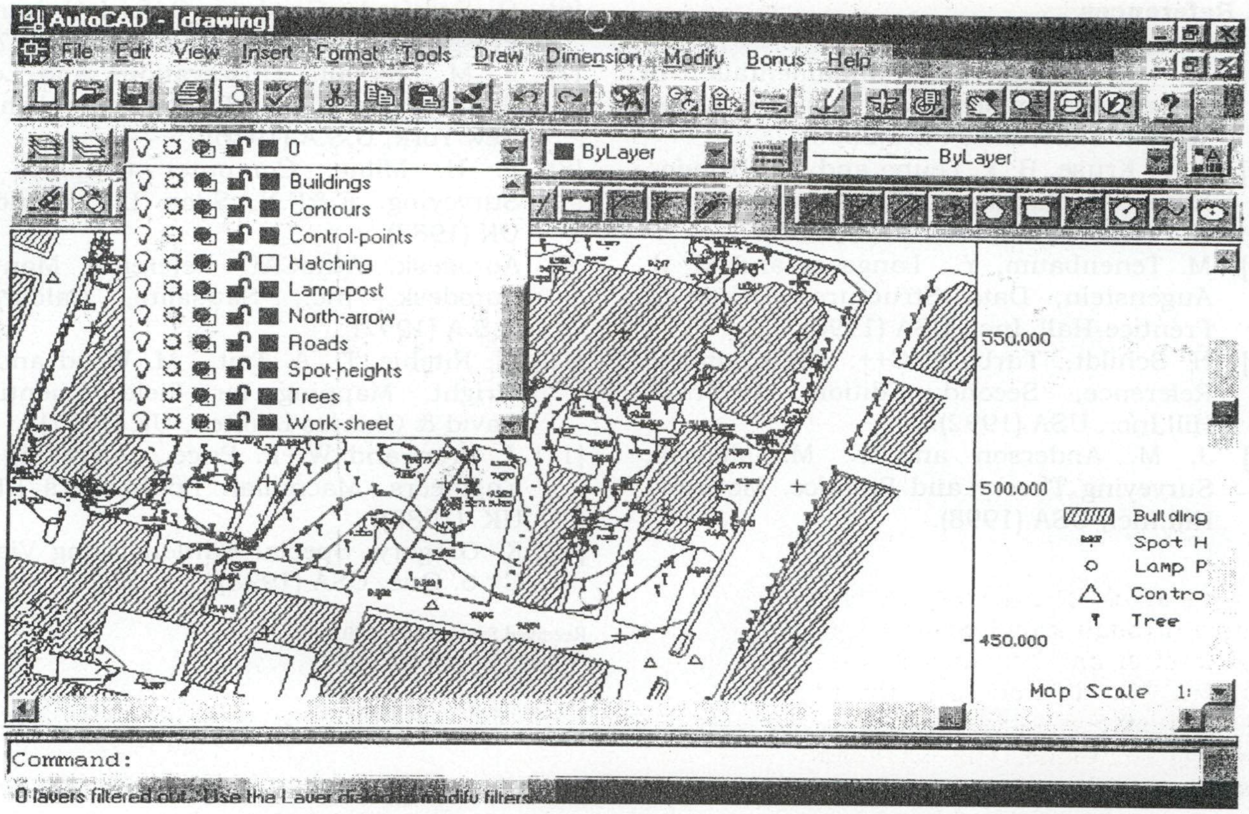

Fig. 7.Generated user-defined layers for the topographic map of the case study area.

8. Conclusions

The results of the case study clearly show that *LandSurMap* can effectively provide a convenient, economical and accurate mapping system for local area mapping, urban mapping or many other potential applications. Moreover, *LandSurMap* provides a window-driven mapping system that is both portable and suitable for use by non-technical users following a short period of training.

The cost effectiveness of *LandSurMap* depends mainly on:

- Processing the obtained data of different sources.
- Combination of a variety of land surveying applications such as networks adjustment, geodetic and plane coordinates transformation, contouring, sectioning, *DTM* generation, and large scale mapping applications into one powerful computer package.
- Generation of its output in a compatible form with the available *CAD/ GIS* packages.
- Simplicity of the hardware requirements for its execution.

The system provides automatic digitized data rather than manual digitization for *GIS* applications. Furthermore, the graphical output of *LandSurMap* is compatible with the most of the known packages for *CAD* and *GIS* applications. The benefits of this compatibility are saving the user's training time, using the experience of the user in operations of specific package for further integrating and implementation of the obtained results and available data, offering an efficient method to global data transferring and retrieving, and saving the cost of extra hardwares or softwares.

LandSurMap is under continuing development and new options and additional features such as 3D-adjustment of geodetic networks are planned for the near future.

The system is quite versatile and provides an affordable tool to the researchers in the universities and academic centers.

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