

A Cost-Effective Land Surveying System for Engineering Applications

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Summary

The field of land surveying is changing dramatically due to the way data is processed, analyzed and presented. Also, there is a growing demand for digital spatial information, coming primarily from the GIS (Geographical Information System) user community. Such a demand has created a strong development potential for a new land surveying software. An overview of the development and capabilities of a land surveying software platform based on the Windows system, SurveyingMap, is presented. Among its many features, SurveyingMap provides a lot of adaptability for networks adjustment, geodetic and plane coordinates transformation, contouring, sectioning, DTM (Digital Terrain Model) generation, and large scale mapping applications. The system output is compatible with well known computer aided drafting (CAD) /GIS packages to expand its scope of applications. SurveyingMap is also suitable for non-technical users due to the user-friendly graphic user interface. The system could be used in engineering, architecture, GIS, and academic teaching and research, among other fields. Two applications of SurveyingMap, extension of field control and large scale mapping, for the case study area are established. The results demonstrate that the system is adaptable and reasonably priced for use by college and university students.

Keywords:

Land surveying; SurveyingMap system; Network adjustment; Coordinates transformation; Large scale mapping; Curve fitting.

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 [1, 2]. The produced control points can be used for topographic and other applications. Complete and accurate boundary or cadastral surveys can be performed as a by-product of the generation of control points process. Furthermore, arbitrary targeted points can be located in order to establish their ground positions for further field surveys. Therefore, 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 programmers has put in an increased demand for digital maps, digital data banks and data transference in well-known formats [3]. For the sake of both efficiency and accuracy, it is often desirable to carry out digitization and editing operations, employing automation techniques, particularly when developing new maps or data bank [4]. Accordingly, the ability to produce automatically digital maps and data banks has gained further importance among surveying firms and their clients [5].

Plotting of large scale maps was purposely selected as one of the most important application areas as large scale maps are necessary 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.

In addition, large scale digital maps with multiple layers in a format that is compatible with GIS and other application packages are required for the ease of use and dependability of the resulting GIS applications [3, 6,7].

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:

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

- 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 generalization, the information available from these maps 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. 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 as described in [8-17], but unfortunately they all possess 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 hence apparent that there is a need for a system that may have maximum cost effectiveness and minimum limitations.

The main subjects of this paper are the development and evaluation of a proposed system called "SurveyingMap". The author came up with the acronym SurveyingMap to describe how land Surveying Techniques are used to create Maps for a wide range of potential applications. SurveyingMap is a name for a software package for solving multipurpose surveying issues.

An overview of the development, capabilities and engineering applications of the proposed system are presented. Two applications of SurveyingMap, extension

of field control and large scale mapping, for case study area are established. The results demonstrate that the proposed system is adaptable and reasonably priced for use by college and university students.

2. Overview of the Proposed System

2.1. Concept of SurveyingMap

The system structure in Figure 1 identifies the primary functions of SurveyingMap. SurveyingMap operations are modular in structure. The five main modules of Networking, Coordinates Transformation, Earthwork Applications, Large Scale Mapping, and Mathematics are initialized and terminated by the main software SurveyingMap.

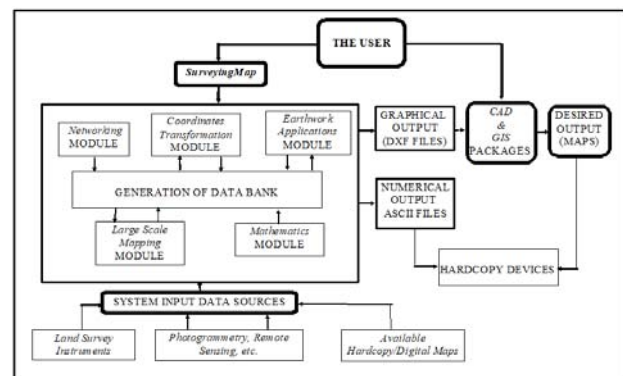


Fig. 1 SurveyingMap Structure

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 carries out the main operations of earthwork applications, sectioning 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.

The system makes use of efficient methods like Data Structuring [18], Random File Access, and Dynamic Memory Allocations [19] for the purpose of automatically processing and displaying the data as well as the results. In addition, the system uses efficient user interfaces in the form of window-driven [20] for facilitating its execution to the user.

2.2. SurveyingMap Input Data Sources

The necessary input data for SurveyingMap is varied according to its modules. Mainly, the software has been designed to process the observations of theodolite, EDM (electronic distance measurement), and total station instruments. The input data may include the horizontal and vertical circle readings, horizontal/inclined distances, heights of the used instrument and prism rod and the object space coordinates of points. SurveyingMap 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 which may be obtained from remote sensing, photogrammetry and GPS techniques, or from existing hard copy/digital topographic map(s).

2.3. Main Functions of SurveyingMap Modules

2.3.1. Networking Module

Networking module performs the main computational phases of the adjustment of networks. This includes:

- 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 [1, 2, 21] and computes the ground coordinates of unknown stations by using least squares technique [22].
- Adjustment of level networks by least squares method: In this case, the distances, differences in height between stations of the network and the known elevations of bench mark(s) (or control point(s)) are entered to a least squares solution for computing the elevations of the unknown stations [1, 21,22].

Networking module uses random file access [19, 23] for effective data processing and file handling. Random file access is a solution to the most important programming issues, such as:

- Reducing the needed time to send the data to or from the storage device to a minimum;
- Documenting the precise location of each data set; and
- Minimizing the size of the storage by continually utilizing and updating the same storage size for various applications.

In addition, the Networking module employs (i) the data structure technique [18] to cut down on CPU time spent searching for specific data in the SurveyingMap data bank and (ii) dynamic memory allocation [19, 24] to

address the majority of issues brought on by limited core memory of personal computers.

The following is a summary of the flexibility that the Networking module provides for network adjustment:

- No restriction for the number and distribution of control points other than the well-known minimum requirements, such as two control points per network [22].
- The editing of input data specifications have remained flexible for practical reasons. If the input formats are consistent, they can be accepted.
- The point-numbering is another important practical feature. Point-numbering is not restricted in any way by the module. The point-numbering is easy and almost natural.
- Weighting observations is possible. From a theoretical standpoint, it is desirable to weight the observations. Additionally, it aids greatly in the detection of gross errors [22].
- Determination of the necessary initial values of unknowns for the iterative solution, such as the X, Y ground coordinates or the elevations of unknown stations.
- An iterative least-squares solution that can show the results of either the final iteration or each iteration.
- Conversion of the adjusted (final) network station coordinates to the desired projection system.
- A number of error messages have been incorporated into the module programs in order to check its operation and find errors in the input data.

The module attains high degree of automation for processing the input data and getting the desired output(s).

The output of the Networking module is always numerical and graphical in the form of ASCII and drawing exchange format (DXF) file formats, respectively. The numerical output includes variance of unit weight, adjusted ground coordinates of stations and their standard deviations (optional), residuals of observations, corrected observations and their cofactor matrix (optional), and dimensions of the error ellipses (optional). Additionally, the module can automatically generate its output in a point-oriented data structural format (which includes elements such as the point number, adjusted ground coordinates, standard deviations, and so on for each point). This makes it possible to properly document the generated results so that they can be retrieved and stored in a data bank. The graphical output includes plots for the network before and after adjustment as well as plots for the adjusted network with error ellipses, if any.

2.3.2. Coordinates Transformation Module

Coordinates Transformation module transforms the coordinates from one defined coordinate system to another [1,2] as follows:

- From polar coordinates to two-dimensional cartesian coordinates.
- From three-dimensional polar coordinates to three-dimensional cartesian coordinates.
- From two-dimensional cartesian coordinates to two-dimensional polar coordinates.
- 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 [1, 21]; latitude and longitude to northing and easting, and northing and easting to latitude and longitude. Besides, 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.

SurveyingMap Data Dank contains the definitions of the used ellipsoids for map projection in the governmental organizations in Egypt. These are 5 ellipsoids for TM projection and 4 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, Clarke 1866 IGN (France) and WGS84. End users refer to coordinates system by pressing buttons. No need to enter long lists of ellipsoid parameters. Consequently, applications become easy for non-technical personnel to operate reliably.

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

2.3.3. Earthwork Applications Module

The primary functions of earthwork applications are carried out by the Earthwork Applications module, which includes:

- **Contours Generation:** Using Kriging interpolation method [25-27], the module creates contours for the selected region. The number of points that can be used to create contours is unlimited. From thousands of points, contours can be created in minutes. Based on the point code, the module searches the SurveyingMap data bank for the required points for contour generation. Label, color, contour level, contour interval, index interval (for heavy contours), etc. may be fully entered by the user or be set as default values. The contours can be seen on the display, saved as a DXF file, sent to a hardcopy device, or exported to a plot file.
- **DTM generation:** The Earthwork Applications module creates the terrain's surface, or DTM, by searching the SurveyingMap data bank for the appropriate points. The types of projection, the surface's rotation and tilt, the type of line, the colors, the size, etc. have predetermined values or can be set by the user. The produced DTM can be seen on the display, printed, plotted, or saved as a DXF file for later use.
- **Utility computation:** For the purpose of computing the earthwork quantities, the module performs a number of functions, including the computation of cuts, fills, and net volumes, as well as surface area above, below, or at a given level.
- **Sectioning:** For the proposed alignment, it includes creating a profile plot and cross sections at predetermined intervals. The proposed work's scope can be specified by two options. The first option includes editing the X, Y ground coordinates of points located along the proposed work's center line. The second option is to use AutoCAD options to display the contour map and draw the proposed work's center line [28]. In addition, the module gives the user the ability to enter cross section specifications (such as the number of points and distances between them) and constant intervals. Last but not least, the desired map scales (horizontal and vertical), map titles, block titles, etc., are entered into the module to generate the desired map as a DXF file.

2.3.4. 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 [5, 24].

- **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, for these reasons, useful for local administration and collection of revenue, management of estates, identification of property as legal documents etc.
- **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.

SurveyingMap makes use of the code number and ground coordinates of specific points on both natural and man-made features [1, 5]. Twelve digitizing modes (options) are programmed to differentiate between features e.g. buildings, roads, spot heights, etc. By pressing the appropriate button and entering the feature's classification code, the feature mode is automatically activated.

The module has two menus on the screen to make it easier and more flexible to create large-scale maps: Worksheet and Feature-by-Feature.

Work sheet menu helps the user to specify grid interval, contour interval, if applicable, map scale, map title, etc.

There are a variety of options in the Feature-by-Feature menu for extracting various features for plotting. The ability for the user to plot the required feature(s) in accordance with the purpose of the map, such as plotting a thematic map for the location of roads, and the elimination of unnecessary feature(s) that could be necessary for map generalization [24] are two of the advantages of generating the map feature by feature.

Large Scale Mapping module provides a variety of options for generating the map, including automatic cutting off of contours within the planimetric features, free contour intervals, and free numbering codes for points. Digital large scale maps of various layers are produced by the module in a format that is compatible with CAD, GIS, and other mapping packages.

2.3.5. Mathematics Module

Mathematics module performs some mathematical operations which are encountered frequently in surveying adjustment and computation problems such as [1, 22]:

- Matrix algebra: It includes sum of matrices, multiplication of matrices and finding the inverse of a matrix.
- 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. Further, the module draws the best fitting curve with/without the original data points to the desirable interval and scale.
- 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.

- 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.

2.4. Engineering Applications of SurveyingMap

SurveyingMap can be used in any situation where a problem can be solved through land surveying.

One of SurveyingMap's primary application areas is the extension and densification of control points, which can be used for topographic applications and other purposes as previously mentioned.

SurveyingMap system can be utilized extensively in any kind of large scale mapping study including urban planning, cadastre, municipal services, power generation, coastal zone monitoring, transportation, telecommunications, utilities, and others.

SurveyingMap has the capability of producing contours and DTM which are necessary for computation of earthwork, sectioning, navigation control systems, and planning.

The system offers automatically digitized data on different layers that is compatible with well-known GIS packages rather than requiring human digitization. SurveyingMap is therefore applicable to a wide range of GIS applications, including environmental studies, planning for agriculture and land use, urban and regional planning, transportation, archaeology, and other related areas.

3. Demonstrating some Applications of SurveyingMap and Results

Some of the above mentioned capabilities of SurveyingMap have been demonstrated in the following taking the case study of the campus of Matria Faculty of Engineering, Egypt. Specially the following tasks have been carried out for the case study:

- Generating the control points; and
 - Generating large scale maps.
- (Note: The shown maps are for demonstration only and not drawn to scale).

3.1. 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, Figure 2 shows a map for the adjusted traverse.

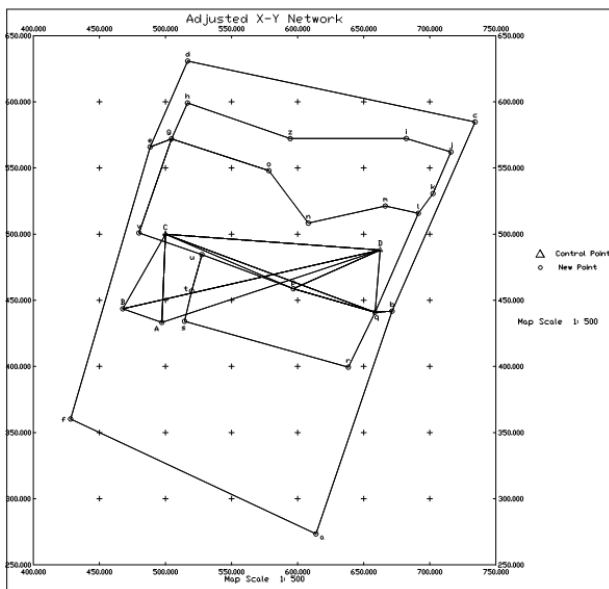


Fig. 2 Adjusted Traverse for the Case Study Area

The levels of traverse stations were determined through level networking procedure [1, 22]. 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 obtaining the adjusted levels of the traverse stations with full statistical results.

3.2. 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 Figures 3 through 5. Large scale topographic map drawn to scale 1:500 with 0.25m contour interval is depicted in Figure 3. Figure 4 shows a cadastral map of the case study drawn to scale 1:500. Figure 5 shows the location of buildings of the selected area illustrating the possibility of preparation of thematic maps. In addition, Large Scale Mapping module produces large scale maps in digital form with user-defined layers as illustrated in Figure 6.

4. Conclusions and Future Work

The case study makes it abundantly clear that SurveyingMap is able to effectively supply a mapping system that is efficient, accurate, and cost-effective for urban mapping, local area mapping, and numerous other potential applications. Additionally, SurveyingMap provides a window-driven mapping system that, after a brief training period, can be utilized by non-technical users.

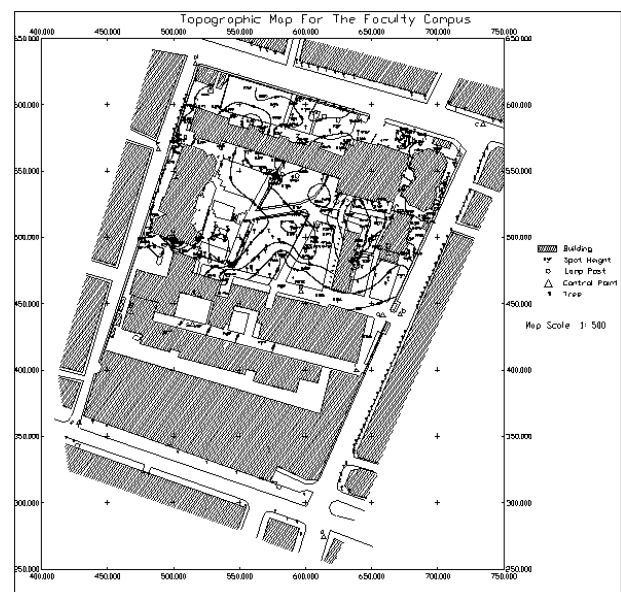


Fig. 3 Topographic Map for the Case Study Area

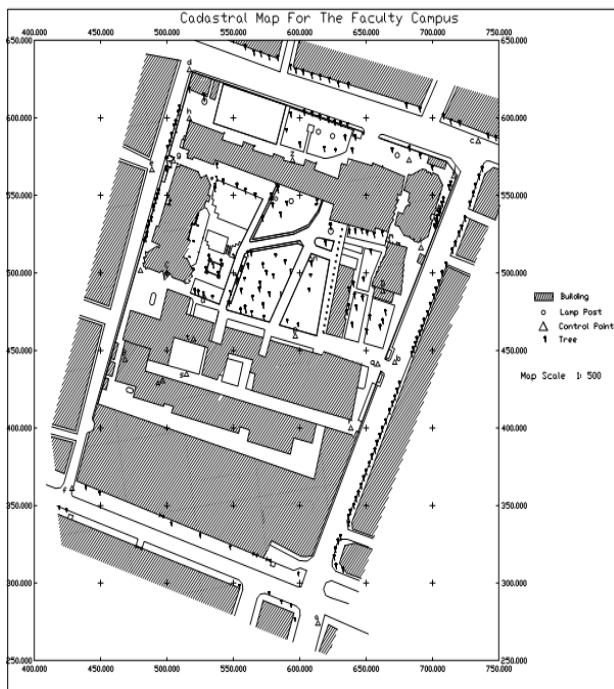


Fig. 4 Cadastral Map for the Case Study Area

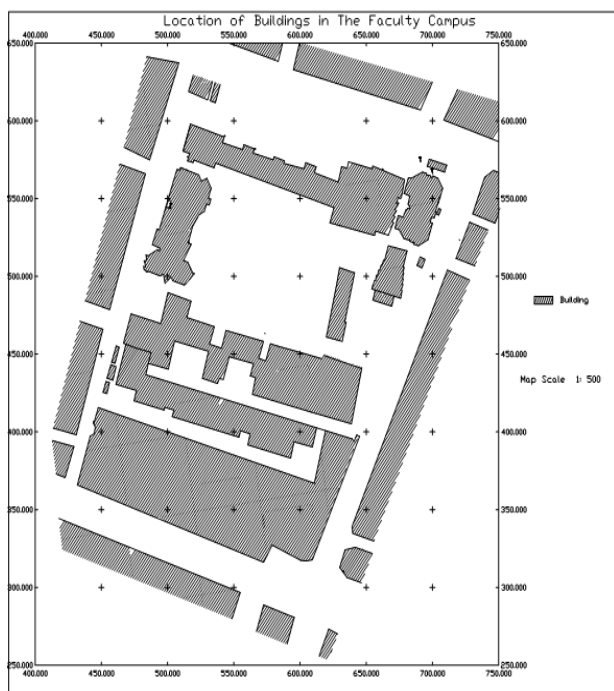


Fig. 5 Location of Buildings in the Case Study Area

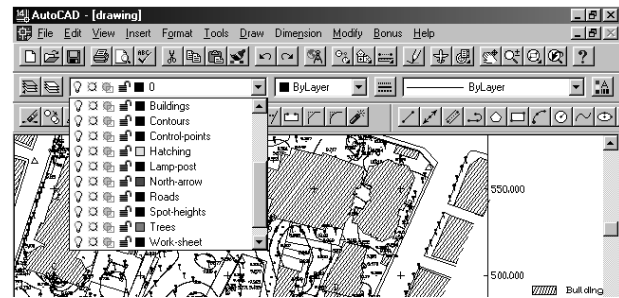


Fig. 6 Generated User-defined Layers for the Topographic Map of the Case Study Area

The cost-effectiveness of SurveyingMap is mostly determined by:

- Processing the data from various sources.
- Consolidation of numerous land surveying applications into a single, potent computer package, including applications for adjusting networks, transforming geodetic and plane coordinates, contouring, sectioning, generating DTMs, and large-scale mapping.
- Producing output that is compatible with the available CAD/GIS packages.
- The simplicity of its hardware requirements.

For GIS applications, the system digitizes data automatically rather than by hand. Additionally, SurveyingMap's graphical output is compatible with the majority of well-known CAD and GIS application packages. The advantages of this compatibility are:

- Using the user's previous experience with a particular package to further integrate and implement the results and data that have been obtained.
- Facilitating the transfer and retrieval of data in an effective and global manner.
- Saving the cost of additional hardware or software.

SurveyingMap is constantly being improved, and new applications, like 3D geodetic network adjustment, are anticipated in the near future.

The system is very adaptable and offers low-cost land surveying system to students and researchers at universities and academic centres.

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