Second Edition

ADVANCED SURVEYING

TOTAL STATION, GPS, GIS AND REMOTE SENSING

Satheesh Gopi
R. Sathikumar
N. Madhu

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ADVANCED SURVEYING

Total Station, GPS, GIS and Remote Sensing

Second Edition

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BRIEF CONTENTS

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PREFACE

Surveying is fundamental to all civil engineering activities, which include construction of buildings, roads, railways, bridges, dams, canals, airports and harbours. Survey data is the integral part of design and execution of all engineering projects. Time is very important in the present scenario and advanced surveying techniques employs precise electronic surveying instruments that are capable of performing most accurate data collection in short time.

There have been far rapider advancements in the area of surveying compared with other divisions of civil engineering. During the last two decades, developments in electronics and optics have led to significant advancements in surveying instruments and techniques. The conventional equipment such as compass, vernier theodolites, dumpy levels have given way to versatile modern digital instruments such as digital levels, electronic theodolites, electronic distance measuring devices, total stations, Global Positioning Systems (GPS) and LIDAR. The traditional surveying techniques was completely replaced by advanced techniques. Manual methods were completely replaced by advanced computerized data collection, digital processing and computer-aided drafting and mapping systems. Modern techniques had evolved with the introduction of satellite-based remote sensing systems and Global Navigational Satellite Systems (GNSS). The field of surveying had undergone rapid changes due to the introduction of most modern electronic instruments and widespread adoption: total station, GPS, digital levels and geographical information systems (GISs). With the introduction of the latest instruments mentioned above and advanced techniques made the preparations of survey maps is very simple and precise.

The main aims of compiling this book is to provide the knowledge of modern techniques and modern instruments such as total station, electronic distance measuring (EDM), GPS and LIDAR and the knowledge of GIS in a comprehensive manner for civil engineering students as well as practicing engineers.

In this new edition, a major organizational change has been done. The revised edition has been specially written keeping in mind the requirements of undergraduate students of engineering. Most of the subject prescribed in undergraduate curricula of civil engineering has been covered in an easy to comprehend manner. This book is also useful to students pursuing GIS. The book deals with modern instruments and techniques used in the field of geoinformatics.

Content of the book is as follows: The book has been organized into four sections. The first part discusses the Fundamentals of GIS, Applications of GIS, Map Projection and Coordinate Systems. The second part deals with the Principles of Total Station, EDM, Surveying Using Total Station and detailed descriptions of most modern surveying equipment such as digital level, micro-optic theodolites, LIDAR and terrestrial scanner. The third part deals with Photogrammetry and Aerial Surveying in detail. The fourth part covers Basics of GPS and Surveying Using GPS. Appendix A deals with the basic Geodetic Aspects required for GPS-based surveying. Appendices B–D provide step-by-step field procedure of various models of total stations.

The detailed structure of the book is as follows:

Chapter 1 presents the fundamental concepts of GIS such as GIS architecture, components of GIS and GIS work flow and categories of GIS.

Chapter 2 discusses about the GIS data models such as spatial, vector, raster and attribute data models. The chapter also discusses digital elevation model (DEM), image data and application of DEM.

Chapter 3 deals with data acquisition in GIS using analogue maps, aerial photographs, satellite imagery, ground surveys, GPS, etc. The chapter also focuses on digitizers, scanners as a source of data input, rasterization and vectorization using various equipment and methods.

Chapter 4 provides details on maps and map projection. It narrates the characteristics of maps, different map projections and construction of map projection.

Chapter 5 presents various coordinate systems in detail. It also covers geoid and reference ellipsoids, and different transformations.

Chapter 6 is devoted to spatial analysis. It presents classification of analytic of GIS, overlay function and network analysis.

Chapter 7 covers various applications of GIS including case studies.

Chapter 8 deals with the basics of total station.

Chapter 9 focuses on measuring principle of EDM, characteristics of EDM, field procedure of EDM and various types of EDMs.

Chapter 10 describes execution of field surveys using total station, which includes field procedures, overview of computerized survey data systems, total station job planning and estimating and trigonometric levelling.

Chapter 11 elaborates data collection procedures to be followed while surveying using total station.

Chapter 12 covers most modern surveying instruments such as automatic levels, digital levels, micro-optic theodolites, LIDAR, digital planimeters and laser levels.

Chapter 13 deals with aerial surveying and details about aerial photogrammetry, terrestrial photogrammetry, different photogrammetric techniques and LIDAR.

Chapter 14 presents the fundamentals of remote sensing.

Chapter 15 deals with the basics of GPS.

Chapter 16 introduces the modern methods of surveying using GPS.

Lecture PPTs are available for download from the Instructor Resource centre at www.pearsoned.co.in/satheeshgopi

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FUNDAMENTAL CONCEPTS OF GEOGRAPHIC INFORMATION SYSTEM 1

Chapter Outline

1.1 INTRODUCTION

GIS stands for *geographic information system*. An information system is a computer program that manages data. A GIS is a type of information system that deals specifically with geographic, or spatial, information. GIS is a rapidly growing technological field that incorporates graphical features with tabular data to assess real-world problems. The GIS began to develop in the 1960s, with the discovery that maps could be programmed using simple code and then stored in a computer, allowing future modifications when necessary. This was a marvellous change from the era of hand cartography when maps had to be created by hand. The earliest version of a GIS was known as computer cartography and involved simple line work to represent land features. From that evolved the concept of overlaying different mapped features on top of each other to determine patterns and causes of spatial phenomena.

The capabilities of GIS have been known from the simple beginnings of computer cartography. At the simplest level, GIS can be thought of as a high-tech equivalent of a map. Paper maps cannot be produced for quicker and more effective storage of data. An easily accessible digital format of maps in GIS enables complex analysis and modelling of data, which was previously not possible with paper maps. The reach of GIS expands into all disciplines and has been used in wide range, such as prioritizing sensitive species habitat, and determining optimal real-estate locations for new businesses.

The keyword to GIS technology is geography. This means that the data, or at least some proportion of the data, are spatial; or in other words, data in some way referred to the locations on earth. Geographic information describes the spatial or location factors of an object or area. This can simply be latitude and longitude, but in most cases more complex factors are included.

A GIS allows users to view, update, query, analyse, combine and manipulate map data. It can take information from different maps and tables and register them to a desired base. It can manage large collections of natural resources and environmental data and the complex data sets needed for urban studies. It can overlay maps to eliminate or include areas based on multiple layers of tabular criteria. It can automatically generate buffers around features such as sensitive land use types.

A GIS operates on many levels. At basic level, it is used as computer cartography for automated mapping. The real power in GIS is through using spatial and statistical methods to analyse attributes and geographic information. The end result of the analysis can be derivative, interpolated or prioritized information.

A GIS can be made up of a variety of software and hardware tools. The important factor is the level of integration of these tools, which provide a smooth operating and fully functional geographic data processing environment. GIS should be viewed as a technology, and not simply as a computer system. GIS provides facilities for data capture, data management, data manipulation and analysis, and the presentation of results in both graphic and report form. It provides a particular emphasis on preserving and utilizing inherent characteristics of spatial data. Today, GIS is a multi-billion-dollar industry employing hundreds of thousands of people worldwide. GIS is taught in schools, colleges and universities throughout the world. Professionals and domain specialists in every discipline are becoming increasingly aware of the advantages of using this technology for addressing their unique spatial problems.

GIS provides the necessary set of tools required for gaining the appropriate insights into the places and processes that drive our environment, society and economy. It provides the means of finding hidden patterns and trends that would have remained undetected using conventional means of looking at data, by combining data from a variety of different sources such as corporate, commercial and government databases, images from cameras and satellites, and data derived from any type of sensor or human observation, and presenting it in the form of a map. GISs are not restricted to the conventional view of geography, that is, that of people and places on the earth's surface. Hidden geographies lie everywhere, and a GIS is the perfect tool to take on voyages of discovery. GIS will help to pave the way for the success of the expedition by providing the means of visualizing and exploring these uncharted territories.

Computer revolution and the advent of cheap desktop computers made an explosion in the use and availability of GIS. GISs are no longer the sole domain of scientists funded by generous research grants, but are available to everyone from a small shop owner to a major corporation at a highly competitive price, allowing virtually anyone to become a player in the global marketplace through the insights fuelled by the geo-revolution. Our perception is built upon the ability to distinguish boundaries and outlines, and effectively store them in our brains as mental images. Thus, maps with their clear and concise definition of area and space provide ample food for thought, a crystal clear concept provided by reams of data in a spreadsheet.

Dr John Snow's well-known cholera map is one of the earliest known examples of GIS. In September 1854, during an outbreak of cholera in a section of the city of London, Dr John Snow, a local physician, decided to test his hypothesis that cholera is a waterborne disease and that the outbreak was a result of contaminated water supplies—a view contrary to the medical beliefs of the time—by drawing a map showing where the victims lived and where the local water pumps were

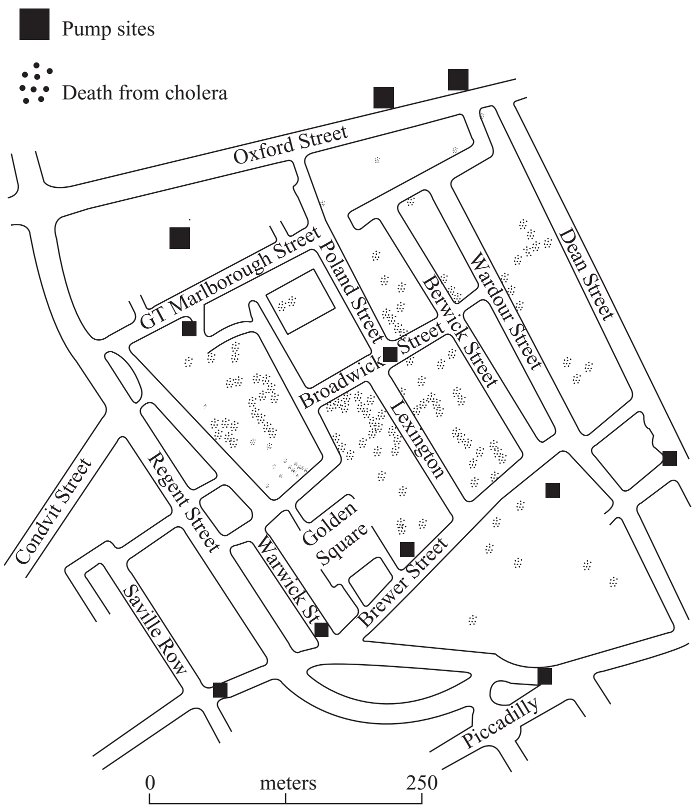

FIGURE 1.1 The first GIS used for identifying an epidemic disease

located (see Fig. 1.1). The map clearly showed a clustering of cholera cases around one of the pumps, and when that pump was shut down, the outbreak stopped. Using the simple means of pen and paper, Dr Snow was able to prove a cause and effect relationship between a contaminated supply of water and instances of disease by using a map to visualize the instances of disease and the location of water pumps. This mapping in epidemiology is cited as the first example to highlight the application of geographic analysis.

GISs, backed by the power of modern computers, allow us to benefit from the visual power of maps and to transcend the limitations of the past. Paper maps, for all their beauty and communicative power, are limited; they are static representations of the world, and the result of a great amount of effort. GIS maps, on the other hand, are dynamic; users can pan, zoom, turn layers on or off, change the scale and their point of perspective a thousand times without any effort at all. The data in a GIS are dynamic and constantly change as new data become available in the system, and through the enormous power of modern computers, a GIS can turn out thousands of maps representing the data from millions of records at a minimum amount of time.

The introduction of topological techniques permitted the data to be connected in a relational sense, in addition to their spatial connections. Thus, it became possible not only to determine where a point (e.g., a hydrant) or a line (e.g., a road) or an area (e.g., a stadium, park) was located, but also to analyse those features with respect to their relation to other special features, connectivity (network analysis) and direction of vectors. The present generation GIS is distinguished from geo-processing of the past by the use of computer automation to integrate geographic data processing tools in a friendly and comprehensive environment.

The advent of sophisticated computer techniques have proliferated the multidisciplinary application of geo-processing methodologies, and provided data integration capabilities that were logistically impossible before. The ability to incorporate spatial data, manage and analyse it, and answer spatial questions are the distinctive characteristics of GIS.

GIS is now becoming an independent discipline in the name of geomatics, geoinformatics or geospatial information science and is used in many departments of government and university.

1.2 VARIOUS DEFINITIONS OF GIS

The GIS is a rapidly growing technology and has been defined in various ways. The following definition of GIS gives a concise description of the term/system: a GIS is a computerized, integrated system used to compile, store, manipulate and output mapped spatial data.

Different definitions of Geographic Information System given by various organizations are as follows:

- Geographic information system, commonly referred to as a GIS, is an integrated set of hardware and software tools used for the manipulation and management of digital spatial (geographic) and related attribute data.
- Geographic information system (GIS) is a computer-based tool for mapping and analysing things that exist and events that happen on earth. GIS technology integrates common database operations such as query and statistical analysis with the unique visualization and geographic analysis benefits offered by maps.
- GIS is an integrated system of computer hardware, software and trained personnel linking topographic, demographic, utility, facility, image and other resource data that are geographically referenced.
- Geographic information system (GIS) is a computer-based information system that enables capturing, modelling, manipulation, retrieval, analysis and presentation of geographically referenced data.

GIS has become an essential part of day-to-day life. People might have not realized about its applications on everyday life. If someone uses an Internet mapping program to find directions, they are actually using a GIS. A new supermarket chain on the corner was probably located using GIS to determine the most effective place to meet customer demand. The system-based definition of GIS may be called ‘functional’, because it is based on the functions that a GIS performs. As each of these functions is performed on the geographic data associated with the GIS, the definition may also be called ‘data-centred’.

From the above definitions, the following observations can be made:

1. GIS database use geo-references as a primary mean to store and access information.
2. GIS integrates technology.
3. GIS can be viewed as a process rather than software/hardware.
4. GIS helps to make better and quick decisions.

1.3 ORDINARY MAPPING TO GISs

Topographic features called as entities have a long history of being portrayed on scaled maps and plans. These maps or plans provided an inventory of scaled or general features that were found in a given geographic area. With the emergence of large databases, which were collected primarily for mapping, attention was given to a new technique for analysing and querying the computer-stored data, which later became the GIS. GIS data can be assembled from existing databases, digitized or scanned from the existing maps and plans, or collected using conventional surveying techniques or by using the global positioning system (GPS).

A GIS is a system which uses geo-referenced data to answer questions. A computer-assisted cartographic system is a set of graphic elements for map display and printing, and is not a GIS. A computer-aided-drafting (CAD) system is a set of graphic elements for engineering and architectural design in which some have GIS modules as add-ons.

GIS in an integrated multidisciplinary science consisting of the following traditional disciplines such as geography, cartography, statistics, remote sensing, computer science, photogrammetry, mathematics, operational research, surveying, civil engineering, geodesy and urban planning. Table 1.1 summarizes how the above disciplines make up GIS with respect to the functions. GIS has many alternative names used over the years with respect to the range of applications and emphasis, as listed below:

1. Land Information System (LIS)
2. AM/FM—Automated Mapping and Facilities Management

TABLE 1.1 Relations of traditional disciplines with GIS

	Functions of GIS								
Discipline	Data Acquisition	Mapping	Pre-Processing	Data Structure	Database	Spatial Analysis	Modeling	Display	Application
Geography		×				×			×
Cartography	×	×						×	×
Remote sensing	×	×				×		×	×
Photogrammetry	×	×						×	×
Surveying	×	×							
Geodesy		×							
Statistics			×		×	×			
Operational research						×	×		
Computer science			×	×	×	×	×		
Mathematics				×		×	×		
Civil engineering	×	×				×	×		
Urban planning	×					×	×		×

3. Environmental Information System (EIS)
4. Resources Information System
5. Planning Information System
6. Spatial Data Handling System

The ability to store data on feature-unique layers permits the simple production of special feature maps. In a GIS, spatial entities have two characteristics, namely, the location and attributes. Coordinates, street address, etc. can give the location and attributes and describe some characteristics of the feature being analysed. GIS has now blossomed into a huge and diverse field of activity. Most activities can be identified as being in one of the two broad fields:

1. Geographic feature-specific activities such as mapping, engineering, environment, resources and agriculture.
2. Cultural or social activities such as market research, census, demographics and socio-economic studies.

The switch from hard copy maps to computerized GIS has provided many benefits. This system can help to do the following:

1. Store and easily update large amount of data.
2. Sort and store spatial features called entities into thematic layers. Data are stored in layers so that complex spatial data can be manipulated and analysed efficiently by layer, rather than trying to deal with the entire database at the same time.
3. Zoom into sections of the displayed data to generate additional graphics, which may be hidden at default scales.
4. Query items of interest to obtain tables of attribute information that may have been tagged to specific points of interest.
5. Analyse both entities and their attribute data using sophisticated computer programs.
6. Prepare maps showing selected thematic layers of interest. One can update maps quickly as new data are assembled.
7. Import stored data (both spatial and non-spatial) electronically from different agencies, and thus save the costs of collecting data.
8. Use the stored data to prepare maps at different scales, for a wide range of purposes.
9. Build and augment a database by combining digital data from all the data-gathering techniques, that is, from surveying, remote sensing, map digitization, scanning and from the Internet.
10. Create new maps by modelling or re-interpreting existing data.

1.4 COMPARISON OF GIS WITH CAD AND OTHER SYSTEMS

Both GIS and CAD are computer based, but CAD is often associated with high-precision engineering and surveying applications, and GIS is more often associated with the lower levels of precision usually required for mapping and planning.

CAD is similar to mapping because it is essentially an inventory of entered data and computed data that can provide answers to the questions: What is it? Where it is located? But CAD has no

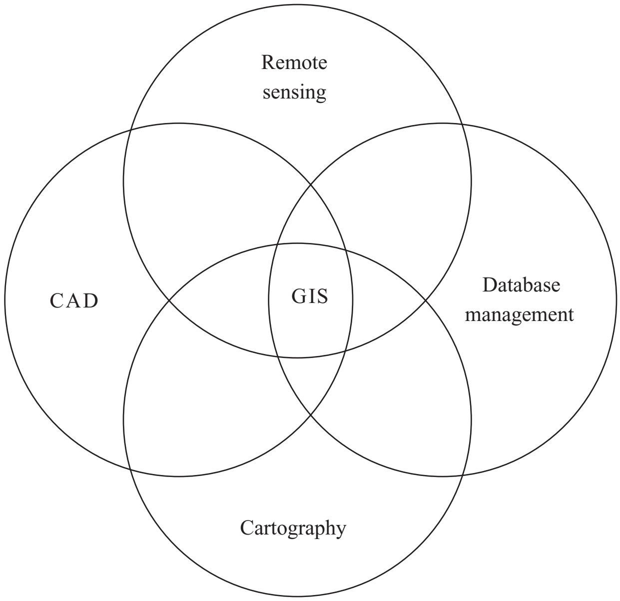

FIGURE 1.2 Relationship of GIS to other main systems

analytical tools to perform spatial analysis. On the other hand, in addition to answering the where and what questions, GIS can model data and provide answers to the spatial and other questions like what occurred? what if ? and what patterns exist? Topology gives GIS the ability to determine spatial relations, such as adjacency and connectivity between physical features or entities.

For establishing a definition of GIS, it is important to outline the relationship of GIS with CAD, computer cartography, database management systems (DBMS) and remote sensing information systems. The relationship of GIS to the other systems is given in Fig. 1.2. A GIS can be termed as a subset of the four listed technologies as in the figure. A true GIS can be distinguished from other systems by the fact that it can be used to conduct special searches and overlays, which actually generate new information. Typical subsets of geographic feature-specific GIS include LIS, AM/FM and geographic information system for transportation (GIS-T).

1.4.1 Land Information System

LIS is a subsidiary of the GIS. LIS is related entirely to land data. It includes information such as size, shape, location, legal description, topography, flood plains, water resources, easements and zoning requirements for each piece of land in the system. The legal descriptions are those bound with the local administration departments. A GIS includes data for a much wider range than that of LIS. The GIS includes not only the data mentioned for LIS, but also includes such things as soil types, depth of ground water, census data, school bus routes, tax maps, fire, police jurisdiction and so on. With an LIS, a user can determine the ownership of property, tax assessments, mortgages, utilities, boundaries, improvements made to the land and other information needed for land appraisal, land acquisition or for other various uses of the land.

1.4.2 Automated Mapping and Facility Management

AM/FM is an important field of GIS activity with macro applications in the management of municipal utilities. Engineers and surveyors can map inventory roadways, pipelines, cables and other municipal infrastructure utilities using AM/FM software programs. These programs also record all relevant characteristics of the utility. For example, in the case of a sewage line the following data have to be recorded: the pipe type, length of run between manholes, inverts and pipe slopes, date of installation and record of maintenance. The program can be designed to issue work orders for a scheduled maintenance automatically and to prepare plans and profiles that show the locations of all services. AM/FM applications manage the physical plant and services of large office and industrial complexes. All services, including electrical, heating, air-conditioning, elevators, fire protection, communications, as well as building design and layout are stored on three-dimensional layer-specific sections of the computer storage.

1.4.3 GIS-T

GIS-T is a subset of GIS. GIS-T refers to the principles and applications of applied GIS to solve transportation problems. GIS can effectively be employed to find, analyse and solve transportation problems. Now GIS-T has been evolved as a specific branch in GIS, to address transportation issues, and now GIS-T has become one of the major applications of GIS. Highway data are usually modelled in vector fashion by digitizing the centre line as lines of arcs and nodes. Lines or arcs join two coordinated points, and nodes are points of intersection with other highway centre lines or other linear features. Highway reference methods are based on the presence or absence of specific attributes to be analysed or displayed, that is, attributes are stored in separate databases categorized by their attribute characteristics.

1.5 GIS ARCHITECTURE (GIS SUBSYSTEMS)

GIS can be understood as a group of subsystems within the framework of a main system. Accordingly, GIS has the following four functional subsystems (see Fig. 1.4):

1. Data input (data input from maps, aerial photos, satellite imageries and from other sources)
2. Data storage and retrieval (data storage retrieval and query)
3. Data manipulation and analysis (data transformation, analysis and modelling)
4. Data output and display (data reporting such as maps, reports and plans)

1.5.1 Data Input

A data input subsystem allows the user to capture, collect and transform spatial and thematic data into digital form. The data inputs are usually derived from a combination of hardcopy maps, aerial photographs, remotely sensed images, reports and survey documents.

There are five types of data entry systems commonly used in a GIS:

1. Keyboard entry (manually entering the data at a computer terminal)
2. Coordinate geometry (entering coordinates of surveyed data using a keyboard)
3. Manual digitizing (widely used method for entering spatial data from maps)

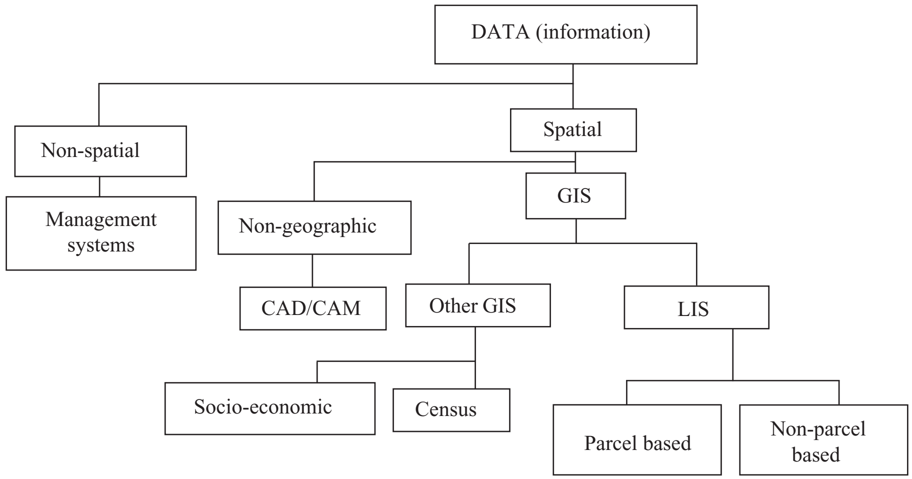

FIGURE 1.3 Flow diagram showing the relation between spatial and non-spatial information with various systems

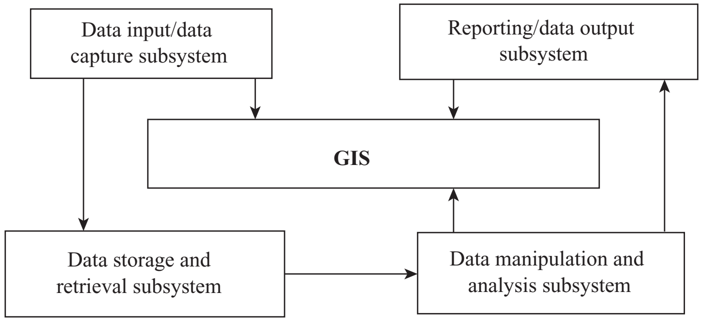

FIGURE 1.4 GIS architecture/GIS subsystems

4. Scanning
5. Input of existing digital files.

1.5.2 Data Storage and Retrieval

The data storage and retrieval subsystem organizes the data, spatial and attribute, in a form which permits it to be quickly retrieved by the user for analysis, and permits rapid and accurate updates to be made to the database. This component usually involves the use of a database management system (DBMS) for maintaining attribute data. Spatial data are usually encoded and maintained in a proprietary file format.

1.5.3 Data Manipulation and Analysis

The data manipulation and analysis subsystem allows the user to define and execute spatial and attribute procedures to generate derived information. This subsystem is commonly thought of as the heart of a GIS, and usually distinguishes it from other DBMS and CAD systems.