

Design Issues in Geographic Information Systems

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Abstract

Data presentation and visualization is an important step towards understandability of data. The humans memorize the information by converting it into a format suitable for storage in their brains. Most of the data in human brain is related to geography and we continuously keep upgrading this geographical information consciously or unconsciously. Such geographical information is shared with peers in the form of maps which is an easy and comprehensive source for transferring geographical information. Such information is generic in nature and valid for everyone using maps. These maps are further simplified by annotating them with symbols and labels for those who do not understand map conventions. The evolution of information systems also enabled people to equip such maps with graphical user interfaces. These interfaces keep data of every object/symbol marked on the map. These interfaces can be customized for different industries. In network based companies like gas, railways and airline companies, geography is vital for decision-making but decisions are not only based upon geographical information but also need other information like attribute information.

GIS stands for geographical information system which provides both geographical and attribute information through single interface. It is an information system that is used to store, retrieve and analyze geographical and non-geographical data together. Unfortunately, the diffusion and adaptation rate of GIS is much smaller in the network based companies of developing countries. There are many reasons for non-diffusion. A study was made to identify different factors for slower diffusion of such a suitable information system for network analysis and mapping, in those companies of developing countries which should adopt the system as first priority. A part of study is presented in this paper in which one of the major reasons for non-diffusion i.e. the graphical user interface of geographic information system (GIS), is discussed. In the study, other reasons for non-diffusion of GIS are also identified but not addressed yet which will be done in future extension of the same study. On the basis of drawbacks identified in existing GIS interface design, a model is proposed to make certain enhancements in the interface. In comparison with existing GIS interfaces, the proposed interface is equipped with display, query, and analysis interface. A

prototype of interface based upon proposed enhancements is given the name of GINU (Graphical User Interface for Novice User) in the study. The acceptance of GINU is found to be greater than the existing interfaces for a GIS.

Keywords: Geographic Information System, GIS, GUI, Interface, Symbols, Standardization, GINU.

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[Note: The complete project from which the paper is extracted is published in Shaheen, Shahbaz, Rehman, & Aurangzeb, 2010.]

Introduction

(**Note:** Different terminologies used in the paper are specific to the domain of GIS for which glossary of terms is given at the end of paper. The words for which definition is given in the glossary are italicized in text).

Geographic Information System (GIS) is an information system designed to capture, store, manipulate and analyze geographical and non-geographical data. It differs from conventional information system because of geographical information manipulation. Although GIS can be used in different companies for different purposes, its use bears much worth in the companies where network analysis and design are in the primary requirements for smooth functioning of the company. Its functions are not only limited to network analysis but also bears good reputation in geographical information representation, assets management, network connectivity tests etc. It helps decision makers to simulate different test cases related to networks and topologies on the desktop instead of applying the same in actual which may bear greater cost. Geographical data storage, manipulation, display, and analysis become more reliable with the emergence of geographic information systems (GIS). The use of GISs in industry is very understandable especially in those industries where execution and operation are dependent upon network analysis and design, e.g., pipeline industry, telecommunication networks, road networks, street networks, and real estate businesses. *Geo-databases* brought incredible change in the mapping of network based information system and *geo-spatial* analysis. *Geo-spatial data* mapping is now a powerful tool for geo-analysis. A GIS is used to map, manipulate, analyze, and display the *spatial and non-spatial data* mapped on geography in an appropriate form. It has broader application domains like identifying the characteristics of *oil and gas reservoirs* by using *isotopic, seismic and geological data* (Shaheen, Shahbaz, Rehman, & Aurangzeb, 2010). The use of GIS in natural resource industry is discussed by various researchers (Shaheen et al., 2010). The said information system is important not only in exploration but also in generating self-revenue by utilizing the services of network based data management (Shah, 2006). Figure 1 shows components of a GIS by giving a pictorial overview of the same in background.

The utility of GIS is very low in developing countries. It is desired to increase the diffusion of spatial technologies in these countries all in planning, development, and maintenance phases but unfortunately, GIS is not well practiced in various explorations and planning departments. Advanced techniques in GIS changed conventional information system by addressing those aspects which constrained the use of conventional information systems in network mapping and analysis. Despite all above, GIS and *remote sensing* is rarely used in such scenarios especially in developing countries. Although, on technology adaptation ranking models, these countries are poorly ranked yet the diffusion of GIS is even lower and may be considered critical (Shaheen et al., 2010). The planning resource persons are investing their efforts to increase the diffusion of GIS for appropriate representation of information.

GIS and *remote sensing* technology is not at a mature stage in Pakistan. Even *Parcel-level systems* are not developed for cities for which the mapping companies are facing many problems (Nazi & Siddiqui, 2006). The recent work which has been done in this context is starting development of GIS from scratch for different *transmission and distribution networks*. But *cartographic mapping* is not all about GIS. It should also have analytical capabilities within the system. The architecture of GIS is layered. It contains multiple layers of data plotted on a base map. The base map itself is considered as one of the layers in a GIS. Two types of data are incorporated in a GIS: Spatial data and *Non-spatial* data. *Spatial data* is plotted in the form of points, lines and polygons on a map. The map is actually cropped from *remotely sensing* satellite image (Korte,

2000). Different image interpretation techniques are provided in literature for analysis of image. Remotely sensed data can be classified into *spatial* and *non-spatial* data. Spatial data is the data related to space like coordinates, latitude, longitude etc. *Non-spatial* data is normal attribute data. For example a building is marked on a satellite map. The latitude and longitude of this building is spatial data related to that building and number of rooms in that building is *non-spatial* attribute. Both spatial and *non-spatial* data is visualized through images and can be analyzed by different methods after which the results of analysis are displayed back to the user through the same image. The user has no need to interact with the data directly (Shaheen, Shahbaz, Guergachi, & Rehman, 2011; Shaheen, Shahbaz, Rehman, & Guergachi, 2011).

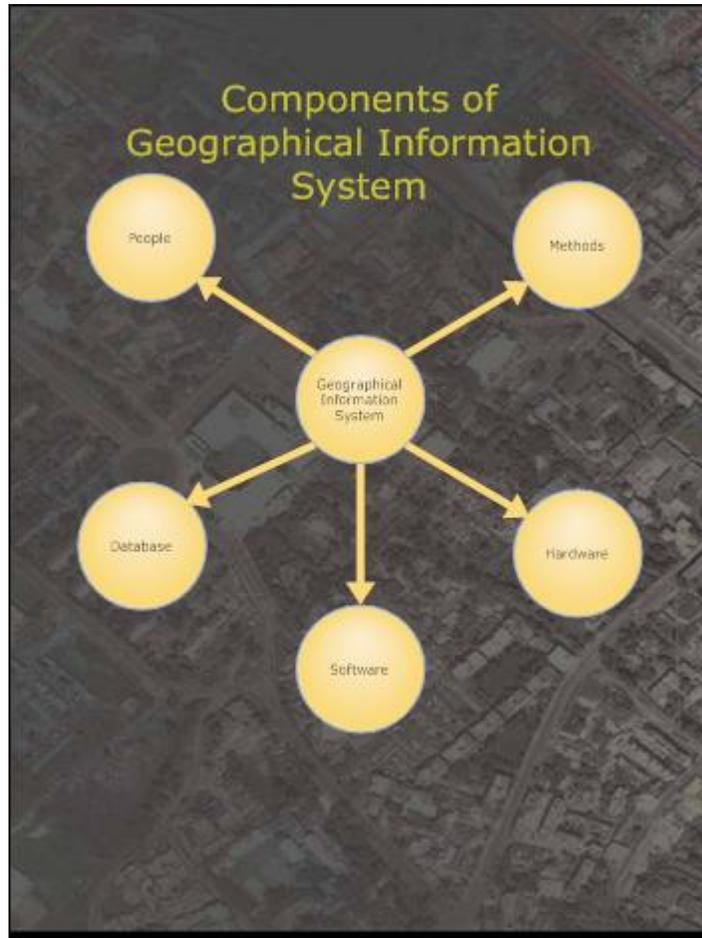


Figure 1: Components of Geographic Information System

As mentioned earlier, the diffusion of GIS in industry across Pakistan and in other developing countries is low. There are many reasons that affect this adoption but the one discussed in this study is the non-friendly interfaces of GIS. This study proposes a model of GIS with friendly interfaces that would easily be accepted by the users in different organizations in Pakistan. The model is prepared in the light of existing information systems which are already in existence in the country. The existing information systems are developed according to the user needs and expertise. Thus, if the GIS would be developed by keeping existing norms of information system in mind, it would obviously cause an increase in diffusion of the geographic information system.

The rest of the paper is organized in a systematic way. The next section presents literature review of the study. The third section discusses the proposed model, and the fourth section is about a test case of the proposed method. The final section draws conclusion and proposes future work.

Literature Review

The use of GIS in developing countries of Asia is much smaller (Yeh, 2004). Technology Adoption Model (TAM) is one of the stronger tools applied in developed world for measuring the acceptance of technology by finding user perceptions (Boudreau, Gefen, & Straub, 2001). Ibrahim Elbeltagi, McBride, and Hardeker (2005) studied the factors influencing the usage of information systems in less developed countries. They concluded from the results that Perceived Ease of Use (PEU) and Perceived Usefulness (PU) affect the use of information systems. The arguments by Goodman and Green (1992), Krovi (1993), and Lu, Hsieh, and Pan (1989) revealed that poverty, trade barriers, and lack of infrastructure affect the usage. An organization's culture also contributes a lot in adoption and use of GIS. De Man and Toorn (2002) underlined the importance of social conditions and cultural desirability in the adoption of GIS. Ian Muehlenaus (2007) identified the extent of GIS ubiquity and diffusion in various states. He concluded that considerable growth with potential in developed countries has been observed in industrial as well as non-industrial sector.

LaBarbera (2006) in the U.S. identified the factors for which the diffusion of GIS is low, and the most prominent factor identified is limited public access of articulation through newspapers and television. General public takes much influence of the topics that are advertised through these mediums. The usage of internet and other technologies is much smaller in remote areas but access to television and print media is much greater than other computer based mediums. A similar practice is also observed in the companies and organizations of these countries. LaBarbera also emphasized that lack of knowledge of technologies is a major reason for non-diffusion of GIS. Furthermore GIS experts and use of the products used for GIS development have not been in public access and use. Non-feedback from clientele where GIS is implemented is also a recognized factor of non-diffusion. There was a time when the same problem persisted in developed countries like in 1994, Dutch market research reflected that municipalities have low confidence in geographic data (Kroode, 1994). Similarly, Masser (1998) identified unavailability of data in digital form as reason for non-usage of GIS.

The industries and organizations in developing countries are not very familiar with the use of information systems. It is illogical to make them use state of the art geo spatial technologies all at once. In this study, we identified a reason for non usage of GIS which is "Non-friendly graphical user interfaces". The organizations where GIS is used up to certain extent are not very much convenient with the graphical user interfaces provided by current GIS software. That is the reason for them either to give up the use of GIS or to establish a separate GIS section with GIS experts. In these companies, users place their query to GIS section which is manipulated by GIS experts to get them back with the results. That is the reason for end user to feel unfriendly with GIS hence not utilizing it in true sense. Similarly the experts have been doing, what is not meant for them to do. They perform basic manipulation activities for the resource persons, which tarnish their technical capabilities and results in job dissatisfaction. Some guidelines for GIS interface design are given by Shaheen et al. (2010) which consist of degree of agreement between users and designers, smart menus, structure of program both at conceptual and physical design level, easy to learn interfaces, direct computation and spatial data presentation. A survey has been made as part of this study in different energy companies of Pakistan to extract the factors causing limited or no usage of GIS in spreader networks. The survey along with field visits to different companies enabled us to conclude on the following enhancements in the design of graphical user interfaces of GIS.

- The companies in Pakistan have been using management information systems, transaction processing systems, and other decision support systems for a long time. They are well aware of its operational and analytical capabilities hence working on it regularly or at least periodically. The interface of a GIS is quite different. The diffusion of other information systems

was quick because of its compatibility with manual system in execution, but GIS is not an alternate to some existing file system. For example national survey sheets are used for *cartographic mapping* in oil and gas companies. The cartography is overlaid on these sheets by using AUTOCAD. The use of AUTOCAD is still popular for such *cartographic mapping* whereas GIS has the capability to digitize existing networks on satellite imagery.

- The labels or annotations used in this information system do not match with the practiced annotations. Since the workforce of every company feels it more convenient to present the scenarios in their own terminologies, they feel more convenient with the practicing technical language which is in use across the organization. It is very difficult for an experienced manager to work on new terminologies especially when the work is time bound and needs faster performance.
- GIS supports multiple statistical functions which increases the utilization of the system in multiple problems. This is not easy for the users to have good knowledge of actual and formal parameters of such functions. The functions need specialized skills of GIS professionals whereas the human moderator skills become bottlenecked when quick information transfer is needed (Egenhofer, 1995). The company can at most provide some mentoring in the form of training to the employees but these trainings are insufficient for the persons from quite different domains of work.
- The resource persons across the companies are more familiar with working on paper maps. Since the used norms of paper maps are quite different from satellite imagery many operational hurdles are observed. The configuration of both of these differs in spatial identification of points as well as in layout (Shaheen, Shahbaz, & Guergachi, 2013).

In the light of the literature, this study is about proposing enhancements in the existing GIS interfaces by using some baseline principles of Human-Computer Interaction (Dix, Finlay, Abowd, & Beale, 2004). The proposed enhancements incorporate the capabilities of simple information system as well as geographic analysis capabilities to made its prospective broader.

Proposed Model

In the light of guidelines given in the literature review section, what we summarize the following points about generic GIS interface design.

1. The interfaces for GIS should be generic and not attract only the interests of special interest groups (may be experts).
2. The GIS interface should be simple enough to be easily adaptable by novice users.
3. The use of the GIS application through interfaces should be user-oriented and supported and provide different orientation depending upon the type of users, i.e., novice, moderate and expert.
4. The user may be facilitated with automated capabilities with less to do by him.
5. Standardization should maximally be attempted to ensure standardization among different interfaces.

On the basis of the above determinations, a model for designing graphical user interface of GIS is presented in Figure 3. A number of flexibilities are introduced in the model so as to provide a workable GIS environment to novice users.

Base Map Options

The existing interfaces of GISs provided by different companies do not include a separate base map selection option. The proposed interface may be equipped with options to select a base map. The user can use the interface to rectify satellite image on different base maps. All the options

related to base map selection are provided on the first/home interface of the application. When one selects the base map for the GIS, the corresponding *rectification* would automatically be applied and the layers would be adjusted.

Interface orientation for different users

The users of a GIS may be provided with different orientations of the GIS interface all depending upon the customization needs of the user. In the proposed interface, the user is provided with an option to define the level of expertise, whether the user is expert, moderate, or novice (the user is provided with pre-defined expertise level from which he is supposed to choose one). Each user will be offered the interface options according to his expertise. In order to demonstrate a scenario of usage, an experienced user may be given the option to use analytical tools and play with the incorporated spatial database and a novice user will only be given privileges to perform basic editing functions like searching a location, printing data, and displaying attributes.

Built in graphical user interfaces

The systems which are currently in use in Pakistan are supported with GIS functionalities at certain places. In these systems, graphical user interfaces are incorporated to record attribute information of a particular data point. For example, in the GIS of a telecommunication company a router is marked in geographic vicinity and its attributes are attached with it through the graphical user interface. These GUIs contain the attributes of different data points and are essential for ease of access. The method to access graphical user interfaces in GIS is so complex that a novice user can't easily adopt its use.

In the proposed interface the graphical user interfaces are attached with the geographic data in a manner that it becomes quite simple for a novice user to get information through the GUI. For example, in an electric power system GIS transformers are marked at various geographic locations. A single mouse click on these installations on the map causes its corresponding graphical user interface to open. The programmatic difficulty involved in providing such facility is not very complex. Another provision in the proposed model is designing of graphical user interfaces through automatic and guided wizards. A novice user feels it more convenient to orient GUI through wizard.

Annotation libraries

Labeling existing diagrams is a method that has been found reliable for enabling users to understand certain phenomenon. The labels by which a diagram is explained is called annotation. The features incorporated on GUIs can simply be provided to the user in the form of labels like labeling a biological diagram. In the proposed model, various annotation libraries are included containing labels with respect to application. The major annotation libraries can label the applications of oil and gas, telecommunication, road networks, rail lines, and power sector. The annotations libraries are equipped with symbology for introducing standardization in symbols to be used in the GIS. This phase is still in progress, since the standardization of symbols for different applications of a GIS is complex and time demanding task. For example, in order to finalize the annotations and symbols for oil and gas industry, it is better to consult American Standards for Mechanical Engineers (ASME). The user is provided with the facility to include new symbols and annotations in built-in libraries.

Components of the interface

The existing interfaces of GIS are more or less based upon the following components;

1. Layered architecture (Layer window): The interfaces provided for GIS functionality always contains a window for stacking layers.
2. Map pane: The pane which actually holds the map which is mostly oriented and filled with geographic map and a few editing tools.
3. Menu bar: Menu bar is provided with the GIS just like other office automation tools.
4. Analytical tools: Different libraries of network statistical analysis tools are appended within GIS interface so as to provide user with the functions which can be applied for network analysis. In order to understand the use of analysis tools in GIS interface, one needs to get expertise skills which are not appropriate. The components are shown in Figure 2.

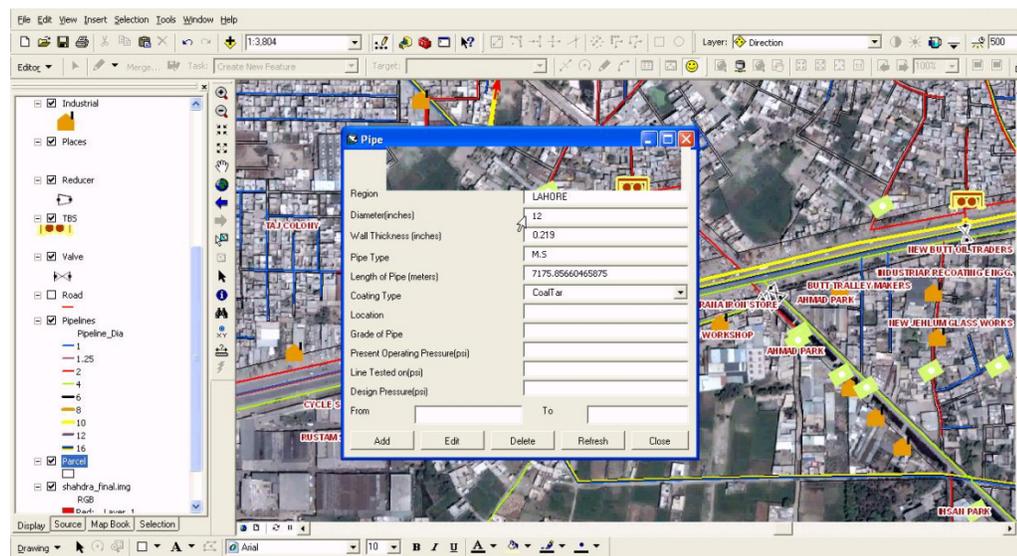


Figure 2: Existing GIS Interface

In the proposed model we have simplified the interface and divided it into three parts:

- (1). Display Interface
- (2). Analysis Interface
- (3). Query Interface

The user is provided with all the basic and frequent functions on the core interface. The provisions explained in the previous section are also included on the main interface. Most of the functions are one-nest; however, there are certain things for which a second nest may be required. The model of the interface is given in Figure 3.

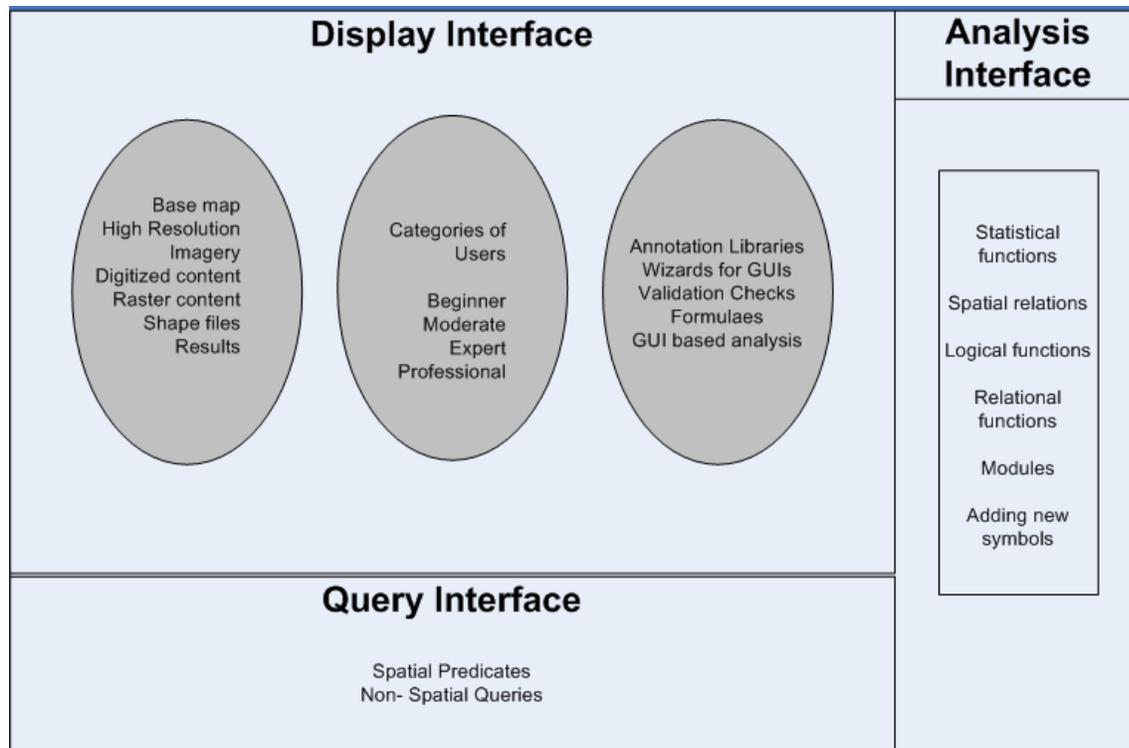


Figure 3: Proposed Interface for GIS

GINU: Geographical Interface for Novice User

The proposed model of the study is implemented through development of software with the name of GINU. GINU stands for Geographical Interface for Novice Users. The interface is specifically designed for novice users. The most common practiced interface for GIS development in Pakistani companies is Esri's ArcGIS. The existing interfaces are not easy to use and have frequently been adapted by the users across companies. The goal of GINU is to increase diffusion of GISs by improving and simplifying the interface. The use of GIS is limited in developing countries because of the above mentioned reasons. GINU integrated the concepts of multiple domains including Human-Computer Interaction, artificial neural networks, and social sciences.

GINU is composed of two types of databases. One is to store spatial and *non-spatial* database just like normal database management in GIS software. An instance of spatial database is proposed (not actually embedded yet) to incorporate virtual machine technology which was proposed by Su, Zhu, and Kong (2008). The second type of database is the one which handles attribute data. The interface is divided into different panes as shown in Figure 4.

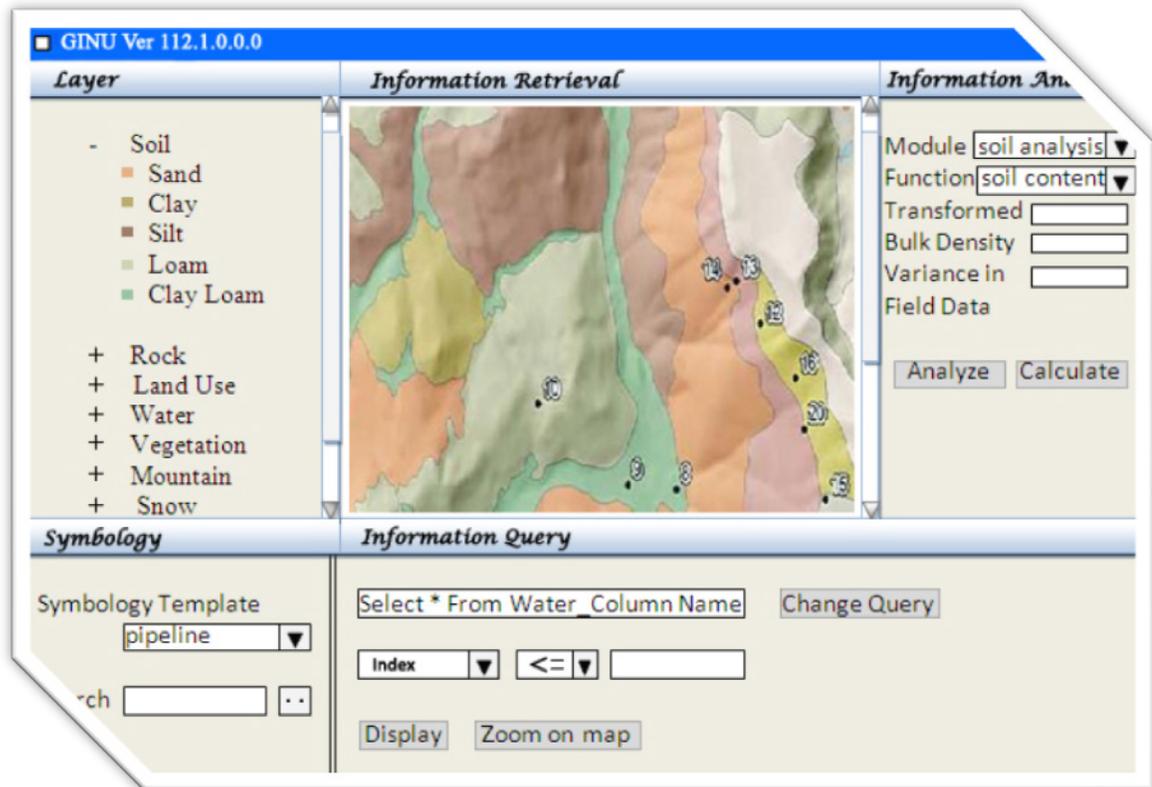


Figure 4: GINU Interface

Conclusion & Future Work

In the study, a model for increasing diffusion of GISs in the companies of developing countries is identified. In the light of the reasons a new comparatively simple and easy to adopt GIS interface is proposed which is basically designed for novice users. This newly designed interface is considered to be an enhancement to existing interfaces used for GIS development and use.

Different components are added in the newly designed interface including standardized symbols, base map, annotation libraries, and expertise wise usage. These inclusions are made to ensure the following:

- Generalization of GIS interfaces for different applications and categories of users
- Ease of use
- Flexibility
- Comprehensibility

Symbology should be incorporated to ensure standardization among different interfaces. The work can be extended to identify and address other reasons of non-diffusion of GIS. These reasons can be accuracy criticality and ease of use in statistical functions. The interface designed in the study with the name of GINU can further be enhanced to include function libraries, built-in queries, built-in spatial predicates, *spatial* and *non-spatial* shape file analysis, and separate shape file and *geo-database* management.

Limitations/ Weakness of the Model

The acceptance of GINU across student communities working for network based companies is found to be greater than existing GIS interfaces. There are still some weaknesses in the model which are found in practical use of GINU by student's communities. The limitations are given as the following:

1. GINU is developed by using java language. The controls incorporated in GINU are found to be non-rigid. For example the certain mouse clicks on the interface can't be realized and need specific attention of the user.
2. The users are at primary stage to interact with GINU. It is difficult to convince user for writing queries in query pane of the interface. The reason for goodness of query pane is that it multiplies the options given to user for posing his question.
3. Many expert users are well versed with the previous GIS interfaces because of their expertise for which they are still reluctant to switch to GINU.
4. There are complaints that the display pane is too small in size and needs much scrolling to view the whole image.

Glossary of Terms

Cartographic mapping: Study and practice of making maps is called cartography. The most popular software for cartographic mapping is AutoCAD.

Distribution Network: The pipeline laid within the cities to supply gas from city gates to door-steps.

Geo-databases: The databases that store data related to earth.

Geo-spatial data: Geological data can be of two types: (1) data that is related to space and (2) data that describes attributes. Geo-spatial data is the geological data related to space (coordinates, x point, etc.).

Geological data: The data which come from research on solid earth materials.

Isotopic data: Radioactive form of a particular element gives isotopic data.

Lineament: Lineament is a linear feature on surface of earth such as fault.

Non-spatial data: The data which is stored with spatial data and which do not represent a feature related to space. For example latitude and longitude are spatial data while number of rooms of in a building is non-spatial.

Parcel-level system: Demarcation of various buildings, streets, housing on satellite image in vector form make parcels.

Rectification: The process of converting satellite image on true coordinate system, i.e., latitude and longitude is called rectification.

Remote Sensing: A method of data collection in which the data is collected through space-borne instruments e.g. satellites or aerial imagery.

Reservoirs: The containers that contain oil, gas or other natural resources.

Seismic data: Oil and natural gas companies use seismic data as their principal source of information to locate oil and natural gas deposits, both to aid in exploration for new deposits and to manage or enhance production from known reservoirs. To gather seismic data, an energy source is used to send sound waves into the subsurface strata. These waves are reflected back to the surface by underground formations, where they are detected by geophones which digitize and record

the reflected waves. Computers are then used to process the raw data to develop an image of underground formations (source: <http://www.ultrapetroleum.com/About-Us/Glossary-of-Terms-14.html>)

Spatial technologies: The technologies that are used for analysis, use and manipulation of spatial data.

Tracer analysis: The analysis of compound's concentration.

Transmission Network: The pipeline for gas through which the gas travels from source (gas well) to gates of cities.

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Biographies



Dr. Muhammad Shaheen, Ph.D., Associate Professor (Computer Science) FAST – NUCES Pakistan was born in Haripur, Pakistan in 1980. He received Bachelors and Masters degree in computer science from University of Peshawar in 2000 and 2002 respectively, and the M.Phil degree from Foundation University Islamabad in 2007. He got his Ph.D degree in computer science from University of Engineering & Technology Lahore Pakistan in 2011. He got gold medals in recognition of his performance in M.Sc and M.Phil. In 2003, he joined Sidat Hyder Morshed Associates Islamabad as computer programmer and in 2004 became Sr. computer programmer. He joined Sui Northern Gas Pipelines Ltd., in the year 2006 where he served as GIS Manager in corporate planning & development department of the company till 2011. Since then he has been serving as Associate Professor (Computer Science) at FAST – NUCES Peshawar. His current research interests include data mining, remote sensing, software metrics, databases, artificial intelligence, industrial problem solving and operations research. Dr. Shaheen has a broader experience of research and development in various domains of computer science. He worked on different projects in the country. He published number of research papers in journals and conferences of international repute. He has also been serving in board of reviewers of different international research journals and conferences. He is a member of SEI, WCE National Academy of science and Informing Science Institute.



Mr. Fazal e Basit was born in Peshawar in 1979. He did his Bachelors in software engineering in Foundation university Islamabad and Masters from NUST-EME Islamabad. He has been serving as Assistant Professor (Computer Science) at FAST-National University Pakistan. He is also designated as Head of Department (Computer Science) in the same university. His area of interest and research is algorithms, data mining and computer programming.