Global Positioning and Geographical Information Systems

A surveying experience in Mt. Everest National Park

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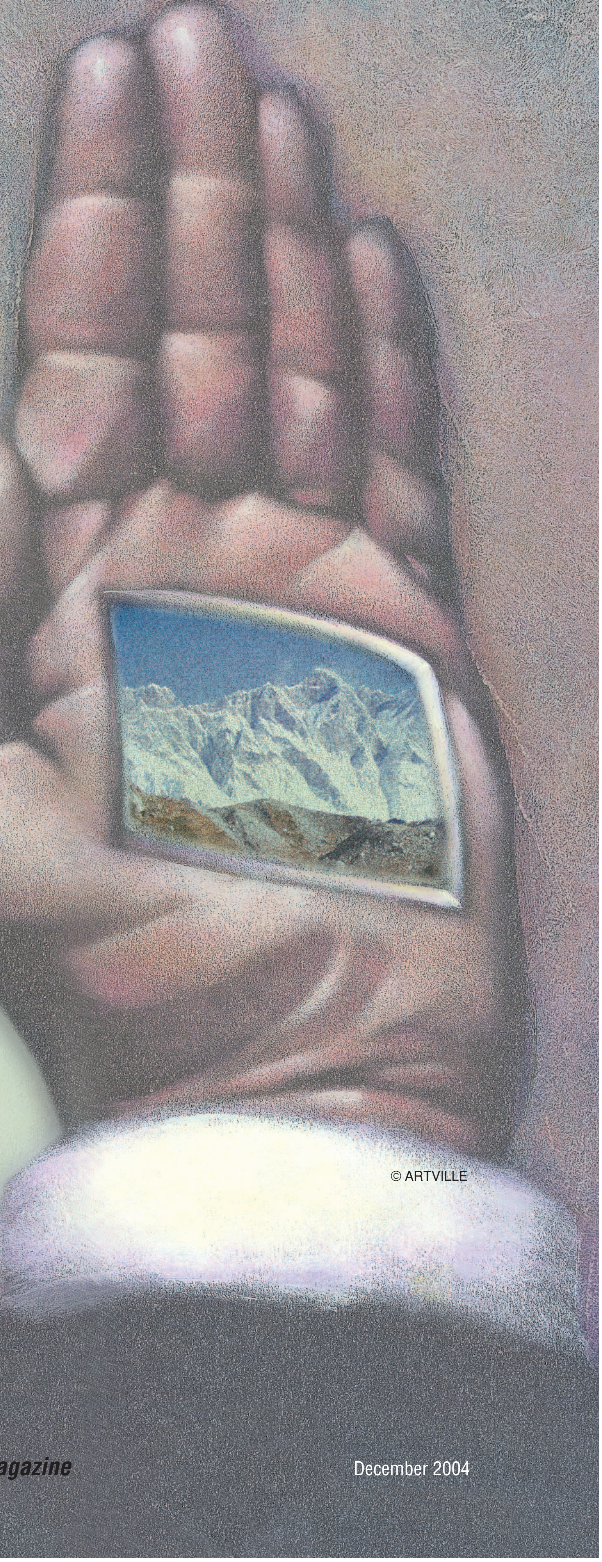

Parks and national institutions all over the world have realized the benefits of using geographical information systems (GISs) to complement exploration route profiles, which enable them to monitor, maintain, and define intervention actions along those routes. To do this, it is necessary to combine global positioning systems (GPSs) with a GIS to ensure position accuracy.

In 2003, the authors helped survey an extended trekking route in a remote area of the Sagarmatha National Park, the national park of Mount Everest in the Himalayan range. The group joined the Changri Nup Glacier Monitoring Expedition under the auspices of the Italian Research Council (EV-K2-CNR project) and the Nepali National Research Institutes (Ronast). The research activity goal was to retrieve the geometrical profile of both the park routes and the tracks leading to the base camps of principal mountains and to develop a GIS for the park [7], [8] (Figure 1). This article presents the results from this trekking experience: the planning phase, the palmtop database design and methods of operation during the experience on the trail, and the incorporation of the data on a GIS Web site, as well as a recent history of route surveys and resources.

Recent History of Route Surveys

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Before GPS became commonly used, a trekking route survey was derived mainly from aerial images. The route profile was directly derived from the image whenever the track was visible and interpolated when it was unclear or hidden by vegetation. The outcome accuracy was acceptable for a cartographic application that satisfied a trekker's needs that didn't require precision. Location accuracy was a secondary goal, provided that the topographical map offered the user adequate indications about the presence of turning points, hairpin bends, change in direction, elevation, and the presence of strategic reference points, such as lakes, rivers, and bridges.

With the availability of GPS in more recent years, this trend is changing. Cartographers now increase accuracy in trekking route surveys to submeter precision by using satellite-based meshes fully compatible with GPS. Additional information, beyond position, can include locations of fire extinguishers, benches, lampposts, pipes, manhole covers, and old trees, just to name a few. It is very costly to obtain information about remote areas and unfeasible for every area.

The surveyor that decides to carry on such work has to provide these items:

- GPS device with a relative position accuracy of 0.3–0.5 m for entries from a GIS; the precision required is generally a function of the map scale
- proximity to a permanent GPS station that provides differential correction (see "A GPS Permanent-Reference Station").

Sources for Position Accuracy

Permanent GPS stations are present in several advanced countries, and their services are continuously available. When a route survey is conducted in countries where such stations are not present, it is necessary to install them for the time of operation whenever the application requires good positioning precision.

In some cases, differential correction can be carried out in real time instead of post-processing the data files. This solution requires a continuous exchange of information between the permanent station and the mobile GPS, e.g., by modem radio or modem cell phone, and is not effective in remote areas, such as surveying a mountaineering environment. Using services from the geostationary satellites can also provide differential correction. The European Geostationary Navigation Overlay Service (EGNOS) or the Wide Area Augmentation System (WAAS) might be available, but today these services do not cover the entire earth's surface. In applications requiring submetric accuracy, with relative positioning based on code, not phase, processing, the GPS station, placed on known coordinates, can be implemented with a low-cost device without the need of considering a double frequency permanent station system.

Another problem associated with the use of GPS, which could impair the effectiveness of the method, is related to the number of visible satellites. A minimum of four satellites must be visible and well placed in the sky [we say with a dilution of precision (DOP) index acceptable] [1], [4]. When a minimal satellite number is not available and the DOP index is not enough, the GPS device cannot operate correctly. This has pushed companies to provide palmtop solutions integrated with the GPS device; they have also provided step-counters, compasses, and low-cost inertial systems, which allow the user to retrieve an estimated position when the GPS signal is not available [5]. Data postprocessing adjusts the track segment.

We can also integrate information coming from the Global Orbiting Navigation Satellite System (GLONASS) constellation. That is the Russian space-based navigation system constellation, sister to the American GPS. Unfortunately, only a few devices allow us to exploit information coming from both satellite systems. The main integration difficulty is differences in frequency of the emitted signals and the datum (WGS84 for GPS and PZ90 for GLONASS). Full compatibility of GPS with the European constellation GALILEO will be possible when it is completed [6]. Frequency and datum will be compatible, and it will allow improvement in position precision in those areas characterized by natural obstacles such as trees and narrow valleys.

Surely, the possibility of having an updated information system allows the trekker to identify and schedule his trip. More importantly, it provides the park management a tool for maintaining, monitoring, planning, and scheduling an eco-compatible development of such a critical environment.

Planning and Organizing the Survey

The Palmtop

Today, several palmtop systems exist that integrate GPS with data processing [9]–[11]. This capability allows the user to assimilate a simple and flexible measurement system with sophisticated software applications for manipulating the acquired data. It is possible to load a GPS palmtop application for designing a suitable database containing topographical and geographical information. During the operational

Fig. 1. Trekking route surveying towards the Mt. Lhotse's south base camp.

A GPS Permanent-Reference Station

A GPS permanent station is a data acquisition and processing station mounting a sophisticated GPS device of known absolute position. The station acquires GPS information with a tuneable sampling rate (e.g., 0.2–2 Hz). Data retrieved allow the system to evaluate the discrepancy between its known position and the estimated one. Such errors, basically introduced by the diffraction interaction of the GPS signal with the ionosphere and the troposphere from the uncertainty associated with the knowledge of the satellite position and from synchronization discrepancies between GPS and satellite clocks, is then used to actively compensate the measurements taken by the mobile surveying GPS device.

This computing method is known as a relative positioning between GPS stations [1]; this process allows the rover GPS to define its own position with meter (1–2 m), submeter (0.5 –0.6 m) or centimeter accuracy, depending on the mobile GPS characteristics. The positioning error is significantly higher when we do not opt for a differential computing method. By considering current devices and no differential positioning between the GPS antennas, we should expect a 10–20 m error in horizontal position and an additional 30% in altitude. Of particular interest is the technique envisaging a differential correction that is broadcast from the permanent GPS station to the GPS acquiring one. Such a correction can be either real time or sent after the acquisition (data post-processing); the former technique is particularly appealing and allows for surveying at a significant distance from the permanent station, for metric and submetric precisions (up to 70–80 Km). In medium accuracy applications where the acquisition campaign is in areas covered by permanent stations modelling trophospheric, ionospheric and satellite orbit errors by means of the virtual reference station (VRS) [2] or multibase stations (MBS) approach [3] then we can move even further from the rover fixed station.

A GPS permanent station.

phase in the field, data insertion is simply carried out by typing the information required, associating a label to an image, and appending a geographical object (e.g., a panoramic point, a temple, or a village) to a track.

The use of such devices is immediately obvious; the weight (e.g., around 0.7 kg) as well as the size (e.g., 20 × 10 × 6 cm) are reasonable and allow a long comfortable acquisition campaign. An external antenna, which can be hidden in a hat, allows the arm carrying the palmtop to be in a resting position, without the need of continuously keeping the internal antenna up towards the sky for satellite signal strength. Moreover, several users can acquire different information, which can be merged together to generate a homogeneous database. The key point is that a specific GPS position will be associated with the geographical information that is unique to it within the resolution of the device.

Satellite Access

Since a GPS-based application suffers from satellite visibility, it is necessary to plan and schedule a route survey to reduce blind areas and maximize the single-point accuracy before any on-the-field measure takes place. This step should not be avoided since it could compromise the effectiveness of the whole acquisition campaign.

You can design an optimal trek survey by using the planning facility made available by software running on portable computers and palmtops or accessing dedicated Internet sites. After having modeled the geometry of the visible sky, the user can search for the hours most suitable for carrying out the experiment. Optimal situations are those that maximize the number of satellites spread out uniformly over the sky to provide a good DOP index. This planning phase is extremely important and should be considered before any retrieval campaign, since satellite visibility may vary in 24 hours from a minimum (without natural obstacles such as mountains or hills) of four to a maximum of ten or 11 (again without natural obstacles). Surely, natural obstacles, such as a valley wing partly hiding the visible satellites, heavily influence the experiment.

Power Supply

A long acquisition campaign in remote areas that lack a power supply can cause unexpected problems, which could impair the whole job. A power supply is necessary to recharge all device batteries, palmtops, digital cameras, and portable computers, which either stores or backs up information regarding the surveyed area as well as filling in missing data. In fact, available palmtop batteries might last up to 20 hours in campaign if used only to retrieve route data and can store about 64 MB. Multimedia information acquired for GIS purpose, such as images, movies, and sounds, will create storage problems, even when considering large removable flash-based devices. Additional batteries must then be considered and, depending on the severity of the environment, 12 V vehicle batteries, inverters, and photovoltaic cells, as well as spare equipment to provide robustness and redundancy, are needed.

The day or night survey should be scheduled to give a phase for battery recharge in the remaining daylight hours. At high altitudes, photovoltaic cells on the back of the rucksack with vehicle batteries, stabilizers, and inverters might be prohibitive for the additional weight and the low oxygen available (50% at 5,500 m compared to sea level).

(a)

(b)

Fig. 2. (a) The GPS reference station that we used (by courtesy of www.montagna.org). (b) The Italian Pyramid Lab (5050 m).

Permanent GPS Station

Apart from equipment issues, acceptable precision can be obtained only with a relative positioning mode that requires a fixed or permanent station in proximity of the retrieving area, and if not available, it must be installed and configured. Our scientific expedition took advantage of the recently installed permanent GPS station [Figure 2(a)] in the Italian EV-K2-CNR research laboratory at 5,050 m [Figure 2(b)] covering the whole Everest National Park area. The station is equipped with a Leica SR530 receiver and a geodetic antenna Choke-ring Leica AT504 sampling data at 30 s or, if required, 1 or 0.5 s.

Programming the GIS Characteristics

The necessity of surveying a trekking route with a GIS application is not solely related to the route survey but also to retrieval of complementary information. A detailed study of the Italian Alpine Club (CAI) [12] has identified the relevant attributes for characterizing a route and its environment. A database already exists from cartography, existing GIS, satellite data, or data acquired in the past and stored in a previously designed database.

We carefully selected the information to be acquired in the field by restricting ourselves only to the strictly necessary data, since acquisition and insertion in the database has a cost, both in time and effort. This is particularly relevant in remote areas. When selecting features and hence, defining the database structure, we kept in mind that the GIS has to deal with hikers, environmental monitoring, and maintenance staff needs.

To balance these different needs, we had to trade off the different requirements for precision in positioning measurement. Hikers require less accuracy in knowing the real profile of a route, or a position and length of a wall supporting it, than the people who have to maintain, monitor, and control it. Minimizing the amount of data to be acquired, definition of the accuracy necessary to the final GIS, automation of the postprocessing phase, and precision definition for the retrieved information are complex issues.

Consider a case in which we wish to retrieve a linear long segment on a given route. A very simple and compact solution to represent it is to associate average attributes to the whole route, such as the average terrain, slope, roughness of the soil, and the starting and ending points. We gain time in inserting the information in the database, whose storage usage is kept minimal, but we lose in specificity. It is obvious that the application designer has to trade off different local requirements based on the final GIS application constraints.

We separated long linear routes into segments to gain specificity and exploit locality information, while segments equal to the GPS accuracy, without differential correction, were considered as single points. In addition, we considered default values inherited by templates for each element to be retrieved to avoid having to type the same invariant information during the track acquisition. Modifications, updates, and data integration can be carried out both during the acquisition campaign and after the retrieval phase.

As a segment of a route is the juxtaposition of GPS-acquired and interpolated points, a route can be intended as the juxtaposition of different segments, or branches, whose data acquisition can be carried out by different groups, in different campaigns. A postprocessing phase will filter, interpolate, and merge different segments, routes, and geographical information into a comprehensive GIS. According to this philosophy, a segment of the trek is a basic entity, an atomic unit in the GIS, and is represented as a table in the relational database. It should be observed that the relational database comprises a set of simple entities, where the relation-derived tables are generated by the application for joining purposes and, in general, do not contain additional information.

Months before the expedition took place, we identified and inserted into the palmtop the elements we could encounter in Mt. Everest National Park. The selections considered the tradeoff between information precision, completeness, and rapidity of compilation during the acquisition campaign and are listed in Table 1.

Once the elements were identified, the next step was to define the field of each element. In this phase, as with a graphical SQL language, we defined the nature of each field and its default value. Each field suggests a predefined (by the designer) set of values to speed up the data compilation phase by means of a pop-up window whose last value is "other," which opens a new data structure in which it is possible to insert a nonprecompiled value. The number of fields is variable and can be extended if necessary, but it must be frozen for consistency when the database is designed and the acquisition campaign starts. Precompiled attributes null typing errors and allow the user to query the database effectively. When filling data in a difficult environment, the probability of typing errors is very high. The name of some elements is not unique (e.g., What is the name of the target village? Chukung, Chukkung or Chhukung).

Table 1. The elements to locate.

Element	Notes	Element	Notes
Route	The segment of trekking route being surveyed. Fields: starting and ending points, type of terrain, etc.	Difficult section	A difficult state within the route segment. Fields: terrain, slope, ropes, crampons, etc.
Services	Services available at a point. Fields: hospitals, post office, telephone, electricity, etc.	Accommodations	Types of different accommodations. Fields: lodge, hotel, camping, etc.
Signals	Vertical signals along the trek. Fields: indications, pole, notes etc.	Point of interest	Point of interest. Fields: position, what can be seen, notes, link to pictures, etc.
Protection elements	Protection elements (e.g., avalanche barriers, walls, etc.). Fields: element type, position, notes, etc.	Public transportation	Public transportation. Fields: bus, airport, heliport, etc.
Handmade elements	Handmade territorial elements (e.g., temples, stupa, bridge, chortens). Fields: element type, nature, position, notes, etc.	Locality	A locality point. Fields: center of village, name, number of inhabitants, number of houses, etc.
Water	Presence of water sources. Fields: type of water, position, drinkable or not, etc.	Other object	It is possible to define an additional element on the fly with an arbitrary number of attributes.

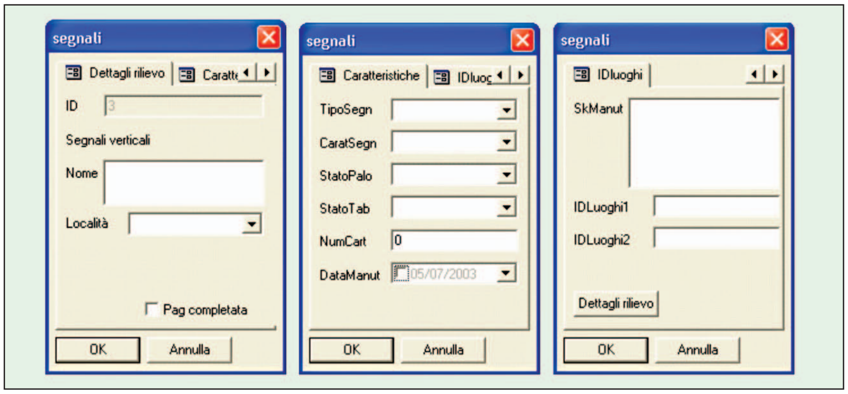

Fig. 3. The signal forms.

Fig. 4. The personalized entity toolbar.

The basic idea was to speed up the data insertion phase, which relies on a palmtop computer and an optical pen, since the environmental conditions could be harsh (e.g., rain, snow, wind) and the terrain difficult. We decided not to consider a traditional element identifier ID, since the primary key was already associated with the topographical information provided by the GPS (a point, or a set of GPS points). We were hoping to provide information with position coordinates, e.g., what villages have lodges with a shower in a 3 km neighborhood of the given GPS point? Or, show the tracks ending in a village (or a GPS point) distant from my GPS position less than 1 km.

Using GPS territorial information, we resolved all problems associated with typing errors and uniqueness. An effective query is when we ask for the mountain above 8600 m whose latitude and longitude are within a 15 km radius from the Pyramid lab point (or the highest mountain in the area). An ineffective query, and prone to data entry errors, is asking for the top of the world mountain, Everest, Sagarmatha, or Qomolangma. Once the relational database was designed, the next step was to select and personalize the software application on the palmtop to create tables, insert fields and constraints, and define the default values in the GIS.

Several applications are available today that can be identified as two families according to the implemented HW/software/operational philosophy. The first one is an "all in one" solution where the GPS receiver, its antenna, and the data processing and storage units are embedded in the same system. De facto, the system is a palmtop that integrates GPS abilities. It is also possible to connect an external antenna to improve the quality of the signal; in some cases the antenna is within a hat with a wire connecting antenna and palmtop. Such devices are quite effective in all operations involved with GPS data acquisition and processing and, as a consequence, are also particularly useful in route surveys. These systems are robust, easy to use, and have good quality hardware and software, but they require costly application software and not all devices support the Windows CE® operating system, which would allow the user a large set of software applications. In general, the "all-in-one" systems are more suitable to sophisticated applications that require real-time, differential corrections.

The second design philosophy is based on a clear separation of the GPS device and its antenna from the PDA processing and storing. It can be easily changed and updated. Examples of this kind of approach are the receivers Leica GS5, Trimble GPS Pathfinder Pocket, and Topcon GMS-100. This type of system supports simple upgrades compared to the "all-in-one" systems, since we can easily change the PDA and update the software and keep the same GPS receiver.

We found that a helpful feature in route surveying was a visible map of the area, even if the precision is not very high. The Trimble Geo XT® palmtop system [9] with ArcPAD® [13] allowed easy integration of information required by the GIS and access to maps and data coming from the GPS unit in real time. Data was inserted with personalized forms, developed with Visual Basic scripts, which eased the data entry phase and provided default values.

Figure 3 shows an example of three subforms for a signal element. The subforms are labeled "survey details" (dettagli rilievo), "characteristics" (caratteristiche), and "locality identifier" (ID luoghi). The first survey subform contains detailed information about vertical signals, by associating the name of the signal (nome) and locality (località); the second subform requires information regarding the type of signal (Tiposegn), characteristic of the signal (CaratSegn), the state of the pole (StatoPalo), an identifier, and the maintenance data (DataManut). The completed page check box (Pag completata) says that the present information is completed and does not need to be reedited at the end of the survey campaign for inserting missing fields (a list of entities to be completed is automatically generated in the postprocessing phase).

In addition to the personalization of the forms, we also worked on ArcPAD by developing controls and toolbars specific to our survey application. We also developed a script for loading the map and all GIS tables directly when loading ArcPAD for execution. An example of a toolbar is given in Figure 4. The selected icon shows a pop-up menu of the elements presented in Table 1.

Development of toolbars and a control mechanism ease the acquisition campaign and allow the user to speed up the

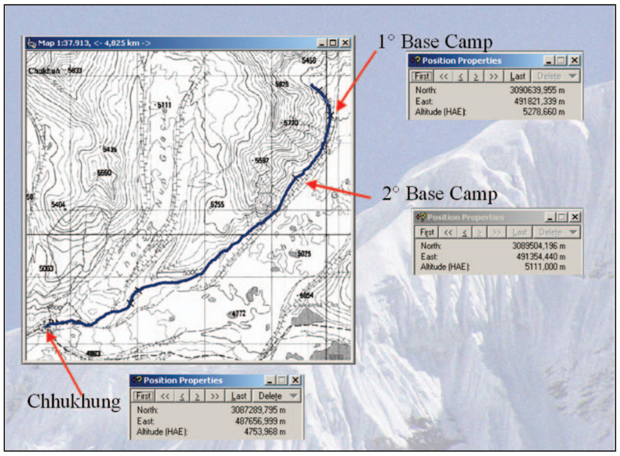

Fig. 5. A surveyed track (Chhukhung-Base camps of Mt. Lhotse).

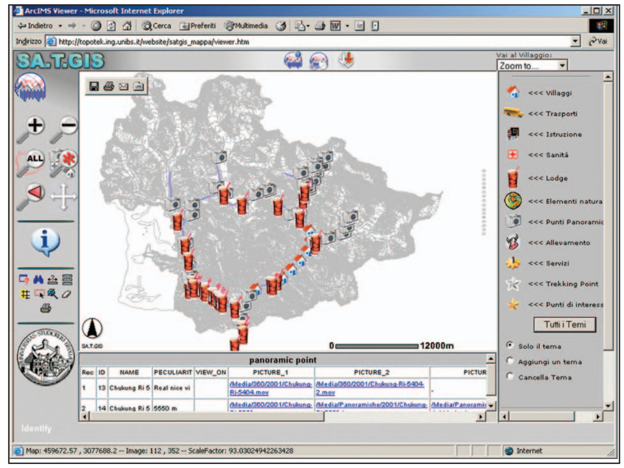

Fig. 6. A first view of the developed Web_GIS.

retrieval phase, hence providing an effective gain in extreme environments.

Steps in Surveying a Route

An example of how all elements can be grouped together is a case where we have to survey a Y-shaped route containing a village at the end of the upper left wing and a spring in the lower segment. We start by synchronizing the acquisition frequency with that of the permanent station in the area (for subsequent differential correction), loading the map, and defining a route entity, e.g., of name track1. We fill the fields of the route entity. The GPS provides topographical data that, retrieved by the software, are stored in the database. We encounter the spring; the route track1 is closed, and we open a water entity. Data are filled in, then the entity is closed; route track1 is resumed. Likewise, we find a signal at the Y cross indicating the end-point directions. We close track1 and create and fill a signal entity. We resume track1 and reach the end of the left wing of the Y-shaped route. We create a locality entity for the village. The next day, we reach the upper right point of the route and we create a route entity of name track2. We move down along the Y and we stop the data retrieval at the intersection points. During the acquisition campaign, we have also retrieved pictures and videos and linked them into the databases with a logic name (label). The postprocessing phase will require the correction data files coming from the permanent station. The program must filter the data and then interpolate to generate a unique route. Multimedia information will then be linked. An example of a retrieved route loaded onto the map is given in Figure 5.

GIS and WEB-GIS Design

The acquisition campaign and the postprocessing activity are the first steps towards the realization of the GIS, allowing the users and the environment monitoring team to carry out queries involving the environment. Of particular interest is publishing the data on a Web_GIS, i.e., a GIS accessed through the Internet, such as the prototypal one we developed for the Mt. Everest National Park (and whose initial framework is visible at the University of Brescia Web site: http://topotek.ing.unibs.it/). We considered the traditional GIS structure in which the user can query the database in a friendly and effective way, as well as zooming into the maps. The zooming feature is dynamic and visualizes the objects stored in the database associated with the selected area. In Web_GIS applications, topographical information is associated with territorial ones, hence inducing spatial relationships among terrestrial objects (e.g., closeness, continuity, and intersection). This characteristic is different from sensitive maps. Relational queries can exploit territorial relationships once formalized by means of SQL or SQL-like constructs.

We considered a three-tier application: a Linux firewall and a Web server, an NT server, and workstation (map server, database). The running application has been optimized and the data updating procedures made as automatic as possible. This is a critical aspect in all Web-based applications, both to speed up the site maintenance and data upgrade, and to remove errors associated with the data entry phase.

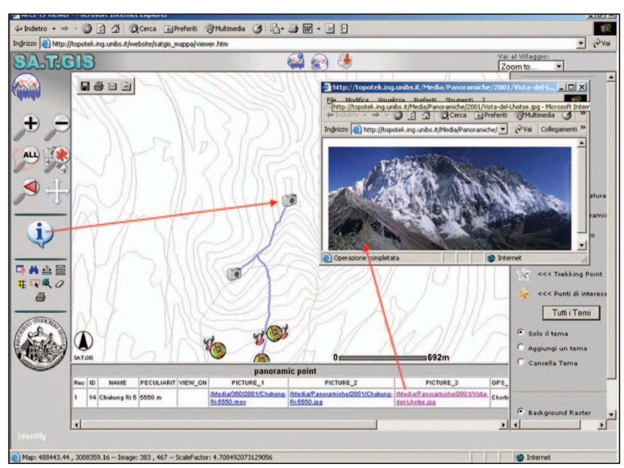

Fig. 7. Zooming and querying the Web_GIS .

An example of the Web_GIS, SA.T.GIS is given in Figure 6.

Different geographical or anthropological objects extracted from the Table 1 elements have been associated with icons to ease and make intuitive the access to the Web_GIS (for instance, the cow icons of Figure 7 represent yak farms, while camera ones represent panoramic points). SA.T.GIS provides a set of graphical tools so that the query can be carried out in a very intuitive way; extensions envisaging SQL queries are under study.

Figure 7 provides a zoomed view of the map; the information button applied to the central camera icon provides the relational outcome in the lower part of the image: we are in a panoramic point, whose name is Chukung Ri (5,500 m); we have a set of pictures and information: selection of picture_3 enables a beautiful view of the Everest-Lhotse-Lhotse Shar range.

Conclusion and Future Work

The development of a GIS, publishable and accessible through the Internet, poses measurements problems that are not trivial. The compromise among GPS precision, application accuracy, database design, and costs all require solution; then the designer has to carefully plan the acquisition campaign in the lab before any field activity takes place. This requires definition of the entities to be measured with the GPS-enabled palmtop, as well as scheduling and planning the route survey activity on the basis of satellite visibility. Harsh and severe environments and inadequate power supply for the instrumentation are further hindrances. The actual Web_GIS is a prototype showing the feasibility of the activity; we are investigating extensions to integrate SQL queries and open source platforms to keep the cost under control in countries such as Nepal.

We strongly feel that, in the future, we should be able to overcome all limits related to the satellite visibility by moving to a third frequency and integrating data coming from the GLONASS constellation; around 2008, GALILEO should also become active. This large availability in satellites will surely push research towards new and more accurate positioning algorithms based both on code and phase.

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