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Geo-data acquisition through mobile GIS and digital video: an urban disaster management perspective☆

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Abstract

For the management of urban disaster risk, periodic updating of building and lifeline geo- databases is crucial, particularly in developing countries where urbanisation rates are very high. However, collecting information on the characteristics of buildings and lifelines through full ground surveys can be very costly and time-consuming. Research into more cost-effective surveying alternatives should be therefore high on the agenda.

This paper explores the use of an off-the-shelf low-cost and rapid method of data collection for the development of a building inventory based on the combination of remote sensing (RS), global positioning systems (GPS), digital video (DV) and geographic information systems (GIS). The method developed consists of a sequence of stages, the first stage involves the use of RS and GIS for stratification and mission planning purposes. The second stage consists of using GPS and DV for the creation of spatially referenced images and the third stage involves the use of GIS for display and analysis. The methodology developed was tested on the Costa Rican city of Cartago and its advantages and disadvantages identified.

Keywords: Disaster management; Building attributes; Mobile GIS; Remote sensing; Digital video

1. Software availability

Two different types of software packages were tested. One group was tested with the objective of analysing the capacity to import points internally tracked by the GPS and export them into a GIS. The second group was tested with the objective of analysing the capture of still images from digital video. ArcPad proved the most adequate software for handling GPS data; it is user-friendly and it allows to virtually skip several steps since it constitutes a mini or light version of ArcView that has the ability to link real-time to a GPS unit. Moreover, it can be customised using the ArcPad Application Builder. For the automated production of still images based on video, the Scenalyzer Live software was the only one amongst those tested that was able to automatically save a sequence of images using the time-code as their filename.

ArcPad (currently v. 6.01)
Developer: ESRI Inc
Website: http://www.esri.com/software/arcpad/index.html
Hardware required: 32 MB (minimum) 64 MB (recommended)
Software required: Windows CE 2.11, 2.12 or 3.0 (pocket PC); Windows 95/98/2000, Windows NT4.0, Windows XP
Program size: 28.3 Mb
Availability: can be purchased and downloaded over the internet
Cost: US$ 495 (US price)

ScenalyzerLive (currently v. 20020509)
Developer: Andreas Winter
Website: http://www.scenalyzer.com
Contact address: Ungargasse 71, A-1030 Vienna, Austria

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Hardware required: A video capture card that uses DV compression (e.g. OHCI 1394-cards, RT2000, DV200/300/500 or PRO-One)
Software required: Windows 98/ME/2000 and Directx8
Program size: 1.2 MB
Availability: can be purchased and downloaded over the internet
Cost: US$ 33 (EU citizens pay US$ 36.60).

2. Introduction

Cities are particularly vulnerable to natural hazards because of higher densities of population, property and economic activities but also due to the interplay that exists between people, buildings, and technological systems. According to United Nations (United Nations Centre for Human Settlements, 1996), in 1975 approximately 38% of the world's population lived in urban areas and they estimate that this figure will reach 60% by the year 2025. United Nations has made a call to put the issue of urban disaster management high on national agendas due to this steady increase in urbanisation.

Smith (1996), amongst many authors, considers that there is an increasing paradox between the outstanding achievements in science and medicine, which make life safer and healthier and the continuing death and destruction associated with natural hazards. Two issues that help explain this disparity are the perception of natural hazards as 'Acts of God' and the multi-disciplinary nature of disaster management. Whenever natural hazards are thought to be of divine nature, the willingness to adopt prevention and reduction measures is limited. The multi-disciplinary nature of disaster management implies that the process is slow and not problem-free, as it requires a great deal of co-ordination. Urbanisation also plays an important role as human beings are both victims and contributors (in the case of human-induced natural hazards and technological hazards). Human-induced hazards include all those modifications to the environment which are made by human beings and that by upsetting the natural balance, trigger disasters. In the case of urban areas, typical examples include:

- Slope modification through terracing for the purpose of urbanisation (mainly for residential development). This causes destabilisation of the ground and leads to landslides.
- Pavement of green areas which prevents rain from draining on-site. This causes an increase in the volume of water in rivers and lakes and leads to floods.

Amongst other dramatic damages, disasters pose a threat to sustainable development as they have the potential to destroy decades of investment and effort, and cause the deviation of resources intended for primary tasks such as education, health and infrastructure. There are numerous examples worldwide where major modifications were made to development programmes due to the deviation of resources necessary to cope with a natural disaster. For example, in Costa Rica the 1994 National Population and Housing Census was postponed for 15 years as funds were deviated to respond to Hurricane Caesar.

The scope of disaster management can be best understood by means of a tri-dimensional matrix (see Fig. 1) describing the three types of elements involved (levels of government, management phase, implementation measure) and the resulting range of possible implementation strategies (Masser and Montoya, 2000). Implementation strategies consist of structural measures which involve the modification of the environment (e.g. restrengthening/demolition of buildings, construction of dykes/drainage) while non-structural measures involve activities such as co-ordination and communication (e.g. emergency drills, warning systems). Disaster management involves a cycle which should consist of an organised effort to mitigate against, prepare for, respond to, and recover from a disaster (Federal Emergency Management Agency, National Emergency Training Center, 1998). The following definitions describe each of the phases of this cycle:

- Mitigation relates to pre-activities that actually eliminate or reduce the chance or the effects of a disaster. Mitigation activities involve the assessment of risk and reducing the potential effects of disasters as well as post-disaster activities to reduce the potential damage of future disasters.
- Preparedness consists of planning how to respond in case an emergency or disaster occurs and working to increase resources available to respond effectively.
- Response refers to activities that occur during and immediately following a disaster. They are designed to provide emergency assistance to victims of the event and reduce the likelihood of secondary damage.
- Recovery constitutes the final phase of the disaster

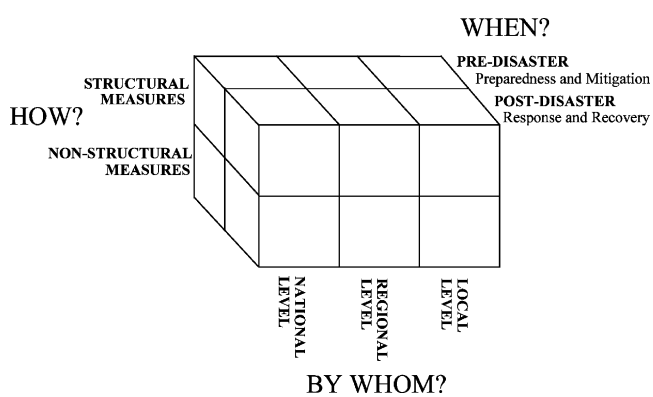

Fig. 1. Scope of disaster management.

management cycle. Recovery continues until all systems return to normal or near normal.

3. Geo-information for strategy formulation

Informed decisions are a prerequisite for the formulation of successful mitigation, response, preparedness and recovery strategies. To a large extent, however, successful strategies depend on the availability of accurate information presented in an appropriate and timely manner. Information is also important as it increases the transparency and accountability of the decision-making process and it can therefore contribute to good governance. Initiatives such as the global disaster information network (GDIN) have recently been launched to increase awareness of the importance and the value of disaster-related information 'the right information, in the right format, to the right person, in time to make the right decision' (Global Disaster Information Network, 2002).

Application of technology and science to solving hazard-related problems is based on definitions of severity of the problem and need. These definitions, in turn, are dependent on adequate baseline data. However, such data are usually incomplete at best, if records exist at all (Tobin and Montz, 1997). Moreover, it is not only a question of supply, but also of supply in an adequate form and level of integration. Supplying decision-makers with raw geographic information is a very common practice which has generally yielded negative results. Decision-makers are often provided with maps of hazard zonation, population density, urban growth and land-use, on which to base their decisions. However, as little attempt had been made to integrate the data sets, the implications of the information are not immediately visible, causing confusion and in the worst cases, the formulation of inadequate policies. Simply stated, decision makers require information that allows them to establish the cost–benefit implications of the various strategies that can be implemented. Consequently, loss forecasts are essential as they establish the amount of damage that can be avoided by investing a given amount of financial resources. The production of loss forecasts requires additional datasets, as well as further steps towards data integration.

One of the biggest challenges in the field of loss forecasting relates to bridging the information gap that exists concerning building inventories. Although cadastral databases are usually available either in analogue or digital format, they tend to be designed for land registration and fiscal purposes only. For this reason, the classification of building types contained in these databases is often useless for natural hazard loss estimation. In the medium- or long-term, cadastral databases (as well as censuses) can be transformed into multifunctional databases and there are already a few governments that are moving in this direction. For example, the new law that governs the Costa Rican cadastre states the need to transform the cadastre into a multifunctional one that serves a wide range of purposes such as improved revenue collection, tourism planning, natural resource protection, agrarian reform, land-use planning, urban and infrastructural planning. This would allow a variety of applications to be developed from the same dataset and this is obviously important from the point of view of the cost–benefit of data production. In the short term, however, low-cost and rapid alternatives must be identified so that disaster management can be carried out. This is obviously important in developing countries where financial resources are scarce.

4. GIS and remote sensing

Problems associated with hazard identification, risk assessment, and developing mitigation solutions are inherently spatial in nature. New and emerging technologies make it feasible to automate labour-intensive tasks and to change dramatically the way emergency management is conducted (Federal Emergency Management Agency, 1997). Important emerging technologies include mobile geographic information systems (Mobile GIS), high-resolution digital remote sensing (RS) imagery, global positioning systems (GPS), computer models, databases and indices as well as digital communication technologies.

Geographic information systems (GIS) have considerable potential for improving urban disaster management since they offer more efficiency and speed in the input, management, manipulation, analysis and output of data/information, but also because of the value of better decisions. GIS works effectively in all four phases of the disaster management cycle. Whether analysing consequences, projecting and predicting, disseminating information, allocating personnel, equipment and resources, getting from A to B, or picking up the pieces in ways that help rather than hinder stricken families, businesses and regions (Amdahl, 2001). It is important to keep in mind that GIS does not come without problems. One important aspect is the acceptance of the tool by decision-makers as it somewhat implies decentralisation of functions and a more bottom-up approach to data management. Another problem relates to the cost–benefit of GIS itself as there is the possibility that the financial investment required to implement a GIS might be lower than the value of better decisions. Zeiler (1999) for example, argues that a GIS is not just a software package, but rather a combination of skilled people, spatial and descriptive data, analytic methods, hardware and software. His definition is useful in the sense that it highlights the various elements that must be taken into account for assessing the costs involved in a GIS project.

In terms of remote sensing (RS), Horn (2001) considers that a recent significant development concerns the new type of digital large-format aerial cameras even though their resolution is still somewhat lower than that achieved by film-based systems. Since the resulting data are already in digital format (and thus directly integratable in a GIS), these sensors are very useful in the disaster response phase which requires rapid assessments to allow rapid and effective action by emergency relief personnel.

Until recently, due to its low resolution, satellite imagery did not play a major role in urban disaster management. Apart from the mapping of urban and vegetation landcover, its main use was in the production of flood and landslide hazard zonations by earth and atmospheric scientists. With the launching of IKONOS 1 in 1999 and QUICKBIRD in 2001, however, an increase is expected in the number of users of satellite imagery amongst the urban geo-information community (e.g. local governments, utility companies). IKONOS offers resolutions of 1 m panchromatic and 4 m multispectral. The cost of a pan-sharpened image (outside North America) is approximately 30 US$ per square kilometre (Space Imaging, 2002). QUICKBIRD offers resolutions of 0.6 m panchromatic and 2.44 m multispectral. The cost of a pan-sharpened image ranges between 40 and 50 US$ per square kilometre (Digital Globe, 2002). In both cases, extra charges apply for tasking orders (non-archive) and for orders below a minimum size. Both sensors offer a revisit time of less than 4 days which means that weather permitting, the images can be obtained very quickly.

Due to their high positional accuracy and ability to log ‘real-time’ to a computer, global positioning systems (GPS) have great potential in disaster management. Individual waypoints or tracks recorded by the GPS can nowadays be displayed real-time in a GIS software package (e.g. ESRI’s ArcPad, for more details refers to the Software availability section) which implies that the data input phase is virtually eliminated. Moreover, with the introduction of palm-top computer systems, it is now possible to capture, manipulate, analyse and visualise data in the field. Mobile GIS enables the distribution of processing capabilities and real-time support for data gathering in the field. Wireless connections between measuring instruments, rugged field computers and a network server enable data transfer and promise increasing interoperability (Sumrada, 2002). These characteristics are particularly relevant during the disaster response phase of the disaster cycle.

Digital video (DV) constitutes a very important method for data collection. It uses charge coupled devices (CCDs) to capture the moving images, but it stores the images in a high-quality, endlessly reproducible, easily edited, digital format.

5. Methodology for ground data capture

During the last decade, there has been a trend towards a decrease in the amount of research into field data collection. In the developing world, however, one of the biggest bottlenecks relates to the availability of spatial and attribute data. This problem is sometimes caused by the lack of a geo-spatial data infrastructure policy, but also by the high cost of conventional data collection and data processing methods. There is no doubt that remotely sensed imagery is useful in raising the feasibility of building inventory generation, although in cases where detailed information is needed, it must be supplemented by ground observations. Ground observations can be time-consuming and can require surveyors in numbers which might not always be available. Consequently, especially in developing countries, research into rapid and economically feasible data collection alternatives for the generation of middle- and high-resolution datasets is still needed.

The methodology hereby discussed consists of three main phases: initial classification of the building stock, mission planning and data capture. The initial classification of the building stock is carried out based on emergency response considerations (see Fig. 2). Buildings essential for rescue and relief operations (e.g. Red Cross, police station, fire-brigade, hospitals) are classified as ‘essential facility, 1st order’. Buildings that have potential as temporary accommodation for those left homeless (e.g. community hall, covered sports field, churches) are classified as ‘essential facility, 2nd order’. All remaining buildings are classified as ‘regular facilities’. This classification allows the application of different survey methods to each group, thus maximising existing financial and human resources. This prioritisation of buildings implies that for example, a hospital is surveyed extensively and possibly even through mathematical-modelling of its structural response, a community hall is surveyed extensively (both inside and outside the building), while a house is surveyed through rapid sidewalk screening techniques. This paper discusses a method of data capture that applies to ‘regular facilities’.

The mission planning phase is carried out with the help of GIS and RS and includes the identification of homogeneous areas and the identification of the optimal route (see Figs. 3 and 4). A great degree of homogeneity exists in urban areas and RS is the ideal method for rapidly identifying homogeneously-built areas (e.g. housing estates, industrial estates). The remotely sensed images required should be either at least medium scale aerial photography (e.g. 1:20 000) or high resolution satellite imagery (e.g. IKONOS, QUICKBIRD). The identification of these areas permits the reduction of the data capture phase, as the characteristics of the buildings within these areas can be inferred from the survey of a

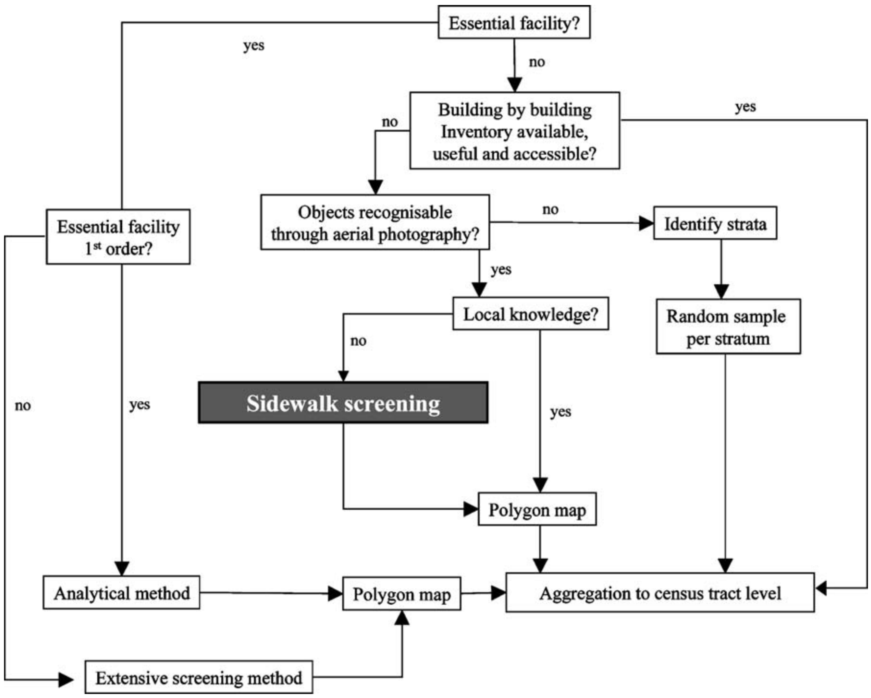

Fig. 2. Flow-chart of building stock classification.

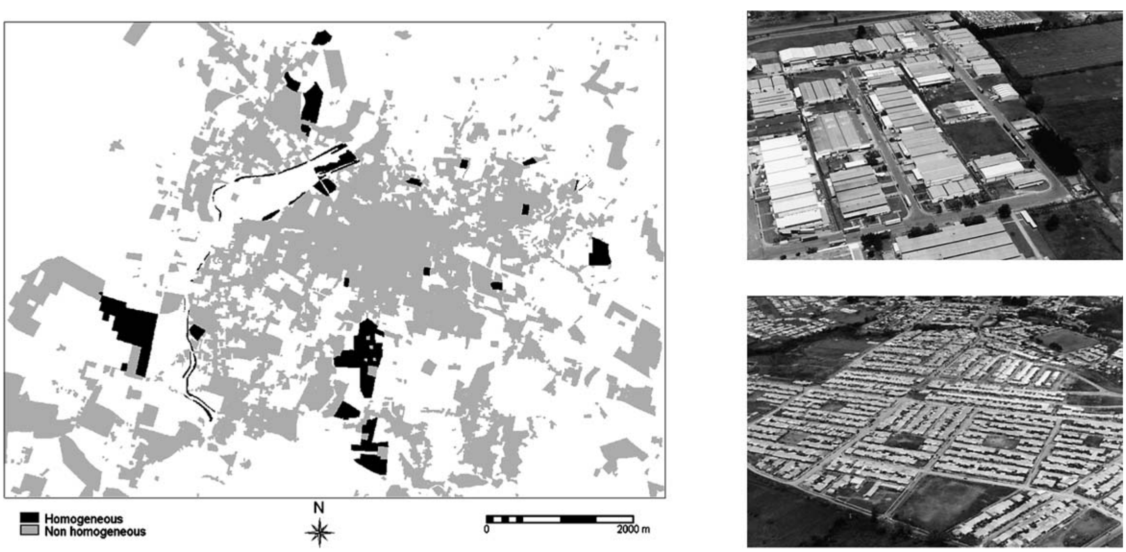

Fig. 3. Mapping of homogeneous areas using remotely sensed images.

single unit per homogenous area (refer to Fig. 4). Once the areas in need of surveying have been identified, GIS is used to identify the optimal route that the moving vehicle must follow to record the video footage.

The method for urban data capture involves the combination of a GPS and digital video (DV) to produce in a first stage, an image of a building's façade of known location. In a second stage, the image is interpreted to extract the required attributes. In the case of seismic building vulnerability, for example, relevant attributes that can be extracted from the image include building material, number of stories, level of maintenance and age of construction. In a third stage, a GIS is used to store and process the data to produce attribute maps. The last stage involves using GIS to integrate these attribute maps with other data layers to produce inputs for urban strategy formulation, such as disaster forecasts. In addition, if this data capture is carried out periodically and for an entire urban area, it cannot only provide multitemporal information related to building vulnerability, but also to increase the efficiency in processes such as revenue collection, law enforcement and conflict resolution.

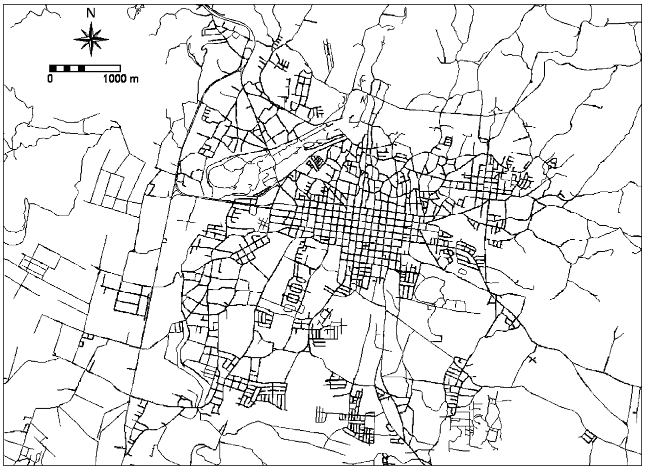

Fig. 4. Use of GIS for route planning for video data capture phase.

The key to an off-the-shelf option for linking up the GPS and the DV entails the synchronisation of the internal clock of the digital video to that of the GPS. This simple synchronisation permits the establishment of the location of the video footage. This video footage offers several advantages:

- It is multifunctional since the classification and other interpretation issues can be decided a posteriori.
- The recording process is not too time-consuming as it can be carried out from a moving vehicle.
- The recording process does not require any technical expertise.
- The costs involved are low compared to conventional sidewalk screening of buildings.

The coverage of a still video image depends on two factors: the angular view of the camera system and its distance to the building's façade. Careful consideration should be given to this issue as in cases were the road is narrow, the coverage will be limited as the view angle in DV cameras tends not to be very wide. Typically, at their widest viewing angle they compare to a standard 50-mm lens of a conventional 35-mm photographic camera. However, by using a screw-in wide-angle adaptor, a view similar to that of a 28-mm lens is achieved. In the case of the Costa Rican city of Cartago, where this methodology was tested, for example, without a wide-angle adapter attached to the DV camera's lens, only the ground floor of buildings would be recorded since the distance from camera to the building's façade can be as little as 4 m to the window of a car driving past.

Most budget GPS units are able to internally record a 'track log' (e.g. coordinates, date, time, altitude, leg length, speed, heading) at intervals typically as little as 1 s. The leg length is particularly important as it indicates the distance between trackpoints. Depending on the minimum plot width allowed in a particular city, one could identify the maximum speed at which the vehicle should circulate in order to have at least one trackpoint per parcel. Another issue that is important to consider is the scheduling of missions mainly due to three reasons:

1. Large vehicles parked along the sidewalk might obstruct visibility. Typical delivery hours should be identified and avoided;
2. Rain drops on the lens, as well as sun glare can hamper the quality of the video image; and
3. Peak traffic hours can cause the recording time to increase considerably.

In terms of the handling of the video footage, DV cameras nowadays offer single mode (video only) or dual mode (video plus digital stills). Even when only single mode cameras are available, images (e.g. JPG, TIF) can be obtained from the footage by means of digital still capturing software packages. Moreover, another even lower-cost alternative is possible by using digital still cameras, provided that the camera offers continuous shooting mode to capture an image (e.g. JPG, TIF) at a sufficiently short time-interval and that the memory card is large enough. In this way, every trackpoint can have an associated image.

A DV capture card was used to capture the 25 fps (frames per second) images, which were later automatically saved as 1 fps images. The software ScenalyzerLive (for details, refer to the section Software availability) allowed to capture the individual still images and automatically provided a filename (refer to Figs. 5 and 6) composed of the DV's time code plus a sequential number (e.g. scene'20010921 08.08.41.jpg). Next, these filenames were modified to account for the particular device used as a 'left' and 'right' camera were used simultaneously (e.g. left'20010921 08.08.41.jpg).

The procedure for obtaining a database that can be used in a GIS environment varies depending on the software used. In the case of Garmin's MapSource, the data have to be first exported into tab-delimited text format, it can be next stripped down from any unwanted characters and finally saved as .DBF since this format is compatible with most GIS software (e.g. ArcView, ILWIS). In other cases such as in ESRI's ArcPad, it is more straightforward as it can automatically generate a file in .DBF format, as well as saving point files in the widely used SHP format. The database can be further purged by using either the leg length or the speed columns to delete all unwanted points resulting from the vehicle being stationary at traffic lights. Since there are left and right window images, a point offset procedure was applied according to the average road/sidewalk width. The still images can be automatically displayed alongside the map by the GIS software through hyperlinking.

Within the GIS, consideration should be given to pro-

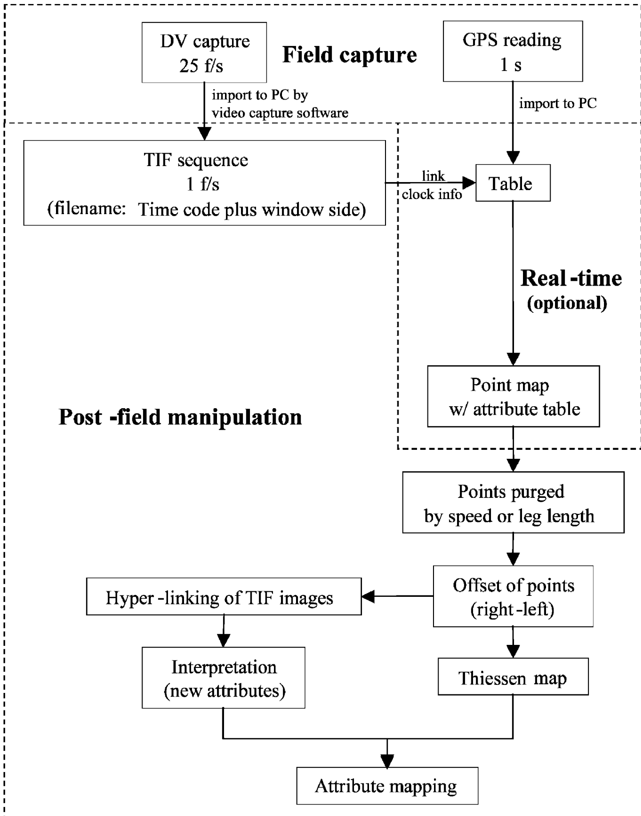

Fig. 5. Flow chart (adapted from Montoya, 2002).

jection conversion to avoid shifts between the GPS trackpoints, any other existing GIS data layers. From the Cartago research, the data from the GPS was initially captured in WGS84. For GIS visualisation and processing purposes, a single coordinate system (and ellipsoid datum) must be used for all the maps. In cases when the GPS trackpoints use a different projection from that of existing data layers, the GIS software package is used to perform the necessary conversions. In this case, WGS84 data were imported into the ILWIS software and then converted into NAD27-CentralAmerica.

The resulting database is next expanded to link the video image file name to each trackpoint on the basis of the clock information. Amongst their many functionalities, most GIS software packages are able to use the *xy* columns of the table to produce a point map, which opens a wide range of possibilities of computer-based spatial querying and processing in vector. Furthermore, depending on the operations available on the software being used, point data can be converted into surface data by interpolating procedures, allowing a number of raster analysis tools to be used.

Most GPS device manufacturers (e.g. Garmin, 2000) agree that one can expect that the data produced by entry-level GPS units without Differential GPS or Wide Area Augmentation System, will have an inherent accuracy in the range of 6–12 m as long as Selective Availability is turned off. Consequently, it may be necessary to avoid area objects (e.g. buildings, parcels) from being represented individually. In this case aggregation of area objects to a unit of lower spatial resolution is necessary before the results are presented to decision-makers. Spatial database generalisation should also be considered when there is uncertainty about the quality of the image interpretation. Such interpretation is carried out after the recording has been made and therefore depending not only on the financial resources, but also on the manpower available, there is the option of interpreting all the images or of interpreting a given number of random or stratified random locations.

Fig. 6. Captured still images from digital video.

6. Conclusions

The city of Cartago provided an interesting case study; it represents a typical example of a medium-sized (e.g. 150 000 inhabitants) Costa Rican city that is located in a highly hazard-prone area and which has been devastated by earthquakes and lahars (mudflows of volcanic origin) on a number of occasions. The municipal government is severely financially constrained and there are very limited data available for the purpose of building loss forecasting of natural disasters. The method developed consisting of digital video, global positioning systems and geographic information systems was tested in the city of Cartago.

The method developed proved a valuable alternative for bridging the gap that exists in many developing countries in the field of sustainable urban inventory generation. It proved useful as it can be used as a generic data collection method, allowing the different departments of a municipality to interpret the spatially referenced images and extract attributes which are useful for particular applications. From a cost–benefit point of view, the method is a sensible alternative as it not only cuts down on the time necessary for the data collection process, but the equipment involved is widely available and furthermore, in many countries this equipment can be hired from commercial companies at affordable prices.

Mobile GIS is a growing technology which makes use of existing off-the-shelf techniques and equipment, and mainly focuses on the linking of various existing resources and data rather than in the development of new stand-alone devices. It therefore constitutes off-the-shelf technology. The development of palm-top devices opens the possibility of increasing the accuracy and speed of the data collection process. Mobile GIS highlights the fact that there is still scope for improvement in urban field data collection, a field which should be not overlooked.

References

Amdahl, G., 2001. Disaster Response: GIS for Safety. Redlands, ESRI.
Digital Globe, 2002. QuickBird Imagery Products Standard Pricing.
Federal Emergency Management Agency, 1997. Multi-Hazard Identification and Risk Assessment: A Cornerstone of the National Mitigation Strategy. Washington.
Federal Emergency Management Agency, National Emergency Training Center, 1998. Introduction to Mitigation Independent Study Course. Federal Emergency Management Agency, Maryland.
Garmin, 2000. GPS for Beginners. Garmin Corporation, Kansas.
Global Disaster Information Network, 2002. International Global Disaster Information Network, Global Disaster Information Network.
Horn, J.A., 2001. Aerial Cameras. In: Janssen, L.L.F. (Ed.), Principles of Remote Sensing. ITC, Enschede.
Masser, I., Montoya, L., 2000. GIS in urban disaster planning. City Development Strategies, 49–52.
Montoya, L., 2002. Urban Disaster Management: A Case Study of Earthquake Risk in Cartago, Costa Rica. ITC, Enschede.
Smith, K., 1996. Environmental Hazards: Assessing Risk and Reducing Disaster. London, Routledge.
Space Imaging, 2002. Space Imaging Commercial Product Pricing Guide.
Sumrada, R., 2002. The shift form stand-alone to web and mobile GIS solutions: Towards distributed application of GIS technology. GIM International 16, 40–43.
Tobin, G.A., Montz, B.E., 1997. Natural Hazards: Explanation and Integration. New York, The Guilford Press.
United Nations Centre for Human Settlements, 1996. An Urbanizing World: Global Report on Human Settlements 1996. Oxford University Press, Oxford.
Zeiler, M., 1999. Modelling our World: The Esri Guide to Geodatabase Design. Environmental Systems Research Institute, Inc, Redlands.