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Leveraging of remote sensing and GIS on mapping in urban and regional planning applications

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Abstract. While remote sensing applications represent a major though still underused source of urban data, the proposed combination between remote sensing and Geo-information System (GIS*)* in urban and regional planning is not fully explored. In order to measure changes in land use, the need of platform in monitoring, recording, and predicting the changes is necessary for planners and developers. In advance technology of mapping process, remote sensing and GIS as tools for urban planning are already recognised. But, due to lack of implementation and awareness about the benefits of these tools, these terms look unusual. Therefore, this paper reviews the history of remote sensing and GIS in urban applications, technical skills and the challenges, and future development of remote sensing and GIS especially for urban development particularly in developing countries.

1. Introduction

In urban planning, mapping plays an important role in the development of the city. An urbanised, well-developed city has industrial, commercial, and residential areas evolved from time to time. [1] stated that urban and regional planning is the art and science of ordering the use of land and the character and sitting of buildings and communication routes so as to secure the maximum practicable degree of economy, convenience, and beauty. Nowadays, remote sensing and Geo-information System (GIS) have been introduced as an initiative to map the urban area. According to [2], urban remote sensing presents renewed opportunities for analysis of the city as a system. Urban planning is essential especially in the developing country to ensure that the city is well-planned and to preserve the sustainability of the environment. Urban planning spatial database analysis is a subset of analytic method in which the objects are repositioned within it [3]. This analysis gives detailed information related to cadastral plan, such as area, perimeter, and lot numbering [5]. However, urban mapping is quite complicated when dealing with remote sensing imagery data sources because of the atmospheric disturbance in high altitude that affects the spectral response of an object such as rooftop. In addition, the rooftop has different type of materials and colours, so the spectral response of the object varies too [6]. Thus, to overcome the problem of mixing pixels, object-oriented classification is applied. Pixels are combined and represent one object. Therefore, this paper reviews the leveraging of remote sensing and GIS for urban mapping in the context of history, techniques, and challenges, as well as the future of remote sensing and GIS in urban mapping.

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2. History of remote sensing and GIS in urban mapping

GIS was originally developed as an environment technology. According to [7], the term "Geographic Information System" (GIS) started in early 1960s in the project of mapping Canada's natural resource. A scholar in civil engineering and planning, Prof. Edgar Harwood from the University of Washington worked on some of the earliest computer mapping software. The finding stated that the Urban and Regional Information System Association has conducted high numbers of influenced conferences and short courses [7-8]. In the early 1990s, GIS began to expand into business market as it became available in personal computer. Since then, it had become more valuable for a broader spectrum of business users [9] and GIS in urban planning trends was identified mostly after that [7][10][11]. According to [12-14][16], GIS is also used in specific planning in non-American countries. Land use is one of the most important criteria in urban development, by using GIS, land uses are being recorded, mapped, monitored, and changes has been updated, planned, and predicted [15-16].

The first Earth observation data used in urban system application were carried out in a map scale of 1:100 000 (80 to 30 m spatial resolution) on the city of North America [17-18]. Later on, the higher spatial resolution data were available with 10m to 20 m enable mapping with more detail with the scale 1:100 000 to 1:25 000 for instance to assess the compact urban area on European cities [4][19]. The higher spatial resolution is capable to provide a notable contribution on rural-to-urban land conversion [18-20], including in estimating housing and population density [21-24].

In 1990s, the use of GIS in town planning in Malaysia started, the same year in which GIS had become popular all over the world. The application of GIS is expected to increase the rationality in generating better planning decision. The success of GIS implementation in urban planning depends on complete and updated data. According to Act 172: Town Planning Act, in urban planning, there are three major levels that encompass the development plans namely National Physical Plan (Federal Level), Structure Plan (State Level), Local Plan, and Special Area Plan (Local Level). In Malaysia, there are certain areas that have been tested using GIS technology for urban planning, such as Kuala Lumpur City Council, City Development Management System and Safe City Monitoring System. GIS applications are not only used in planning process, but they are also used for monitoring purposes, thus the data in the applications should be as recent as possible. In addition, the remote sensing applications are also being used in order to get the most recent data in the fastest ways.

3. Remote sensing as a platform to urban applications and its challenges

Generally, remote sensing activities include recording, observing, and perceiving (sensing) object or targets far away from that place (remote). By using remote sensing technology, the sensor scans the object on Earth and the output will be represented in digital images that contain digital number and spectral reflectance of the object of interest. Rooftop from brick material, an example of an object of interest, has different digital numbers and reflectance. Digital number, radiance, and reflectance can each be defined in various definitions. Digital number is the value of pixel that describes the image that has not yet been calibrated into physically meaningful units. Radiance is the amount of radiation emitted from an area including radiation from neighbouring surface, cloud, and the target itself. Reflectance is the proportion of the radiation striking a surface to the radiation reflected off of it. Therefore, materials can be identified by reflectance spectra. So, these materials are required to correct an image to reflectance as a primary step. According to [25], the spectral library for urban area acquired from 400–1100 nm is the range from visible band to infrared band. Other than that, urban built-up materials (e.g., roofs and roads) are best identified and separated by wavelength [26-28]. Hyper spectral data can give good results in separation of different materials of rooftops because the bandwidth is specific and the range is very small. Roofs and roads have specific absorption features associated with mineral or material properties that make them up. However, the interaction of atmospheric condition disturbs the reflectance of materials from rooftop, so the spectral reflectance of target does not represent the actual reflectance. In order to overcome these problems, atmospheric correction is crucial to remove the presence of spectral reflectance aerosol. There are many types of atmospheric correction methods such as MOTRAN [29] and 6s [30]. However, in remote sensing, the assumption of flat ground is used to model the signal at ground and sensor level even though in cities with very high spatial resolution, this assumption is no longer valid according to Thomas *et al* [31] because of the complexity introduced by relief. Therefore, it requires a new formalism adapted in this case namely AMARTIS v2 [31].

The interpretation of different urban objects is not only subject to radiometric factor as the spectral reflectance values can correspond to too many objects. Confusing features of extraction can be made. For instance, a tiled roof does not reflect the same way as a concrete low roof or terrace. On the other hand, geometric factor only arises more problems because a similar geometric shape can refer to too many objects. Therefore, geometric and radiometric factors should be combined so that urban structure can be identified more easily [32]. In Puissant and Weber's research, they found that 5 m resolution was adapted to identify wide road of approximately 15 m, while 2.5 m resolution allowed secondary road network to be identified. In order to study urban morphology and to distinguish three main constitutive objects of urban structure, normally resolution that is less than 0.80 m is necessary. If the cases is the houses is urban smaller object less 5 m inside a functional of 0.80 m resolution is necessary. Puissant and Weber also found that automatic extraction feature can be done using lower than 1 m spatial resolution. However, some adjustments still need to be done. Finally, simple visual interpretation remains the most accurate method because human operator can extract the information from very high spatial resolution relatively easily by considering radiometric and geometric factors [33].

4. Future GIS in urban mapping

Remote sensing methods have been widely applied in mapping land surface features in urban areas. Several recent developments in remote sensing have the potential to significantly improve the mapping of urban areas [2]. A new technology of GIS namely hybrid GIS solution combines spatial database and server-based geospatial processing system with a consumer-oriented geospatial visualisation components. The hybrid GIS can support the urban development by creating opportunities for technology communities and planners to embellish the process of plan development and management through modelling. Before this, urban planners are facing a problem with maps that are not geometrically correct and unscaled and they only rely on traditional GIS tools for urban development planning. The evolution of GIS into an enterprise-wide system has led to the identification of potential problems in urban development. Indeed, this technology enables many agencies to respond to those problems efficiently and the results are rapidly shared with the public. These Internet-based mapping platforms are able to create public-facing portal that leverages digital database of land parcel, whereas the land parcel is created by using aerial imagery and satellite as well as surveying with GPS. In the presence of GPS, the location of an area is determined so that better planning for urban growth can be decided and made. With this hybrid GIS, planners can develop 3D city model, terrain for interactive mapping, and Internet-based urban information system featuring aerial view. This powerful tool is capable to view city for example zoning, parcels, building outlines, address, land contour, and slope. It also includes areas prone to flooding as a permit for construction, demolition, and land use changes. The benefits are not just for planning and development purposes but also for sustaining the urban development in order to avoid anthropogenic disaster in the city.

5. Conclusion

Remote sensing and GIS really help the planners to monitor the changes in urban land use. Besides, the invention of high spatial resolution imagery allows the automatic extraction of urban features to be done easily, added with prior knowledge of image interpretation. Hyper spectral imagery is able to distinguish the materials of rooftop because of the sensitivity of the sensor and the range of bandwidth is small and precise. The evolution of future GIS requires a high capacity of processors in the computer, in order to process the data efficiently.

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