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Enhancing environmental sustainability through advanced data acquisition and remote sensing application for coastal monitoring

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Abstract

Advances in coastline monitoring techniques have transformed our understanding of coastal dynamics and morphological changes (Laurel et al 1998). This review examines the evolution and effectiveness of various data acquisition methods, from traditional ground surveys to modern remote sensing technologies. Recent developments highlight the capabilities of remote sensing platforms, particularly Landsat 7 ETM+ imagery, in providing comprehensive coastal monitoring solutions through spectral signature analysis (Goward et al., 2001). The literature demonstrates how different data acquisition techniques offer varying advantages in capturing coastline changes, with remote sensing emerging as a particularly effective tool for large-scale, long-term monitoring. Analysis of available technologies shows marked variations in their applications, from aerial photography's historical significance to modern satellite imagery's broad spatial coverage and high temporal resolution. The review emphasizes the complementary nature of different monitoring approaches, while highlighting the increasing importance of automated digital image processing methods. Existing studies have established remote sensing as a valuable tool for understanding coastline dynamics, though integration with traditional surveying methods remains important for comprehensive coastal monitoring. This paper synthesizes current knowledge of coastline data acquisition techniques, examining their relative strengths and limitations while identifying areas where technological advancement may further improve coastal monitoring capabilities.

Keywords: Environmental Sustainability; Data Acquisition Techniques; Remote Sensing; Coastline Monitoring; Technological Advancement

1. Introduction

Remote sensing has emerged as a tool in monitoring and analyzing coastline dynamics, offering capabilities for understanding coastal changes across temporal and spatial scales (Malthus et al 2003). The ability to acquire, process, and analyze coastline data through various remote sensing techniques has revolutionized our approach to coastal studies and management.

Historically, coastline monitoring relied heavily on ground-based surveys and manual observations, which were both time-consuming and limited in spatial coverage (Appeaning et al 2010). The advent of advanced remote sensing technologies, from aerial photography to satellite imagery, has transformed our ability to study coastline changes systematically and comprehensively (Chen et al 2003). These technologies provide researchers and coastal managers

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with powerful tools to track shoreline movements, assess coastal erosion, and monitor land-use changes in coastal zones.

The integration of various data acquisition techniques, coupled with advances in digital image processing and analysis, has created new opportunities for understanding coastal processes and informing coastal management decisions (Van et al 1998).

2. Coastline data acquisition techniques

Various data acquisition techniques have been developed to map the position and shape of coastline over time (Thieler and Danforth, 1994). They include ground surveys, aerial photography, satellite imagery, mobile GPS, and airborne LIDAR.

2.1. Traditional Methods

Ground surveys provide direct contact between researchers and the coast, offering reliable data for studying small-scale processes in limited areas. These methods ensure high accuracy through detailed measurements and direct observation of coastal features. While ground surveys remain fundamental for validation and detailed local studies, they are time-consuming, limited in spatial coverage, and generally provide coarse spatial resolution when considering larger coastal areas.

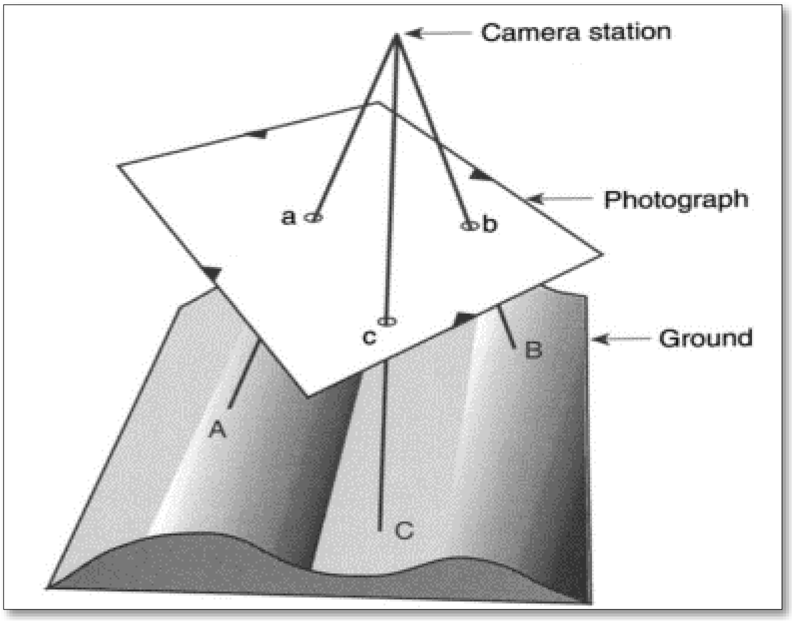

Figure 1 Understanding the principles of Aerial Photography (Adapted from Thieler et al 1994)

2.2. Modern Remote Sensing Technologies

Aerial Photography has traditionally served as the primary remote sensing tool for coastal monitoring. Conventional aerial photography operates in the visible spectrum, while infrared aerial photography (wavelength range 0.7-14 micrometers) offers enhanced capabilities for detecting moisture content and vegetation health. This technology provides large area coverage and enables both two and three-dimensional measurements of coastal features. However, aerial photography faces limitations including weather dependency, daylight-only operation, and the requirement for extensive image rectification. (Ritchie et al, 1988).

Satellite imagery has revolutionized coastal monitoring through systems including the Landsat series (now featuring Landsat 7 ETM), SPOT satellites, and high-resolution platforms like Ikonos, WorldView, and Sentinel. These systems can generate accurate Coastal Terrain Models (CTM), which are digital representations of coastal topography essential for monitoring and analysis. Modern satellite systems offer regular coverage with resolutions reaching one meter or better, enabling detailed coastal change detection (Li 1998).

Synthetic Aperture Radar (SAR) technology represents a significant advancement in coastal monitoring, offering unique capabilities including all-weather and day/night operation. SAR systems operate across various wavelength bands including X-band (2.5-3.75 cm), C-band (3.75-7.5 cm), and L-band (15-30 cm), each offering specific advantages for coastal mapping. Technology excels in providing enhanced contrast between water and land surfaces, making it particularly valuable for coastline delineation and change detection studies. (Lee and Jurkevich, 1990; Mason and Davenport, 1996; Schwäbisch et al., 1997). Extraction of coastlines from radar images is facilitated by a larger contrast in backscatter signals received from the water and the land.

Both aerial photos and satellite imagery need to go through geocoding and orthorectification before coastline feature extraction. This is necessary to introduce geographic coordinates using ground control points and compensate for image geometric distortions due to various reasons. The development of the Global Positioning System (GPS), especially differential GPS, provided a new avenue for data collections. By driving along, the coastline the geographical coordinates of coastline position can be automatically recorded by GPS receiver. Mobile GPS technology can map areas with high precision, although it is time consuming and costly. Airborne light detection and ranging (LIDAR) is an aircraft-based method that can generate a high-accuracy Coastal Terrain Model. Coastal Terrain Model can be intersected with predicted water surface levels to obtain coastline positions at any specific time.

This method is the most reliable to obtain the prediction of high-water (HWL) and low-water levels (LWL) that enclose the shoreline position. Coastline data acquisition is one of the most labor-intensive undertakings in coastal studies. Traditionally it was performed manually, digitizing shoreline from topographic maps, or interpreting and tracing shoreline from aerial photographs.

Recent technological developments allowed its automation by using digital image processing methods. When data is under raster format, software tools can be used to automatically extract the coastline (Lee and Jurkevich 1990, Shon and Jezek 1999). Most of the tools that can extract the coastline from aerial photographs or satellite images can identify the thin wet sand zone from its own spectral signature, which is different from land and water. But the same tools are ineffective over large areas because the elements that define shoreline have different spectral signatures. An automated method for coastline extraction from raster images was developed by Liu and Jezek (2003), who implemented a new technique based on the canny edge detector algorithm. This method proved to be a reliable tool to extract shoreline along extensive coasts. Currently, the high temporal resolution and increasing spatial resolution of remote sensing systems are available for detecting and monitoring coastline movements (White and El Asmar, 1999). Although remote sensing can easily delineate the shoreline in some places, wet tidal areas still represent a problem, and conventional field-based surveying remains as the most reliable approach to determine shoreline position change over short time scales (Ryu et al. 2002).

Table 1 Comparison of Data Acquisition Methods

Method	Spatial Resolution	Temporal Coverage	Cost	Main Advantages	Limitations
Ground Survey	Very High (<1m)	Limited	High	High accuracy	Time-consuming
Aerial Photography	High (0.1-1m)	Periodic	Medium	3D capability	Weather dependent
Satellite Imagery	Medium-High (0.5-30m)	Regular	Medium-High	Large coverage	Cloud interference
SAR	Medium (1-100m)	Regular	High	All-weather	Complex processing
LIDAR	Very High (<1m)	On-demand	Very High	High accuracy	Cost

3. Remote sensing-based analysis of shoreline dynamics

Remote sensing is a useful tool to detect coastline change. It plays an important role for spatial data acquisition from an economic perspective (Gens 2010). Digital spatial data analysis and mapping; remote sensing and GIS are widely applied in environmental and natural resources monitoring. Optical images are simple to interpret and easily obtainable (Blaschke et al 2000). Furthermore, absorption of infrared wavelength region by water and its strong reflectance by vegetation and soil make such images an ideal combination for mapping the spatial distribution of land and water. Hence, band 4 of Landsat data in near infrared spectral range (MSS4: 0.8-0.11 μm, TM4:0.76-0.90 μm) suitable for measuring outlines of water bodies. As high-resolution data is costly, uncommon, and often entirely unavailable for a long period for the study area, Landsat satellite images were used as source material. Additionally, Landsat satellite images represent the world's longest continuously acquired collection of space-based land remote sensing data.

Remote sensing technique allows for observation and measurement of coastline without direct contact. The most widely used are aerial photographs taken from airplanes at relatively low speed and steady altitude. Aerial photographs can provide two or three-dimensional measurements and have the advantage of covering much larger areas than ground survey methods (Paine et al 2012). Aerial photographs should be considered as historical records, since they represent objects at a given location at a precise time. But they also have some disadvantages, since they can only be taken in daylight and through clear skies (which makes them weather dependent), cannot properly represent objects in motion, and they require rectification to compensate for image distortions (Ritchie et al, 1988). Infrared aerial photography technology can capture images beyond the reach of the human eye. It is useful for coastline mapping.

Over the last two decades there has been an increasing use of satellite imagery. Landsat and Spot and one-meter resolution Ikonos satellite images can be used to generate relatively accurate Coastal Terrain Models (CTM) (Li 1998).

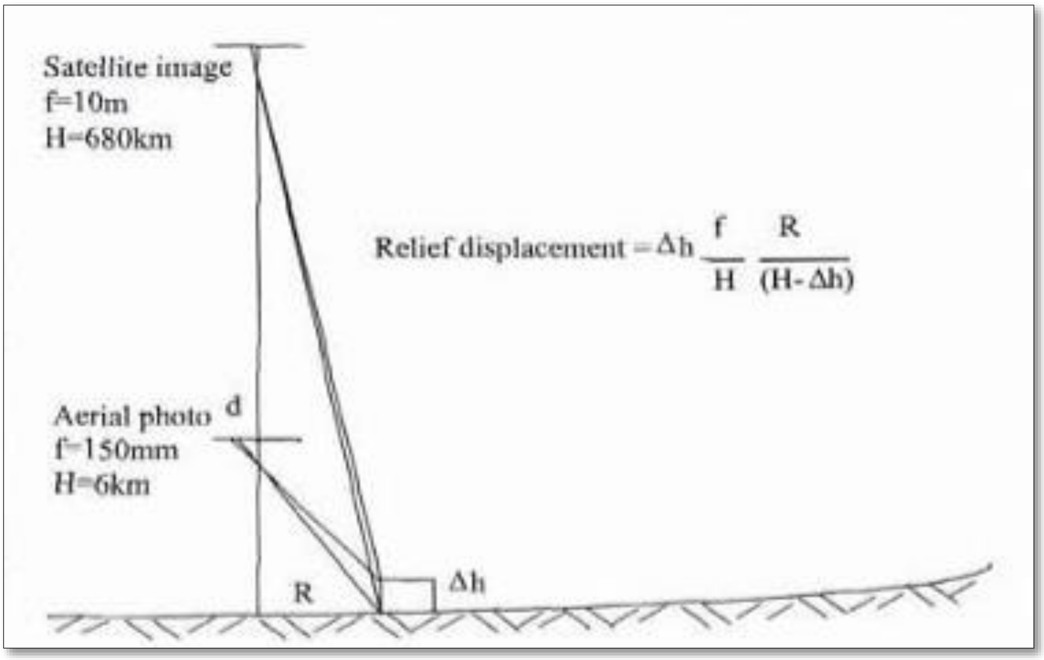

Figure 2 Illustration of Relief Displacement in Aerial and Satellite Imagery. (Li, 1998)

Coastline data acquisition is one of the most labor-intensive undertakings in coastal studies. Traditionally it was performed manually, digitizing shoreline from topographic maps, or interpreting and tracing shoreline from aerial photographs. Recent technological developments allowed its automation by using digital image processing methods. Currently, the high temporal resolution and increasing spatial resolution of remote sensing systems are available for detecting and monitoring shoreline movements (White and El Asmar, 1999). Although remote sensing can easily delineate the coastline in some places, wet tidal areas still represent a problem, and conventional field-based surveying remains as the most reliable approach to determine coastline position change over short time scales (Ryu et al. 2002), however for this research long time scale is involved.

'Everything in nature has its own unique distribution of reflected, emitted, and absorbed radiation. These spectral characteristics can and if ingeniously exploited be used to distinguish one thing from another or the changes that have occurred in a particular place over a period or to obtain information about shape, size, and other physical and chemical properties (Parker and Wolff, 1965).

Thus, Spectral signature can be used to determine the change dynamics that has occurred in coastline region, the knowledge of Spectral signature would enable us know the feature which has changed. For instance, has waterbodies area has turned into an industry, each feature has its unique spectral number and by comparing the response pattern of each feature, we may be able to distinguish between features of both sensed images and notice the changes.

4. Conclusion and recommendation

The reviewed literature collectively emphasizes the significant advancements in coastline data acquisition techniques and remote sensing applications over recent decades. Published studies consistently demonstrate the evolution from traditional ground surveys to sophisticated remote sensing technologies, highlighting how these methods have enhanced our ability to monitor and understand coastal dynamics. The synthesis of existing research underscores the crucial role of various data acquisition methods, from aerial photography to satellite imagery, in providing comprehensive coastal monitoring solutions.

Current literature reveals that while remote sensing technologies, particularly Landsat imagery, have revolutionized coastline monitoring, integration with traditional survey methods remains vital for validation and detailed local assessments. The review highlights existing challenges in data acquisition, particularly in wet tidal areas where conventional field-based surveying continues to provide the most reliable short-term measurements. The development of automated coastline extraction methods has significantly improved data processing efficiency, though challenges remain in standardizing these approaches across diverse coastal environments.

4.1. Looking forward, several recommendations emerge:

- Further development of automated digital image processing methods to enhance coastline extraction accuracy
- Integration of multiple data acquisition techniques to provide more comprehensive coastal monitoring
- Exploration of newer satellite systems and sensors beyond Landsat 7 ETM+
- Development of standardized protocols for combining different data acquisition methods
- Investment in advanced technologies like LIDAR for high-accuracy coastal terrain modeling

Future research should focus on addressing the limitations of current data acquisition techniques while leveraging emerging technologies to improve coastal monitoring capabilities. Emphasis should be placed on developing cost-effective, efficient methods that can provide both broad spatial coverage and high temporal resolution for sustainable coastal management practices.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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