PRE-PROCESSING AND CLASSIFICATION OF AIRBORNE HYPERSPECTRAL DATA FOR WETLANDS MAPPING

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For my family and Irene.

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ABSTRACT

The focus of this study is on information extraction from wetland areas using Pushbroom Hyperspectral Imager (PHI) data in Sungai Kisap, Langkawi. PHI data with high spatial and spectral resolution (2 m spatial and 5 nm spectral resolution) is very sensitive to variations in the reflectance of an object's surface. Therefore, hyperspectral data pre-processing (i.e. radiometric correction, geometric correction and data mosaicking, topographic normalization, data masking, spectral data reduction and spatial data reduction) were employed to ensure that data used for wetland information extraction are well corrected. To enable the feature extraction, two sets of spectral libraries (one for land cover classes and another for mangrove classes) were created from a field campaign. Feature extraction using a thresholding technique was employed to extract information from the PHI data. Two data classification techniques were also used, namely (1) Spectral Angle Mapper, and (2) Binary Encoding. Four land cover classes and four mangrove classes had been successfully extracted from PHI data. A spectral Angle Mapper classified PHI image with spectral angle 0.3 radian gives the best classification result over 80 % of overall accuracy with Kappa Coefficient of 0.557. Other classifiers tested also give reasonable results (over 70% of overall accuracy). The final outputs of this study are a land cover map and a mangrove classes map of Sungai Kisap area.

ABSTRAK

Kajian ini memfokuskan tentang penjanaan maklumat tanah bencah di Sungai Kisap, Langkawi dengan menggunakan data *Pushbroom Hypersectral Imager* (PHI). Data PHI yang mempunyai resolusi ruang dan spektral yang tinggi (2 m resolusi ruang dan 5 nm untuk resolusi spektral) adalah sangat sensitif kepada pembalikan yang dipancarkan oleh permukaan objek. Dengan itu, pra-pemprosesan data *hyperspectral* (iaitu pembetulan radiometri, pembetulan geometri, penggabungan data, normalisasi topografi, topengan data, pengurangan data spektral dan pengurangan data ruang) telah dijalankan bagi tujuan memastikan data yang digunakan untuk menjana maklumat tanah bencah telahpun dibetulkan. Bagi membolehkan penjanaan maklumat dijalankan, dua set *spectral library* (satu untuk jenis litupan tanah dan satu lagi untuk kelas-kelas paya bakau yang wujud di kawasan kajian) telah dibentuk daripada data yang dikumpul melalui kerja lapangan. Teknik *thresholding* telah digunakan bagi menjanakan maklumat daripada data PHI. Dua teknik pengkelasan data iaitu (1) *Spectral Angle Mapper*, dan (2) *Binary Encoding* juga telah digunakan dalam kajian ini. Empat kelas untuk jenis liputan tanah dan empat kelas jenis paya bakau telah dijana daripada data PHI. Imej PHI yang telah dikelaskan dengan Spectral Angle Mapper dengan sudut 0.3 radian memberikan hasil pengkelasan yang terbaik iaitu dengan ketepatan keseluruhan melebihi 80% dan *Kappa Coefficient* setinggi 0.557. Pengkelas lain yang turut diuji dalam kajian ini juga memberikan keputusan yang memuaskan (melebihi 70% ketepatan keseluruhan). Hasil akhir kajian ini ialah peta liputan tanah dan peta hutan paya bakau untuk kawasan Sungai Kisap.

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LIST OF ABBREVIATIONS

AIS	-	Airborne Imaging System
ASAS	-	Advance Solid State Array Spectrometer
ASCII	-	American Standard Code for Information Interchange
AVIRIS	-	Airborne Visible/Infrared Imaging Spectrometer
AVHRR		Advanced Very High Resolution Radiometer
BE	-	Binary Encoding
CAS	-	Chinese Academy of Science
CASI	-	Compact Airborne Spectrographic Imager
CIR	-	Colour Infrared
DC	-	Dark Current
DEM	-	Digital Elevation Model
ERDAS	-	Earth Resources Data Analysis System
FOV	-	Field-of-View
GCP	-	Ground Control Point
GPS	-	Global Positioning System
HIRIS	-	High Resolution Imaging Spectrometer
HRV	-	High Resolution Visible
IARR	-	Internal Average Relative Reflectance
IDL	-	Interactive Data Language
IFOV	-	Instantaneous Field-of-View
IR	-	Infrared
JERS	-	Japanese Earth Resources Satellite
JPL	-	Jet Propulsion Lab
MACRES	-	Malaysia Centre for Remote Sensing
MESSR	-	Multispectral Electronic Self-Scanning Radiometer
MIR	-	Middle Infrared
MNF	-	Minimum Noise Fraction

MOS	-	Marine Observation Satellite
MSS	-	Multispectral Scanner
NASA	-	National Aeronautics and Space Administration
NOAA	-	National Oceanic & Atmospheric Administration
OMIS	-	Operational Modular Imaging Spectrometer
PCA	-	Principal Components Analysis
PHI	-	Pushbroom Hyperspectral Imager
PPI	-	Pixel Purity Index
RMSE	-	Root Mean Square Error
ROI	-	Region of Interest
SAM	-	Spectral Angle Mapper
S/N	-	Signal-to-Noise
SAR	-	Synthetic Aperture Radar
SIS	-	Scanning Imaging Spectroradiometer
SITP	-	Shanghai Institute of Technical Physics
SPOT	-	Satellite Pour l'Observation de la Terre
TIR	-	Thermal Infrared
TM	-	Thematic Mapper
USGS	-	United States Geological Survey
VI	-	Vegetation Index
VNIR	-	Visible Near Infrared

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Wetland systems, generally defined as transitional areas between permanently flooded deepwater environments and well-drained uplands (Watzin and Gosselink, 1992), are important ecological systems that contribute a wide array of biological, social and economic benefits. Wetlands provide habitats for rare, endangered and commercially or recreationally important fish and wildlife species. They also serve as focal points for outdoor recreation, and provide an important function in water quality improvement, floodwater storage, storm surge reduction as well as groundwater recharge (Greeson et al., 1979; Mitsch and Gosselink, 1986; Tiner, 1984). It is extremely difficult, time consuming and inaccurate to perform ground-based wetland characterization. Some researches have demonstrated that remote sensing techniques are cost effective methods to inventory and monitor wetland area due to its spatial, spectral and temporal resolution (Gross and Klemas, 1986; Jensen et al., 1991).

Remote sensing provides an important tool for exploring, monitoring, and analyzing wetland systems. Remote Sensing data acquired from aircraft and satellite platforms have been widely used for mapping wetlands and for analyzing changes to wetland systems. Remote sensing was used to monitor the changing condition of native vegetation along the Tanque Verde Creek, Arizona, US, during 1983 to 1989 using Landsat Multispectral Scanner (MSS) (Lee and Marsh, 1995). Lyon (1993) demonstrated the potential of remote sensing technique for mapping and measurement of coastal and lacustrine resources. This study has led to a better understanding of water characteristics recorded by Landsat TM and NOAA AVHRR data, apart from the methodology to be adopted to measure other related parameters such as non-point sediment for quantifying wetlands.

Early studies in the early 90's of wetlands using remote sensing techniques have widely focussed on using multispectral scanner data which are quite limited in terms of spatial and spectral resolution. Multispectral scanners measure the radiation reflected by surface features in several portions of the spectrum and convert these analogue measurements into digital counts, usually using an 8-bit (0-255) range. By using statistical techniques such as Principal Component Analysis and image classification techniques to analyze the distinct way in which different surface features reflect radiation in different parts of the spectrum, it is possible to characterize the surface features which make up an area. When the radiation reflected by a surface feature is measured only by multispectral scanners in four to ten broad portions of the spectrum (which are known as bands), it is difficult to differentiate between surfaces with cover types that are similar in nature (such as wetland flora), or to detect subtle changes in the cover types which are of interest (Aardt, 2000; Wynne, 2001). The broad nature of the spectral bands acts to mask the subtle differences in spectral response of similar cover types (Huang et al., 2003). When the spectral and spatial limitations of multispectral scanners are considered, one can begin to appreciate the difficulties in using data from these sensors for mapping and analyzing areas as complex as wetlands. To overcome such limitations, the hyperspectral sensor is therefore being of great interest.

A hyperspectral sensor is, in fact, an extension of a multispectral scanner. But unlike multispectral scanners, it is capable of measuring up to hundreds of very narrow portions of the spectrum (Lillesand and Keifer, 1999). A hyperspectral sensor revolutionizes the utility of remotely sensed data for mapping and monitoring wetlands by eliminating the prior limitations of spectral resolution. With hyperspectral sensors, it may be possible to map individual wetland plant species, as well as to detect very subtle changes in the wetland systems, such as the early signs of stress.

1.2 Importance of Wetland Study

Wetlands are places to be avoided and, yet, to be developed. Many people think wetlands should be drained and filled in to be used for housing or commercial developments or as depositories for human-generated waste materials. However, coastal wetlands provide humans with a remarkable variety of benefits. They serve as spawning and nursery grounds for many species of marine fish and shellfish, providing 70 per cent of Malaysia's seafood, including shrimp, clams, crabs and haddock. Wetlands are also the breeding grounds and habitats for waterfowls and other wildlife. Some species spend their entire life in wetlands, while others use them primarily as nesting, feeding or resting grounds.

Wetlands also help to reduce the frequency, level and velocity of floods and riverbank erosions. They act as natural sponges that absorb floodwater and help to protect the adjacent and downstream areas from flood damages. Many wetlands also recharge groundwater aquifers by holding water and allowing it to filter into the ground slowly.

Some scientists have said, "Nothing is wasted in a mangrove forest". Indeed, mangroves represent a rich and diverse living resource. They serve as a link between marine and terrestrial ecosystems and are also clearly important to the stability and maintenance of various adjoining ecosystem, such as sea grass beds and coral reefs.

There are many benefits that the mangrove forest provide for both man and nature. In addition to providing protection from high winds and erosion on our coasts and providing a home to many plant and animal species, mangrove forest also have economic and social value to local communities. For example, mangrove plants shed large numbers of nutrient-rich leaves which are either broken down by fungi and bacteria or are eaten by small crabs that live on the forest floor. Decaying organic material breaks down into small particles (detritus) which are covered with a protein-rich bacterial film. Detritus is the food source for many species of molluscs (snails), crustaceans (crabs, shrimps and prawns) and fish, which in turn are the food source for larger animals. Nutrients released into the water through the breakdown of leaves, wood and roots also feed the plankton and algae that form part of the mangrove ecosystem.

Mangrove forests are important to the economy of villagers living in or near mangroves. The mangrove forest acts as a nursery for many commercial fish species and thus, makes mangrove forest essential for the sustainability of the commercial fishing industry. Other valuable products of the mangrove forest include charcoal, fire wood, wood distillation, wood chips and medicines. Mangrove forests are also valuable socially, acting as a classroom or a place of research. Taking care of the mangrove forest and fostering this care provides a great social service. Learning to use mangrove forest products sustainably and passing on this knowledge to future generations leads to a healthy and sustainable environment.

1.3 Problem Statement

Remote sensing can be used as a tool to monitor the sustainable environment. Wetland vegetation species are very sensitive to environmental changes. For example, wetland vegetation species may be a good indicator of the environmental changes once the anticipated biophysical parameters are determined. Other wetland vegetation species can be sensed by the sensors which operate in the wider optical wavelengths, noticeable by naked human eyes. As the concerns for wetland protection grow, wetland delineation is also becoming more important. There are two ways to employ remote sensing techniques in wetland studies. Firstly, it is for resource mapping of a wetland system, involving the acquisition of baseline data on type, extent and health of the wetland communities. Secondly, it involves change detection analysis within wetland communities, either natural or anthropogenic (Lee and Lunetta, 1995).

In wetland studies that employ remote sensing techniques, two widely used data are satellite and airborne colour infrared (CIR) images (Madden et al., 1999;

Welch, 1996). The first and second generation satellite data[1] mostly do not have adequate spatial resolution to differentiate between detailed ground information. The airborne CIR images were then used to complement the satellite data. Both of these data complement each other when studying large extent of area where airborne data can be very costly to acquire, and are mostly used when detailed studies involve smaller area of interest. In order to delineate wetlands properly, the recent airborne hyperspectral remote sensing data therefore meet the needs in terms of both spatial and spectral resolution.

There are some pre-processing requirements that should be first addressed when applying the hyperspectral analysis tools. These include the creation of a spectral library and the calibration of hyperspectral data. A spectral library is needed to compare the spectra recorded by the sensor to the spectra collected in the field work as a reference to find out the endmember[2]. Most of the spectral libraries available created by Jet Propulsion Lab, (JPL) and United States Geological Society, (USGS) are more focused on geological study such as mineral exploration. Recently, USGS has started developing spectral libraries for common vegetation types. In Malaysia, a complete set of hyperspectral libraries has yet to be developed. Therefore, to study Malaysian wetland vegetations using hyperspectral data, a new set of spectral libraries is needed. These libraries should be complete because different regions of study may need a different spectral library to increase the accuracy of the study.

Information extraction from hyperspectral data can be separated into two different methods, namely: (1) feature extraction, in which only target objects of interest are extracted from the hyperspectral data by selecting thresholds of bandwidth, and (2) data classifications which involve the using of classifiers (such as Spectral Angle Mapper, Binary Encoding etc.) to classify the hyperspectral data into different classes (Schowengerdt, 1997; Lillesand and Keifer, 1999). Among the two available methods, it is worthwhile to test the fitness of the model and classifier in

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[1] First generation of satellite data refer to Landsat MSS and second generation of satellite data refer to Landsat TM, SPOT and other multispectral sensors with broad bands spectral resolution.

[2] Known as a class in multispectral data

wetland study, and how accurately both methods could achieve the objective of wetland information extraction from hyperspectral data. The objectives and scope of this research are defined in the next two sections.

1.4 Objectives of the Study

The objectives of the study are:

1. To examine and analyse models for feature extraction and classification from hyperspectral data for wetland mapping;

2. To examine and analyse the calibration of hyperspectral data prior to wetland mapping;

3. To create a spectral library to enable hyperspectral processing for identifying and delineating land cover types and mangrove genera available in the study area and;

4. To carry out accuracy assessment of wetland mapping of hyperspectral data using the feature extraction and classification models identified in (1).

1.5 Scope of the Study

1. Hyperspectral data used in this study is confined to airborne Pushbroom Hyperspectral Imager (PHI) data. The data for this study is available from a Malaysia-China joint research project, with Malaysia Centre for Remote Sensing (MACRES) as the secretariat. It is the only hyperspectral data available for wetland study in the study area, Langkawi Island.

2. A series of pre-processing works were employed prior to wetland and information extraction from the hyperspectral data. The data calibration processes include performing of radiometric correction, geometric correction, topographic normalization, data masking and spatial and spectral data reduction.

3. A complete spectral library requires that data in land cover types and mangrove classes (rhizophra, bruguiera, aviecennia and sonneratia) be built for the processing of hyperspectral data. The result of the process can be used to extract wetland area information. The spectral library created is tested with a spectral analyst model prior to data classification.

4. Accuracy assessment was carried out to test the classification results of the hyperspectral data that are subsequently obtained. Two thematic maps are generated, one for land cover classes and another for mangrove classes.

1.6 Location of Study Area

The study area selected in this study is the coastal area near Sungai Kisap. It is located in the eastern part of Langkawi Island, extending between latitudes 10°22'23" N to 10°23'55" N and longitudes 103° 1' 28" E to 103° 4'42" E as shown in Figure 1.1.

The study area was selected based on: (1) the variety of wetland types and (2) the availability of airborne hyperspectral data over the study area. The study area is covered with different types of land cover such as primary forest, scrub, wetland and urban area.

A large portion of the study area is wetland in which mangrove trees are the dominant flora. The shoreline of the study area and riverside of Sungai Kisap are laced in areas with mangrove swamps which are still untouched in most of the places and retain their natural characteristics

The topography of the study area ranges from flat to undulating hilly area. The elevation level varies from 5 to 319 meters above mean sea level. Nearly 30 percent of the study area is located in hilly areas while most of the rest are wetland and other types of vegetation which have relatively flat terrain.

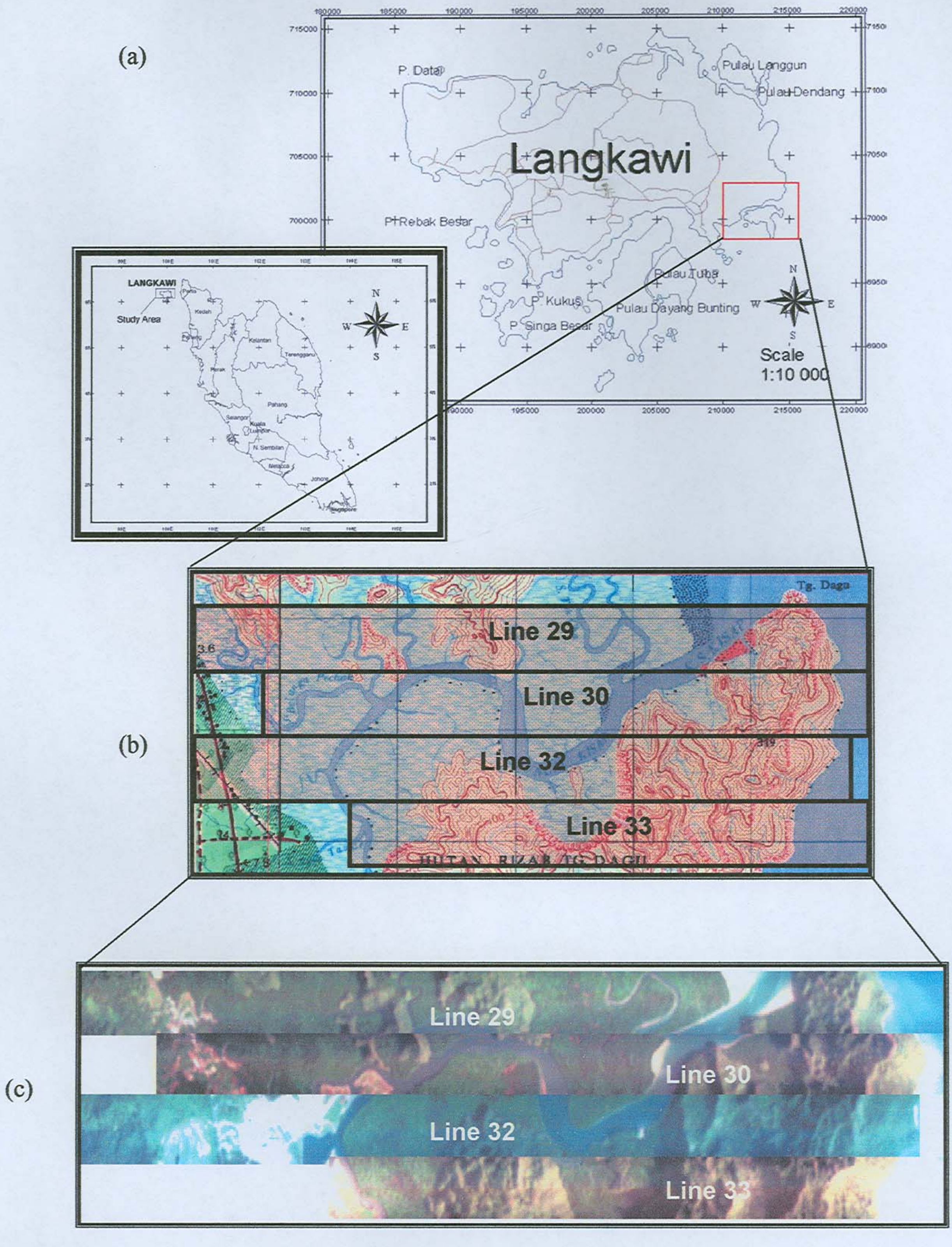

Figure 1.1: Study area; (a) location map, (b) corresponding four hyperspectral line superimposed on the topographic map of study area and (c) the hyperspectral data (raw).

1.7 Thesis Outline

This thesis comprises six chapters in which Chapter 1 explains the research background of the study and gives the problem statement, objectives and scope of the study. The review of the hyperspectral remote sensing technique, together with its applications and works previously done with remote sensing techniques for wetland studies are addressed in Chapter 2. The literature review on wetland studies, especially on mangrove classes recognition, are also addressed in this chapter. In Chapter 3, acquisition of hyperspectral data, pre-processing and image enhancements employed in the study are discussed. Data acquisition includes the collecting of field and image spectra for spectral library. All the pre-processing works including radiometric calibration, geometric correction and data mosaicing, data masking, topographic normalization and image enhancements (Minimum Noise Fraction and Pixel Purity Index), which are done prior to feature extraction and data classification, are also presented in this chapter. Chapter 4 presents the flow for creating a spectral library for land cover classes, vegetation types and mangrove classes for the use of hyperspectral data processing. The feature extraction process and data classification, which are carried out using different approaches (i.e. Spectral Angle Mapper and Binary Encoding) on hyperspectral data, are discussed in Chapter 5. Results and analyses of the feature extraction and classification are also presented and discussed in this chapter. Conclusions of the research and recommendations for future work are given in Chapter 6.

remote sensing data. By using space-borne hyperspectral data, the problem of geometric distortion occurring in data mosaicking can be reduced.

iii. Additional real time in-situ spectra should be collected for wetland plant communities under various environment conditions. This will help to improve the classification result by increasing the producer accuracy during the classification process.

iv. To study wetlands using hyperspectral data, a more complete set of wetland spectral library is needed. The spectral library created in this study is mostly limited to mangrove species and there are still some other plants existing in wetland communities.

v. Probability based classification techniques like Maximum Likelihood is worth trying with hyperspectral data. All the classification techniques examined in this study are categorized as shape-based techniques, which use the spectral elements to perform classification on hyperspectral data.

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