UNIVERSITI PUTRA MALAYSIA

NEAR REAL TIME PROCESSING OF NOAA AVHRR SATELLITE DATA

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By

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Thesis Submitted in Fulfillment of the Requirements for the Degree of Master of Science in the Faculty of Engineering
Universiti Putra Malaysia

March 1998

Dedicated

To

My Parents

ACKNOWLEDGEMENTS

It is my pleasure to express my deepest gratitude and appreciation to Dr. Shattri B. Mansor, the chairman of my supervisory committee for his guidance and inspiration during the research period. I would also like to express thanks to my co-supervisors Professor Dr. Mohd. Ibrahim Hj. Mohamed, Dept. of Environmental Studies, Faculty of Science and Environmental Studies and Dr. Abd. Rahman Ramli, Head, Dept. of Computer and Communication System Engineering for their kind supervision and suggestions to carry out my works properly.

I would like to thank all the members of Geomatic Engineering Unit, Faculty of Engineering for their technical advice and cooperation. I am grateful to Remote Sensing Unit, SEAFDEC, Terengganu, Malaysia for providing satellite data and sea surface temperature ground truth data. I would like to thank Mr. Khairul Nizar Badaruddin for supplying the coefficients for sea surface temperature extraction algorithms.

This research was supported by Malaysian Government IRPA Project No. 01-02-04-0141 "Application of Remote Sensing & GIS Techniques in Fish Forecasting" and I am too much grateful to the project leader (Dr. Shattri B. Mansor) as he managed a scholarship from the project for me. I am grateful to the Government of the People's Republic of Bangladesh for providing one way air ticket for this course of study.

My parents have provided mental support and encouragement for my higher studies. I would like to extend my appreciation to all of my well-wishers including my parents.

TABLE OF CONTENTS

LIST OF TABLES

Tables **Page**

LIST OF FIGURES

LIST OF ABBREVIATIONS

AVHRR	Advanced Very High Resolution Radiometer
C	Celsius
cm	Centimeter
DN	Digital Number
E	East
GAC	Global Area Coverage
GCPs	Ground Control Points
GHz	GigaHertz
HRPT	High Resolution Picture Transmission
K	Kelvin
km	kilometer
L	Line Number
m	meter
MCSST	Multichannel Sea Surface Temperature
N	North
NASA	National Aeronautics and Space Administration
NESDIS	National Environmental Satellite, Data and Information Services
NOAA	National Oceanic and Atmospheric Administration
NORAD	North American Air Defense Command
P	Row Nubmer
RSO	Rectified Skew Orthomorphic
S	South
SEADEC	South East Asia Fisheries Development Center
SST	Sea Surface Temperature
TIROS	Television Infrared Observation Satellite
TLE	Two Line Elements
UTM	Universal Transverse Mercator
W	West

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirements for the degree of Master of Science.

NEAR REAL TIME PROCESSING OF NOAA AVHRR SATELLITE DATA

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QUAZI KHALID HASSAN

March 1998

Chairman : Dr. Shattri B. Mansor

Faculty : Engineering

This thesis describes near real time processing of NOAA AVHRR satellite raw data which includes automatic geocoding approach followed by cloud masking techniques and sea surface temperature extraction algorithm implemented over South China Sea.

For geocoding of the images an orbital model has been used followed by Earth location determination algorithms. Different models have been implemented based on radiative transfer equations for extracting sea surface temperature from satellite data, namely single channel, split-window, spatiotemporal split-window technique and multichannel sea surface temperature. There are five cloud masking techniques namely gross cloud check, spatial coherence method, dynamic visible and near infrared method, ratio of near infrared reflectance to visible reflectance and channel difference method have been implemented.

The accuracy of the geocoding is within 2-10 km. Sea surface temperature from satellite data has been compared with ground truth data and standard deviation

for sea surface temperature is within 0.1 - 0.75 degree Celsius. The cloud masking techniques are capable to produce noncontaminated pixels in the imagery.

All the works have been carried out by customization of EASI/PACE environment of PCI software and the developed techniques are fully automatic in nature. These developments can be used for fish forecasting and monitoring of oil spill over Malaysian sea water.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master of Sains.

HASIL KAJIAN PEMPROSESAN DATA SATELIT NOAA AVHRR MASA ANGATA TERHAMPIR

Oleh

QUAZI KHALID HASSAN

Mac 1998

Pengerusl : Dr. Shattrl B. Mansor

Fakultl : Kejuruteraan

Tesis ini menerangkan hasil kajian pemprosesan NOAA AVHRR masa nyata terhampir. Ia juga merangkumi teknik pembetulan pengkodan automatik, penopengan awan dan suhu permukaan laut bagi perairan Laut China Selatan.

Untuk pembetulan pengkodan imej, model orbit telah digunakan beserta algorithma bagi menentukan lokasi koordinat bumi. Pelbagai model telah digunakan berdasarkan persamaan pemindahan tenaga sinaran untuk menentukan suhu permukaan laut dari data satelit. Di antara model-model tersebut ialah jalur tunggal, pisahan tetingkap, teknik pisahan tetingkap ruang masa dan suhu permukaan laut berbilang jalur. Sementara bagi tujuan menentukan penopengan awan, 5 kaedah telah dilaksanakan, iaitu semak awan kasar, kaedah jelas ruang, kaedah tampak dinamik dan inframerah dekat, nisbah kepada kepantulan inframerah dekat ke pantulan tampak dan kaedah bezaan saluran.

Ketepatan pengkodan adalah dalam 2-10 km. Suhu permukaan laut yang di perolehi dari imej satelit telah di bandingkan dengan data kesahihan lapangan dan sisihan piawai suhu permukaan laut ialah 0.1 - 0.75 darjah selsius. Teknik penopengan awan pula berupaya untuk menghasilkan piksel yang bebas dari kesan awan.

Semua prosesan di atas dilakukan dengan mengguna perisian PCI, di mana proses dibuat secara automatik. Prosidur ini boleh digunakan untuk kajian ramalan kawasan perikanan dan pengawasan tumpahan minyak di perairan Malaysia.

CHAPTER I

INTRODUCTION

The role of satellites in monitoring condition of the Earth's atmosphere and surface is an increasingly important one. The imagery obtained from the satellite is most useful in the disciplines of the coastal features since vast areas of the ocean cannot be sampled adequately by other means. This introductory chapter represents a discussion on TIROS-N/NOAA series of polar-orbiting satellites history, Advanced Very High Resolution Radiometer (AVHRR) instrument, processing steps, objectives of this research, structure of this thesis and finally scope of this research.

TIROS-N/NOAA Satellites

The first series of environmental satellites were launched by USA as TIROS-N. A total of ten TIROS satellites were launched between 1960 and 1965, each equipped with a small television camera. The TIROS series of essentially experimental satellites was followed in 1966 by an operational series of satellites termed the TIROS operational system. The satellites themselves were termed ESSA (Environmental Science Service Administration) satellites after their operators, the US Environmental Science Service Administration. There were nine ESSA satellites launched in between 1966 and 1969 and they provide routine daily observations on a world-wide basis.

The second series of weather satellites was the Improved TIROS Operational System (ITOS). The first satellite was launched in 1970. The ITOS satellites were termed NOAA, named after their operators the National Oceanic and Atmospheric Administration, which was the successor to ESSA.

The third series of operational meteorological satellites designated TIROS-N was first launched in 1978 and this has been followed by NOAA-6 to NOAA-14. The main objective of these satellites is to provide a stable platform in space upon which can be mounted many advanced instruments to collect data concerning cloud cover, the Earth's atmosphere, oceanographic features like fish gathering zones and several other quantities. Table 1 contains the history of the TIROS-N and NOAA series.

Table 1 : History of TIROS-N / NOAA series

Number	Satellite Launch Date	Service Dates
TIROS-N	10/13/78	10/19/78 - 01/30/80
NOAA-6	06/27/79	06/27/79 - 11/16/86
NOAA-7	06/23/81	08/24/81 - 06/07/86
NOAA-8	03/28/83	05/03/83 - 10/31/85
NOAA-9	12/12/84	02/25/85 - Present
NOAA-10	09/17/86	11/17/86 - Present
NOAA-11	09/24/88	11/08/88 - 09/13/94
NOAA-12	05/14/91	05/14/91 - Present
NOAA-14	12/30/94	12/30/94 - Present

(Source : Kidwell 1995)

NOAA-B which was launched on May 29,1980, failed to achieve orbit after the launching of NOAA-6 (i.e. NOAA-A). NOAA-13 had been launched on August 9, 1993, but failed due to an electrical short circuit in the solar array.

The TIROS-N/NOAA series of satellites operate in near-polar, sun-synchronous orbits. The orbital period is about 102 minutes which produces 14.1 orbits per day. The orbit altitude is about 850 km, with an orbital speed of about 6.6 km/sec.

The Advanced Very High Resolution Radiometer (AVHRR)

The Advanced Very High Resolution Radiometer (AVHRR) is one of most important instrument carried by the NOAA satellite. An AVHRR is a broad-band, four or five channel (depending on the model) scanner, sensing in the visible, near-infrared, and thermal infrared portions of the electromagnetic spectrum. The spectral characteristics of the TIROS-N/NOAA AVHRR instrument is listed in Table 2 and some characteristics of the TIROS-N/NOAA AVHRR are in Table 3 (Kidwell 1995).

Table 2 : Spectral characteristics of the AVHRR instruments (in μm)

Channel	TIROS-N	NOAA-6,8,10	NOAA-7,9,11,12,14	IFOV(milliradians)
1	0.55 - 0.9	0.58 - 0.68	0.58 - 0.68	1.39
2	0.725 - 1.10	0.725 - 1.10	0.725 - 1.10	1.41
3	3.55 - 3.93	3.55 - 3.93	3.55 - 3.93	1.51
4	10.50 - 11.50	10.50 - 11.50	10.3 - 11.3	1.41
5	Ch 4 repeated	Ch 4 repeated	11.5 - 12.5	1.30

(Source : Kidwell 1995)

Table 3 : Some characteristics of the TIROS-N/NOAA AVHRR

Characteristics	TIROS-N/NOAA
Radiometric resolution	10 bits
Spectral resolution	ch. 1 Visible
	ch. 2 near IR
	ch. 3 IR
	ch. 4 IR
	ch. 5 IR
View angle	± 55.3846 degrees
Ground resolution at nadir	1.1 x 1.1 km
Swath width	3000 km
Repeat coverage intervals	12 hours

Signals from the AVHRR are converted to digital form by means of a 10-bit analogue-to- digital converter, and the channels are time multiplexed together with other data by means of an on board computer called the manipulated Information Rate Processor. The data are transmitted to ground stations by means of a split-phase/phase-shifted keyed signal at a bit rate of 665400 bits/s, the carrier frequency is 1.7 GHz (high-resolution picture transmission). There is also a second transmission, at a rate of 137 MHz, where a reduced resolution signal is present.

Concept of Near Real Time Processing

The image data directly obtained from satellite has no significance without performing some important processing. Most of the satellite ground receiving station process the raw data after reception. At the present moment, there is no on line data transmission system in between the satellite ground station SEAFDEC (South East Asia Fisheries Development Center), Terengganu, Malaysia and Universiti Putra Malaysia. Upon carrying the data from SEAFDEC, an automatic processing environment is developed. All the customized procedures can be handled at operator level. Due to automatic processing facilities, the raw data upon reception can be processed within a very short time. This is why the system support developed in the scope of this research can be termed as "near real time processing" system.

Processing Steps

In order to satisfy real time monitoring and forecasting of the oceanographic features from space, it is necessary to process the satellite data on real time basis. The raw data received by the ground station is not useable before some processing steps like geocoding (i.e. geometric correction), cloud masking, sea surface temperature extraction etc. Due to Earth geometry, the acquired image of the surface is distorted, so geometric correction is needed. The sensor on board records the radiance values of the ground in terms of digital number. So, it is needed to convert these digital number values to radiance values for getting surface temperature. Features extraction from space is usually interrupted due to the presence of cloud at the time of acquiring imagery. The following subsections discuss about geocoding of the raw imagery, cloud masking and sea surface temperature extraction.

Geocoding of the Raw Imagery

The geometric distortion of satellite imagery is due to a variety of factors like rotation of the Earth during image acquisition, the finite scan rate of the sensor, the field of view of the scanner, the curvature of the Earth, panoramic effects related to image geometry, variations in platform altitude, attitude and velocity (Bernstein 1983). For compensating these distortions, the imagery needs to be geocoded. This geocoding also establishes relationship between individual pixel behavior and ground truth measurements.

Geocoding of satellite imagery is a task of locating latitude/longitude with any point in terms of line/row in the image. The raw data as received by the receiving station do not have relationship in-between geographical latitude/longitude and image elements line/row. The relation in between geographical position (latitude/longitude) and co-ordinates of the acquired image (line/pixel) is as equation (1.1) :

$$L = f(\theta,\phi) \quad \text{and} \quad P = f(\theta,\phi) \qquad (1.1)$$

Where

θ = latitude ; ϕ = longitude

L = line number in the image

P = row number in the image

Sea Surface Temperature

Sea surface temperature (SST) appears to be a parameter that could be easily defined as the temperature of the sea surface. It is true that SST is difficult to measure, and different measurement techniques result in different SSTs because they are actually measuring different things.

The oldest method of measuring the sea surface temperature is to dip a bucket into the sea, pull it out and measure the temperature with a thermometer. This is simple and straightforward, and gives the temperature of the water somewhere in the top meter or less. The drawback, however, is that it requires someone to manually dip the bucket in the ocean. A variation of this technique is to have the thermometer already in the bucket, place the bucket in the ocean, and leave the bucket in the sea for several minutes while the thermometer stabilizes.

As the desire for more automated measurements has increased, ship intake ports have been fitted with temperature probes and used to provide a continuous record of the temperature everywhere the ship goes. This is sometimes called the "along-track system". The main problem with this method is the intake depth of the water is not known. There is no standard depth for placing the intake ports and the depth varies according to the design of the ship. They are typically more than a meter below the surface. In addition, ships tend to move in the water, vertically as well as other directions; thus the depth of the intake ports in the water change constantly. In addition, if the temperature sensor is not located at the intake port, the water must travel some distance in a pipe into the ship before its temperature is taken, possibly allowing time for some temperature change.

The use of satellites for the estimation of the SST has provided an enormous leap in our ability to view the spatial and temporal variation in SST. The satellite measures two or more wavelengths in the infrared part of the spectrum; these wavelengths are chosen to be both i) within the peak of the blackbody radiation expected from the Earth and ii) transmit well through the atmosphere. The satellite SST provides both a synoptic view of the ocean and a high frequency of repeat views, allowing the examination of basin-wide upper ocean dynamics. A given area may be viewed four or more times per day.

There are also several difficulties with this type of measurement. First, because all the radiation comes from the top "skin" of the sea, approximately the top 1 mm or less, it may not represent the bulk temperature of the upper meter of ocean. This makes it difficult to compare the measurements from shipboard methods, complicating ground truth efforts. Secondly, it cannot look through clouds, creating "fair weather bias" in the long term trends of SST. However, these difficulties are small compared to the benefits in understanding gained from satellite SST estimates.

The SST shows many of the world's major currents, such as the Gulf Stream; it can also show current-related anomalies such as cold and warm core eddies. The locations of these features can be of importance to a wide variety of individuals, from fisherman attempting to locate good fishing grounds to sailors looking for the fastest route riding with the current. The SST can also be an indicator of hospitable conditions for many species of plants, fish, and mammals, and can provide advance warning of dangerous conditions. Monitoring the SST could alert scientists to potential future blooms.

Cloud Masking

The presence of cloud in satellite imagery is one of the most important obstacles for extraction accurate sea surface temperature. The impact of cloud on feature extraction from space depends upon the nature of the cloud. For an example, low stratus and fog having very closer temperatures to that of underlying surface, are difficult to detect at infrared wavelengths over sea surface. Cloud should be masked in order to get noncontaminated pixels in the imagery to support any sorts of oceanographic phenomenon studies.

Objectives

The aim of this work is to eliminate the geometrical distortions from the AVHRR on the TIROS-N/NOAA series of polar-orbiting meteorological satellites and geocode the raw images for further research. The on line geocoding of the imagery is needed for the monitoring and forecasting of real time features from the space.

The second objective is to implement sea surface temperature extraction algorithm over South China Sea.

Thirdly cloud masking techniques are to be implemented to get cloud free image elements for further interpretation of the features.

These three objectives of this research are going to support a real time fish forecasting and oil spill project over South China Sea.

Structure of the Thesis

This thesis is divided into six chapters. Chapter I illustrates the background of the objectives. Chapter II provides literature review of current work and finds suitable techniques to reach the goal. Chapter III describes the models for automatic geocoding of the NOAA AVHRR raw data. This chapter is the backbone of this research as this geocoded imagery is used for further interpretation. Chapter IV describes the models for retrieving sea surface temperature from NOAA-14 AVHRR data and cloud masking algorithms. Chapter V provides description of the software development, the results and discussion of the works of chapter III and IV. The results of the SST from satellite data have been compared with ground truth data. Chapter VI concerns the conclusions from preceding chapters and highlights areas requiring further research.