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Direct NOAA Imagery Extraction System for Data Acquisition of Rice Growth Modeling

R.V. Hari Ginardi[1,2], I. Handoko[1,3] & Kudang B. Seminar[4]

[1]MIT Study Program, Bogor Agricultural University, SEAMEO BIOTROP Campus, Jalan Raya Tajur km 6, PO Box 116, Bogor, Indonesia
[2]Institut Teknologi Sepuluh November, Surabaya, Indonesia
[3]Faculty of Mathematics and Natural Sciences, Bogor Agricultural University, Jalan Raya Pajajaran, Bogor, Indonesia.
[4]Faculty of Agricultural Technology, Bogor Agricultural University, Darmaga Campus, Bogor, Indonesia.

Abstract

This research presents a new method for processing remote sensing data. A customized tool was developed to handle data acquisition for a rice growth model using daily NDVI data from NOAA AVHRR satellite. This tool automates several basic remote sensing steps to produce NDVI dataset for a specific study area including image retrieval, image rectification, NDVI calculation, re-sampling, and data masking.

The architecture of this system considers the above application be used as an independent tool which can be executed directly from computer console, or called by other applications as a sub module. To meet this requirement, the output of the system is declared to be compatible with input data format specification of the current rice growth model. We used the Shierary-rice model (Handoko, 1994) as the main system.

Our focus in developing this application was the automation process of NOAA AVHRR image rectification without using any vector / map as a reference for coordinate registration. Coordinate registration was extracted from the NOAA imagery itself. This methodology enables the use of NOAA imagery for every area in the earth surface, even there is no digital map available for the area.

Evaluation and validation were performed to ensure that this system works properly according to the design. We compared our system with current methodology using available remote sensing tool.

Key Words : NOAA, NDVI, crop model, *Shierary*, rice, Java, remote sensing

1. Introduction

1.1. Managing Natural Resources using Information Technology

Natural resources management is an inherently and increasingly complex task. To provide formal yet practical decision support it requires a new approach to support a more open and participatory decision making process. A new paradigm of man-machine systems is needed where the emphasis is no longer on finding an optimal solution to a well defined problem, but rather to support the various phases of the problem definition and solving process.

Management of natural resources requires integration of often very large volumes of disperse information from numerous sources; the coupling of this information with efficient tools for assessment and evaluation that allow broad, interactive participation in the planning, assessment, decision making process and effective methods of communicating results and findings to a broad audience. Information technology, and in particular, the integration of database management systems, GIS, remote sensing and image processing, simulation and multi-criteria optimization models, expert systems, and computer graphics provide some of the tools for effective decision support in natural resources management.

Integration of complex and powerful software tools in problem oriented systems provides direct and easy access to large volumes of data. It supports interactive analysis and helps displaying and interpreting results in a format which is directly understandable and useful for decision making processes. Integrated information systems can support a more interactive, exploratory, and parti-cipatory, and thus useful and effective approach to natural resources planning and management.

From a technical point of view, many basic tools are available and the underlying concepts have been well developed. And new technologies such as wide area networks and their promise of easy access to potentially large volumes of information are rapidly becoming available.

To summarize, the need for better tools to handle even more critical environmental and resource management problems is obvious. The integration of models with geographic information systems, expert systems, interactive graphics, generating a virtual reality version of the decision problem, is a promising and challenging development in environmental systems analysis, strategic decision support, and applied informatics. The biggest challenge, however, seems to be the integration of new information technologies and more or less mature formal methods of analysis into institutional structures and societal processes, that is, putting these tools to work in practice.

1.2. Crop Growth Modeling

Deterministic crop growth model as a basis for crop growth monitoring and yield forecasting is already operational. The coverage area of current model has been developed from a sample size area to regional / national applications which is very useful for regional agricultural planning.

Major components of crop growth modeling are crop variables, particularly leaf area index (LAI), soil variables (soil water content, nitrogen content), meteorological variables (solar radiation, temperature, relative humidity, rainfall and wind speed), and methods of cultivation. For a dynamic modeling with a daily time resolution, the soil variables can be determined from ground truth measurements; cultivation characteristics (*i.e.* sowing time, cultivars) can be derived from land use survey; and meteorological variables can be measured from a recorded daily data using ground weather station. Crop variables are simulated daily as outputs of the models.

NOAA-AVHRR dataset provides useful information for the extension over wide land surfaces. It has many important points to be used as inputs for crop growth modeling: remotely sensed crop variables and climatic information. This covers a wide area of data acquisition, availability of daily data acquisition, high resolution sensor, and reasonable cost.

NOAA-AVHRR dataset, as the daily input for crop growth models, should be supported by a series of processes to extract the important information from remotely sensed data in a specific imagery format to become readable data input for the model. These include import process to image processing software, image rectification using available GIS data, NDVI calculation, data filtering using GIS land-use data, and exporting the result to the format specified by the crop model. Most of those processes take a large amount of time and they require specific tools and skilled operators.

1.3. Motivation and Objectives

Current research on applying remote sensing data for crop growth modeling emphasizes measuring NDVI value to calculate leaf area index. This value can overide the need of daily climate to calculate the biomass. The processes of measuring NDVI and calculating LAI in remote sensing are based on raster data model using the image processing method. This paper introduces an automation process of NOAA-AVHRR imagery extraction. The output is restricted to obtain NDVI values of rice field in Java Island as an input for rice growth modeling from daily NOAA AVHRR data. The optimization of the whole system, affected by this automation process will be evaluated.

We consider an automation process module as appropriate for this objective. This module was developed using C++ language as an independent application running on Windows operating system. The main input for the application is NOAA AVHRR dataset. The additional input is a rice field filter dataset file. Spatial and temporal data of NOAA AVHRR dataset can be examined from the dataset content. The optimization of data structure, memory management and file handling was also considered to make the program run faster and efficient.

1.4. Research Boundary Scheme

This research is a part of managing natural resources using information technology. An overall system for rice growth modeling was constructed from four important sub-systems : geographic information system, remote

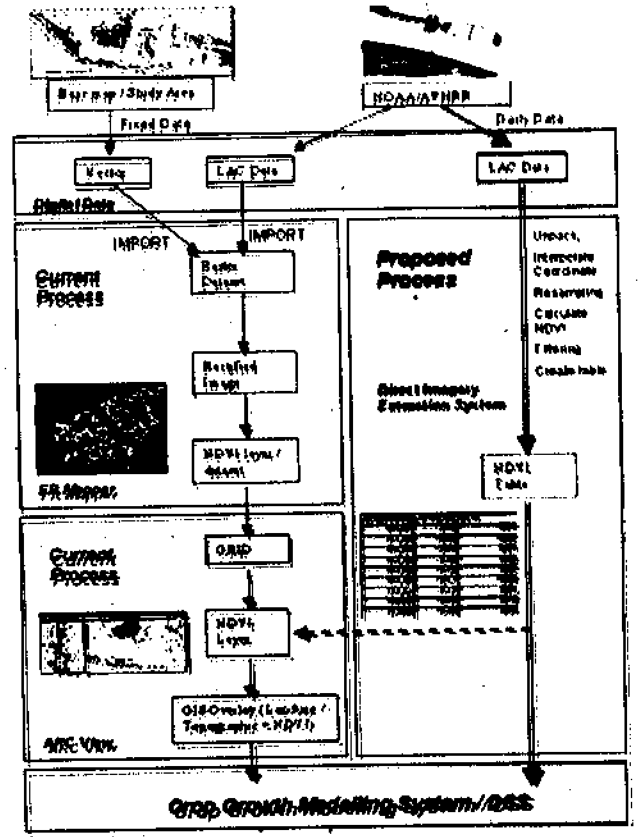

Figure 1. Block Diagram of Proposed System

sensing, dynamic modeling, and decision support system. The automation process using Visual C++ programming was designed to improve data acquisition method of dynamic rice growth model. Figure 1 shows the system block diagram.

1.5. Research Output

Prototype of direct NOAA imagery extraction system has been developed and implemented using C++ programming language. The program was tested with a series of NOAA dataset starting from 1 May 2000 to 30 June 2000. The dataset was used to verify the capability of handling current daily NOAA data to support the current research of SARI (Satellite Assessment of Rice in Indonesia) project.

Vector map was used to visually verify the rectification process. ArcView GIS was employed to display and compare the raster NDVI dataset to ensure the image processing / remote sensing module runs properly. This vector map was also used to visually verify the spatial mask / filtering of rice field process.

The final result of this automation process is a list of NDVI data of selected cells or rice field area. This data is saved in a standard ASCII tabular format for future use in modeling application.

Our major contribution is an integrated data handling module that is customized and optimized for supporting daily NDVI data acquisition for rice growth modeling. This module involves image processing and GIS analysis without the need of specific expensive software and skilled operator. All controls to the module are fed using command line parameters.

2. Background

Natural resources management has become a multidiscipline cooperation and research. Basically, GIS, remote sensing, modeling, and decision support system can be integrated as shown in Figure 2.

Many researches on information technology for natural resources management use a forementioned basic integration scheme. Sophisticated tools for remote sensing and GIS are currently available. Decision support

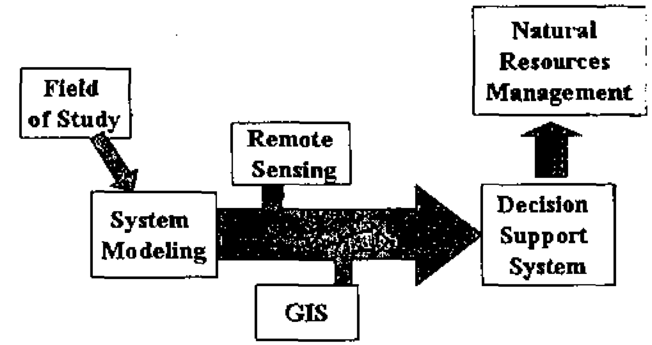

Figure 2. Managing Natural Resources

system module and modeling module are specific tools that are designed to be used in certain type of natural resources management. Currently, there are many researches in developing dynamic model for natural resources management. One of the dynamic models for agriculture is crop growth model.

2.1. Crop Growth Model

In the early development of deterministic and mechanistic crop growth modeling, system behavior was defined to simulate the actual crop growth of a certain species in a limited area of data observation. The area of data observation was restricted to reduce the cost and time to acquire real data. Scaling up process was used to predict the result of model over wider area from a limited space of observation data.

Timely and accurate crop yield forecasts on a regional scale are becoming increasingly important to policy makers, commodity trade and food industry to support their decisions. Recently, other methods for yield forecasting are being explored based on new techniques such as simulation, geographic information system (GIS) and remote sensing technology. Satellite remote sensing provides opportunity to measure actual crop growth and development.

Tamme van der Wal (1996) used remote sensing data from satellite to calibrate a crop simulation model WOFOST in Sevilla, Spain. The other satellite imagery combination for crop yield assesment had been applied in Poland (Dabrowska, 1996), where 30 NOAA-AVHRR images combined with SAR data and LandsatTM image were used to determine NDVI and soil moisture, and to calculate LAI from those two indices.

NOAA-AVHRR data have already been demonstrated useful for eco-climatic classification, because of the abundant environmental information contained in NDVI and thermal infrared images (Derrien *et al.*, 1992, Benedetti *et al.*, 1994). The performance of NOAA-AVHRR was evaluated in Tuscany, Italy for climatic data extraction, and showed that it could provide useful information for the extension of fundamental climatic parameters over wide land surfaces. (Claudio Conese *et al.*, 1996).

Other trial to determine evapotranspiration using surface temperature from NOAA Satellite over Hungary was reported from 1992 to 1994 (Dunkel *et al.*, 1996). Other work using NOAA imagery for enhancing rice growth modeling and yield forecasting is currently conducted in China (1996-2003) and also in Indonesia (SARI project, since 1998). The capability of NOAA-AVHRR data to estimate LAI for agrometeorological models was evaluated in Finland (1995) by comparing LAI from field measurement and LAI estimated from NOAA-AVHRR satellite imagery (Kuittinen *et al.*, 1995).

2.5. NOAA AVHRR Dataset Extraction

Dynamic crop growth modeling using NOAA AVHRR datasets as input to determine LAI is currently developed in Indonesia. The dynamic crop growth modeling contains several main sub-models and their specific tools: input data handling, remote sensing, geographic information system, crop growth model, and decision support system.

Remote Sensing tools provide various image processing capability such as image display (view), enhancement, rectification, manipulation, classification and format conversion. Only very limited features are used for supporting this modeling purpose. GIS tools also provide various spatial analysis features for digital map processing, but very limited features that can be used to support this modeling purpose. Reducing the use of sophisticated and expensive software was considered as one of the advantages of making the model feasible to be operated using daily NOAA-AVHRR data. A customized application should be developed to extract the NDVI information directly from NOAA-AVHRR imagery and produce a numerical table containing earth locations (longitude and latitude) and their corresponding NDVI values.

NOAA AVHRR Data structure and processing method are available on the internet, and can be obtained through NOAA Official website. The NOAA dataset user is described in NOAA Polar Orbiter Data user guide (NOAA POD Guide). NOAA Imagery extraction system was designed based on this user guide and Windows programming environment.

2.6. Surface Interpolation

Remotely sensed data was constructed by a matrix of digital number corresponding to a certain observation point on the earth surface. Since the sensor scans the reflectance of features on the earth surface in the form of spheroid, the observation points are not linearly distributed. To interpolate the observation value (*e.g.* NDVI) from known observation points into the entire surface of coverage area, the interpolation process from reference points should be performed. This process is also a part of image rectification (Lillesand, 1994). Re-sampling process is required to fill the matrix cell value. For natural resources management or feature's detection, the nearest neighborhood re-sampling method is commonly used. This method sets the value of each target cell to the closest known point value (Lillesand, 1994).

III. Materials and Methods

3.1. Research Material

The output of this research was designed to support currently established rice growth model in SARI project. Since the rice growth dynamic model had already been established (Handoko 1994), this research focused on data preparation for the model. The raw data input from NOAA AVHRR dataset were processed to produce NDVI as data input for the model by the use of a computer programming language.

a. Study area : Java Island. The landuse map and other data are in ArcView format. All maps are in Geographic Coordinate System using decimal degree unit, with a map scale of 1 : 250,000. Java Island covers about 70% of rice field in Indonesia.

b. Satellite Imagery data: NOAA-AVHRR 14 daily data, downloaded from NOAA website (http://www.saa.noaa.gov) in LAC (Local Area Coverage) format. Temporal data boundary for this research is daily data from 01 January 1999 until 16 June 2000.

c. Spatio-temporal data handling : File naming convention to handle daily input data and output data. Daily data consist of raw imagery data, rectified imagery data, NDVI imagery data, filtered imagery data. Spatial resolution of the observation is 100 ha for each pixel. Temporal resolution is daily.

d. Processing schedule : Data acquisition, image processing, NDVI calculation, filtering rice field data and file handling.

e. Programming constraints : Program flowchart is shown in Figure 3. This flowchart shows general steps of the extraction method. There are several constraints should be considered in this application:

1) Windows Memory management. Program should optimize the use of computer memory to reduce the I/O process. Most of windows based compiler such as Delphi or Visual C++ support the memory handling system.

2) High speed processing (efficient algorithm). Program should optimize the program flow to minimize the processing time.

3) Huge dataset. Program should be capable to handle a very big dataset file and manage a multi-temporal data.

4) Spatial and temporal database. Program considers NOAA-AVHRR dataset imagery as spatial databases. The data structure was based on NOAA POD Guide documentation.

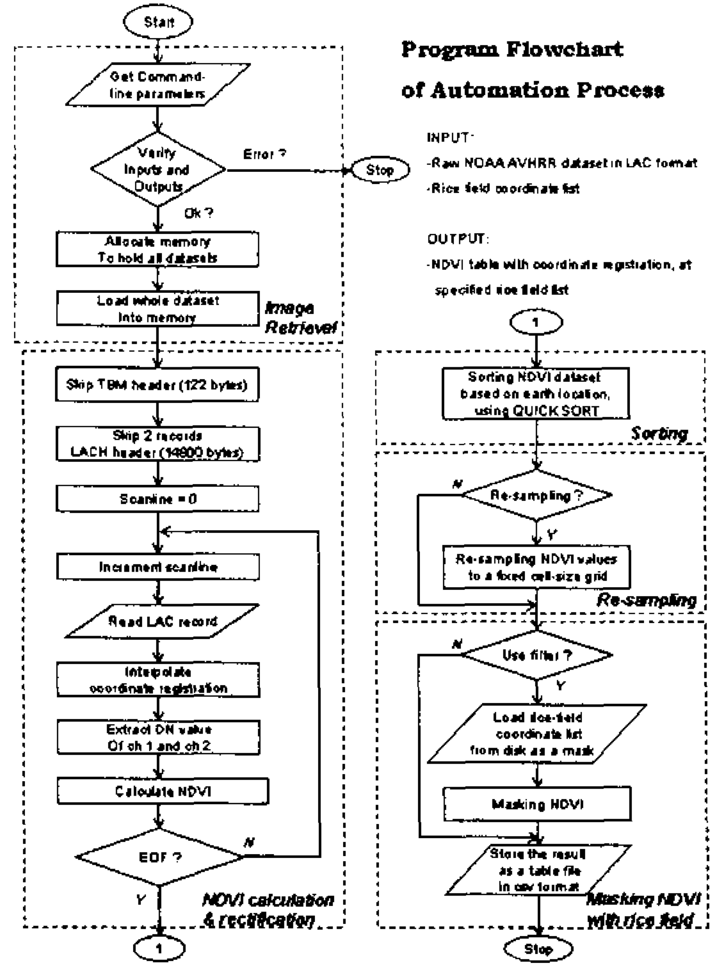

Figure 3. Flowchart of Extraction System

4. Prototype of Direct NOAA Imagery Extraction System

4.1. System Design

This application implements a basic database and data structure design that supports current NOAA AVHRR Dataset formats as the required input format for Shierary rice growth model. General data flow diagram for this system is shown in Figure 4.

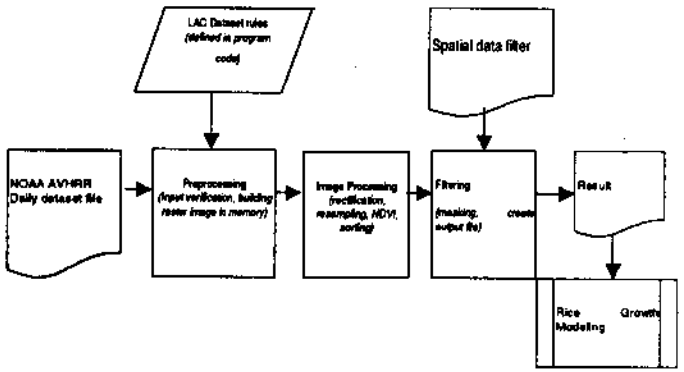

Figure 4. General Data Flow Diagram

The general data flow diagram shown above was used to design the architecture of our proposed system. The system would integrate preprocessing, image processing and filtering steps into one application program to reduce the input-output redundancy. The NOAA AVHRR image datasets and spatial data filter are ready and stored as files in a disc storage system. Spatial and temporal data management for this image inventory was not included in our system architecture. Output of this application is also stored as a file for future use by the rice growth model.

We use the batch methods for our proposed system. An additional program was also designed to support this system. It converts the output file from our application to a readable table format by ArcView GIS software. The system's architecture diagram is shown in Figure 5.

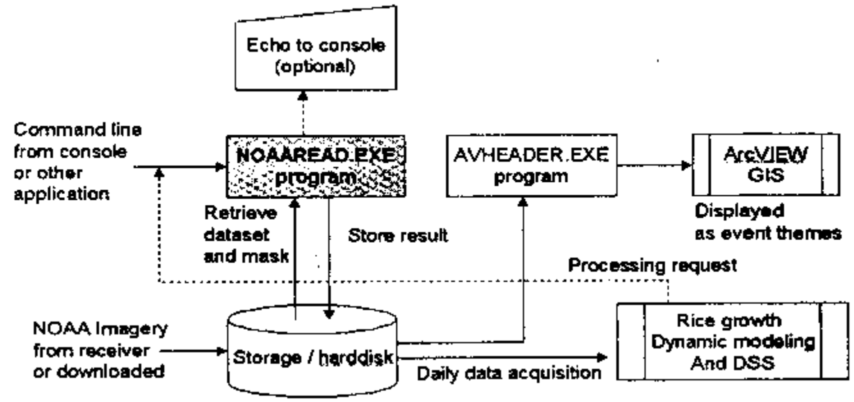

Figure 5. System architecture

4..2. Image Retrieval Sub-module

The first part of our application is image retrieval sub module. This sub module is invoked / executed by user or other modules using command line parameters. It prepares the memory allocation to hold the dataset. By loading the dataset into computer memory and performing the operation in computer memory, we can reduce disk input/output processing time. This is because memory access is much faster than that of disk access.

4.3. DVI Calculation

After the dataset is loaded into computer memory, the next process is video channel data decoding. This step converts 10 bits packed data from dataset into array. Each scan line is stored in 2 consecutive 7400-bytes records. The program extracts the channel 1 and channel 2 data, calculates NDVI from these 2 channels, and stores the results in a two-dimension array.

4.4. Image Rectification

There are 2,048 points in a LAC/HRPT scan line. The above NDVI sub module calculates NDVI values of each 2,048 points in a LAC scan line. The **Earth location data** (latitude and longitude) are sampled every 40 points starting at point 25 (25, 65, 105,..., 1945, 1985, 2025). There are 51 possible Earth location values for each scan line. Latitude or longitude value is stored in two-byte fields in 1/128th unit of a degree (0 to 180E positive, 0 to 180W negative).

The rectification sub module uses linear distribution method to determine earth location value of every pixel in a scan line. The interval between two known earth locations is 40 pixels. Using the mathematical model, we can calculate the earth location of pixel (x_i, y_i) between two known values (x_1, y_1) and (x_2, y_2) :

$$Dx = (x_2 - x_1)/40$$
$$Dy = (y_2 - y_1)/40$$
$$x_i = x_1 + i.\ Dx$$
$$y_i = y_1 + i.\ Dy$$

4.5. Grid Interpolation

The result of image rectification sub module can be considered as an actual data acquisition of NDVI. Every pixel represents the NDVI value and its corresponding corresponding earth location. However, for spatial analysis, this data is not suitable because it represents the series of evaluation points. Each record does not represent a fixed area size. The problem will rise when this data should be linked with existing rice field grid. The rice field map is a fixed interval raster pattern, known as a grid. To convert the known NDVI location into a fixed interval, an interpolation or re-sampling process is required. Nearest neighborhood re-sampling is commonly used in remote sensing since this method keeps the original value of the spectral information.

4.6.. Spatial Filtering

The term *filtering* in this step means eliminating pixels that fall outside the rice field as specified in rice field location table. In computer programming terminology, this process is also called *masking*, where NDVI dataset as the original data will be selected only for the predefined rice filed location using the rice field table as a mask dataset.

Some considerations in developing this masking sub-module are:

a. The masking process uses sequential search to find the matched earth location between NDVI dataset and rice filed dataset. Sequential search only works if both dataset have been sorted. Rice field dataset is sorted only once when this data was prepared. NDVI dataset is sorted in computer memory prior to the masking process.
b. The rice field dataset is set in two-digit decimal places. To match these two dataset, the NDVI dataset should also be in the same precision. The masking result will also stored with earth location precision of two digit decimal places.

5. Results and Discussion

5.1. Introduction

To test the automation process developed in the previous section, we built a prototype application that implements the remote sensing task as described in the previous section. To support this application, we prepared NOAA dataset (downloaded from NOAA website), digital map for Java Island, and other related data from SARI project. Additional minor tools are also developed to complete this research. These tools include a metadata extraction from LAC dataset, a stopwatch, comma delimiter to space delimiter converter, and ASCII delimited table to ArcView table converter. Most of these supporting tools were developed using Turbo Pascal 7.0.

It is hard to find comparable prototypes because it is a relatively new field of interest of using daily NOAA data for a dynamic modeling of natural resources management. However, we can use a visual comparison with a current remote sensing and GIS process. We used ERMapper 6.1 for windows and ArcView 3.1 for windows to do this visualization and comparison. The actual result of our application was ASCII tables containing a list of NDVI in specified study area, with specified NOAA satellite imagery dates of acquisition. This format of output data was chosen to support the current rice growth model in SARI project.

With the recent progress of SARI project, the rice growth model was tested in five assorted areas of the following regencies areas: Purwakarta, Karawang, Subang, Mojokerto and Pasuruan, which covers almost 20,000 km² of rice fields. The rice field cell locations of those areas are available in separate files(i.e onefile for each area). We simulate the use of our application by the rice growth modeling in two different scales: regency base (kabupaten) and the entire area of Java Island (regional). Based on the limitation of rice field database, we used the entire area in Java Island to simulate the filtering process of rice field in Java Island.
Rice field mask was prepared using ArcView GIS and Microsoft Excel. Rice field mask for Karawang has 1078 cells (107,800 ha), and Java Island mask has 107168 cells (10,716,800 ha).

After the NOAA imagery and masked dataset were ready in the storage, the next step was processing the imagery using both the automation process and current remote sensing software. This step compared the complexities, difficulties, and advantages of each method.

We used the Java vector map to verify the rectification result. By comparing the rectification result with the raw image, we can obviously distinguish the significant distortion of raw NOAA AVHRR dataset at the outer side of the images. The density of pixels in the outer side of the images is lower than that of the inner parts of the image.

Because the distribution of observation points is not linearly , the NDVI value of target cells of the study area are probably unavailable. Based on this consideration, it is important to determine the spatial distortion of NOAA imagery first, before using it for NDVI analysis. Figure 6 shows detailed (zoomed) NDVI image of Eastern part of Java Island from the NOAA Imagery.

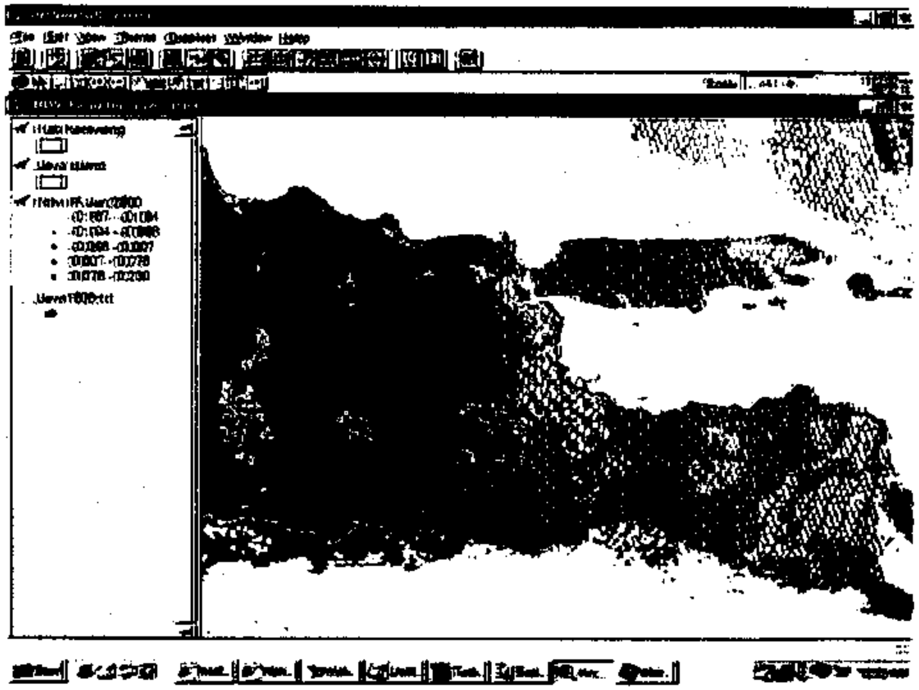

Figure 6. NDVI image of East Java, 08 June 2000

5.2. Masked NDVI

Functioning data acquisition tools for rice growth modeling, this application program supports masking process to obtain NDVI values of specified locations of the earth. The program was tested to mask NDVI valuesof three series of datasets of specified rice field cells of Karawang, West Java. The output of this NDVI masking was also converted into supported ArcView ASCII delimited format for visual interpretation. The visual output of masked process is presented in Figure 7.

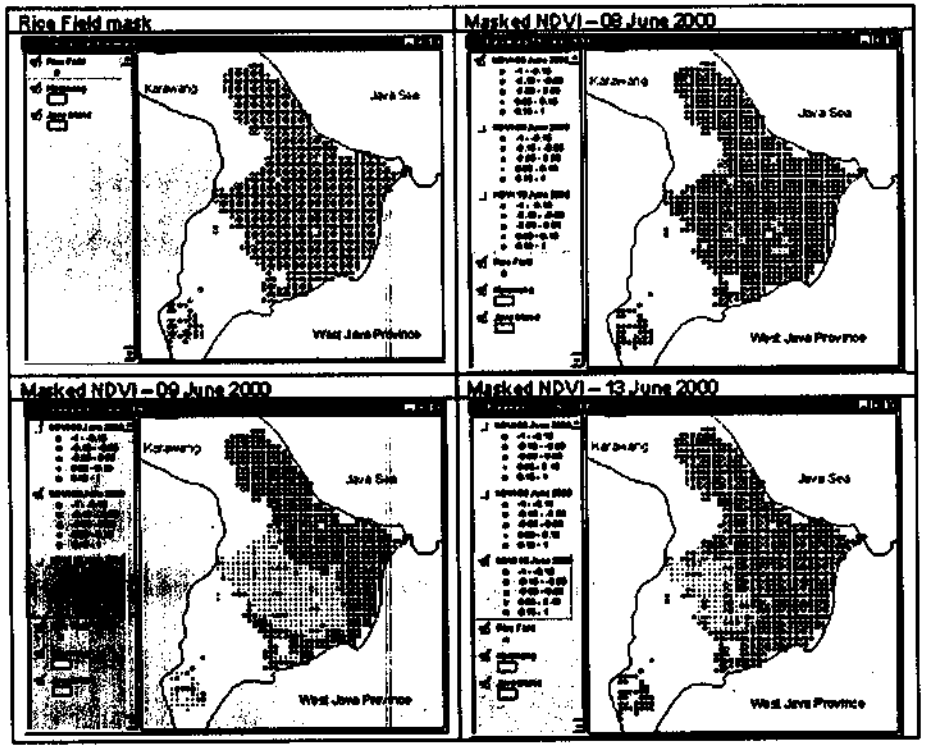

Figure 7. The visual output of masked NDVI on 8, 9 and 13 June 2000.

The masking process was also performed using the entire Java Island as the masker. Even this process does not represent the actual usage of NDVI acquisition for rice growth modeling, this evaluation process provides general information about the execution time to capture more than 100,000 cells of rice fields. This value is comparable to the total rice field area throughout Indonesia. To compare the actual NDVI distribution with the masking results after re-sampling process, we run the application using three series of NOAA data-sets. Table 1 shows the summary of NDVI distribution results. The execution time of these processes and the comparison with current methods will be discussed in the next section.

Table 1. Summary of NDVI Distribution

Acquisition Date	Karawang (1,078 cells)			
	Without Interpolation		With Interpolation	
	cells	%	cells	%
8-Jun-00	902	83.8	991	92.1
9-Jun-00	951	88.2	1,010	93.7
13-Jun-00	426	39.6	750	69.7
	Whole Java Island (107,168 cells)			
8-Jun-00	65,495	61.2	89,404	83.4
9-Jun-00	84,493	78.8	97,315	90.8
13-Jun-00	61,831	57.7	86,807	81

5.3. Validation

The final check of this application was a series of testing / validation processes. The results of this validation process are shown in Table 2. It shows that the system performs satisfactorily and this will support the application of the Shierary-rice crop model for rice monitoring.

Table 2. Application Testing Result

No	Item to check	Remarks	Testing result
1	NDVI value range check	Valid range: -1.00 ≤ NDVI ≤ 1.00	VALID. The NDVI range also exactly the same as calculated in ERMapper
2	Coordinate registration	All pixels should have their earth location value, visual verification using ArcView GIS	VALID. The rectification result is much better than GCPs methods in remote sensing with manual entry GCPs
3	File size flexibility	Run the application with various imagery size and different coordinate range	OK. Regardless the image file size, the program runs properly.
4	Filter / masking validation	Compare the output of application with and without specified filter dataset using ArcView GIS	OK. The masking sub module can filter the dataset using the specified filter dataset.
5	Re-sampling validation	Compare the output of application with and without re-sampling using ArcView GIS	The selected NDVI value before re-sampling: 40-80%, after re-sampling: 70-94%.
6	Processor speed factor	Run the application in several machine with different speed of processor with the same file. Compare the elapsed time.	Program was tested in three types of computer: Pentium 166 MHz with 32 MB RAM, Pentium II-266 MHz with 64 MB RAM and Pentium III-450 MHz, 64 MB RAM. The elapsed time in Pentium III-450 MHz is much faster than the others.
7	Memory size factor	Run the application in 32 MB and 64 MB RAM computer system and compare the elapsed time.	Significantly changed
8	Link with the rice growth modeling application	Include this module as a sub module in dynamic rice growth application. The modeling application was developed using Visual Basic.	The modeling application uses its standard procedure to open the saved file on the disk. This system supported the current system with the readable NDVI file. We don't need to develop a communication or handshaking between those two application in computer memory.

6. Conclusions

Managing natural resources using daily basis NOAA AVHRR satellite imagery as the input for dynamic modeling requires a supportive tool to automate the data acquisition. This prototype of automation tool has the capability of handling the basic operation of image processing task efficiently.

NOAA AVHRR dataset is very useful for managing natural resources since the data are delivered with their earth location references. This feature enables the use of remote sensing data for the area without using any ground control point such as ocean, forest, or mountainous area. From this research, we also found several significant improvements in managing natural resources information using this automation process :

- Batch processing method is very useful to evaluate a temporal series of NDVI data for a single cell or a series of cells.
- Batch processing method as a part of rice growth modeling system enables the computer application for dynamic model using daily remote sensing data without image processing software.
- Optimation in memory-based data handling can reduce processing time of remote sensing data significantly without reducing data quality.
- Automation in image rectification produces more accurate rectified dataset as a spatial data input for future analysis. The ground control points (GCPs) are linearly distributed in all dataset. The GCP to total pixel ratio is 1:40, while the ratio for manual GCPs collection is as low as 1:100,000.

Output of this application is customized in a format readable by current rice growth model. The general format is ASCII delimited file. We introduced a converter to an ASCII x-y-z format for ArcView compatibility. There are several data format that support geo-referenced raster dataset such as Geo-TIFF, ERDAS IMG, and ERMapper ERS data type. Conversion of the output into those formats is a challenging process for data exchange among applications.

Image rectification process in this research uses a linear transformation of GCPs method. Refinement of this rectification is also a significant contribution in NOAA data processing because the accurate coordinate registration is a key for the precision of data acquisition. NOAA AVHRR dataset includes geometric information of satellite position, angle, and other mathematical variables for future automation in rectification.

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