A Rainfall Monitoring System in Thailand by Using Image Processing Technology

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ABSTRACT

The Weather Research and Forecasting (WRF) modelling system is designed and developed to be a flexible atmospheric simulation system. It produces the images to display the three days rainfall forecasts. Therefore, the rainfall monitoring system has been created to calculate the volume of accumulated rainfall within six consecutive days (three days forecast and three days after) by applying the image processing technology with WRF images outputs. This work aims to assist in flood disaster monitoring. The outcomes of this system are the list of province names that have the highest accumulated rainfall volumes by applying the erosion of image processing filter and the intersection and buffer spatial operations to the WRF images.

Keywords

Rainfall monitor; Image processing; Morphology; Erosion convolution; Weather Research and Forecasting model.

1. INTRODUCTION

Over the past several years, Thailand experienced flooding and got harder every year. Therefore, for coping with the flood occurrence, we have designed the concept and developed the monitoring system to forecast the accumulated rainfall and warn when there is a heavy amount of precipitation falling in any areas. In this work, the rainfall forecasts data applying for analysis have been obtained from the meteorological model. We have used the Weather Research and Forecasting or WRF model to produce WRF images to display the rainfall forecasts as shown in Figure 1.

The collections of WRF images are the image output data from WRF model which can be calculated and displayed the accumulated rainfall in short-terms forecasts. Then, these WRF images are also the input data of the rainfall monitoring system that these images display the accumulated rainfall for 3 days forecast as shown in Figure 2 and 3 days after. In addition, the WRF images are produced every 12 hours.

Image processing technique in this article is to calculate the accumulated rainfall for 3 days forecast (including the current day) and 3 days after in the area of Thailand. The obtained information are used to study and analyse the rainfall amount in Thailand's provinces to assist in the water management and monitor the areas that may have high water amount accumulation which is caused flooding. Thus, the purpose of this work is to monitor and analyse the flood disasters in Thailand. By applying the basic functions of image processing, this work determines the accumulated rainfall during the period of 6 days. The image data are the system inputs that show the rainfall amounts with the colour values.

In image processing, we use mathematical morphology to identify and extract image that represents and describes the properties of form or shape within the image. Morphology is formulated in terms of set theory. The basic idea is to probe an image with a template shape or a mask, which is called structuring element, to quantify the manner in which the structuring element fits within a given image [6].
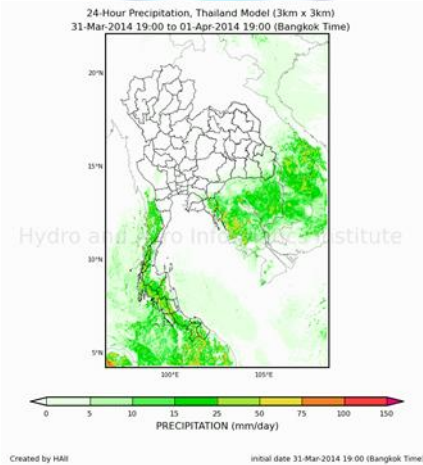

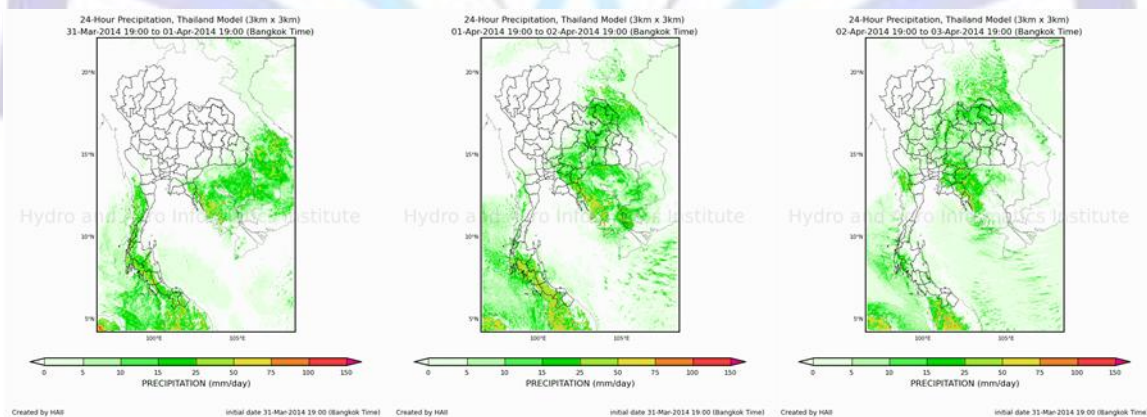**Fig 1: The image output of WRF post-processing**

Fig 2: WRF images show the accumulated rainfall for 3 days forecast

The remaining of this paper is organized as follows: Section 2 presents the general background information about the research. Section 3 proposes the whole rainfall monitoring system architecture and the detail of each process. In Section 4, the implementation of the rainfall monitoring system is shown. Finally, Section 5 is the conclusion.

2. BACKGROUND

The rainfall monitoring system has several basic technologies applied in each process. The erosion is one of fundamental implementation of morphological operation. It is applied to binary images to erode away the boundaries of regions of foreground pixels [5]. The *Intersection* and *Buffer* spatial operations are applied to determine the provinces area from images. Moreover, the rainfall forecast images in this system are the results of WRF model. All previous mentioned technologies are described in the followings.

2.1 Weather Research and Forecasting Model

The Weather Research and Forecasting (WRF) Model [7] is a mesoscale numerical weather prediction system designed to serve both atmospheric research and operational forecasting needs. The effort to develop WRF began in the latter part of the 1990's and was a collaborative partnership principally among the National Centre for Atmospheric Research (NCAR), the National Oceanic and Atmospheric Administration (represented by the National Centres for Environmental Prediction (NCEP) and the (then) Forecast Systems Laboratory (FSL)), the Air Force Weather Agency (AFWA), the Naval Research Laboratory, the University of Oklahoma, and the Federal Aviation Administration (FAA). The WRF model supports a variety of capabilities. These include as follows [7]:

- Real-data and idealized simulations
- Various lateral boundary condition options for real-data and idealized simulations
- Three-dimensional analysis nudging
- Observation nudging
- Regional and global applications
- Digital filter initialization
- etc.

WRF is a model that is primarily intended for short-term weather forecasts. This model can predict the amount of rainfall, wind, temperature, etc. The results of this model are the data set stored in the NetCDF format (Network Common Data Form).

2.2 Morphology Image Processing

An image consists of a set of coordinates. Morphological image processing is a collection of non-linear operations related to the shape of features in an image. Morphological operations rely on the relative ordering of the binary image pixel values. An object in a binary image consists of any group of connected pixels. The properties in binary images are the shape, size and location of the objects in the image. Morphological techniques probe an image with a small shape or template called a structuring element. The structuring element is positioned at all possible locations in the image and it is compared with the corresponding neighbourhood of pixels as shown in Figure 3 [2]. Structuring elements play in morphological image processing the same role as convolution kernels in linear image filtering.
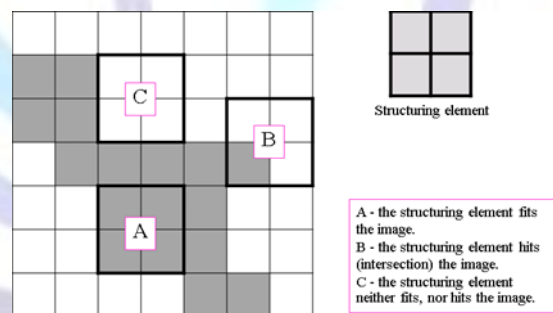

Fig 3: Morphological operation: probing of an image with a structuring element

2.2.1 Convolution Kernel

Convolution is a simple mathematical operation which is fundamental to many common image processing operators. Convolution provides a way of multiplying two number arrays, generally of different sizes, but of the same dimensionality, to produce a third array of numbers of the same dimensionality. The convolution is performed by sliding the kernel over the image, generally starting at the top left corner, so as to move the kernel through all the positions where the kernel fits entirely within the boundaries of the image. If the image has M rows and N columns, and the kernel has m rows and n columns, then the size of the output image will have $M - m + 1$ rows, and $N - n + 1$ columns [4].

Mathematically we can write the convolution as following formula (1) [4].

$$O(i, j) = \sum_{k=1}^{m} \sum_{l=1}^{n} I(i + k - 1, j + l - 1)K(k, l) \qquad (1)$$

where i runs from 1 to $M - m + 1$ and j runs from 1 to $N - n + 1$.

2.2.2 Erosion

To perform erosion of a binary image, we successively place the center pixel of the structuring element on each foreground pixel (value 1). If any of the neighborhood pixels are background pixels (value 0), then the foreground pixel is switched to background. Formally, the erosion of image A by structuring element B is denoted A ⊖ B. The mechanics of dilation and erosion operate in a very similar way to the convolution kernels employed in spatial filtering. The structuring element slides over the image so that its center pixel successively lies on top of each foreground or background pixel as appropriate. The new value of each image pixel then depends on the values of the pixels in the neighborhoods defined by the structuring element [8]. Figure 4 shows the results of erosion on a binary image [8].
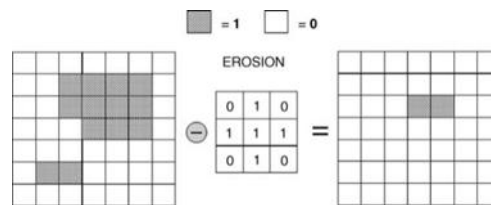

Fig 4: Erosion: a foreground pixel only remains a foreground pixel if the 1s in the structuring element (in this example, a cross) are wholly contained within the image foreground. If not, it becomes a background pixel

2.3 Geographic Information System

A Geographic Information System or GIS dataset is the spatial representation of real-world features. These features are described with their attributes that are the non-spatial data. There are two ways to represent the feature and attribute of data in a GIS: as vector data types or as raster data types. Both data types are the basic data structures for storing GIS data [1].

2.3.1 Spatial Data Types

First, a vector GIS data layer is stored as a set of coordinates. It represents the real-world features using basic GIS elements: points, lines and polygons. Point represents the locations such as villages, wells, schools, etc. Line represents the path passing through two or more different points such as rivers, roads, railways, etc. Polygon represents the close path or the boundary. One advantage of vector type is the ability to store multiple attribute data for each feature [1]. Three features mentioned above are illustrated in Figure 5. Second, the raster GIS data layers represent real-world features by dividing data into equal-sized cells or pixels [1]. The raster data structure is illustrated in Figure 6. One pixel of raster data can contain only one value.

Fig 5: Three vector data representations of real world features

Fig 6: The raster data is divided and collected into pixels

2.3.2 Spatial Operations

The spatial operations are the GIS processing functions to perform spatial analysis. The geometry *Intersection* and *Buffer* have been applied to match the areas in this work [3].

- Buffering geometry function generates geometry by encircling geometry at a specified distance as shown in Figure 7 [3].
- Intersection of geometries function returns the intersection set of two geometries. The intersection set is always returned as a collection that is the minimum dimension of the source geometries. If the geometries do not intersect or if the intersection results in a dimension less than both source geometries, an empty geometry is returned. Figure 8 illustrates some examples of the Intersection geometry function [3].
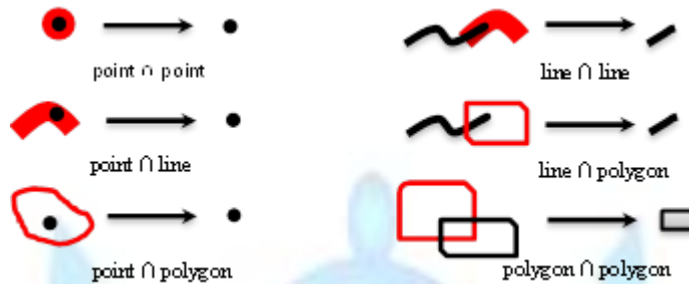
Fig 7: Some examples of the Buffering geometry function

Fig 8: Some examples of the Intersection geometry function

3. THE RAINFALL MONITORING SYSTEM

The rainfall monitoring system has been developed to track water volume which is caused by rainfall. The information obtained from the analysis of this system can be used for early warning flood disasters and managing water resources. It helps communities to prepare for floods. Thus, the system architecture is described in the following.

3.1 System Architecture
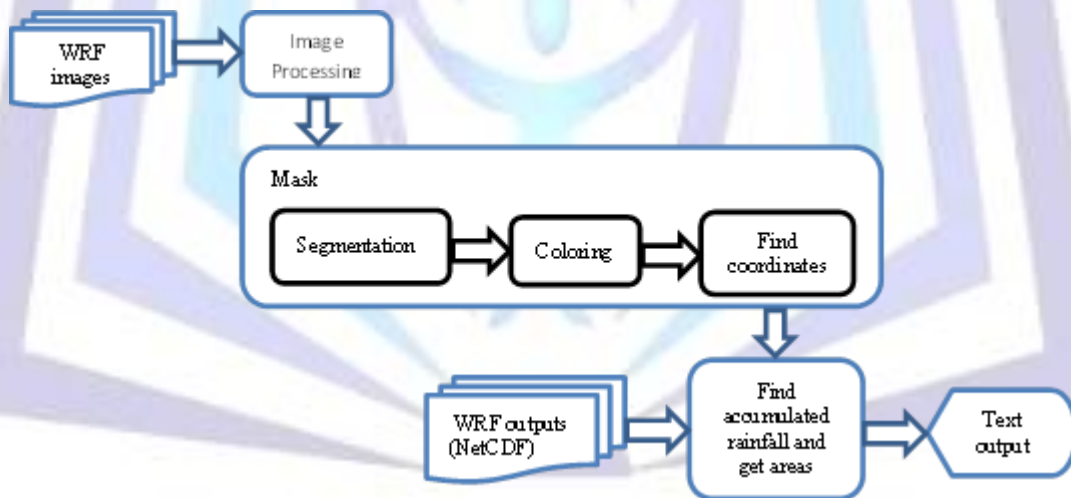
Fig 9: The rainfall forecasting system architecture

As the architecture in Figure 9, a rainfall monitoring system using image processing technology is divided into three following steps.

3.1.1 Segmentation

The segmentation is the images separation according to the interesting part. The traditional image outputs of WRF post-processing consist of the message whether it is the time, date, rainfall scale, and etc. From these images, our interest area is in the visual part of Thailand boundary in the frame. We cropped the interesting area of output images to generate a mask or template in the next step.

The separation of the original images, firstly, we had to find out the four corner pixels of image as Figure 10. Secondly, these four corner pixels were used in the process of cut off the images which were cut with the picture editor program as shown in Figure 11.

The next step of the segmentation is to eliminate unwanted colour out of the image. The colours eliminated were the colours that represent the rainfall volumes. How was that used white colour (RGB: 255,255,255) instead the colours which were eliminated. After eliminating unwanted colours out, it would not have the colour of rainfall volumes in the image. However, the spatial boundary of the image remained as shown in Figure 12.
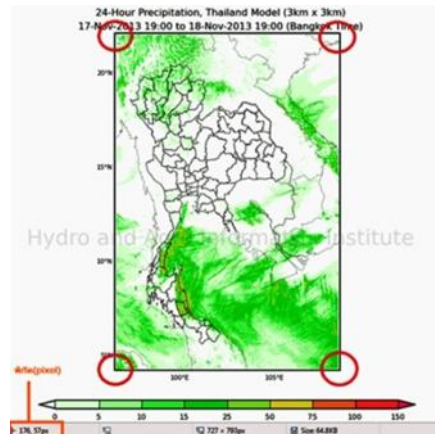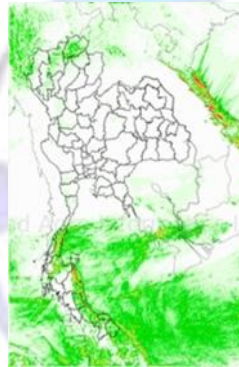

Fig 10: The WRF output image with four corner pixels

Fig 11: The WRF output image is crop

Fig 12: The WRF output image that the colours are eliminated

3.1.2 Map Colouring

After eliminating the colours out until the image had the only remaining boundary area, the colours were added in each boundary area by uniquely colour as shown in Figure 13. The image which was filled the colours in the province areas was brought to calculate the pixels of each province boundary. A group of mentioned pixels can be used to find the amount of rainfall in the next step.

Fig 13: The WRF image which the uniquely colour was added in each boundary area was used to be the mask

3.1.3 The Pixels Finding and Storing

The colouring image was used as a mask or a template to find the coordinates of each province boundary. Each province had its own particular colour which was processed from the Map Colouring step. Therefore, the colours were used to separate province and find their coordinates from the images. These coordinates were collected as a mask. The rainfall data in NetCDF files which was the outputs of the model was stored in the ordered pair of latitude and longitude. However, since the beginning of the image (0, 0) being the position did not match with the beginning in the NetCDF file which was the world coordinates. The beginning of image was the position (0, 0) in the upper left, but in NetCDF the position (0, 0) at the bottom left. Therefore, the mask image was vertically rotated to obtain the corresponding beginning position. Figure 14-16 are shown the pixels finding and storing processes.
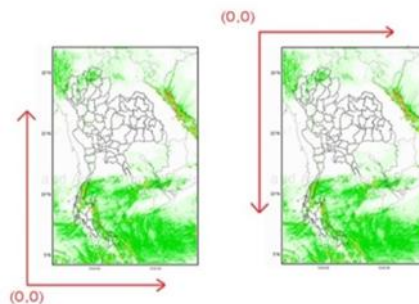

Fig 14: A comparison between the beginnings of rainfall data in NetCDF (left) with pixel from the image (right)
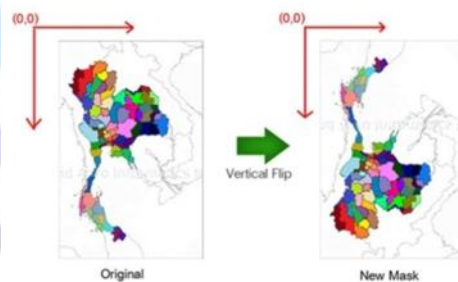

Fig 15: The vertically rotated mask image

Fig 16: A comparison between the NetCDF's beginning with the beginning of the new mask image

How to extract the boundary coordinates of each province was to determine the extent of colour. The colour codes were obtained from the procedure of colour filling in each country or Map Colouring step. As the colour filling to the image, we also kept the code (R, G, B) of each colour to be used to determine the province boundaries. If the coordinates were in the areas of the interesting colours, they were collected. For example, the determined colour code of Yala province (R, G, B) was (200, 100, 50) and then found the area with using that colour and saved the coordinates of that colour as shown in Figure 17. A number of colour pixels were also collected to be used to calculate the average rainfall in each area. The previous mentioned process was repeatedly executed until all provinces in Thailand done. All coordinates were then saved in a python file format (.py) to create a mask image. Due to this work, the program was written with python programming language.
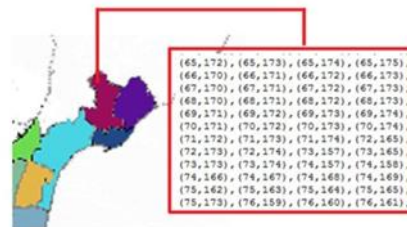

Fig 17: A sample of Yala area and its coordinates

3.2 The Volume of Rainfall Calculation

The volume of rainfall calculating from WRF outputs used the coordinates obtained from the mask to find and extract the rainfall volume in each pixel. The rainfall volumes were calculated from RAINC and RAINNC variables and TIMES variables of WRF model outputs. The rainfall volumes were accumulated in all time frames. That meant each time frame had the increased cumulative rainfall until the last of time frames. The number of time frames depends on the determined term in forecasts of WRF model such that if WRF is defined to predict 3 days, it should have 73 time frames of the output. However, equation (2) is the formula to calculate the hourly accumulated rainfall and equation (3) is the equation to calculate the daily accumulated rainfall. The hourly accumulated rainfall volume is the result of an hour earlier rainfall minus the rainfall at the current hour.

$$R_{hourly} = R(T_h) - R(T_{h-1}) \qquad (2)$$

$$R_{daily} = R(T_{dh}) - R(T_{dh-1}) \qquad (3)$$

where $h = \{1, 2, 3, ..., 25\}$ is each time frame on one day, $dh = \{24, 48, 72, ...\}$ is total time frames on n days, and $n = \{1, 2, 3, ...\}$.

The accumulated rainfall amounts were taken to calculate the average rainfall in areas with dividing by the province area. We used the number of colour pixels in each province instead of the provinces area value (the number of pixels was saved in pixels finding step). For example, Yala's rainfall volume equalled to 2000 mm. divided by the area of Yala (the number of colour pixels of Yala) which was 200 pixels, so it would be 2000/200 and equalled to 10.00 mm. This calculation can be written a formula as Equation (4).

$$R_{Avg.of\ province} = R_{sum} / A \qquad (4)$$

where R_{sum} is the sum of rainfall volumes in a province and A is the province area.

4. IMPLEMENTATION

The rainfall monitoring system that calculates the accumulated rainfall for 3 days forecast (including the current day) and 3 days after of the WRF model was developed with Python, PHP, and JavaScript programming languages. The user interface was created on the website as shown in Figure 18. The system can calculate the volumes of accumulated rainfall that users select the range of rainfall, date, range of time forecast and spatial boundary. The rainfall results from the system can be displayed as the table descending sorted by rainfall volumes as shown in Figure 19.
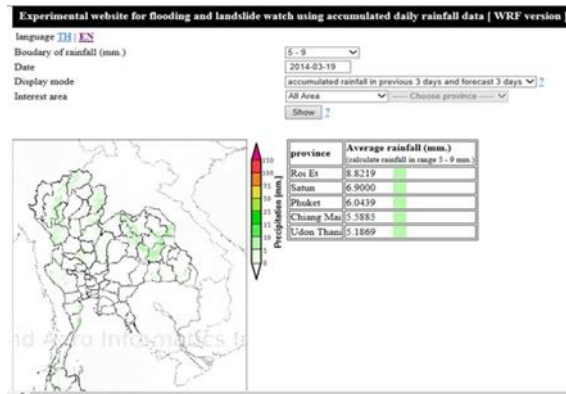
Fig 18: A sample of warning system user interface

Fig 19: The table shows the average rainfall in areas sort by descending

In addition, Figure 20 shows a sample of image obtained by processing the outputs of WRF on monitoring system website.
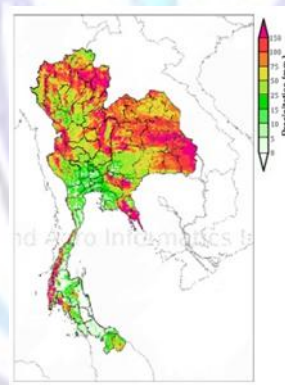

Fig 20: A sample of image obtained by processing the output of WRF on monitoring website

5. CONCLUSIONS

The rainfall monitoring system using image processing technology has been developed to track the accumulated rainfall in Thailand's provinces within 6 consecutive days. These rainfall data for the past 3 days and 3 days forecast can be derived from the calculation of WRF model. The WRF model has produced 75% accurate precipitation. The development of such a system applied *Erosion Convolution* which is a basic technique of image processing to reduce noise of the image or clarify colours that are unclear. In addition, *Buffer* and *Intersection* of spatial data were applied to identify the areas in the images that need monitoring and warning.

For the system development in the future, the system will be downscaled to clarify the rainfall data with high resolution and more accurate of images which have been displayed in the rainfall forecast in each district of the provinces.

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