RECONSTRUCTING CLOUD FREE SPOT/VEGETATION USING HARMONIC ANALYSIS WITH LOCAL MAXIMUM FITTING

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KEY WORDS: Reconstruction, Harmonic Analysis, NDVI, LMF, SPOT/VEGETATION

ABSTRACT

The satellite data of low resolution such as SPOT/VEGETATION, NOAA/AVHRR and TERRA/MODIS etc. are very effective in vegetation analysis on global scale. Especially, the satellite data that are observed everyday is suitable for time series analysis such as illegal logging, forest fire, seasonal vegetation change and forest change. But, in these satellite data noises due to influence of cloud and mosaic are included, and disturb due analysis. The result is always an image with data gaps. This study aims to reconstruct time-series data without cloud, noise and gap. Basic ideas used for the reconstruction are Harmonic Analysis and Local Maximum Fitting (LMF) algorithm. We tried to reconstruct smooth and gapless data. This Harmonic Reconstruction(HR) process was applied to 36-image series of SPOT/VEGETATION S10 product NDVI data of 1 year covering most Asian region. S10 product is 10 days synthesis by Maximum NDVI method. First, Local Maximum Fitting was conducted to exclude abnormal data. Next, amplitude strength and phase parameter classified by period were calculated by Harmonic Analysis. By fitting these in cosine equation, the data were reconstructed. As a result, it could reproduce smooth data with which influence of cloud and noise is little. In addition, it should be noted that specification of the used PC and the remote sensing software are not more than standard ones. It could also save the processing time by 90% or more in comparison with the ones by other similar model fitting process. For user's convenience difficult programming is not necessary and this process is simple to handle.

1. USE DATA AND ANALYSIS SYSTEM

Introduction of use data (Figure 1) and analysis system is as follows.

- **Use data:** SPOT/VEGETATION S10 product (10 days synthesis) NDVI-band
  2002/Jan/1 – 2002/Dec/21 (36 datasets)
  8774line*6721column*8bits / data
- **Software:** TNT/Mips V6.9,V7.0DV (MicroImages, Inc.)
- **Computer:** Dual Zeon1.7Ghz, 2GB RAM

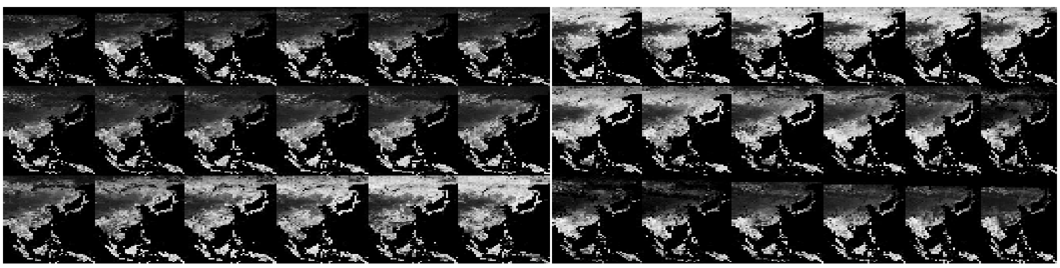


Figure 1 Use data

2. PROCESS FLOW

Reconstruction of time-series data is composed of the following three steps:

-Step 1. Local Maximum Fitting : Exclusion of abnormal data
-Step 2. Harmonic Analysis : Separation of magnitude and phase
-Step 3. Reconstruction of data : Substitution into the modeling formula

This series of process is called Harmonic Reconstruction (HR).
Details of each step are described below.

3. LOCAL MAXIMUM FITTING (LMF)

Local Maximum Fitting was applied to the S10 product NDVI data of one year in order to exclude apparently abnormal data (Sawada, H. and Sawada, Y., 2002). This is the method to obtain the maximum value A of four points before continuous time-series data and the maximum value B of four points after continuous time-series data in order to give the minimum values of both A and B to be their pixel values, respectively (Figure 2). This process was applied to all data as well as all pixels. This process has excluded data with remarkably low value due to adverse effect of cloud coverage or snow. This processing was performed by the program created using macro language "SML" of TNT/Mips (Figure 3).

Before----------- After
t1 t2 t3 t4 t5 t6 t7

Maximum A = MAX(t1,t2,t3,t4)

Maximum B = MAX(t4,t5,t6,t7)
t4' = MIN(Maximum A, Maximum B)

t1-t7 : NDV at each time point
t4' : Value of t4 after filtering

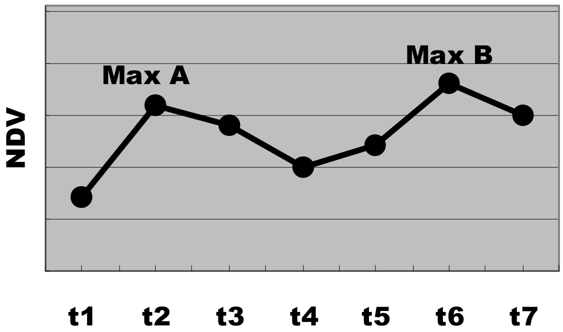
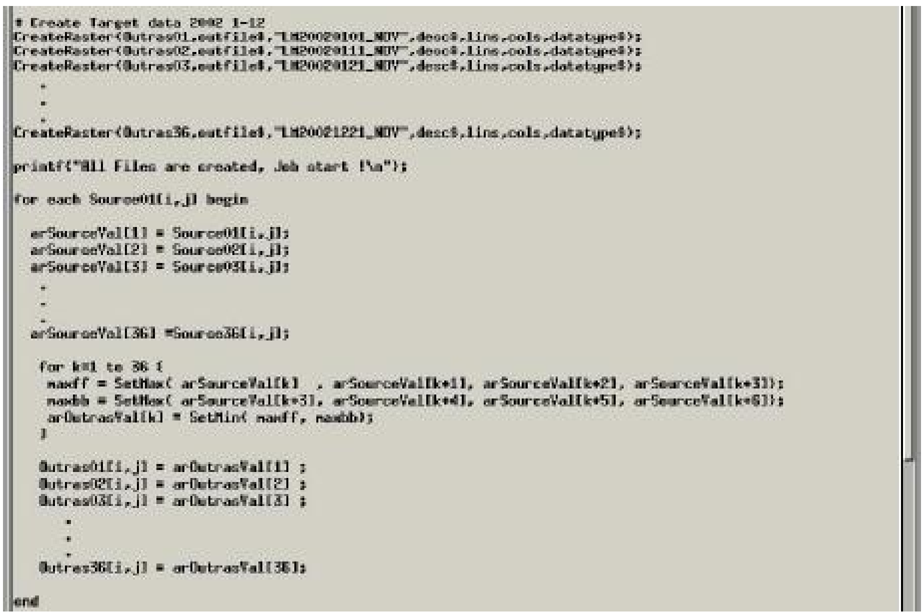


Figure 2 Local Maximum Fitting



```
# Create Target data 2002 1-12
CreateRaster(Outras01,outfile$,"LM20020101_NDV",desc$,lins,cols,datatype$);
CreateRaster(Outras02,outfile$,"LM20020111_NDV",desc$,lins,cols,datatype$);
CreateRaster(Outras03,outfile$,"LM20020121_NDV",desc$,lins,cols,datatype$);
   .
   .
   .
CreateRaster(Outras36,outfile$,"LM20021221_NDV",desc$,lins,cols,datatype$);

printf("All Files are created, Job start !\n");

for each Source01[i,j] begin

  arSourceVal[1] = Source01[i,j];
  arSourceVal[2] = Source02[i,j];
  arSourceVal[3] = Source03[i,j];
   .
   .
   .
  arSourceVal[36] =Source36[i,j];

   for k=1 to 36 {
    maxff = SetMax( arSourceVal[k]  , arSourceVal[k+1], arSourceVal[k+2], arSourceVal[k+3]);
    maxbb = SetMax( arSourceVal[k+3], arSourceVal[k+4], arSourceVal[k+5], arSourceVal[k+6]);
    arOutrasVal[k] = SetMin( maxff, maxbb);
   }

   Outras01[i,j] = arOutrasVal[1] ;
   Outras02[i,j] = arOutrasVal[2] ;
   Outras03[i,j] = arOutrasVal[3] ;
      .
      .
      .
   Outras36[i,j] = arOutrasVal[36];

end
```

Figure 3 Program of Local Maximum Fitting (part)

4. HARMONIC ANALYSIS

Next, Harmonic Analysis was conducted using 36-data set of one year with Local Maximum Fitting applied. This allowed the creation of parameter images of additive, magnitude (size of the wave) per period, and phase (offset of the wave). The following parameter images were created using the period number of six (Table 1, Figure 4). As a result, period components were separated into magnitude and phase by the unit of pixels. This process was conducted using the standard application "Harmonic Series" which was supplied with TNT/Mips (Figure 5).

Table 1 Parameter image by Harmonic Analysis

Period	**Amplitude**	**Phase**	**Direct current**
			Additive
1-year period term	Magnitude-1	Phase-1	
6-month period term	Magnitude-2	Phase-2	
4-month period term	Magnitude-3	Phase-3	
3-month period term	Magnitude-4	Phase-4	
2-month period term	Magnitude-5	Phase-5	
1-month period term	Magnitude-6	Phase-6	

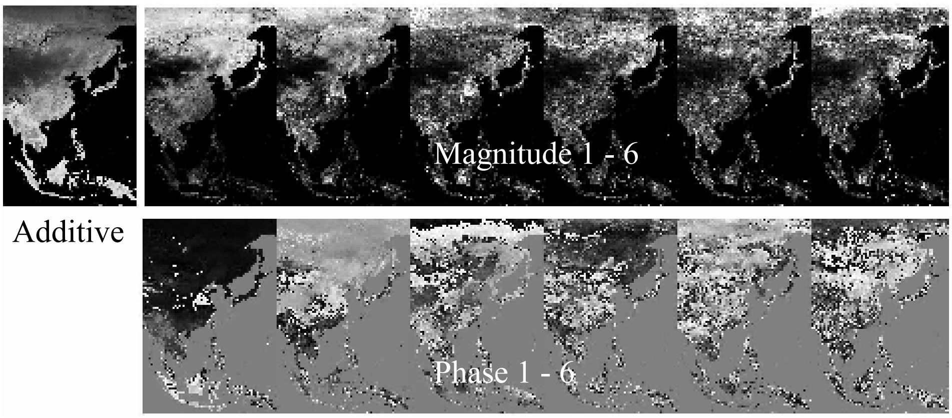


Figure 4 Parameter Images

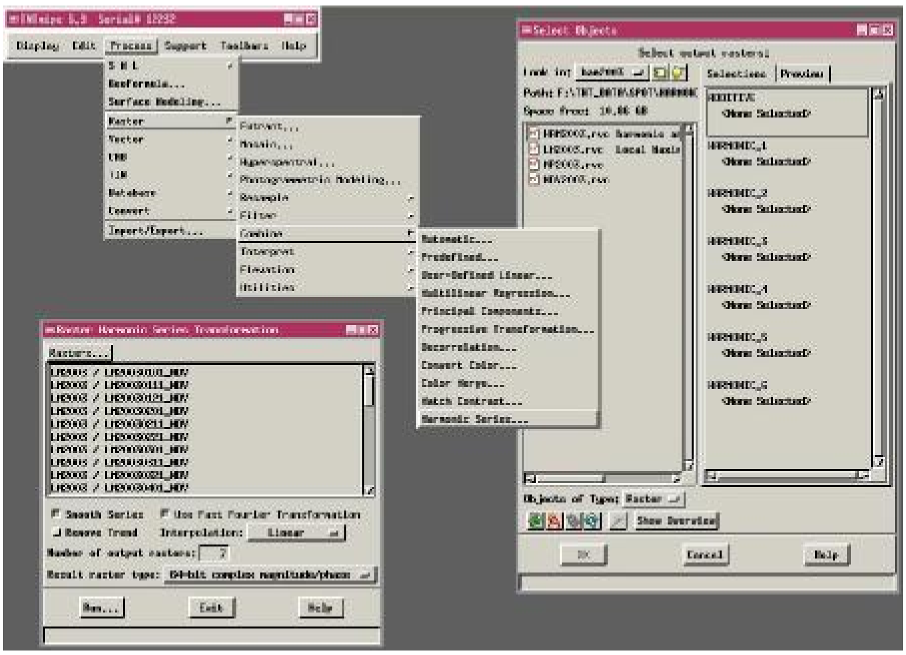


Figure 5 "Harmonic Series" on TNT/Mips

5. DATA RECONSTRUCTION

Last, each parameter of additive, magnitude, and phase obtained by Harmonic Analysis was substituted into the equation below to perform the reconstruction of time-series data (36-data set of one year) (M.E.Jakubauskas et al., 2001). This processing was performed by the program created using macro language "SML" of TNT/Mips (Figure 6).

$$f(t) = c_0 + \sum_{n=1}^{\infty} c_n \cos(\frac{2\pi nt}{L} - \phi_n)$$

$c_0 : Additive$

$c_n : 2 \times Magnitude(n)$

$\phi_n : Phase(n)$

$n : times\ of\ harmonic$

$L : number\ of\ timeseries$

$t : times(1\ to\ L)$

```
# ADT   : Additive
# MG1-6 : Magnitude 1-6
# PH1-6 : Phase 1-6

nt=36;  # number of times per year

GetInputRasters(ADT,MG1,MG2,MG3,MG4,MG5,MG6,PH1,PH2,PH3,PH4,PH5,PH6);

col=NumCols(ADT);
lin=NumLins(ADT);

# Output file & object name
file$="F:/TNT_DATA/SPOT/HARMONIC/ham2002/HAM2002.rvc";
obj1$="ham2002_";
string description$="harmonic analysis modeling";

for t = 1 to nt begin

   string str1$ = NumToStr(t);
   string objstr$=sprintf("%s%s", obj1$, str1$);
   print(objstr$);
   CreateRaster(HA, file$, objstr$, description$, lin, col, "8-bit unsigned");

   for each HA[i,j] begin
      a1=2*MG1[i,j]*cos(2*PI*1*t/nt-PH1[i,j]);
      a2=2*MG2[i,j]*cos(2*PI*2*t/nt-PH2[i,j]);
      a3=2*MG3[i,j]*cos(2*PI*3*t/nt-PH3[i,j]);
      a4=2*MG4[i,j]*cos(2*PI*4*t/nt-PH4[i,j]);
      a5=2*MG5[i,j]*cos(2*PI*5*t/nt-PH5[i,j]);
      a6=2*MG6[i,j]*cos(2*PI*6*t/nt-PH6[i,j]);
      HA[i,j]= ADT[i,j] + a1 + a2 + a3 + a4 + a5 + a6;
   end

   CopySubobjects(ADT,HA,"georef");
   CreateHistogram(HA);
   CreatePyramid(HA);
   CloseRaster(HA);
end

print(" end");
```

Figure 6 Program of Harmonic Reconstruction

6. RESULT

Comparisons of raw data, Local Maximum Fitting data, and reconstruction data obtained by Harmonic Analysis are shown in Figure 7. DN (Digital Number) of one pixel with 36 files obtained in one year is represented using graphs. Raw data has been found to have a great amount of noise due to adverse effect such as gaps at the time of cloud coverage, snow, or mosaic. Thanks to Local Maximum Fitting, low values which are believed to be noise are successfully excluded. Further gap was excluded from the data reconstructed by Harmonic Analysis, resulting in smooth waveform.

Figure 8 shows images of raw data, Local Maximum Fitting data, and reconstructed data by Harmonic Analysis. The effectiveness of reconstruction by Harmonic Analysis explained using graphs in Figure 7 can be confirmed in the image. Moreover, this data reconstruction conducts the process in the unit of pixels to the time axis, disregarding surrounding pixels. However, surface noise such as mosaic gap is found to be removed.

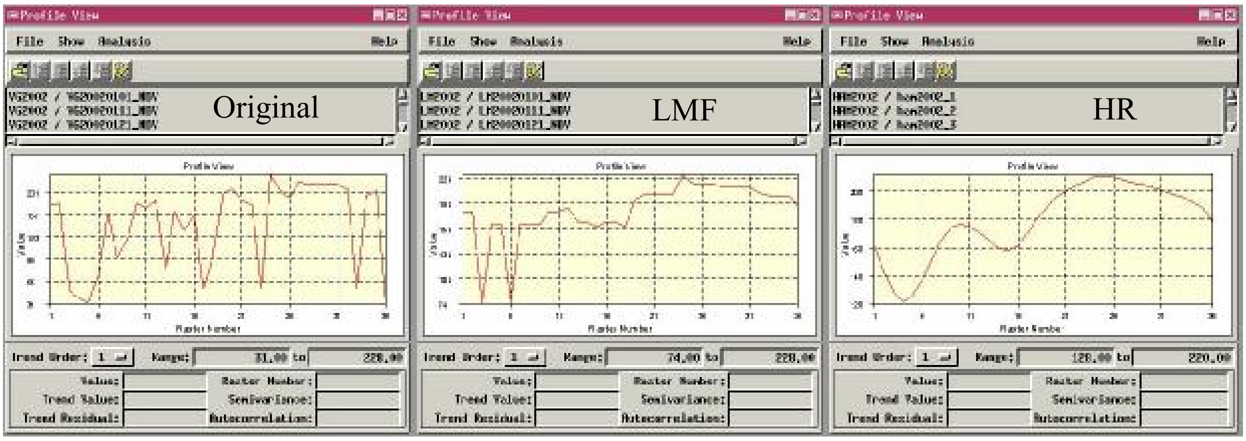


Figure 7 Profile of original, Local Maximum Fitting and Harmonic Reconstruction data

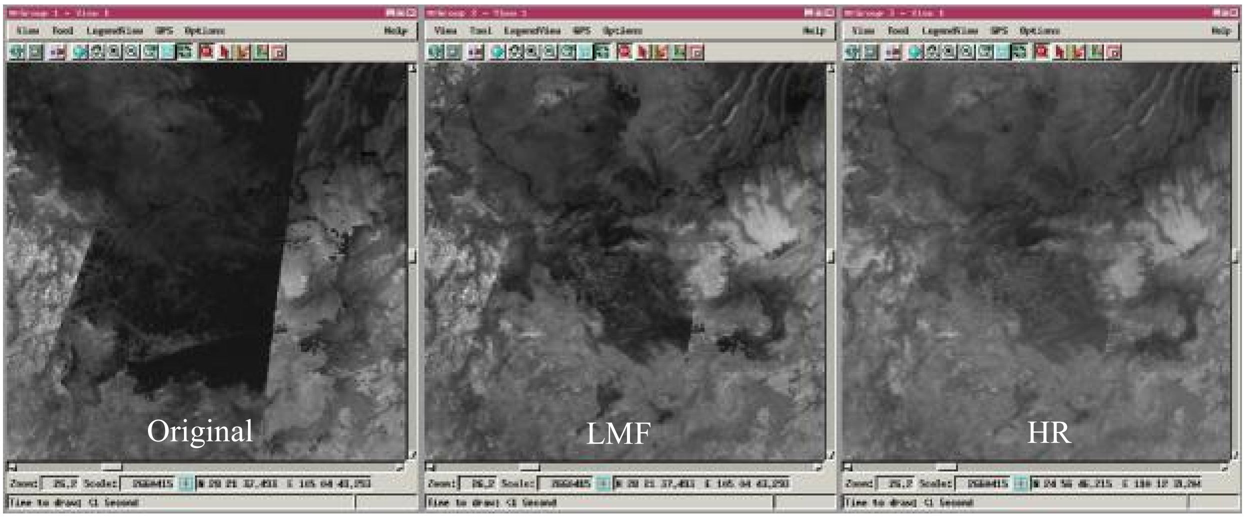


Figure 8 Original, Local Maximum Fitting and Harmonic Reconstruction images

CONCLUSION

Reconstruction of time-series data was conducted using an existing application in this study, providing a confirmation of great effectiveness. It took approximately 18 hours to process the data with a file size of 2GB per year. In the future, a process routine composed of three steps is planned to be unified and more simplified. In addition, band data other than NDVI data is also expected to be reconstructed in order to verify the reliability of data.

References

M.E.Jakubauskas, D.R.Legates & J.H.Kastens, 2001. Harmonic Analysis of Time-Series AVHRR NDVI Data, Photogrammetric Engineering & Remote Sensing.

Sawada, H., Sawada, Y. 2002. Modeling of vegetation seasonal change based on high frequency observation satellite. Environmental Information Science Papers. Vol. 16.