CORRELATION BETWEEN GROUND-BASED AND LANDSAT 8 IMAGES FOR MODELING RICE CROP PHENOLOGY

Narut Soontranon, Siam Lawawirojwong, and Prasit Maksin
Geo-Informatics and Space Technology Development Agency (GISTDA)
120 The Government Complex, Building B
6–7th Floor, Chaeng Wattana Road, Lak Si, Bangkok, Thailand 10210
E-mail: {narut, siam, prasit}@gistda.or.th

KEY WORDS: Phenology, Rice crop, Landsat-8, Field Server, Linear regression

ABSTRACT: Ground-based and satellite images are compared and evaluated for modeling the phenology of rice field in Thailand. The phenology is based on Excessive Green index (ExG), which is computed from RGB images (visible range). The ground-based images are obtained from field cameras installed at the rice fields. Given a corresponding pixel, the satellite images referred to Landsat-8 "LS-8" are used for calibrating and modeling with the ground-based images. An advantage of LS-8 is a spatial resolution at 30 meters, which is a high and efficient resolution for the rice field monitoring. To track stages of the rice field, the phenology curves are extracted for significant features: SoS/EoS (Start/End of growing Season). It should be noted that the SoS/EoS are automatically obtained from the phenology curve processing. Using linear regression approach, the results show that the phenology obtained from LS-8 images has a good correlation with the ground-based images since the SoS/EoS parameters have been represented less value of day-shift error. Regarding to the experiments, LS-8 is able to use for monitoring the rice fields in a wide region. In the future, increasing the accuracy of SoS/EoS on LS-8, it can be used as input data for developing applications such as crop prediction, yield estimation, etc.

1. Introduction

Rice is one of the main staple foods consumed by more than half of the world's population, especially in Asia. In several countries, the rice production is a significant information related to "socio-economics" impact. An accurate map of rice crop monitoring is useful for balancing demand-supply in the global rice market. The accurate rice map can be produced by integrating several technologies such as satellite, ground-based sensors (field server), etc. With regard to Earth Observation Satellite (EOS) technology, the acquired images can be used to monitor the rice fields. However, the satellite image is a type of data acquired remotely which provides limited accuracy in terms of geometry and radiometry. To increase the accuracy, it requires a near surface acquisition such as field survey, ground-based sensors, etc. Instead of the field survey by experts, the ground-based sensors "near surface" is an automatic system for acquiring the field data. In Thailand, Agriculture Monitoring System (AMS) includes the ground-based sensors for obtaining the data from agricultural fields such as rice, sugarcane, coconut, cassava, para-rubber, etc. Using an equipment called Field Server "FS" as shown in Figure 1, the daily images and weather conditions can be obtained. This study will focus on the rice field images [Soontranon et al., 2015].

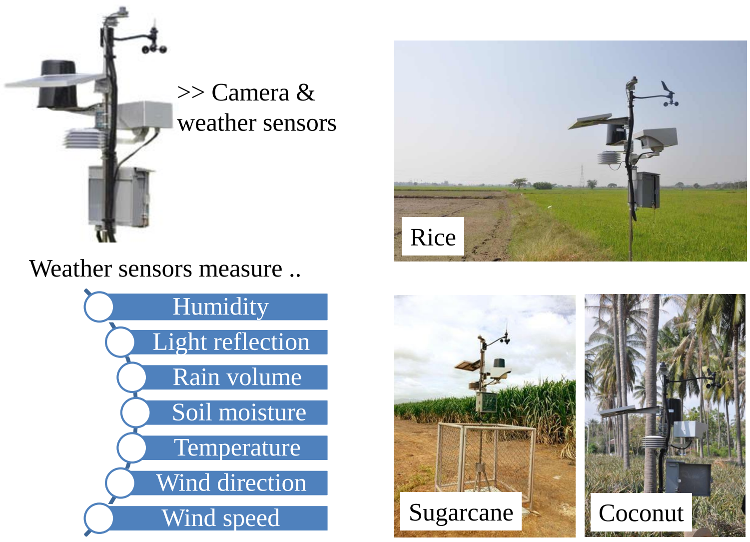
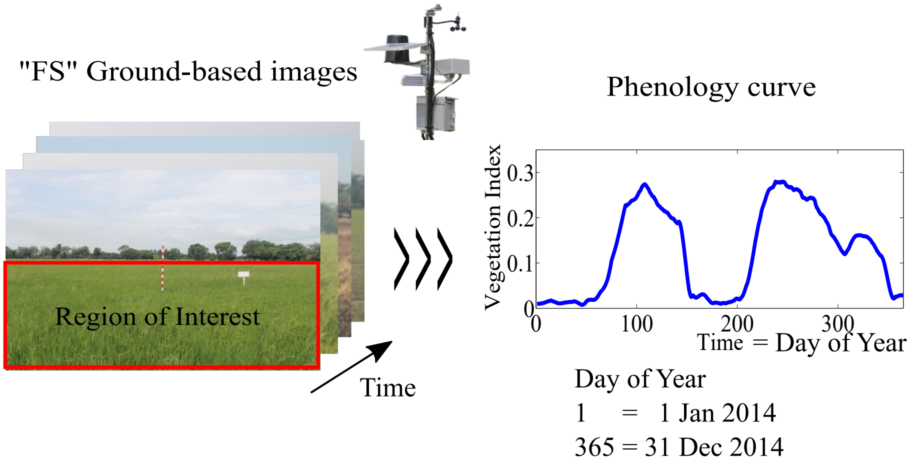
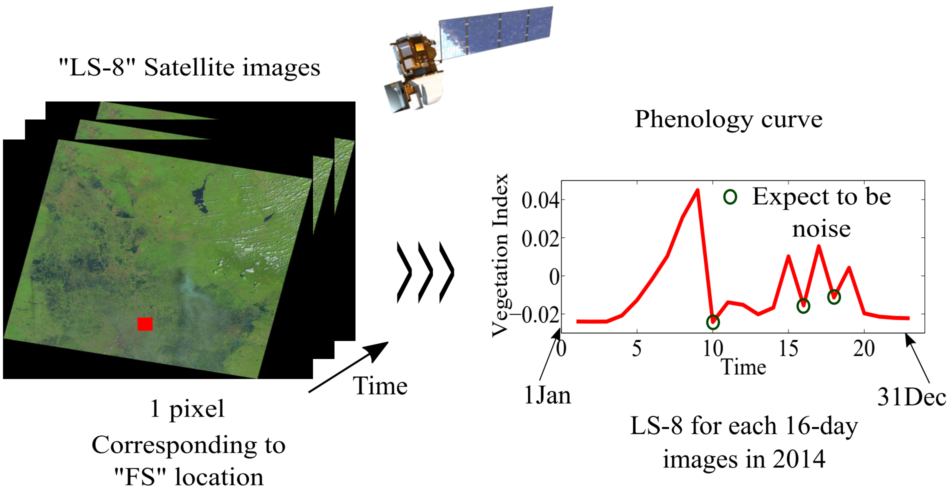


Figure 1: Field Server "FS" components and installation.



(a) Phenology from FS images



(b) Phenology from LS-8 images

Figure 2: Phenology curves obtained from FS and LS-8 images.

The ground-based (FS) images are computed for a parameter known as phenology, which represents a curve of green level in an observed period. The phenology obtained from FS images is shown in Figure 2(a). It can be used to indicate stages of the rice field [Soontranon et al., 2015]. Moreover, a relation between the ground-based and satellite phenologies is useful for several applications such as rice area estimation, crop prediction, yield assessment, etc. Given the relation of the two phenologies, a calibration model can be computed and used to increase the accuracy of satellite data application. Considering the satellite images, a well-known satellite platform providing the open access data is MODIS (Moderate Resolution Imaging Spectroradiometer) [Son et al., 2014]. MODIS provides daily images and 8/16-days composite images. The composite images represent the best pixel of all 8/16-days, which are processed to reduce the noise such as cloud cover, atmospheric interference, etc. However, MODIS images have spatial resolution at 250 meters, which is difficult to observe non-organized areas such as multi-plant farms and small farms representing non-homogeneous plants. Another satellite platform providing the open access data is known as Landsat [Li et al., 2014]. The most recent satellite, Landsat-8 “LS-8” launched in 2013, has spatial resolution at 30 meters with 16-days repetition (temporal resolution). To obtain higher spatial resolution, this paper will use LS-8 images for rice field monitoring. Due to the less temporal resolution and noise effects as shown in Figure 2(b), it is necessary to compute an efficient phenology by reducing the noise effects in the processing of LS-8 data.

The rest of the paper is organized as follows. Section 2 explains the phenology comparison, which consists of data processing, linear regression and rice crop feature. Section 3 provides the experiments from four rice fields. Section 4 concludes the study and discusses about the future work.

2. Phenology comparison

A parameter for the rice crop monitoring is often referred to the phenology obtained from Vegetation Index (VI) in a period of time. In this study, two sets of images (FS and LS-8) are compared and the phenologies of two data sets are analyzed for validation and calibration purposes. For FS images, the standard camera is used to acquire daily images in the form of RGB images. Vegetation index is based on "Excessive Green index (ExG $= 2g - r - b$)", which is efficiently computed from RGB images [Woebbecke et al., 1995]. It should be noted that 'rgb' is the normalized 'RGB'. With the similar concept, the satellite (LS-8) images are selected for three bands [Li et al., 2014] corresponding to RGB images and they are compared with the ground-based images.

2.1. Data Processing

Ground-based images (FS) : A set of daily images acquired from the rice field is used to compute for the phenology, which represents difference green levels during the observed period. The phenology curve can be used to accurately classify the stages of rice field, which is used as the ground truth data. To obtain the phenology from FS images, more details can be found in [Soontranon et al., 2015].

Satellite images (LS-8) : Referring to FS location (latitude/longitude) of the rice field, a corresponding pixel is selected for computing the phenology curve. LS-8 satellite provides 16 days time-series images which requires an efficient tool [Jönsson and Eklundh, 2004] for processing the data generally containing the noise due to atmospheric interference such as cloud, rain, fog. However, there are some limitations particularly when more satellite images (historical data) are required in order to obtain the smooth phenology (noise removal). In this paper, we propose algorithms that can be used to obtain the smooth phenology with less satellite images.

Algorithm 1 : Phenology after noise removal (forward)

Input : $\mathbf{P}$ Output : $\mathbf{P_{for}}$

for i = 1:2 **do**
  $\mathbf{P_{for}} \leftarrow \mathbf{P}$
  for t = 1:N **do**
    $\delta(t) \leftarrow \|\mathbf{P}[t+1] - \mathbf{P}[t]\|_2$
    if $\delta(t) > THR$ **then**
      $\mathbf{P_{for}}[t+1] \leftarrow \frac{\mathbf{P}[t+2]+\mathbf{P}[t]}{2}$
    end if
  end for
  $\mathbf{P} \leftarrow \mathbf{P_{for}}$
end for
return $\mathbf{P_{for}}$

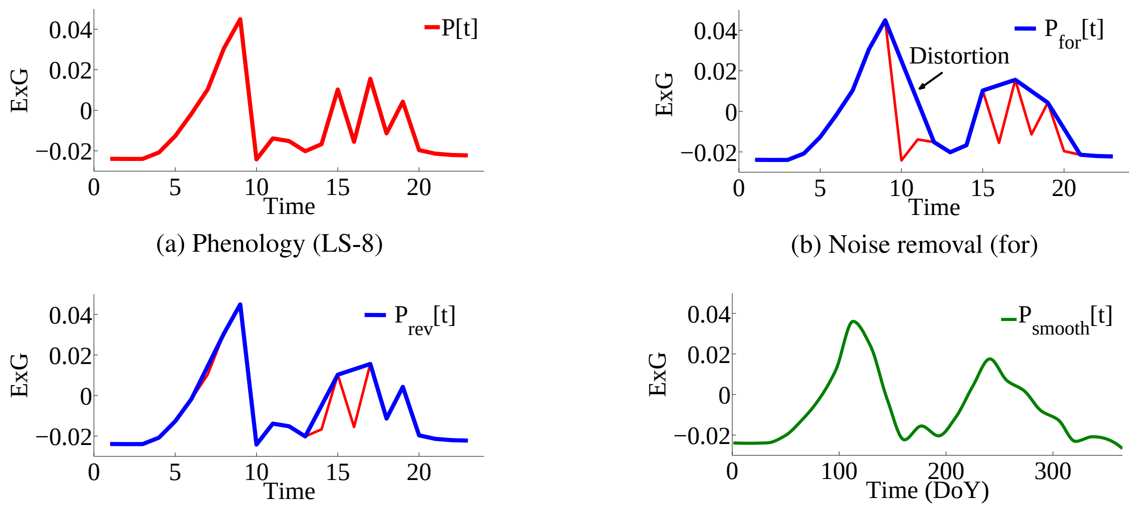
Algorithm 2 : Smooth phenology

Input : $\mathbf{P}, \mathbf{P_{for}}, \mathbf{P_{rev}}$ Output : $\mathbf{P_{smooth}}$

for t = 1:N **do**
  if $\|\mathbf{P_{for}}[t] - \mathbf{P}[t]\|_2 < \|\mathbf{P_{rev}}[t] - \mathbf{P}[t]\|_2$ **then**
    $\mathbf{P}[t] \leftarrow \mathbf{P_{for}}[t]$
  else
    $\mathbf{P}[t] \leftarrow \mathbf{P_{rev}}[t]$
  end if
end for
$\mathbf{P_{smooth}} \leftarrow \text{Smooth}(\mathbf{P})$
$\mathbf{P_{smooth}} \leftarrow \text{Interpolate}_{\text{DoY}}(\mathbf{P_{smooth}})$
return $\mathbf{P_{smooth}}$

The proposed algorithms are used for recomputing noisy points. By taking into consideration the phenology curve ($\mathbf{P}$), the noisy points are generally represented by a low level of the phenology. Relying on this assumption, the neighbor points should not fluctuate. The algorithm computes a difference value (δ) between $\mathbf{P}[t]$ and $\mathbf{P}[t+1]$. If the difference value is higher than a threshold level, the point $\mathbf{P}[t+1]$ is assumed as the noise. The algorithm will recomputed the new value of $\mathbf{P}[t+1]$ by interpolating two neighbor points ($\mathbf{P}[t]$ and $\mathbf{P}[t+2]$). The threshold is calculated from $THR = \mu + \sigma$, where μ is a mean of $\delta(t)$ and σ is a standard deviation of $\delta(t)$. As explained in Algorithm 1, the noisy points are expected to be removed after repeating by two iterations. The noise removal algorithm takes into account two directions; forward ($\mathbf{P_{for}}$) and reverse ($\mathbf{P_{rev}}$). It should be noted that $\mathbf{P_{rev}}$ is also obtained from the Algorithm 1 by re-arranging the time axis of $\mathbf{P}$. By comparing to the raw data (LS-8), the updated phenology will select the closest point between forward $\mathbf{P_{for}}$ and reverse $\mathbf{P_{rev}}$ directions as shown in Algorithm 2. Finally, the smooth phenology ($\mathbf{P_{smooth}}$) can be obtained by using Savitzky-Golay filter. For calibrating and modeling with the ground-based phenology, the smooth phenology ($\mathbf{P_{smooth}}$) will compute values for 365 days (DoY) using bi-linear interpolation. By using the proposed algorithms, the smooth phenology can be obtained as presented in Figure 3.

During the cultivated period of rice field, a characteristic of the phenology, the green level is gradually increased (green-up) and decreased (senescence). Discussing about the proposed algorithms, two iterations are required to process in case of two neighbor points were immediately dropped by interference. Two directions of moving filter are applied for preserving the curve pattern. In Figure 3(a), the phenology curve is initially obtained from LS-8. In Figure 3(b), the cultivated curve is biased with only forward computation representing distortion. In Figure 3(c), the curve is reformed by using reverse computation. Finally, the smooth phenology is presented in Figure 3(d).



(a) Phenology (LS-8)

(b) Noise removal (for)

(c) Noise removal (rev)

(d) Smooth phenology

Figure 3: Smooth phenology based on LS-8 selected pixel.

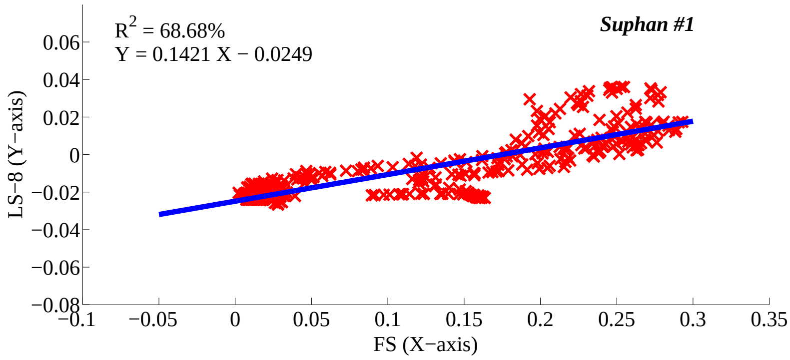


Figure 4: R^2 and Linear estimation.

2.2. Linear Regression

Given the smooth phenology of FS as a ground-truth data, the smooth phenology of LS-8 is compared and evaluated using linear regression approach. The resulting linear equation is then used to fit and compute for the proportional reduction in squared error (R^2) as shown in Figure 4. Using the estimated linear equation, LS-8 phenology is re-calculated as shown in Figure 5.

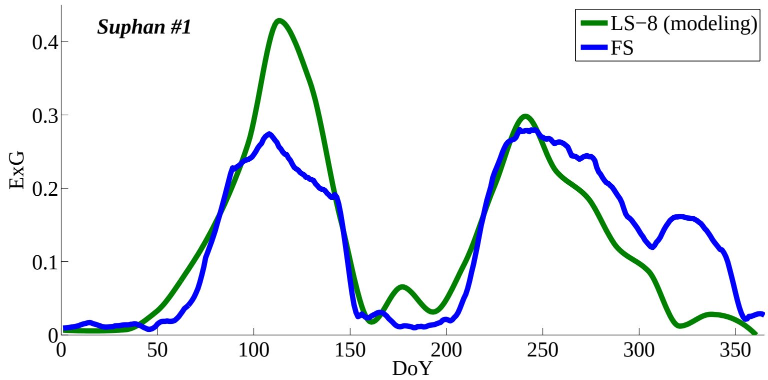
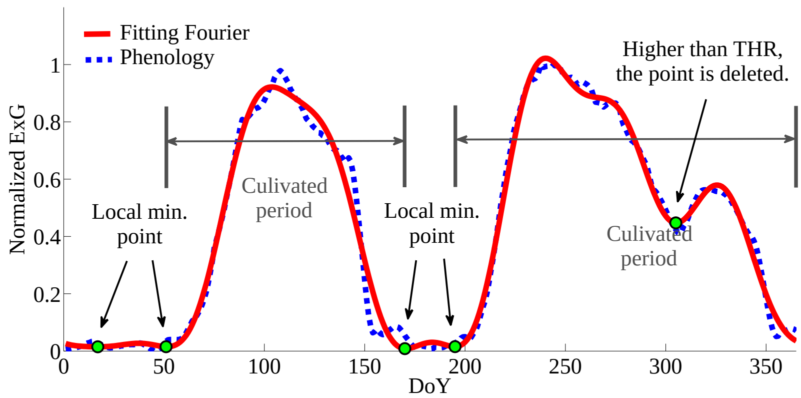


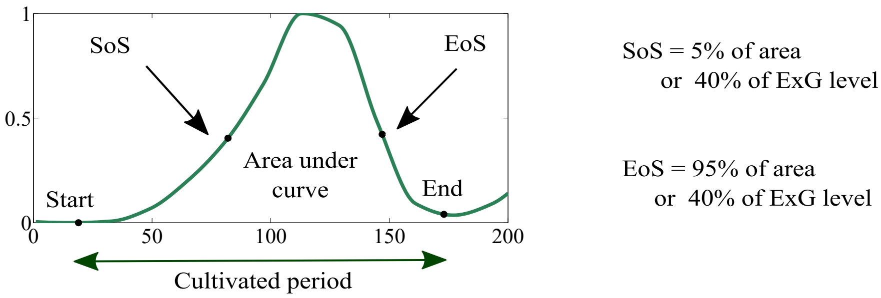
Figure 5: LS-8 modeling based on FS phenology

2.3. Rice crop feature

To extract rice crop feature, the phenology curve is initially processed to detect the cultivated period in Figure 6(a). The phenology is fitted by an 8^{th} order Fourier series to apply for single/double crops (per year), which are the most cultivated types in Thailand. Local minimum points on Fourier curve are used to define for the sub-curves. The area of each sub-curve is computed for classifying cultivated period. Given the cultivated period, SoS/EoS (start/end of growing season) are extracted by using the criteria in Figure 6(b). Rice crop feature is defined by three parameters: SoS/EoS and area under cultivated period. SoS/EoS are related to stages of rice field. The area will be used for estimating biomass and yield assessment in the future. A comparison of rice crop features between FS and LS-8 is presented in Figure 7.



(a) Fitting Fourier for cultivated period detection.



(b) SoS/EoS on the cultivated period.

Figure 6: Rice crop feature (SoS/EoS and area).

Table 1: Comparison of FS and LS-8 phenologies on the rice field in 2014.

FS location	**(SoS,EoS)$_{\text{LS-8}}$**	**△(SoS,EoS)**	**△Area**	**#Crop**	R^2	$Y = aX + b$
Suphan #1	$(83, 144), (220, 278)$	$(-6, 2), (0, 62)$	$-3.87, -11.05$	2 (√)	68.68	$0.1421X - 0.0249$
Suphan #2	(n/a, 57), (157, 238)	(n/a, 26), (6, 11)	n/a, −3.23	2 (√)	52.55	$0.1133X - 0.0180$
Roi-Et	$(215, 316)$	$(3, -4)$	-3.73	1 (√)	58.16	$0.1264X - 0.0255$
Chiang Rai	(n/a, 133), (233, 305)	(n/a, −1), (−28, 13)	n/a, 8.66	2 (√)	57.69	$0.0610X - 0.0223$
Average	–	13.5 days	6.11	100%(√)	59.27	–

Note: **(SoS,EoS)$_{\text{LS-8}}$** presents the 1st and 2nd crops as follows $(\text{SoS}_1, \text{EoS}_1), (\text{SoS}_2, \text{EoS}_2)$.
n/a means the (SoS,EoS) cannot detected e.g. started before 2014.
△(SoS,EoS) computes from $\{(\text{SoS}, \text{EoS})_{\text{FS}} - (\text{SoS}, \text{EoS})_{\text{LS-8}}\}$.
△Area computes from $\{\text{Area}_{\text{FS}} - \text{Area}_{\text{LS-8}}\}$ represented by $\triangle\text{Area}_1, \triangle\text{Area}_2$
#Crop is the number of crops (LS-8) detected by our approach. (√) means #Crop is correct.

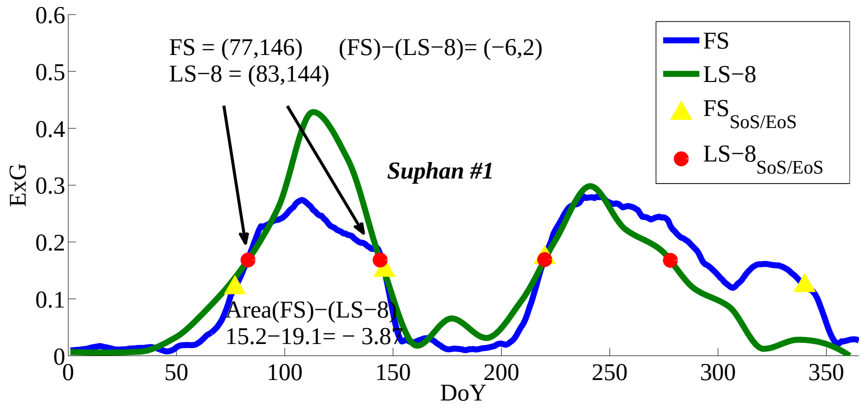


Figure 7: SoS/EoS and area extracted from two phenologies (see Table 1, *Suphan #1*).

3. Experiments

Referring to the AMS-Thailand, four rice fields in Thailand (Suphan #1, #2, Roi-Et and Chiang Rai) were used for the experiments. Comparative results between FS and LS-8 are summarized in Table 1, it shows (SoS/EoS)$_{\text{LS-8}}$ extracted from LS-8. △(SoS,EoS) means the difference of days shift between FS and LS-8 (see also Figure 7). The average days shift is approximately 13.5 days, which is satisfied for 16 days of LS-8 data. R^2 obtained from the linear regression is 59.27% of average value. The average R^2 is not very high because the phenologies from FS and LS-8 are different patterns. However, the phenologies provide sufficient information to accurately extract the number of crops (single/double crops) which are the most significant information for yield assessment in the next step.

4. Conclusion and future works

The paper investigated the relation of rice field phenology between the ground-based (FS) and satellite (LS-8) images. The phenology was obtained by using ExG index based on RGB bands. FS daily images were computed to the phenology and used as the ground-truth data. For the satellite images, LS-8 provides 16-days images with atmospheric interference that needs to be reduced. The proposed method is used for obtaining the smooth phenology that initially removes the data expected to be noise due to cloud, rain, etc. The noise is reduced by observing the neighbor points and computing for two directions (forward, reverse). The proposed method is less complex and fast computation. It also requires less (historical) satellite images comparing with the existing methods (2 neighbor images for 2 iterations). Based on linear regression, using FS phenology as the ground truth, LS-8 phenology can provide the good correlation (average $R^2 \approx 59\%$) although the data were obtained from different sensors and platforms. The comparison is referred by three significant parameters of cultivation period as follows: SoS/EoS and area under curve.

The future work will integrate other satellite data (e.g. MODIS) in order to obtain more accurate model. Rice crop feature (area under curve) will be used for yield assessment. The proposed algorithms will be applied for the other crops such as sugarcane, cassava, etc.

References

[Jönsson and Eklundh, 2004] Jönsson, P. and Eklundh, L. (2004). Timesat–a program for analyzing time-series of satellite sensor data. *Computers & Geosciences*, 30(8):833–845.

[Li et al., 2014] Li, P., Jiang, L., and Feng, Z. (2014). Cross-comparison of vegetation indices derived from landsat-7 enhanced thematic mapper plus (etm+) and landsat-8 operational land imager (oli) sensors. *Remote Sensing*, 6(1):310–329.

[Son et al., 2014] Son, N.-T., Chen, C.-F., Chen, C.-R., Duc, H.-N., and Chang, L.-Y. (2014). A phenology-based classification of time-series modis data for rice crop monitoring in mekong delta, vietnam. *Remote Sensing*, 6(1):135–156.

[Soontranon et al., 2015] Soontranon, N., Srestasathiern, P., and Rakwatin, P. (2015). Rice crop calendar based on phenology analysis from time-series images. *Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON), 2015 12th International Conference on*, pages 1–5.

[Woebbecke et al., 1995] Woebbecke, D., Meyer, G., Von Bargen, K., and Mortensen, D. (1995). Color indices for weed identification under various soil, residue, and lighting conditions. *Transactions of the ASAE*, 38(1):259–269.