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Local Validation of MODIS Global Leaf Area Index (LAI) Product over Temperate Forest

Sun-Hwa Kim and Kyu-Sung Lee

Department of Geoinformatic Engineering, Inha University

Abstract : MODIS LAI product has been one of key variable for analyzing the quantitative aspects of terrestrial ecology at global scale. This study was designed to validate MODIS global LAI product for regional application. To examine the quality of MODIS LAI data, we developed a reference LAI surface that was derived by relating the ground LAI measurements to Landsat ETM+ reflectance. The study area, the Kwangneung Experiment Forest in Korea, covers mixed deciduous and coniferous species of temperate forest. Ground measurements of LAI were conducted at 30 sample plots by using a photo-optical instrument during the growing season of 2002. Ground measured LAI data were then related to the ETM+ reflectance to produce a continuous map of LAI surface over the study area. From the comparison between the MODIS LAI and the reference LAI, it was found that the MODIS LAI values were slightly higher at the forestland. Considering the limitations of producing the reference LAI surface and the uncertainty of the input variable for the MODIS LAI algorithm, such small discrepancy may not be significant.

Key Words : LAI, MODIS, Validation, Ground Measurement, ETM+ Reflectance, Forest.

1. Introduction

Leaf area index (LAI), defined as projected leaf area per units ground surface area, is an important structural variable of vegetation because it is directly related to the exchange of energy, CO2, and water from vegetation canopies (Sellers *et al.*, 1986). The estimation of LAI using remotely sensed data have been a primary interest for many ecological applications from landscape to global scales. During the last three decades, there have been continuing efforts to develop the empirical algorithms of relating ground measured LAI to spectral reflectance or to spectral vegetation indices (Turner *et al.*, 1999). Numerous spectral vegetation indices (VI) have been applied for LAI estimation, in which the normalized difference vegetation index (NDVI) was the most commonly used (Chen and Cihlar, 1996; Calson and Reley, 1997). Several factors have certain influence on the LAI-VI relationships and include vegetation type, canopy structure, background (soil and litter), atmospheric conditions, and topographic effects (Panferov *et al.*, 2001; Tian *et al.*, 2000; Chen and Cihlar, 1996; Turner *et al.*, 1999; Fassnacht and Stith, 1997).

With the launch of the EOS Terra satellite in 1999,

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the Moderate Resolution Imaging Spectrometer (MODIS) has begun to deliver 1km global scale LAI products. MODIS LAI product is processed with rather refined and enhanced algorithms and would be used as a key variable in several fields of global environment and terrestrial ecology (Knyazikhin *et al.*, 1998). Validation of the MODIS LAI algorithm is an important part of the EOS program (Myneni *et al.*, 2002). One of such validation approaches is inverting local and empirical relationship between LAI and spectral reflectance relationship (Turner *et al.*, 1999). Since MODIS LAI product has relatively short history, there are not enough studies of validating the product.

Although MODIS LAI product is primarily designed at global and continental scales, it has a lot of potential for several regional applications of ecology, including the monitoring of forest vegetation and agricultural crops, and the estimate evapotranspiration. This study is designed to validate MODIS LAI product over temperate forest region where the temporal variation of LAI is very high. The validity of MODIS global LAI product is being analyzed at several study sites throughout the world and it is rare to find any study sites of temperate forest in northeast Asia. Once we can determine the validity of MODIS global LAI product at this region, it could be used as an invaluable source of information at regional and local scale.

2. Methods

1) Study Site

The study site, Kwangneung Experiment Forest, is located about 30km northeast from Seoul, Korea and covers about $10 \times 14km^2$ area (Fig. 1). The Kwangneng Experiment Forest includes diverse species of mixed deciduous and coniferous trees. Since the forestland has been preserved and managed for research purposes

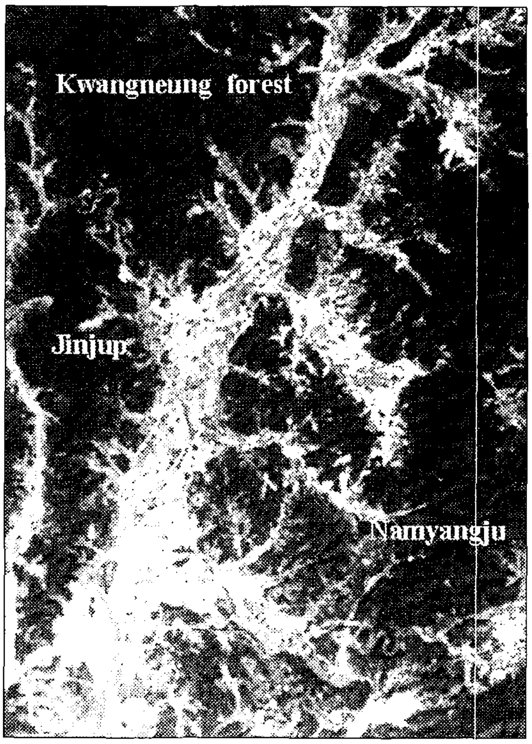

Fig. 1. Landsat-7 ETM+ image of the Kwangneung Experiment Forest ($10 \times 14km^2$).

during the last 80 years, it has relatively detailed ground truth data that include forest stand map showing the species, age, density and mean diameter at breast height (DBH).

2) Ground Measurement of LAI

Although the accurate measurement of LAI is crucial to relate the satellite observed surface reflectance, it is often difficult to obtain reliable ground-truth of LAI. This is particularly true at forest vegetation where the amount and distribution of leaves are much more complex than other biome such as grassland and agricultural crop. Ground measurement of LAI can be divided into two major approaches of direct and indirect methods (Chen *et al.*, 1997; Gower *et al.*, 1999). The direct method includes destructive harvest, litterfall collection, and application of allometric equations. Although direct measurement is relatively simple and perhaps accurate, it can only be applied to very limited number of trees and sites because it requires a great amount of time and effort. To overcome such limitations in direct method, indirect method using optical measurement techniques have been developed. Several commercial optical instruments have been used to indirectly estimate LAI. The basic concept of optical LAI measurement is to invert a radiation model that describes the amount of light penetrating tree canopy as a function of leaf area and distribution.

In this study, we used a photo-optical instrument (Delta-T) that captures hemispherical photographs of canopy. The instrument is placed 1m above the ground and takes digital photos of vertical canopy view using fish eye lens (Fig. 2). The hemispherical view of canopy image was then digitally processed to estimate LAI. To obtain LAI from the photo, users need to provide the maximum leaf brightness value. LAI is estimated by calculating gap fraction and zenith angle.

We have selected 30 sample plots for LAI measurement and assigned 10 plots per each of deciduous, coniferous, and mixed forest type. The exact coordinates of every plot was determined by Global Positioning System (GPS) and field survey and matched with the geo-referenced ETM+ data. Every plot is at least 100m apart from each other. Within each plot, LAI was measured at three points and the mean value was used to represent the LAI of the plot. The ground LAI measurement was carried on June 26 and September 11, 2002.

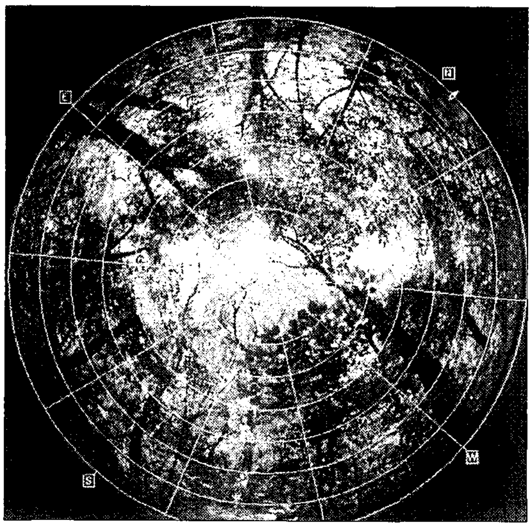

Fig. 2. Hemispheric view of canopy to estimate LAI using Delta-T photo-optical instrument.

LAI value calculated from hemispheric canopy photo is often referred to 'effective LAI', which does not account for non-random distribution of foliage (Chen and Chilar, 1996). In practice, LAI and effective LAI are nearly identical in tree canopies having relatively ordinary distribution without certain clumping. However, leaf clumping is quite obvious in most stands of coniferous and deciduous forest and it is necessary to correct for the clumping factor (Chen and Chilar, 1996). Table 1 shows the effective LAI values of 30 plots that are indirectly estimated by the optical instrument. In overall, the LAI values of June measurement are higher than the ones of September.

3) Generation of Reference LAI Surface

In an attempt to validate MODIS LAI product, we have constructed a reference map of LAI surface by relating the ground measured LAI to Landsat-7 ETM+ spectral reflectance. Such empirical models are commonly used to derive continuous estimates for biophysical variables such as percent canopy cover, biomass, and LAI. For this study, two scenes of Landsat ETM+ data were obtained (Table 2). Since LAI is

Table 1. Ground measured LAI over the study site during the growing season of 2002.

Date	Forest type	Number of plots	Range of LAI
June 26, 2002	Conifer	10	4.08 - 5.4
	Deciduous	10	3.91 - 5.16
	Mixed	10	3.3 - 5.0
Sep. 11, 2002	Conifer	10	3.32 - 4.16
	Deciduous	10	3.08 - 4.58
	Mixed	10	2.62 - 3.79

Table 2. Landsat-7 ETM+ data used for the study.

Acquisition date	June 30, 1999	Sept. 4, 2000
Sun zenith angle	24.543°	36.61°
Sun azimuth angle	118.92°	140.06°

largely influenced by phenology of forest vegetation, Landsat ETM+ data was acquired at nearly the same day of year as the ground LAI measurements.

Fig. 3 shows the overall process of ETM+ data to construct reference LAI surfaces using ground measured LAI. ETM+ data were initially registered to a plane rectangular coordinate using 20 ground control points that were obtained from 1:5,000 scale topographic maps. To extract the surface reflectance of pixels, rather than raw digital number (DN) value, ETM+ data were further processed to reduce topographic and atmospheric effects. DN value of the original image was converted to radiance by applying sensor's gain and bias coefficients that were obtained from image headers. Since the study area is located in mountainous terrain, the topographic effect by the illumination difference is very clear. To reduce the topographic effect, we used an empirical method that normalizes the illumination difference by applying the Minnaert's constant calculated from digital elevation model (DEM) and digital map of forest stand. The detailed information on the topographic correction can be found in Lee and Yoon (1997).

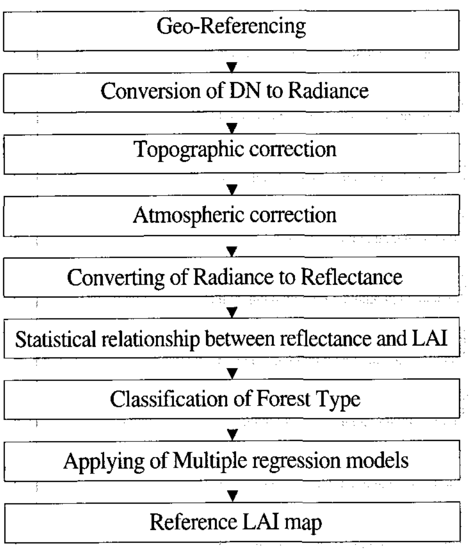

Fig. 3. Process of constructing a reference map of continuous LAI surface using Landsat ETM+ and ground measured LAI.

Although the atmospheric correction of Landsat images has been frequently attempted, there is a certain limitation of obtaining necessary information regarding the atmospheric parameters at the time of image capture. In this study, we used a modified dark object subtraction method, which corrects for path radiance and sun angle effects without the atmospheric data (Chavez, 1996). After topographic and atmospheric corrections, the radiance values were converted to percent reflectance. Mean spectral reflectance value was extracted from the 2 × 2 pixel window that spans each of the 30 ground plots.

The reference LAI surface was created by relating the ground measured LAI to ETM+ reflectance. ETM+ reflectance of six spectral bands was compared with ground LAI value. Since the ground LAI values were obtained from the three different forest types of coniferous, deciduous, and mixed, the correlation between spectral reflectance and ground LAI were not very significant when all LAI data of the 30 plots were combined. Instead, we analyzed the statistical relationship between ETM+ reflectance and ground LAI by forest type. To build the optimal statistical regression model to estimate LAI for entire study area, we compared several sets of independent variables that are subset of a few spectral bands and/or vegetation indices. The best regression model to relate the ground LAI to the ETM+ reflectance was obtained when we used all six bands.

Three multiple regression models were built for each of three forest types. To apply the empirical LAI models, we had to categorize the entire study area into three layers of forest types. The categorization of three forest types was achieved by a standard land cover classification routine using the multispectral ETM+ data. The reference map of LAI surface was made after combining the three layers of LAI estimate for each forest type. Two sets of reference LAI map were created for the June and September data. Although the major portion of the study area is forest, it also includes small and segmented agricultural areas. The LAI value for the croplands (mostly rice paddy) was adopted from the previous study by Hong *et al.* (1998).

4) Extraction of MODIS LAI product

The operational algorithm for producing MODIS LAI data uses two other MODIS land products of the surface reflectance (MOD09) and land cover (MOD12). Fig. 4 shows the schematic flow to produce the eight-day cloud free LAI product. The 1km resolution MODIS LAI products are distributed every 8 days, which corresponds to the maximum value composition interval to remove cloud cover. LAI values are calculated by mathematical inversion of a rather sophisticated canopy reflectance (CR) model that uses bi-directional reflectance factor. If the CR model-based main algorithm fails, a backup algorithm based on the empirical relationship with vegetation index is triggered to estimate LAI.

In this study, the two MODIS LAI images corresponding to the ETM+ data were used. Since the MODIS LAI value is separately calculated by cover

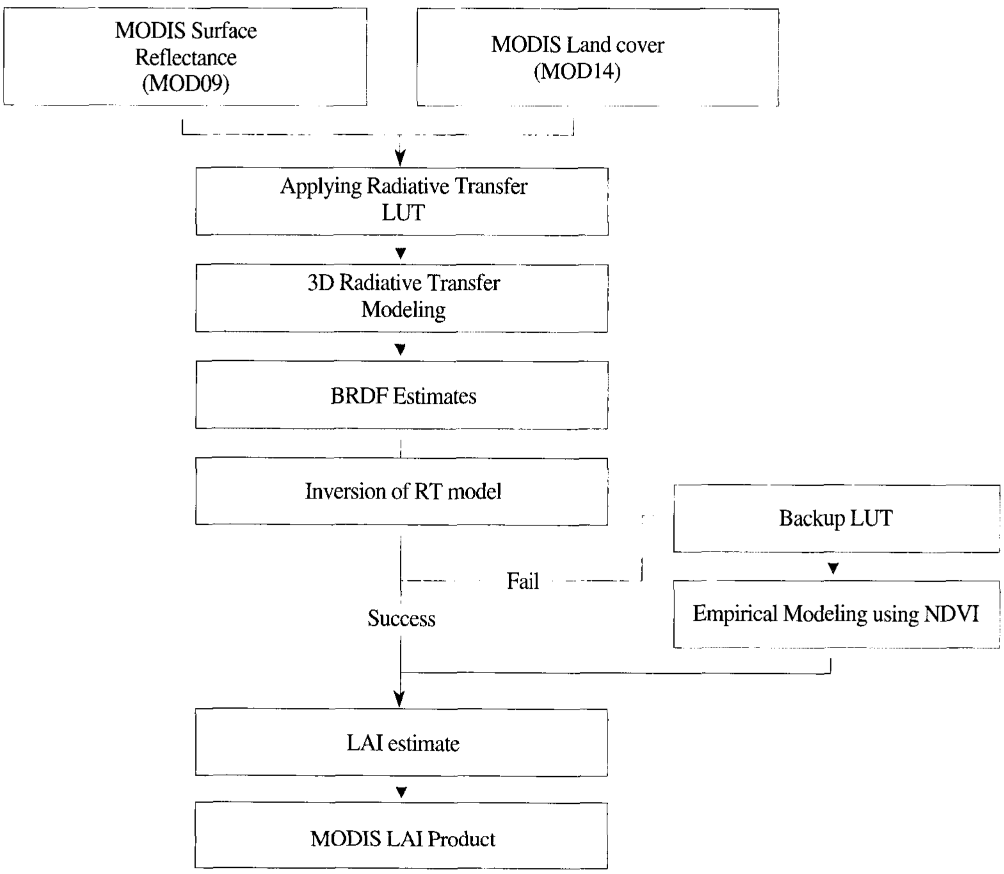

Fig. 4. Schematic flow of producing MODIS LAI product.

type, the MODIS land cover products were also obtained. MODIS land products can be directly obtained from the Earth Observing System Data Gateway (EOS, 2003). The MODIS LAI supplied by the EOSDG is originally referenced by the sinusoidal map projection. To compare with the reference LAI map of the study site, the MODIS products were geo-referenced to the Transverse Mercator map projection by using the MODIS reprojection tool (MRT) software provided by NASA. To compare the reference LAI surface with MODIS LAI product, the reference LAI map having 28.5m pixel was resampled to 1km pixel size.

The MODIS LAI data were compared with the reference LAI surface that had been re-sampled to 1km pixel size. The comparison between the MODIS products and the reference data was conducted not only for the LAI value itself but also for the land cover type because the MODIS LAI estimation largely depends on land cover. MODIS LAI algorithm is dependent on six cover types of different biomes and the misclassification of biome can fatally influence the quality of LAI value (Tian *et al.*, 2000; Wang *et al.*, 2001).

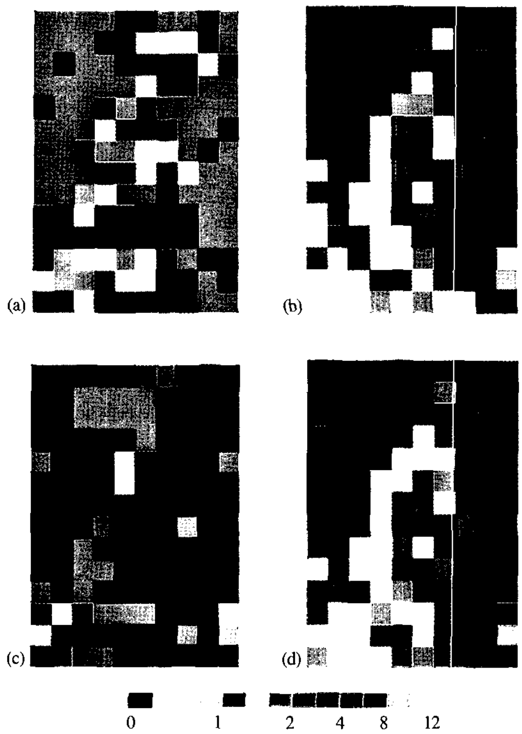

Fig. 5. Comparison between the MODIS LAI (a,c) and the reference LAI (b,d) for June (top) and September (bottom).

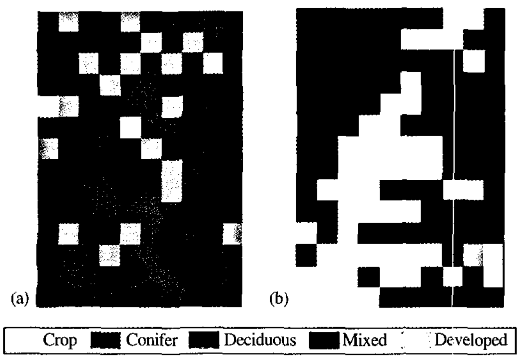

Fig. 6. Land cover map of the ETM+ reference (a) and the MODIS product (b).

3. Results and Discussions

As expected, the reference LAI surface maps of June and September show that the Kwangneung Experiment Forest (upper left portion in Figs. 5 and 6) shows the highest LAI compared to the other forested areas. As seen in Table 1, the reference LAI surface of June appears to have higher LAI values than September LAI map. Comparing with existing forest stand map, the high LAI is corresponding with natural stands of deciduous species.

Fig. 5 shows the comparison between the MODIS LAI and the reference LAI maps for the whole study area of $10 \times 14km^2$. It appears that the MODIS LAI estimates are higher than the reference LAI surface in both June and September data. The mean LAI value of the MODIS product is about 1.3 higher than the one of the reference map (Table 3). Although the mean LAI values of whole study area are slightly different between MODIS LAI and reference LAI, the spatial pattern the

Table 3. Simple statistics of MODIS LAI and reference LAI map using ETM+.

Date	LAI surface	Whole area		Forest	
		Mean	Std.	Mean	std
June	Reference	2.66	1.32	3.43	1.00
	MODIS	3.82	2.19	4.79	1.86
September	Reference	2.60	1.28	3.34	1.03
	MODIS	3.95	1.43	4.16	1.09

LAI values are quite similar between two maps. When we compare the spatial pattern of the two LAI maps, the MODIS LAI also shows higher values in both forest and non-forest area. This is particularly clear at the non-forest area. The non-forest areas were mostly road, residential, and bare soil and masked out with zero LAI value in the original 28.5m pixel reference LAI map. Although the non-forest pixels have gained a very small LAI values (less than 1.0) during the resampling procedure, they are still lower than the MODIS LAI.

Since the MODIS LAI values are estimated by the six cover types of different biomes, it is worthwhile to examine the MODIS land cover map used for the production of the MODIS LAI. Fig. 6 compares the land cover maps of the MODIS products and the ETM+ classification. Although the study area includes coniferous, deciduous, and mixed stands of temperate forest, the most forestlands were classified into a single class of mixed forest in the MODIS land cover map. In addition, although the study area includes relatively large area of developed lands, such as residential and industrial area, they are mostly classified into agricultural crop area. The classification accuracy of the MODIS land cover product is only 14.3% as assessed by the reference land cover classification using the Landsat ETM+. However, the classification accuracy of forestland is relatively high (81.7%) when we combine three forest types (deciduous, conifers, mixed forest) into a single forest class. The LAI values within only the forestland are still high with the MODIS product as compared to the reference LAI map (Table 3).

The discrepancy between the MODIS LAI and the reference LAI can be explained by several factors. In this study, the reference LAI map is based on the 'effective LAI' value as measured by the photo-optical instrument, which is known to be lower than the actual LAI value (Chen and Cihlar, 1996). In addition, since the device was set up at 1m above the ground, the ground measured LAI values ignored the leaf mass existed in under-story vegetation. Considering the under-estimated LAI values by the photo-optical measurement, the small difference between the two LAI surfaces is not very significant. Another reason for the discrepancy may be due to the misclassification of MODIS land cover product that is directly influences the outcome of LAI estimate. The evaluation of MODIS LAI has been only carried out over relatively small area of temperate forest with rather limited ground reference data. Since the collection of reliable and accurate ground measurement of LAI is very difficult and time-consuming, the validation of MODIS LAI should be restricted to such small area.

Table 4. Classification accuracy of the MODIS land cover assessed by the ETM+ classification.

Reference \ MODIS	Conifer	Deciduous	Mixed	Cropland	Developed	Total
Conifer	0	0	13	6	0	19
Deciduous	3	2	32	4	0	41
Mixed	3	0	17	5	0	22
Crop	0	0	1	1	0	2
Developed	1	0	24	31	0	56
Total	4	2	87	47	0	140

Overall accuracy = 14.3% (20/140)

4. Conclusions

During the last decades, NASA has spent a great amount of time and efforts to develop the global ecological variables by using satellite data from the earth observing system (EOS) program. The MODIS global LAI product is one of such variables that are now being provided. To use such valuable information at regional and local scales, it is crucial to validate the quality of the product. In this study, we made a simple and direct comparison between the MODIS LAI data and the reference LAI surface that was derived by an empirical approach to relate the ground measured LAI to Landsat ETM+ reflectance.

Although the validation can be further expanded into larger areas, the preliminary results obtained from this study indicate that the MODIS LAI product is not much different from the reference data and can be used at local and regional scale. At the temperate forest, the MODIS LAI estimates were slightly higher (0.82 - 1.36) than the reference LAI values during the leaf-on season of June and September. The discrepancy between the MODIS LAI and the reference LAI may be caused by the uncertainties in the input variables of MODIS cover type, reflectance, and algorithm itself. Furthermore, since there has been very limited information regarding the actual values of LAI in Korea the production of reliable and accurate LAI surface is extremely difficult. The photo-optical instrument used for the ground LAI measurement in this study has not been fully calibrated and it is necessary to verify the LAI estimates.

The validations of MODIS LAI product are being carried out at the several study sites throughout the world. Due to the 1km spatial resolution of the data, the validation is often restricted by the size of test area and the collection of accurate ground-truth data. Temperate forest is even more complicated than any other ecosystems, which include a variety of species and stand structure. It may be premature to derive any concrete statement on the quality of the MODIS LAI estimate until the extensive and careful validations are completed.

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