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Inspection Standards for Applying UAV Photogrammetry to River Topographic Surveys

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The Ministry of Land, Infrastructure, and Transport of Korea has established a basic river plan to be implemented every 10 years for the systematic reorganization and management of rivers. However, the conventional river topographic survey method requires considerable time and cost. To overcome this problem, work regulations have been established and applied to efficiently conduct river topographic surveys using unmanned aerial vehicles (UAVs). However, in these work regulations, there are no inspection standards for the mosaic orthophotos and digital elevation models (DEMs) acquired from UAVs. In addition, when conducting river topographic surveys using UAVs, ground control point (GCP) surveys are often not performed, which decreases the accuracy of the results. Rivers have topographic elements, such as banks, crests, and berms, with elevation differences. Therefore, it is necessary to perform a GCP survey of the field when river topographic surveys are conducted using UAVs. To determine the necessity of GCP surveying, in this study, we evaluated the accuracy of mosaic orthophotos and DEMs acquired using UAVs with and without GCP surveying. Without GCP surveying, the root mean square error (RMSE) of the mosaic orthophotos was ±19.110 m and that of the DEMs was ±6.950 m. However, with GCP surveying, the RMSE of the mosaic orthophotos was ±0.057 m and that of the DEMs was ±0.024 m. Therefore, it is concluded that a GCP survey is necessary in river topographic surveys with UAV photogrammetry. On the basis of the study results, the inspection criteria for applying UAV photogrammetry to river topographic surveys were divided into aerial triangulation accuracy criteria, orthophoto inspection criteria, and DEM inspection criteria, and presented as numerical values.

1. Introduction

The Ministry of Land, Infrastructure, and Transport (MOLIT) of Korea has established a basic river plan based on the Guidelines for the Establishment of a River Basic Plan (MOLIT Notification No. 2018-992).(1) The plan is intended for the systematic reorganization and management of rivers in an environmentally friendly manner. However, in Korea, where 70% of the land is mountainous and many rivers exist, the watershed area is large, and considerable time

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and cost are required to investigate the topography. To overcome this problem, the Iksan Regional Land Management Agency of MOLIT prepared draft UAV-based river topographic survey work guidelines for the river maintenance plan in 2017.(2) These guidelines are intended to set detailed standards for conducting river topographic surveys using UAVs to implement an efficient river maintenance plan. However, these guidelines lack inspection criteria for mosaic orthophotos and digital elevation models (DEMs) produced by UAVs; the inspection criteria for conventional aerial photogrammetry are therefore applied. In addition, a river is divided into inner and outer areas based on the embankment, and is composed of terrain with elevation differences from the crest to the riverbed. Therefore, a ground control point (GCP) survey of the field is essential when conducting topographic surveys using UAVs; however, river topographic surveys are often conducted using UAVs without GCP surveys.

The purpose of this study was to evaluate the accuracy of UAV results with and without GCP surveys of the river topography to verify their necessity and to suggest appropriate inspection criteria for river topographic surveys when using UAV photogrammetry. In this study, a test bed in the river area was selected, UAV imaging was performed, and data were processed by dividing the GCP survey results into cases with and without a GCP survey. The accuracy of the mosaic orthophotos and DEMs obtained was evaluated. Figure 1 shows a flowchart of the research content and procedures used in this study.

Nordberg *et al.* announced a vision for helicopter-based surveying in 2002(3) and concluded that an aerial vehicle can be used for river surveys. Since 2002, research on watershed investigation or river bathymetry using remote sensing technology has continued(4–8) alongside research on UAV-based mapping.(9–13) A commonality between UAV photogrammetry and laser scanning is that both can be used to obtain point cloud data of an object. Hence, research on mapping or mobile mapping using laser scanners has been ongoing.(14–18) Eisenbeiβ established the theory of UAV photogrammetry through his Ph.D. dissertation,(19) and since then, UAVs

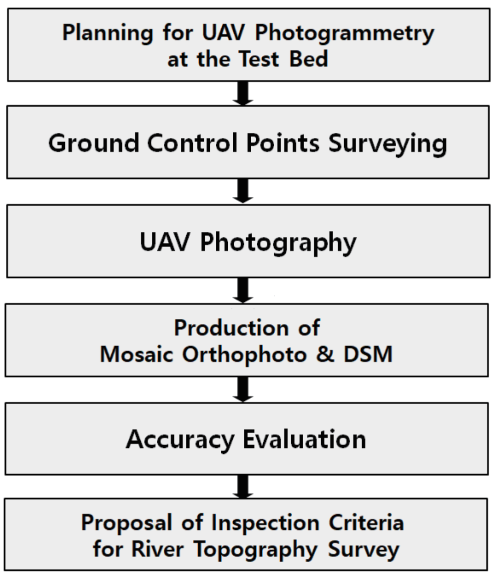


Fig. 1. Procedure for proposed inspection criteria.

have been more actively utilized in many fields. Because UAV photogrammetry can be used to perform mapping more rapidly and cheaply than conventional aerial photogrammetry, most early research focused on large-scale mapping and accuracy verification.[20–24] The International Society for Photogrammetry and Remote Sensing holds a UAV-Geomatics conference every two years, and mapping and accuracy verification research accounted for a quarter of the 192 papers published at the conferences held in 2011, 2013, and 2015. The use of UAVs in the construction field is increasing because it is possible to create a 3D model of an object using structure-from-motion technology. With the promotion of smart construction in many countries, such as the UK,[25] Japan,[26] and Korea,[27] 3D models created using UAVs are being increasingly employed. Three-dimensional models based on point cloud data have been used in building information model (BIM) design,[28] ICT construction management,[29–31] and infrastructure maintenance.[32,33] In a study related to river surveys using UAVs, Watanabe and Kawahara produced a digital surface model (DSM) of the Jyoge River with a maximum height error of 4 cm.[34] Claude *et al.* reported that a UAV-only system can meet decimeter accuracy requirements.[35] Hemmelder *et al.* concluded that UAV products have sufficient accuracy for river monitoring.[36]

2. Materials and Methods

2.1 River topographic surveys and use of UAVs

In accordance with the River Act, the River Management Agency must establish a basic river plan every 10 years and implement it in accordance with the Guidelines for Establishing a Basic River Plan.[1] Guidelines for establishing a basic river plan include investigation of the river topography, watershed area, flow path extension, watershed average width, and watershed shape coefficient. In 2017, the Iksan Regional Land Management Agency of MOLIT prepared draft UAV-based river topographic survey work guidelines for the river maintenance plan. These guidelines are intended to set detailed standards, such as for river topographic surveys and quality inspection, and to implement an efficient river maintenance plan. Guidelines for river topographic surveys using a UAV were prepared. A topographic survey of rivers is conducted using either a national digital basic map or UAV photogrammetry. Underwater topographic surveys are conducted using water depth surveys, and river topographic surveys are conducted by dividing them into land and underwater topographic surveys. In a land topographic survey, mosaic orthophotos and a DEM are produced by UAV photogrammetry of the land surface from the embankment to the location of the water and by acquiring the necessary data. A DEM is a model of the ground surface obtained by removing artificial and natural features from the DSM obtained using the UAV. Table 1 compares the conventional river survey method with the UAV-based river survey method. As shown in Fig. 2, the river is composed of an embankment and several small berms, involving terrain with many elevation differences from the crest to the riverbed. Therefore, a GCP survey of the field is essential when conducting a river topographic survey using UAVs; however, a GCP survey is often not performed, which has a significant impact on the accuracy of the results.

Table 1
Comparison of two topographic survey methods applied to rivers.

Conventional method	UAV photogrammetry method
Surveying processes include frame surveying, longitudinal surveying, and cross-sectional surveying. Considerable time required for surveying.	New technologies, such as UAV photogrammetry and green LiDAR, eliminate unnecessary processes, improving work efficiency.
Information omitted by acquiring 2D linear information at regular intervals.	3D surface information obtained to increase accuracy and usability.
High accuracy maintained only for surveying and sampling section. Difficult to verify accuracy of non-irradiated parts.	Accuracy required for basic river maintenance plan should be ensured, rather than aiming for too high precision.
High cost of river survey when river maintenance master plan established.	River topographic survey using UAV increases economic efficiency.

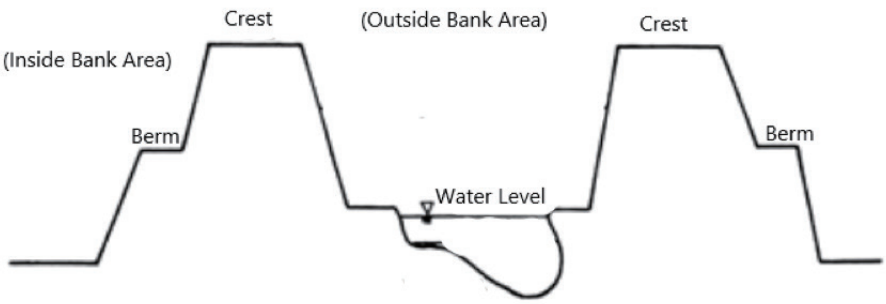


Fig. 2 General shape of a river.

As listed in Table 1, the conventional river topographic survey method includes GCP surveying, longitudinal surveying, and cross-sectional surveying. These take considerable time and have a high cost, and the accuracy is not constant.

By introducing UAV photogrammetry for river topographic surveys, unnecessary processes can be eliminated, thus improving the work efficiency and economic efficiency. In addition, the accuracy of the river topography can be increased by producing mosaic orthophotos and DEMs. Hence, a work rule was created to introduce UAV photogrammetry into river topographic surveys. However, when performing a river topographic survey using UAV photogrammetry in a river field, the UAV photogrammetry results often exclude GCP coordinates because of the omission of the GCP survey. Although this approach can help perform work quickly, it significantly decreases the accuracy.

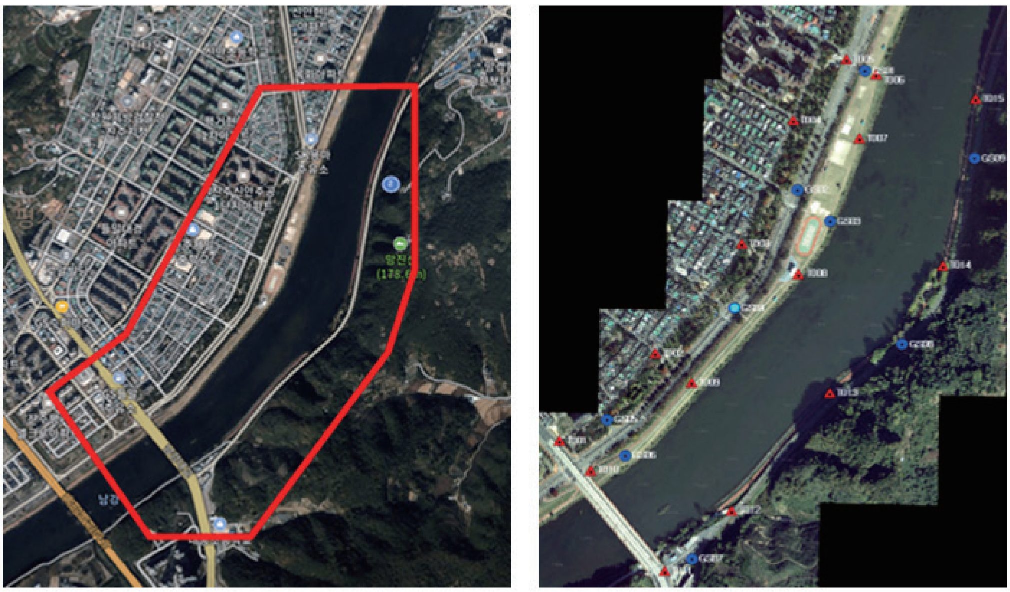
To overcome this problem, in this study, UAV photogrammetry was performed, and the results were produced by dividing them into cases with and without a GCP survey. The necessity of the GCP survey was shown by comparing the accuracies of the two sets of results.

2.2 Selection of test bed and GCP survey

The test bed for this study was located along approximately 1 km of the Nam River in Pyeonggeo-dong, Jinju-si, and Gyeongsangnam-do. Figure 3(a) shows the test bed and Fig. 3(b) shows the distribution of the GCPs and checkpoints (CPs) in the test bed.[37] Fifteen GCPs and nine CPs were selected in accordance with the Unmanned Aerial Vehicle (UAV) Surveying Regulations of the National Geographic Information Institute (NGII).[38] According to Article 9 of these regulations, the GCPs should be evenly placed in consideration of the shape of the work area, course direction, and so forth. The GCPs should also be located at points that can be clearly distinguished in the image, and there should be at least nine GCPs per 1 km^2 area or 1 km length. According to Article 11, the number of CPs should be at least one-third of the number of GCPs, and a sufficient number must be ensured according to the difficulty of the work. The minimum allowable numbers of GCPs and CPs are nine and three, respectively. To achieve the aims of the study, fifteen GCPs and nine CPs were used. Table 2 shows the 3D coordinates of the GCPs and CPs obtained from the GNSS Network-RTK survey.[37]

2.3 UAV photogrammetry and data processing

Before performing the UAV photogrammetry, flight approval and photographing permission were obtained, and the flight altitude and flight course were planned while considering the flight range, flight course, and overlapping ratio of the test bed. Matrice 210-RTK and Inspire 2 UAVs



(a) (b)

Fig. 3. (Color online) (a) Nam River test bed in Jinju and (b) distribution of GCPs (red triangles) and check points (blue circles).

Table 2
Three-dimensional coordinates of the fifteen GCPs and nine CPs.

Point No.	X (m)	Y (m)	Z (m)	Remark
T001	286286.369	114742.664	26.380	GCP
T002	286491.479	114957.779	27.605	GCP
T003	286747.943	115150.747	27.662	GCP
T004	287037.675	115267.000	27.778	GCP
T005	287180.304	115384.860	27.970	GCP
T006	287144.741	115451.969	23.847	GCP
T007	286995.295	115414.913	23.424	GCP
T008	286677.499	115278.532	22.343	GCP
T009	286423.404	115039.143	22.831	GCP
T010	286217.547	114812.667	26.665	GCP
T011	285980.535	114979.400	30.081	GCP
T012	286122.919	115129.043	29.582	GCP
T013	286398.353	115347.386	22.880	GCP
T014	286697.045	115601.727	23.257	GCP
T015	287088.103	115674.430	22.996	GCP
GS01	287152.579	115427.777	23.891	CP
GS02	286873.957	115277.002	27.953	CP
GS03	286800.534	115348.617	22.425	CP
GS04	286597.070	115134.979	27.729	CP
GS05	286335.956	114850.292	26.915	CP
GS06	286251.539	114890.309	22.600	CP
GS07	286009.559	115040.540	35.391	CP
GS08	286511.950	115510.937	28.125	CP
GS09	286948.170	115673.014	28.560	CP

(DJI, China) and Zenmuse X5S cameras were used. Pix4DMapper software was used for data processing of the original image acquired by the two UAVs. First, aerial triangulation was performed using GCP coordinates, and a DSM and mosaic orthophoto of the test bed were produced. Figure 4(a) shows the footprint of the UAV flight, Fig. 4(b) shows the mosaic orthophoto, and Fig. 4(c) shows the DSM of the test bed.[37]

3. Results

3.1 Accuracy evaluation for aerial triangulation

Aerial triangulation refers to the process of obtaining the coordinates of all objects in an image using a small number of GCP coordinates. Therefore, the 3D coordinates of the GCPs are required, and the performance of aerial triangulation is a measure for judging the mapping accuracy. The criteria for evaluating aerial triangulation in UAV photogrammetry are currently the same as those employed in conventional aerial photogrammetry because no new criteria have been proposed. Table 3 presents the existing criteria, the results of this study, and the criteria we propose for river topographic surveys.

The accuracy of the aerial triangulation is stipulated in Article 56 of the Aerial Photogrammetry Regulations.[39] For digital topographic maps with a scale ranging from 1:1000

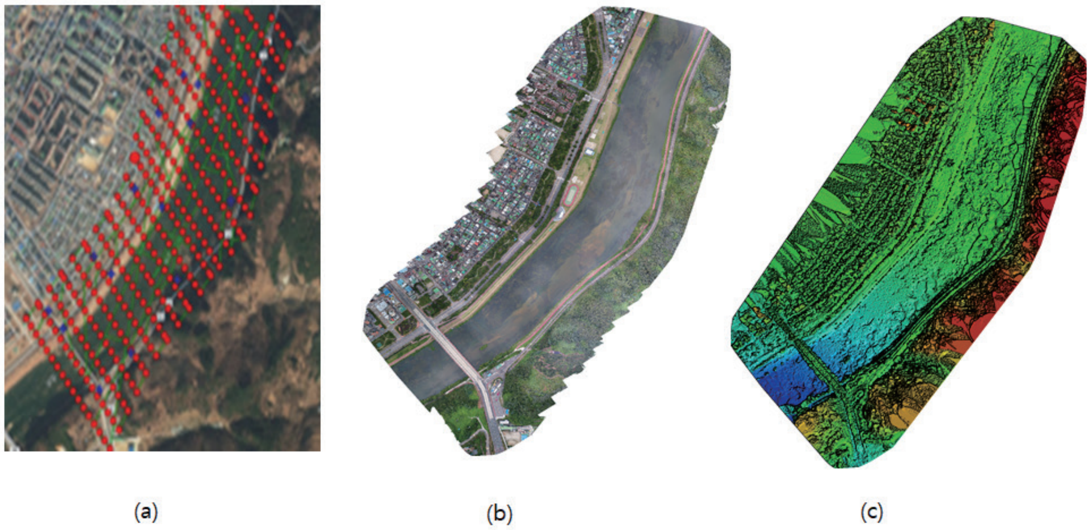


Fig. 4. (Color online) (a) Footprint of the UAV flight, (b) mosaic orthophoto of the test bed, and (c) DSM of the test bed.

Table 3
Existing and proposed evaluation criteria and research results for aerial triangulation.

	Existing criteria for aerial photogrammetry	Study results		Proposed criteria for river topographic surveys	
Scale	1:1000–1:1200	1:300		1:200–1:500	
GSD	0.12 m	0.05 m		0.03	
		Δ*XY*	Δ*Z*	Δ*XY*	Δ*Z*
RMSE	±0.2 m	±0.019 m	±0.007 m	±0.10 m	±0.15 m
Maximum	0.40 m	0.032 m	0.013 m	0.20 m	0.30 m

to 1:1200 and a ground sample distance (GSD) within 0.12 m, the root mean square error (RMSE) should be within ±0.20 m and the maximum error (difference) should be within 0.40 m. The results of this study show that the RMSE of Δ*XY* is ±0.019 m and the maximum difference is 0.032 m when the GSD is 0.05 m, and the RMSE of Δ*Z* is ±0.007 m and the maximum difference is 0.013 m. Therefore, by comprehensively considering the existing Aerial Photogrammetry Regulations and the research results, we propose the following criteria for river topographic surveys: a horizontal RMSE of ±0.10 m, a maximum difference of 0.2 m for Δ*XY*, a vertical RMSE of ±0.15 m, and a maximum difference of 0.30 m for Δ*Z*.

3.2 Accuracy evaluation for mosaic orthophotos

Orthophoto inspection was verified using the horizontal position error in orthophoto production. The horizontal position error of a printed orthophoto image must be within 1.0 mm, as stipulated in Article 35 of the Regulations for Image Map Production.(40) Table 4 summarizes these criteria along with our research results and proposed inspection criteria for orthophotos.

Table 4
Existing and proposed evaluation criteria and research results for orthophoto production.

	Existing criteria for orthophoto production	Study results	Proposed criteria for orthophoto production
Scale	1:1000	1:300	1:200–1:500
GSD	—	0.05 m	0.05 m
RMSE	—	±0.057 m	±0.1 m
Maximum	0.1 mm	0.084 m	0.1 m (1:200)–0.25 m (1:500)

The accuracy of the orthophotos is currently stipulated as 1.0 mm on a map with a scale of 1:1000; thus, the ground distance is 1.0 m. However, if a UAV is used, this value can be significantly reduced. As shown in Table 4, when the scale is 1:300 and the GSD is 0.05 m, the RMSE is ±0.057 m and the maximum difference is 0.084 m. Therefore, the inspection criteria for orthophotos produced by UAV photogrammetry proposed in this study are an RMSE of ±0.1 m and a maximum difference of 0.1 m (scale 1:200) to 0.25 m (scale 1:500).

3.3 Accuracy evaluation for digital elevation model

The DEM is a grid elevation model of the ground obtained by removing artificial and natural features using the auto-classification function in the DSM obtained from UAV photogrammetry. The accuracy of the DEM was verified using the vertical position error, and the criteria are presented in Article 44 of the Aerial Laser Surveying Regulations.(41) In addition to these criteria, the verification results of the DEM obtained in this study and our newly proposed criteria are presented in Table 5.

The existing verification criteria for the DEM are an RMSE of ±0.24 m and a maximum difference of 0.05 m when the grid spacing is 0.1 m × 0.1 m. In this study, the RMSE is ±0.024 m when the grid spacing is 0.05 m × 0.05 m, and the maximum difference is 0.056 m. Therefore, the inspection criteria for the DEM produced by UAV photogrammetry proposed in this study are an RMSE of ±0.15 m and a maximum difference of 0.25 m when the grid spacing is 0.05 m × 0.05 m.

3.4 Accuracy evaluation for mosaic orthophotos and DEMs without GCP survey

Because of the significant difference in the elevation of river structures, such as the crest, berm, and riverbed, if a GCP survey is not performed, the mosaic orthophotos and DEMs will show significant errors. In this case, most of the coordinates are measured and entered on

Table 5
Existing and proposed evaluation criteria and research results for DEM (unit: m).

	Existing criteria for orthophoto production (m)	Study results	Proposed criteria for orthophoto production
Grid spacing	0.1 × 0.1	0.05 × 0.05	0.05 × 0.05
RMSE	±0.24	±0.024	±0.15
Maximum	0.5	0.056	0.25

Table 6
Accuracy evaluation for mosaic orthophotos and DEM produced without GCP survey (unit: m).

	Horizontal accuracy (m)	Vertical accuracy (m)
RMSE	±19.110	±6.950
Maximum	20.512	11.236
Minimum	16.932	1.519

Google Maps; however, this still causes a significant error. In this study, the mosaic orthophotos and DEMs were prepared using Pix4DMapper without a GCP survey or coordinate measurement from Google Maps, and the accuracy was evaluated using the GCP coordinates. Table 6 presents the results.

When the GCP survey was not performed, the RMSE of the mosaic orthophoto was ±19.110 m and that of the DEM was ±6.950 m. These values exceed the existing inspection standards for aerial photogrammetry; thus, this product cannot be used for river topographic surveys. Therefore, it is concluded that a GCP survey is necessary for river topographic surveys with UAV photogrammetry.

4. Conclusions

The first goal of this study was to identify the necessity of GCP surveying in river topographic surveys using UAVs. For this purpose, UAV photogrammetry was performed on a test bed, data were processed by dividing them into cases with and without GCP surveying, and mosaic orthophotos and DEMs were produced. By evaluating the accuracy of mosaic orthophotos and DEMs generated for these two cases, the following results were obtained. First, without GCP surveying, the RMSE of the mosaic orthophoto was ±19.110 m and that of the DEM was ±6.950 m. However, with GCP surveying, the RMSE of the mosaic orthophoto was ±0.057 m and that of the DEM was ±0.024 m. Therefore, it is concluded that a GCP survey is necessary for river topographic surveys with UAV photogrammetry.

The second goal of this study was to propose inspection standards for applying UAV photogrammetry to river topographic surveys. To achieve this, the existing inspection criteria for aerial photogrammetry were examined for a test bed in the Namgang area of Jinju, and UAV photogrammetry was performed. On the basis of the results and existing inspection criteria of UAV photogrammetry, the following inspection criteria for river topographic surveys were proposed:

For aerial triangulation in river topographic surveys: RMSE of ±0.10 m, maximum difference of 0.2 m for ΔXY, RMSE of ±0.15 m for ΔZ, and maximum difference of 0.30 m.

For orthophotos produced by UAV photogrammetry: RMSE of ±0.1 m and maximum difference of 0.1 m (scale 1:200) to 0.25 m (scale 1:200–1:500, GSD 0.03 m) (scale 1:500).

For the DEM produced by UAV photogrammetry: RMSE of ±0.15 m and maximum difference of 0.25 m when the grid spacing is 0.05 m × 0.05 m.

If the reasonable inspection standards proposed in this study are applied to river topographic surveys, UAV photogrammetry can be performed more actively and more accurate results can be obtained.

Acknowledgments

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