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Construction of Multi-Dimensional Ortho-Images with a Digital Camera and the Multi-Image Connection Method

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디지털카메라와 다중영상접합법을 이용한 다차원 정사영상의 구축

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Abstract Essential to the establishment of such 3D spatial information are the laser scanning technology to obtain high-precision 3D point group data and the photography-metric camera to obtain high-resolution multispectral image information. The photography-metric camera, however, lacks in usability for its broad scope of utilization due to the high purchase price, difficult purchase channel, and low applicability. This study thus set out to investigate a technique to establish multi-dimensional ortho-image data with a single lens reflex digital camera of high speed and easy accessibility for general users. That is, the study remodeled a single lens reflex digital camera and calibrated the remodeled camera to establish 3D multispectral image information, which is the essential data of 3D spatial information. Multi-dimensional ortho-image data were collected by surveying the reference points for stereo photos, taking multispectral shots of the objects, and converting them into ortho-images.

Key Words : 3D spatial information, ortho-image, photography, digital camera, multispectral

요 약 3차원 공간정보를 구축하기 위해서는 고정밀의 3차원 점군데이터를 취득할 수 있는 레이저스캐닝 기술과 고해상도의 다중분광 영상정보를 취득할 수 있는 사진측량용 카메라의 활용은 필수이다. 그러나 사진측량용 카메라는 장비특성상 높은 구입비와 어려운 구입경로, 낮은 적용성으로 폭넓은 활용분야에 비해 활용성이 떨어진다. 따라서 일반사용자가 빠르고 간편하게 접근할 수 있는 디지털카메라를 이용하여 다차원 정사영상을 구축하는 기법을 연구하였다. 즉 3차원공간정보의 핵심자료인 3차원 다중분광영상정보를 구축하기 위해 디지털카메라를 개조하고 캘리브레이션 작업을 수행하였다. 스테레오 사진측량을 위한 기준점 측량과 관측대상에 대한 다중분광촬영, 정사영상으로의 변환 등을 거쳐 다차원 정사영상을 구축하였다.

주제어 : 3차원 공간정보, 정사영상, 사진측량, 디지털카메라, 다중분광

1. Introduction

Three-dimensional spatial information is the basis of various new business creation models and also the nation's basic core spatial information to create new businesses with the service fused and combined with

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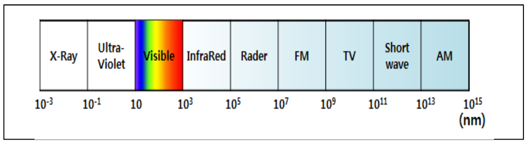
the IT industry. In South Korea, the Ministry of Land, Infrastructure and Transport has provided active support for the ongoing implementation of the 3D Spatial Information Establishment Project through the Basic National Spatial Information Plan. In other words, 3D spatial information is the essential foundation of land informatization and also very important information not only to complete the 3D project for the land, but also for general considerable synergy effects in all kinds of scientific fields including prevention of disasters, public sector, local government affairs, military, and life. The establishment of 3D spatial information requires a variety of equipment to implement advanced surveying technologies[1,2,10,11]. Especially essential are the terrestrial LiDAR to implement the laser scanning technology to obtain high-precision 3D point group data and the photography-surveying camera to obtain high-resolution multispectral image information[6,12]. Also needed are the GPS receiver and processor technology to obtain the reference point data to set the geodetic coordinate system of 3D data. Such diverse technologies and positioning equipment are in need for 3D spatial information establishment, and the photography-survey camera is particularly essential to build multi-dimensional spatial information, the core data of 3D spatial information[3,7]. However, the camera is characterized by high purchase price, difficult purchase channel, and low applicability and also lacks in usability for its broad scope of utilization. A new methodology is thus required to replace the old photography-surveying camera so that common users can obtain multi-dimensional image information in a fast and easy way[8,9]. The present study thus set out to propose a methodology easily accessible by common users to establish 3D multispectral image information, the core data of 3D spatial information[4,5]. For the purpose, the study proposed the remodeling plan of a single lens reflex digital camera to replace the old photography-surveying camera or the detailed design related to the altered camera structure and also the method of establishing multispectral image data with the remodeled digital camera.

2. Multispectral Image Data

2.1 Multispectral Image

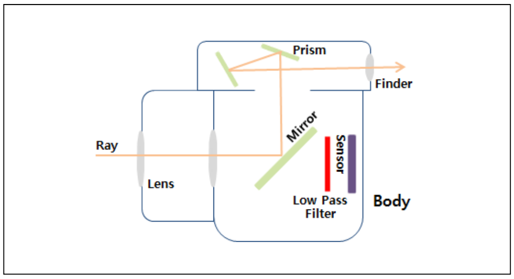
Three-dimensional spatial information consists of multispectral images and digital terrain models and presents terrain information in 3D through data fusion. Multispectral images include the data obtained by sensing the electromagnetic radiation energy emitted from such a radiation source as the sun and reflected on the object and collecting it by the spectral wavelength. Although the commonly used spectral images come from the visible ray wavelength, recent years have witnessed the increasing uses of multispectral images from the near-infrared ray wavelength as well as the visible ray wavelength. The images of visible ray wavelength are in the range of 0.38~0.78㎛ and can be made as color images by combining three light source colors of red, green and blue. Near-infrared generally falls in the range of 0.75 ~3㎛ wavelength, but the value of 0.7~1.5㎛ wavelength is the usually used in the near-infrared range. Near-infrared boasts high usability, has the shortest wavelength in the infrared range, and allows for various examinations and analyses in relation to vegetation through the vigor of vegetation, thus claiming the greatest importance.



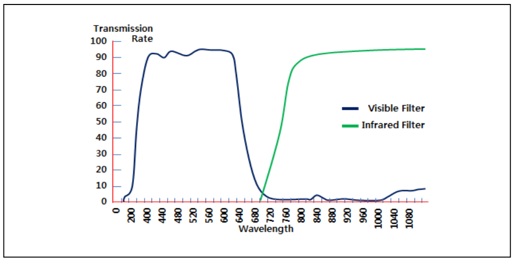
[Fig. 1] The visible ray and near-infrared wavelength

2.2 Multispectral Digital Camera

In general, the color information (R, G, and B) in terrestrial photographs is obtained by using the sensors in the visible ray range. There should be a terrestrial near-infrared camera with near-infrared sensors to obtain near-infrared images. In recent years, a single lens reflex digital camera has improved in the sensor degree and resolution to the degree of application to terrestrial photography survey and easily offers the image information of the visible ray wavelength. However, it is necessary to remodel a single lens reflex digital camera in a way that allows for obtaining near-infrared wavelength images in order to get such images. A general single lens reflex digital camera follows the principle of an image coming in through the lens and going through the low pass filter and only the visible ray getting trapped inside the image sensor. The low pass filter works to prevent the infrared and ultraviolet ray and let only the visible ray through.



[Fig. 2] The camera structure

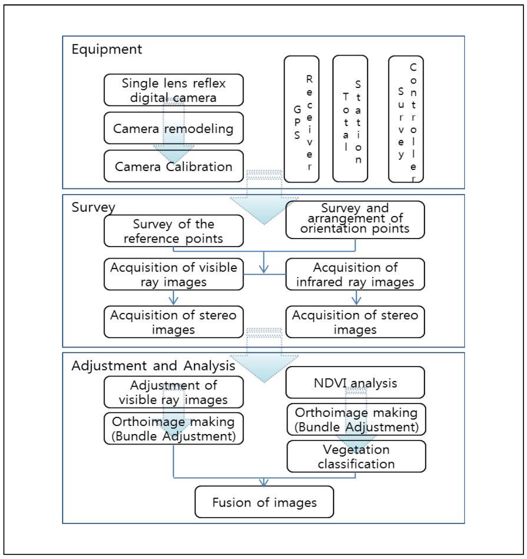


[Fig. 3] The transmission characteristics of the visible ray filter and the near-infrared filter

The old common camera allows for obtaining only images in the visible ray range due to the low pass filter, which raises a need to remove the low pass filter and install the near-infrared filter to have the sensitivity characteristics even in the near-infrared range.

2.3 The Process of Multispectral Image Establishment

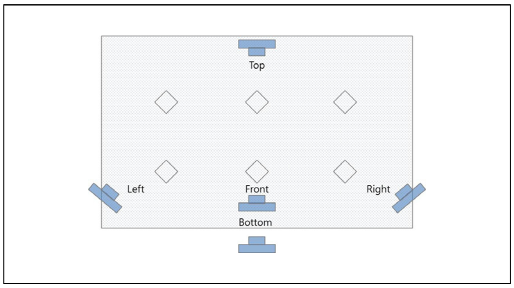
Turning multispectral images into 3D image information requires a series of processes including the preparation of survey equipment, survey, adjustment, and analysis.



[Fig. 4] The process of multispectral image establishment

2.3.1 Camera Calibration

A single lens reflex digital camera provides the multispectral image information of the object, but it should be followed by the process of image processing to obtain 3D image information. Accurate results can be ensured only with the accurate internal orientation elements of the camera and lens. The present study thus decided to obtain image data and use them to calculate calibrations as seen in the figure below.



[Fig. 5] The process of obtaining images for camera calibration

The internal orientation elements include the focal length, principal movement, and radial distortion coefficient of the camera. Camera calibration is needed the values of those internal orientation elements.

2.3.2 Survey and Ortho-Image Making

The photographs of the object surveyed with a digital camera are taken through central projection. Photographs taken through central projection include many terrain distortions, which are caused by the winding terrain, the film and scanner distortion, the lens distortion, and the atmosphere and earth curvature distortion. The bundle adjustment method is used to correct such distortions and make ortho-images. The bundle adjustment method obtains the absolute coordinates with the photograph coordinates as the basic unit. By using the method, one can simultaneously obtain the camera location, inclination, and 3D coordinates in multiple images with the orientation point. The basic mathematical model equation of the method is the collinearity condition equation (Equation (1)), which is based on the condition that random points(X_p, Y_p, Z_p) in space should be on the same straight line as their corresponding image points (x, y) and the shooting center(X_o, Y_o, Z_o) of the camera.

$$
\begin{aligned}
&x(X, Y, Z; \omega, \varphi, \kappa, X_o, Y_o, Z_o, x_o, f) \\
&= x_o - f\frac{r_{11}(X_p - X_o) + r_{12}(Y_p - Y_o) + r_{13}(Z_p - Z_o)}{r_{31}(X_p - X_o) + r_{32}(Y_p - Y_o) + r_{33}(Z_p - Z_o)} \\
&y(X, Y, Z; \omega, \varphi, \kappa, X_o, Y_o, Z_o, x_o, f) \\
&= y_o - f\frac{r_{21}(X_p - X_o) + r_{22}(Y_p - Y_o) + r_{23}(Z_p - Z_o)}{r_{31}(X_p - X_o) + r_{32}(Y_p - Y_o) + r_{33}(Z_p - Z_o)}
\end{aligned} \quad (1)
$$

Here, ω and φ, κ the orientation factors, X and Y, Z the terrestrial point coordinates, f focal length, and r_{ij} the rotational conversion matrix element.

2.3.3 Vegetation Analysis with the Near-Infrared Image Information

The vegetation index is used to extract vegetation with such image data as terrestrial photographs. The vegetation index has no unit and offers the radiation measurement to indicate the relative distribution and activity of green vegetation. Equation (2) shows how to obtain the Normalized Difference Vegetation Index (NDVI).

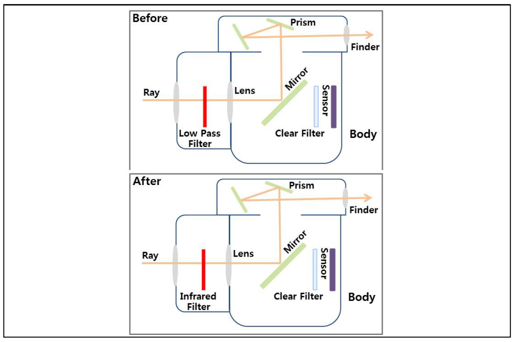
$$
NDVI = [\frac{(NIR - Red)}{(NIR + Red)} + 1] \times 128 \quad (2)
$$

Here, NIR is the value of the near-infrared range, and “Red” points to the color red in the visible ray range.

3. Establishment and Analysis of Multispectral Images

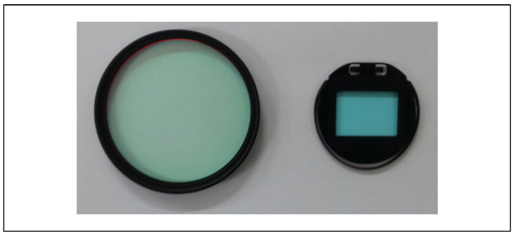
3.1 Digital Camera Remodeling and Filter Choice

There is a need to remodel a common single lens reflex digital camera in order to obtain the images from the visible and near-infrared ray range with it.



[Fig. 6] The structure of the remodeled camera

Used in the present study was the EOS 60D model by Canon with the image sensor of CMOS (APS-C, 1:1.6) and approximately 17.90 megapixels. Remodeling happened in two steps: Step 1 involved the location change of the low pass filter, which was moved from the front of the image sensor in the basic camera structure to the front of the lens mount; and Step 2 involved the movement of the near-infrared filter to the front of the lens mount, in which case it was ensured that the low pass filter and the IR filter would be replaceable. Remodeled through Steps 1 and 2, the camera was capable of obtaining images from the visible and near-infrared ray range.



[Fig. 7] The adopted visible and near-infrared ray filter

The near-infrared filter obtains only the near-infrared information and should be selected by taking the reflective characteristics of vegetation into consideration. Vegetation has the highest reflectance in the range of approximately 750㎚ ~ 950㎚, which led to the selection of the filter in the same range for the study.

3.2 Reference Point Survey and Multispectral Image Shooting

3.2.1 Reference Point Survey

Reference points are needed to arrange the orientation points and obtain the coordinates used to make ortho-images. Generally used are GPS capable of 3D coordinate survey and the 3D coordinate surveying instrument. In the present study, two reference points were set to obtain absolute coordinates based on the Korean geodetic system via GPS survey. Twelve orientations were set on the object side, and absolute coordinates were obtained with TotalStation, a 3D coordinate surveying instrument.

〈Table 1〉 The Reference Points

Coordinate	Reference Point 1	Reference Point 2
X(m)	212847.500	212855.281
Y(m)	378915.901	378947.121
Z(m)	41.820	41.892

〈Table 2〉 The Orientation Points

Orientation Point	X(m)	Y(m)	Z(m)
1	212782.737	379024.616	58.018
2	212782.738	379024.614	50.757
3	212792.847	379024.244	58.04
4	212792.863	379024.255	50.755
5	212811.399	379020.449	57.878
6	212810.687	379020.569	54.247
7	212810.685	379020.564	50.606
8	212828.23	379017.65	58.051
9	212837.323	379014.426	58.06
10	212837.327	379014.429	54.403
11	212837.33	379014.428	50.801
12	212836.049	379014.679	43.519

3.2.2 Camera Calibration

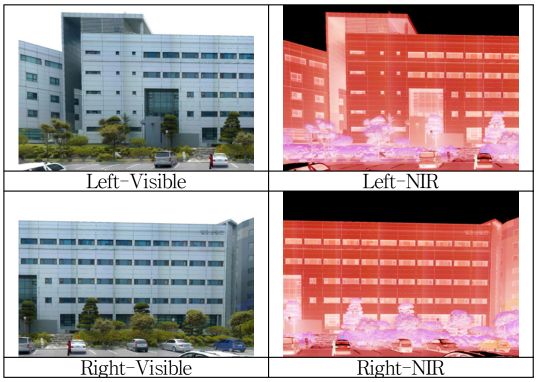
A devoted sheet was used for calibration. It contained points arranged in a certain grid form and was installed at a proper location. Camera shooting took place at five locations with a random interval between them based on the sheet. The obtained data were then used to calculate the internal orientation elements of the camera.

〈Table 3〉 The calibration results

Item	Value
Focal Length	18.100361
Xp	10.728531
Yp	7.309114
Distortion Model	2
k1	5.637088e-004
k2	-1.596990e-006
p1	1.569950e-004
p2	7.039235e-005
X Resolution	0.0042
Y Resolution	0.0042

3.2.3 Visible and Near-Infrared Ray Image Shooting

The remodeled digital camera was used to shoot the subject structure, which was filed by applying a visible and near-infrared ray filter to each side of the building. A picture was taken both on the right and left side with overlap in order to make a stereo image for each cross section (Figure 8). The obtained images were saved as a RAW file (CR2 format) and JPG format.

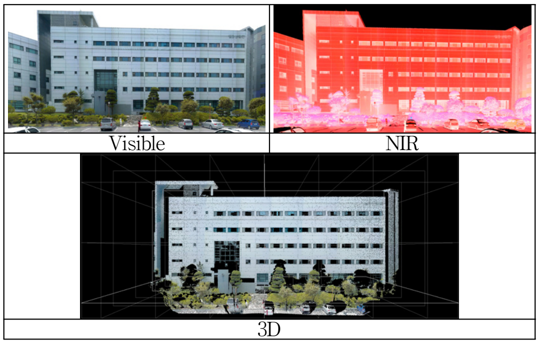


[Fig. 8] The visible and near-infrared ray image shooting (left and right)

4. Image Classification and Adjustment

4.1 Ortho-Image Making

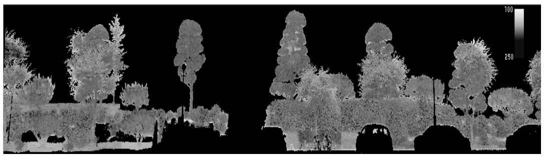
Ortho-images were adjusted with the bundle adjustment method. As a result, standard deviation was 0.0052 in the X direction, 0.0052 in the Y direction, and 0.0052 in the Z direction.



[Fig. 9] The Ortho-Image

4.2 Establishment of NDVI Images

The green band was selected because green has the highest reflectivity according to the reflective characteristics of vegetation in order to calculate NDVI. The range of NDVI was set in 0 ~ 255. Vegetation was in the range of 100~250 with approximately 0.5% misclassification, which seems to be attributed to the shadows and the reflection of building windows.



[Fig. 10] The NDVI-Image

4.3 Analysis and Consideration of Ortho-Images

The orientation points (absolute coordinates) were compared with the image coordinates (point of interest) to calculate the accuracy of ortho-image coordinates and obtain standard deviation (Table 4). Those results show that 3D location information can be provided with image coordinates. That is, one can survey the 3D absolute coordinates of a desired point by using ortho-images.

<Table 4> The accuracy of image coordinates

Coordinate	X(m)	Y(m)	Z(m)
poi1	0.0007	0.0007	0.0007
poi2	0.0009	0.0009	0.0009
poi3	0.011	0.011	0.011
poi4	0.015	0.015	0.015
poi5	0.0004	0.0004	0.0004
poi6	0.0020	0.0020	0.0020
Average(m)	0.0005	0.0005	0.0005

Near-infrared images are applicable to a variety of fields and especially provide image information specialized for the extraction and analysis of vegetation. The present study extracted vegetation based on the NDVI results to explore the possibility of vegetation extraction with near-infrared ortho-images.

The images were reclassified into the pixels in the vegetation range and those out of the vegetation range to analyze the vegetation values based on the NDVI results. As a result, vegetation recorded 97% accuracy.

<Table 5> The vegetation extraction results

Item	Vegetation	Others
NDVI result	374,257	1,000,017
Field data	373,853	1,002,380
Misclassification	11,228	2,363

The image pixels of misclassification not classified as vegetation seem to be influenced by the shadows and building windows. After field study, it was found that misclassification happened at the boundary point (the gap between the vegetation leaves) of vegetation, the shadow of vegetation, and the boundary point of vegetation reflected on the window. Such misclassification records 0.3% in the vegetation item but poses no problem for application to research.

[Fig. 11] The images extracted only with vegetation values

5. Conclusions

The study proposed how to remodel the old photography-survey camera and establish multispectral image data with it in order to investigate a technique of establishing multi-dimensional ortho-image data with a single lens reflex digital camera, reaching the following conclusions:

First, the study was able to propose a structural design plan to obtain image information from the visible and near-infrared wavelength by remodeling a single lens reflex digital camera, especially in obtaining each piece of image information effectively by adopting a filter that took into account the characteristics of the visible and near-infrared wavelength. The study also found that it had full potential to be used as a way to easily obtain concerned information by general users.

Secondly, the study made ortho-images to convert multi-dimensional image information (visible and near-infrared image information) into an absolute coordinates scale and obtained the average accuracy of 0.0040m. In addition, the accuracy results of image coordinates indicate that the obtained results are fully applicable as 3D image information.

Finally, the research results can offer users 3D locations and image information, which are in line with the components of 3D spatial information. By using the results, users can access and utilize 3D-based location and image information in a fast and easy manner.

The research findings can help general users establish the spatial information of the real world in 3D-based locations and images and make active use of them in all kinds of social and scientific fields including prevention of disasters.

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