

2015

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### Recommended Citation

Kim, Se-Yul; Lee, Dong-Gook; Lee, Jung-Bin; Jang, Byung-Jin; You, Ji-Ho; and Lee, Hyun-Jik, (2015) "The Development of Web3D-based Open-pit Mine Monitoring System," *Free and Open Source Software for Geospatial (FOSS4G) Conference Proceedings*: Vol. 15 , Article 52.

DOI: <https://doi.org/10.7275/R5W09431>

Available at: <https://scholarworks.umass.edu/foss4g/vol15/iss1/52>

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## ABSTRACT

*Large-scale open-pit mines are critical infrastructure for acquiring natural resources. However, this type of mine can experience environmental and safety problems during operations and thus requires continuous monitoring.*

*In this study, a web three-dimensional(3D)-based monitoring system is constructed using geospatial information open platform and open-source geospatial information software which targets open-pit mines in Gangwon-do, Korea. The purpose is to develop a monitoring system of open-pit mines that enables any person to monitor the topographic and environmental changes caused by mine operations and to develop and restore the area's ecology.*

*Open-pit mines were classified into active or inactive mines and monitoring items and methodologies were established for each type of mine. Cesium which is a WebGL-based open-source platform was chosen as it supports dynamic data visualization and hardware-accelerated graphics related to elapsed time which is the essential factor in the monitoring.*

*The open-pit mine monitoring system was developed based on the geospatial database which contains information required for mine monitoring as time elapses, and by developing the open-source-based system software. The geospatial information database for monitoring consists of digital imagery and terrain data and also includes vector data and the restoration plan data. The basic geospatial information used in the monitoring includes high resolution ortho image(GSD 0.5 m or above) for all areas of the mines. This is acquired by periodically using an airborne laser scanning system and a LiDAR DEM (grid size 1m × 1 m). In addition, geospatial information data were acquired by using an UAV and terrestrial LiDAR for small-scale areas; these tools are frequently used for rapid and irregular data acquisition.*

*The geospatial information acquired for the monitoring of the open-pit mines represents various spatial resolutions and different terrain data. The database was constructed by converging this geospatial information with the Cesium-based geospatial information open platform of the ESRI World Imagery map and with SDK World Terrain meshes. The problems that resulted from the process of fusing aerial imagery and terrain data were solved in the Cesium-based open source environment.*

*The prototype menu for the monitoring system was designed according to the monitoring item which was determined by the type of mine. The scene of the mine and changes in terrain were controlled and analyzed using the raster function of PostGIS according to the elapsed time. Using the GeoServer, the aerial imagery, terrain and restoration information for each period were serviced using the web standard interface, and the monitoring system was completed by visualizing these elements in Cesium in 3D format according to the elapsed time.*

*This study has established a monitoring methodology for open-pit mines according to the type of mine and proposes a method for upgrading the imagery and terrain data required for monitoring. The study also showed the possibility of developing a Web3D-based open-pit mine monitoring system that is applicable to a wide range of mashup service developments.*

## 1. INTRODUCTION

## 1.1 The purpose and necessity of research

Compared to the underground mining, open-pit mining tends to ensure considerably safer operation, while returning higher yield than the former type of mining, leading to lower prime cost, mass production and supply. Open-pit mining, however, has drawbacks as well, accompanying: forest damage, mine-waste, dust, wastewater and tailing discharge, slag sedimentation, ground subsidence and runoff, and land slide. These defects, which may cause environmental disaster, have been the primary factor for the regulation of open-pit mining.

Likewise, the massive open-pit mines of Taebaek Mountains in the Baekdoo Mountain range continues to incur civil petitions as the region's need for eco-friendly development and restoration is high due to its ecological value of nesting rarely found botanical colonies and animal communities original to the region.

The government, to address the problem, has established *Mining Damage Prevention and Restoration Act (2005)* to minimize mine damage of the environment, ecology and the forest caused by the development of open-pit mines, while ecologically restoring already damaged open-pit mines. Operating open-pit mines, with the above measure enacted, have to manage the topographical and environmental alteration. Within the management process, periodic and precise monitoring technique for the eco-friendly restoration of the mines is a necessity; in order to achieve this efficiently, development of a monitoring system is required.

Research on the method of restoration of open-pit mines, however, tends to be insufficient worldwide, while domestic level on management and accumulation of present state data regarding the topographical alteration incurred by the development and restoration of open-pit mines relies on digital topographic maps and site surveys.

This research will aim to establish a web3D-based monitoring system on open-pit mines in Gangwon province(South Korea), using geospatial information open platform and open-source GIS software; the monitoring system that would be easily approachable even to the public will support eco-friendly development and restoration of open-pit mines in the region, as well as indicate alterations in topography and environment occurred by operation of mines. Also, by suggesting methods on optimal sensing and upgrading of the system, the research will propose a scheme on servicing the system based on geospatial information and open platform, contributing to the preservation of environmental ecology of the Baekdoo Mountain range.

## 1.2 Trend of research

The research on the monitoring of open-pit mines was conducted by Froese et al. (2008), using airborne LiDAR (Light Detection and Ranging) and satellite InSAR (Interferometric SAR) technique, mapping and monitoring mines via calculation of quantitative information regarding geospatial patterns.

Brown et al.(2007), to monitor a nearly 2km wide open-pit mine, combined a GNSS receiver and robotic total station equipment during the process.

Kim et al.(2003) have designed fully automatic modified monitoring system software using RTK GPS, enhancing the conventional monitoring system.

Shong(2013) has conducted a research on the new V-World based environmental geographic information system for environment analysis. The author has utilized geospatial information open platform and open source software in this study.

Jang et al.(2013) have proposed a frame regarding an establishment of 3D geospatial information system that would provide service linkage with geospatial information open platform, thereby suggesting methods of servicing 3D geographic information by its category.

Singh et al.(2012) have utilized open source software and standard to develop a web-based GIS application for the information system on natural resources.

Yin et al.(2009) mentioned the adequacy of application layer, service layer, functioning layer and saving layer; they planned and established the visualization system and vector geospatial data management according to the framework.

Ji et al.(2012), using open source GIS software GeoServer and Open-Layers, have depicted the realization of web service of Seoul's MRDB (Multiple Representation DataBase).

The existing studies and researches have high interest on the utilization of geospatial information open platform and open source GIS and have applied to a variety of field, but the main aspect of these researches remain on the analysis of alterations by DEM (Digital Elevation Model) and on the suggestions concerning the management system of mines.

### **1.3 Scope and direction of research**

This research has its base on assisting eco-friendly development and restoration of open-pit mines, and on providing easy access to the public on topographical and environmental changes regarding the operation of mines through the web3D-based monitoring system using open source GIS software.

Prior to the commence of the development of the monitoring system on open-pit mines, subject mines were divided into two categories of active mines and inactive mines to establish the methodology on monitoring and to classify monitoring areas to plan geospatial information database.

The geospatial information database consists of digital imagery and terrain data, and of which future restoration plans were formulated with vector data.

Basic geospatial information used in the open-pit mine monitoring system was accumulated with periodic acquirement of high-resolution ortho image (GSD 0.5m or above) of the mining region taken with airborne laser scanning system and LiDAR DEM (Digital Elevation Model: Grid size 1m x 1m) data.

Development of the open-pit mine monitoring system was conducted on different factors, of selecting adequate geospatial information open platform, of upgrading geospatial information database, and of developing a monitoring system based on open source.

The selection of geospatial information open platform was based on the prior research analyzing WWJ (World Wind Java) and Cesium in comparison, of which focused on dynamic-data visualization, support of hardware-accelerated graphics; in result, Cesium, a WebGL-based open source platform which met both criteria, was chosen as the platform for the monitoring system.

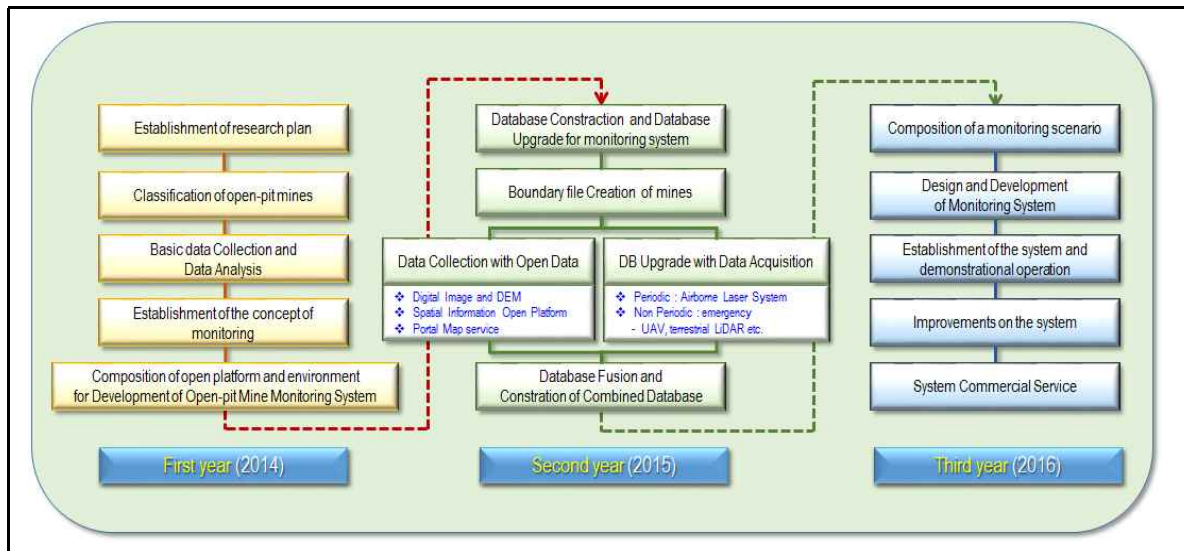
The development of the prototype of monitoring system was based on different types of mines' monitoring areas set up. Scenic and terrain change alterations throughout time were managed and analyzed using Raster mechanism of PostGIS, Periodic aerial image, geographical information and restoration information were serviced as a web-standard interface using GeoServer; all of the above combined was then integrated and visualized three-dimensionally into a service on Cesium, establishing the monitoring system capable of sensing periodic changes in the region.

Also, the geospatial information provided by Cesium based geospatial information open platform that this research has utilized lacks adequacy and precision for monitoring in terms of image resolution or size of DEM's grid. Therefore, this research has performed a periodic data acquisition using airborne laser surveying and non periodic acquisition in a small-scale region of interest using UAV system or terrestrial LiDAR, thereby enhancing the resolution of the image required for monitoring and reducing the size of the grid of DEM, upgrading geospatial information as a result.

Geospatial information acquired for monitoring of open-pit mines indicate information

in a variety of geospatial resolution and geographical data; this information was integrated with original image (ESRI world imagery map) that consists Cesium-based geospatial information open platform and terrain data (STK World Terrain Meshes) to establish a geospatial information database for the monitoring. Various problems during the process of integrating image and terrain data were solved under Cesium-based open source environment.

The main process of the study described above is as follows in Figure 1:



**Figure 1. Main process of this research**

## 2. TYPES OF OPEN-PIT MINES AND CONCEPT OF MONITORING

### 2.1 Types of open-pit mines

Gangwon province has approximately 116 open-pit mines, which of 64 are mining limestone. Open-pit mines, according to their state of operation, are categorized into either active or inactive mines. Active mines, in accordance with the mining act, are mines that are mining minerals or planning to mine minerals and are excavating ground, with the approval of the authority. Inactive mines are mines that have been put on the inactive status according to the approval and are not mining minerals.

Active mines, due to continuous mining and restoring processes, have a variety of factors concerning topographical changes. Inactive mines have been postponed from mining or have completed mining in the region; these mines are exposed to collapse or safety accidents.

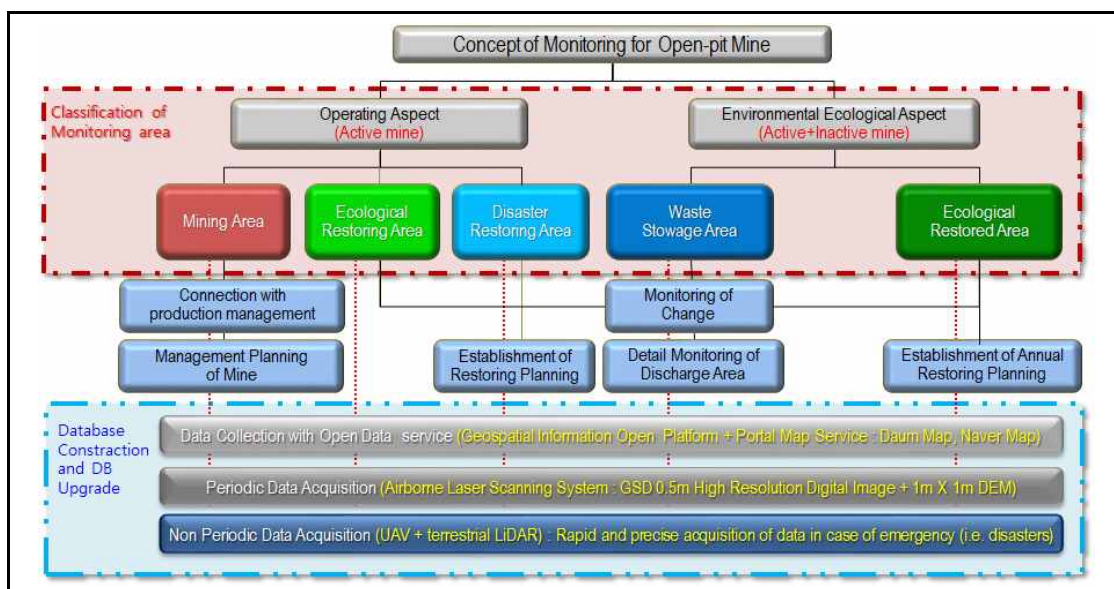
This research aims to develop a monitoring system which targets active and inactive mines with considerable scale and need for monitoring. To establish the concept and definition of active mine, Lafarge Halla Cement mine located in Okgye-myeon of Gangneung; Dongyang Cement mine in Samcheok was selected as a mine representing the inactive state. Figure 2 is the change of image over time of the two representative mines.

### 2.2 Establishment of monitoring concepts for open-pit mines

To efficiently and systematically monitor open-pit mines, the establishment of monitoring concepts according to their types is crucial. In this research, the monitoring concepts of open-pit mines were classified as operating aspect and environmental ecological aspect. Operating aspects, factors which are created by operating active mines, should contain causes occurred by restoration and operation plans of mines, not to mention restoring and/or operating areas themselves. Environmental ecological aspects concern change to the environment caused by mining operation, restoration and other specific management plans.

Monitoring concept on operating aspects include mining area, disaster restoring area and ecological restoring area, while environmental ecological aspect consist of waste stowage area and ecological restored area. Mining area, waste stowage area and ecological restoring area are areas with continuous change in terrain, in need of periodic monitoring. Disaster restoring area, on the other hand, is vulnerable to sudden terrain changes triggered by natural or artificial inputs, making the speed and urgency of monitoring most critical. Ecological restored area is an area that has been reached to its former original ecological state; it thus has little or no terrain alteration over time, with the exception of vegetation. Due to such characteristic, ecological restored areas lack urgency and importance of monitoring.

To efficiently monitor open-pit mines according to the set monitoring concept, collection, acquisition and fusion of basic data for monitoring should be accompanied. If a periodical data acquisition is needed concerning environmental ecological or operating aspects of the mines, an annual, year-by-year restoration and cyclic mine operation plan should be established using annual or biennial aerial photogrammetry and airborne laser surveying that would aid processing a high-resolution digital ortho image and DEM of the mining region. Non periodic data acquisition is a necessary process in case of disasters or civil petitions addressing monitoring of mines. In a given situation where non periodic data acquisition is needed, UAV or terrestrial LiDAR, which are inexpensive and require less procedures, will be utilized to gain DEM and high-resolution ortho image of the area of interest to maximize the efficiency and potential of the monitoring system's ability to restore the area. Figure 2 shows the classification of monitoring areas of open-pit mines and data acquisition method.



**Figure 2. Classification of monitoring area and data acquisition method**

### 2.3 Classification of monitoring area using basic geospatial information

Basic geospatial information is a basic data on the monitoring system of open-pit mines; with the information, the possibility of monitoring alterations in open-pit mines was tested using geospatial information analysis method. This research, to monitor the alteration of open-pit, active mines, has conducted airborne laser surveying twice in 2007 and 2014 of Lafarge Halla Cement mine. Monitoring analysis of the alteration of open-pit mines was divided into two basic frames, image-based analysis and DEM-based analysis. Differential image method, utilizing digital ortho image, was used in the image-based monitoring analysis, while earth-volume calculation and residual DEM was used in the DEM-based monitoring analysis. With application of the two methods of monitoring analysis, this research has verified the validity of the criteria of monitoring set up previously and has

utilized such measures to the development of monitoring method.

### 2.3.1 Image-based monitoring area classification analysis

Differential image method which makes use of high-resolution ortho image, calculates difference between pixel changes in an image over different time and prints image. The differential between digital ortho image of 2007 and of 2014 of the active mine is as follows in Figure 3. As shown in Figure 4, differential image analysis indicated alterations in topography and enabled the classification of the region into ecological restoration area, disaster restoring area and waste stowage area. Figure 5 indicates results of specified areas such as mining area, disaster restoring area, ecological restored area, waste stowage area in different times as a comparison. Mining area, as shown in Figure 5(a), was described with light brown tone, as well as the disaster restoring area of Figure 5(b), since the area was originally restored but collapsed over time. Figure 5(c) is a ecological restoring area, which is visualized as light grey due to the stowage of waste rocks, resulting in changes of vegetation.

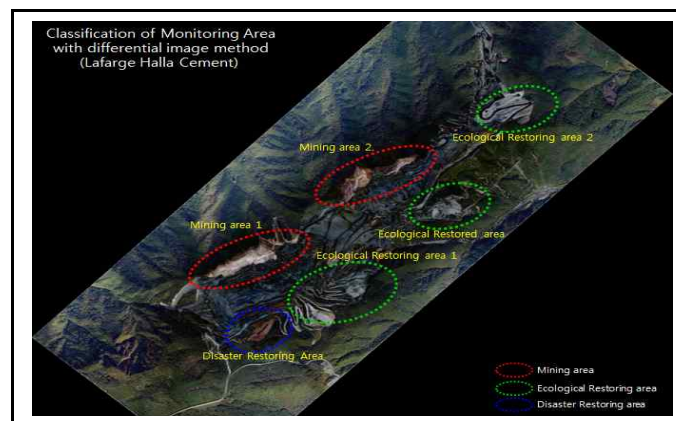


Figure 3. Classification of monitoring area using digital image

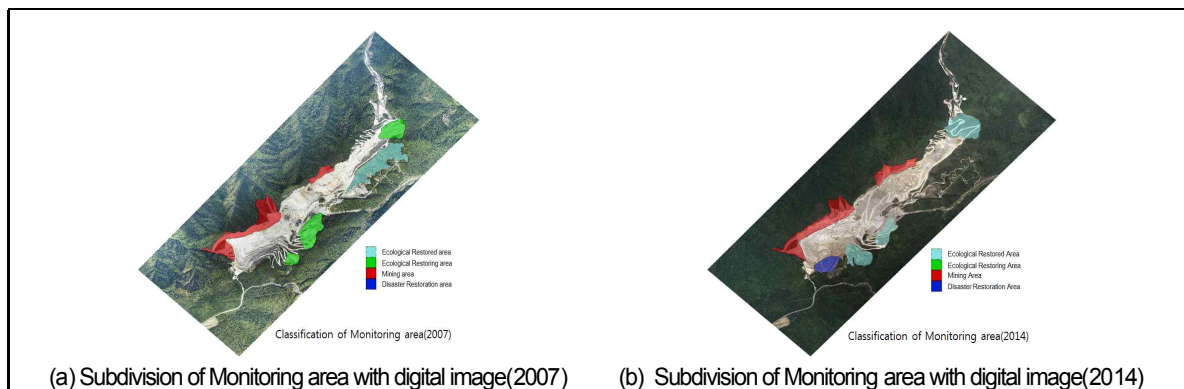
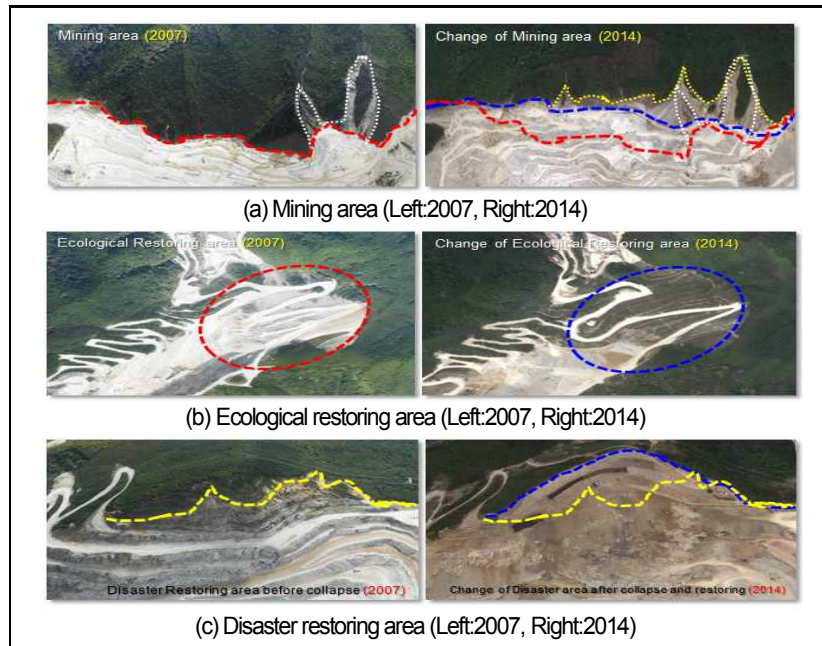


Figure 4. Detail classification of monitoring area with digital image

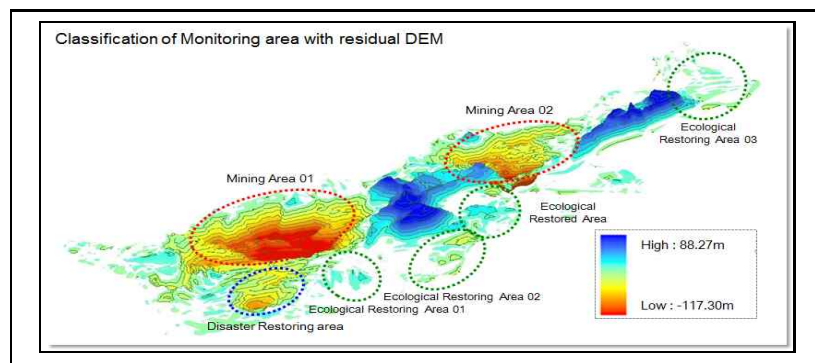




**Figure 5. Change detection by each monitoring area with digital image**

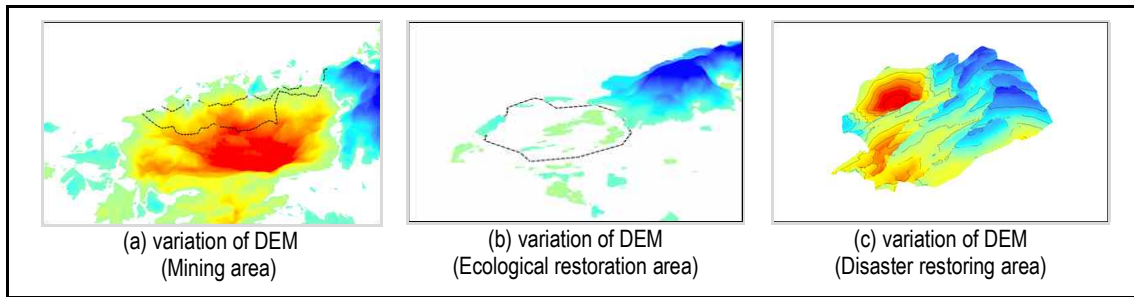
### 2.3.2 DEM-base monitoring area analysis

To comprehend topographical changes over time, 1m×1m DEM of the mining area was created via LiDAR data obtained from airborne laser surveying that had been conducted twice. Residual DEM was obtained between DEM of 2007 and 2014, which then changes were analyzed. In residual DEM analysis, unlike that of differential image analysis, three-dimensional visualization of terrain change was possible. Also, with quantitative analysis, operational areas of mining and waste stowage area were able to be specifically classified, with regards to the noticeable difference in earth-volume of the area. Figure 6 shows the residual DEM(1m×1m Grid Size) of an active mine, indicating considerable changes in terrain after 7 years of mine operation.



**Figure 6. Residual DEM of active mine in elapse of time**

Figure 7 is the residual DEM and the perimeters of mines of 2014 and 2007 overlapped. Figure 7(a) is the mining area of the active mine which has created additional volume of earth due to the extension of mining area in 2014. Figure 7(b) is an area where ecological restoration after mining has been performed. According to the restoration plan, waste rock and vegetation has been stowed and planted, showing little difference in DEM in elapse of time. Disaster restoring area of Figure 7(c) has been restored from collapse of transmission line; the restoration also has caused the alteration in topography and creation of earth volume.



**Figure 7. Change detection of monitoring area with residual DEM analysis**

Earth-volume analysis in elapse of time of the active mine's monitoring area classified by image differential analysis as shown in Table 1. The mining area of active mine was calculated to be  $-31,110,170.7\text{m}^3$ . 89.5% of the volume occurred from ground cutting, while 5.87% of ground stack occurred due to formation of operational roads. Continuous operation of mine resulted in the expansion of this area. Additional ground cutting of  $-1,453,513.61\text{m}^3$  incurred due to transmission line collapse in 2012, compared to the original ground-cut area in 2007 prior to the disaster. 78.41% of the volume occurred from ground cutting, while 8.14% of ground stack occurred due to formation of operational roads. Finally, in the ecological restoring area where mining has ended, ground stack was  $+404,167.78\text{m}^3$ ; of this, 27.12% of ground stack and 22.34% of ground cutting volume was utilized for restoration by stowing waste rocks or forming operational roads. 50.03% of the entire area showed no change, having difference of 0m.

**Table 1. Changes in earth-volume of monitoring area with residual DEM analysis**

Monitoring area	interval	Area(m <sup>2</sup> )	ratio(%)	Sum of Volume(m <sup>3</sup> )
Mining area	-50 m below	14,901	11.75	-3,110,170.7
	-50m ~ 0m	98,600	77.75	
	non change	5,868	4.63	
	0m ~ 30m	7,441	5.87	
Disaster Restoring area	-50m below	4,602	5.65	-1,453,513.6
	-50m ~ 0m	59,307	72.76	
	non change	10,961	13.45	
	0m ~ 10m	6,368	7.81	
Ecological Restoring area	10m above	269	0.33	404,167.8
	-10m below	11,332	4.96	
	-10m ~ 0m	40,900	17.89	
	non change	114,398	50.03	
	0m ~ 10m	36,504	15.97	
	10 m above	25,512	11.16	

### 3. DEVELOPMENT OF OPEN-PIT MINE MONITORING SYSTEM

#### 3.1 Selection of geospatial information open platform

To effectively perform the development of open-pit mine monitoring system, a geospatial information open platform with high accessibility and usage should be selected as the base platform. 3D geospatial information open platform WWJ (WorldWindJAVA) and Cesium were compared to choose the most adequate platform suitable for open-pit mine monitoring system.

Both of WWJ and Cesium have 3D Viewing and provide the function with source, enabling developers to develop programs according to their needs

3D modeling is a crucial function on which key terrain features or restoration plans are expressed through geospatial information open platform. WWJ provides xml, kml format, while Cesium expresses animated 3D models using kml, GeoJSON and TopoJSON format.

Also, the primary image and quality of terrain features of Gangwon region provided by

geospatial information open platform were put into comparison. WWJ uses LANDSAT7 image as its basic image and SRTMv2 (Shuttle Radar Terrain Model with a grid of 30m) as its DEM. On the other hand, Cesium utilizes Microsoft's Bingmap and ESRI World imagery map based on IKONOS satellite image with up to grid of 1.0m as its basic image; however, in the region of research, Gangwon, the image was mixed with comparatively lower geospatial resolution images, while the update of geospatial information was also lacking.

The DEM consists of STK World Terrain Meshes, which can express from 3m to 90m in range of the area. Table 2 is analysis of the characteristics of World Wind Java and Cesium in comparison.

Cesium comprises of basic data that has higher quality than World Win JAVA, with the advantage of offering a variety of 3D modeling format; such advantage has made Cesium the platform to be utilized in the research. The quality and renewal of geospatial information provided by Cesium, however, was not sufficient for utilization in the monitoring system that this research aims to create and develop; therefore, additional upgrading of image and topographical information was found to be urgent.

**Table 2. Characteristics of geospatial information open platform WWJ and Cesium**

item	WWJ(World Wind JAVA)	Cesium
Digital image	Bing - TerraColor : GSD 15m - LANDSAT 7 : GSD 30m	Bing - TerraColor : GSD 15m ESRI World Imagery map - IKONOS : GSD 1.0m
DEM	SRTM - global : 1km, USA : 30m SRTMv2 - don't provided in KOREA	STK World Terrain Meshes - 1km(global), 90m(Korea), 3m(USA) - National Elevation Dataset(NED) - EU-DEM - Australia SRTM-derived 1 Second DEM
Language	JAVA SDK	JAVAScript+HTML
3D model	XML format	KML, GeoJSON, TopoJSON format

### 3.2 Design and development of the system using open source programming

#### 3.2.1 Composition of development environment for open-pit mine monitoring system

The open-pit mine monitoring system was developed with geospatial information open platform, along with open source-based GIS software. Open-pit mine monitoring system consists of client, middleware, server, DBMS and data and to be serviced through web browser.

Client is able to visualize changes and restoration blueprints in 3D, to overlap DEM terrain with aerial and satellite ortho images in different, free points of view. Middleware links the client and the server to interexchange data. Server provides the data client requests through middleware. DBMS manages and organizes data for effective data usage.

PostGIS and GeoServer were selected as DB server and middleware; Apache was chosen as the webserver. PostGIS receives general information, DEM and mine perimeters and provides them to Cesium through Geoserver and Apache in HTML and WMS format. DEM and ortho image is set to be provided on Cesium through Geoserver, the middleware, as WMS. The components of the open-pit mining monitoring system are as follows in Figure 8.

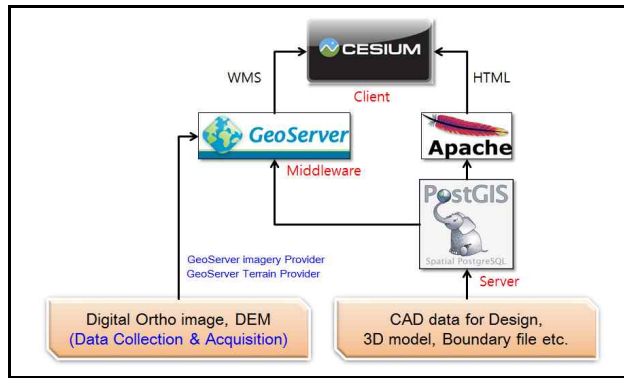


Figure 8. Development environment for monitoring system

### 3.2.2 Design and realization of open-pit mine monitoring system

The open-pit mine monitoring system should be composited in a way that anyone can easily use. Therefore, the intention was to design an intuitive and practical UI (User Interface).

Crucial functions considered to be required for the monitoring system were divided into basic function and analysis function. Basic function is a function that provides basic information concerning the monitoring mine and command to express changes of the mine in 3D. Analysis function is a function which allows users to analyze points of interest in the case that users are aware of a mine's operating and restoring plan and alterations caused by changes in elapse of time. The open-pit monitoring system is developed with an information window that provides a search engine that would find a mine of interest, operation status of the searched mine, type of mineral mined and the address of the mine. Also, functions showing mining, and restoration layouts, present and past forms, residual DEM, and true elevation and topographical angle of any set point in mines are being developed to enhance the effectiveness and efficiency of the system. The start-up screen of the monitoring system is planned to be visualized as shown in Figure 9. Current progress of the research focuses on 3D Viewing and comparison between DEM and mining region's elapsed image. More effort is put in to continuously improve the monitoring system.

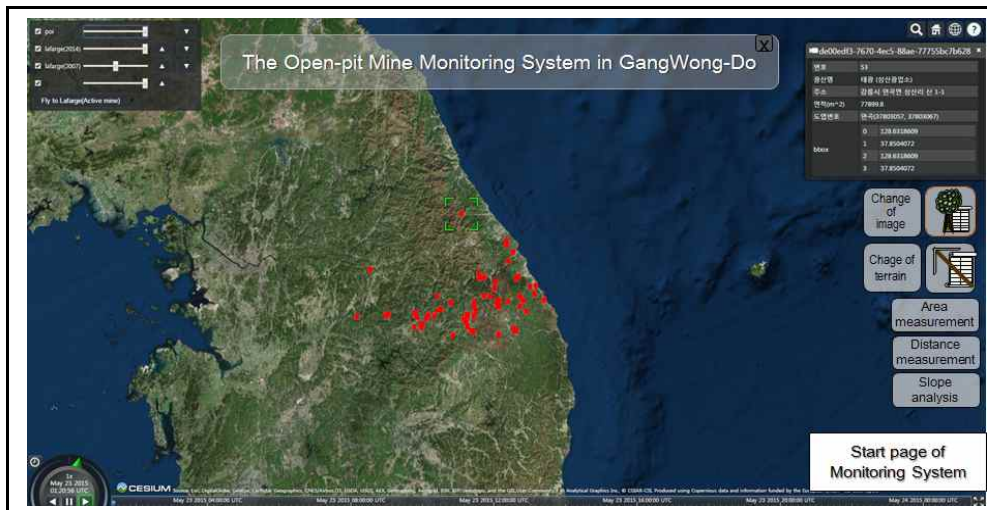
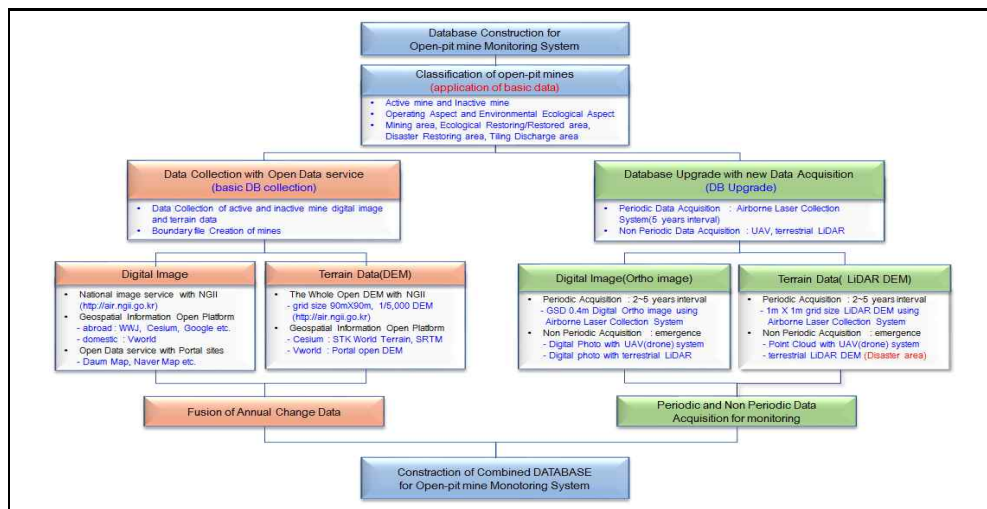


Figure 9. Composition of start-up screen of the monitoring system

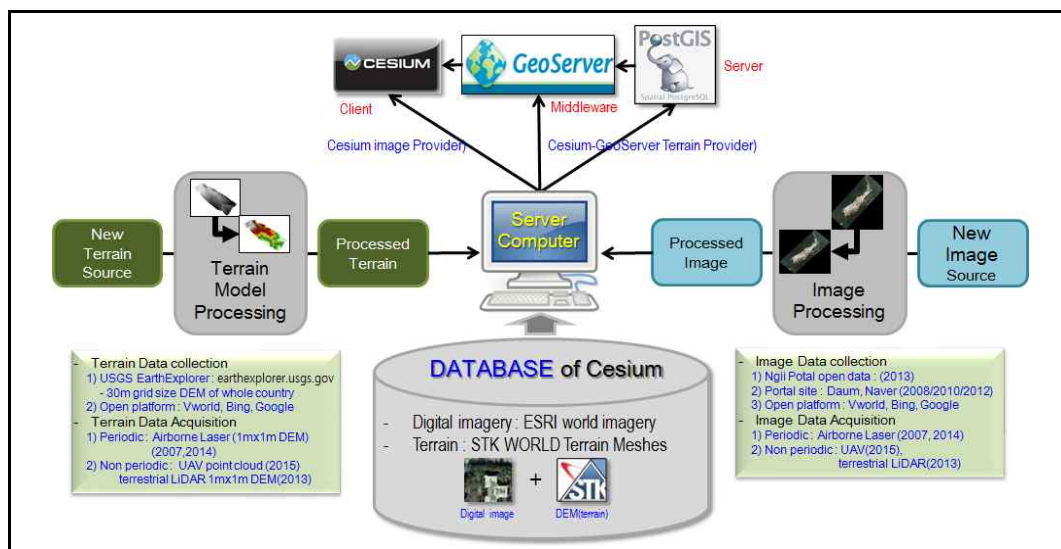
### 3.3 Database upgrade for efficient monitoring

The open-pit mine monitoring system has to be updated at all times, in terms of digital ortho image and DEM, to detect and analyze change of open-pit mines, and should be capable of constant data upload and comparison with elapsed data. Therefore, methods concerning the upgrade of ortho image and DEM data on Cesium, the geospatial information

open platform utilized in open-pit mine monitoring system, were established. Figure 10 is the process and method for data upgrading of digital image and DEM. Figure 11 is diagram of combined database construction for open-pit mine monitoring system.



**Figure 10. Main process of DB construction for the monitoring system**



**Figure 11. Construction of combined DB for monitoring system**

### 3.3.1 Methods of upgrading digital image

The coordinate system of Cesium is WGS84, converted from coordinates of ortho-image utilized for upgrading the monitoring system. To register and issue the ortho-image with converted coordinates on GeoServer, work space and repository, along with a layer should be created, and the image should be issued in Geotiff format. Finally, using Image Provider, the ortho-image and GeoServer are linked to visualize newly registered image on Cesium. Figure 12 is a workflow of the process concerning the upload of ortho-images on Cesium, while Figure 13 shows an example of an uploaded ortho image expressed in Cesium. Due to the difference in color impression between uploaded and background images, the uploaded image needs refinement; such problem will be minimized as histogram and color matching are rebalanced.

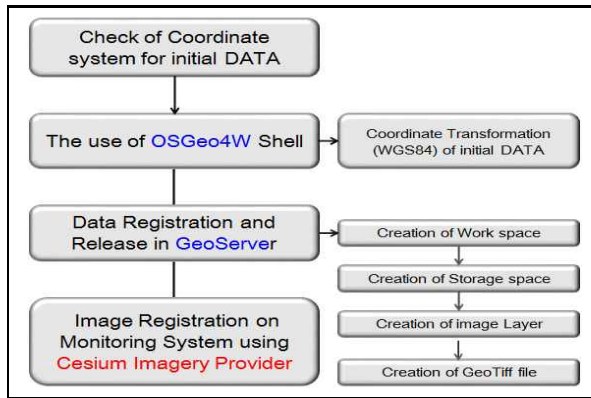


Figure 12. Process of ortho image uploading on monitoring DB

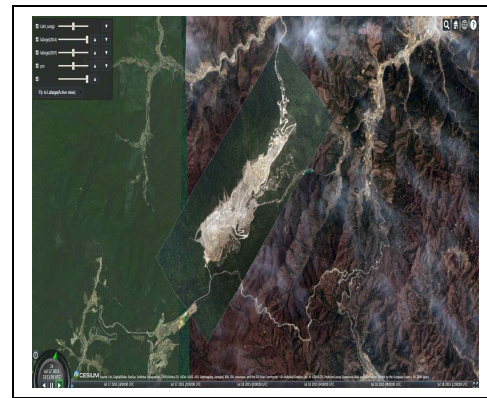


Figure 13. Digital ortho image newly uploaded on Cesium

### 3.3.2 Methods of upgrading terrain DEM

Cesium’s DEM, unlike image upload, cannot be uploaded by registering topographical data on GeoServer ; because of such limitation, Cesium-GeoserverTerrainProvider written by kaktus40 on GitHub was taken into reference to upload DEM on Cesium. Cesium-GeoserverTerrainProvider expresses DEM through assigning height value on Raster DEM at GeoServer. The DEM uploaded on Cesium is based on 1second SRTM DEM and LiDAR data of 2014. To merge the SRTM DEM and LiDAR data of 2014, Raster Calculator provided by SAGA of QGIS was utilized. Figure 14 is the diagram regarding the upload of DEM on Cesium. CrossDomain error occurs when DEM is put on Cesium through GeoserverTerrainProvider; Jetty’s CrossDomain solution was used to cope with the problem. DEM values on Cesium, however, was regarded as whole numbers on the platform; because of this, elevation difference such as that of Figure 15 occurred, fragmenting the terrain. This problem needs to be solved.

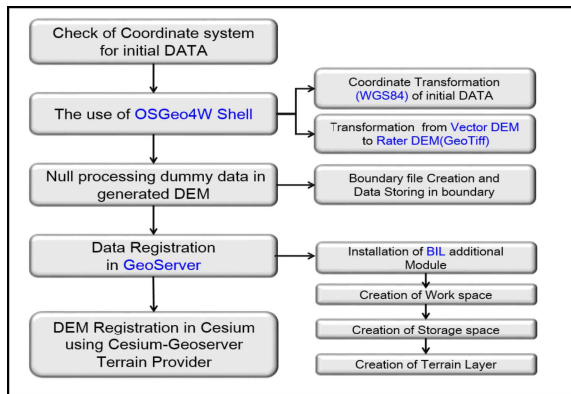


Figure 14. Process of DEM uploading on monitoring DB



Figure 15. Problem of uploading DEM on Cesium

### 3.3.3 Change detection of monitoring areas

The monitoring of open-pit mines is a monitoring which detects the topographical change over time; this research utilized digital image and DEM for the monitoring. Table 3 is the data inventory accumulated through this research, concerning the database of monitoring.

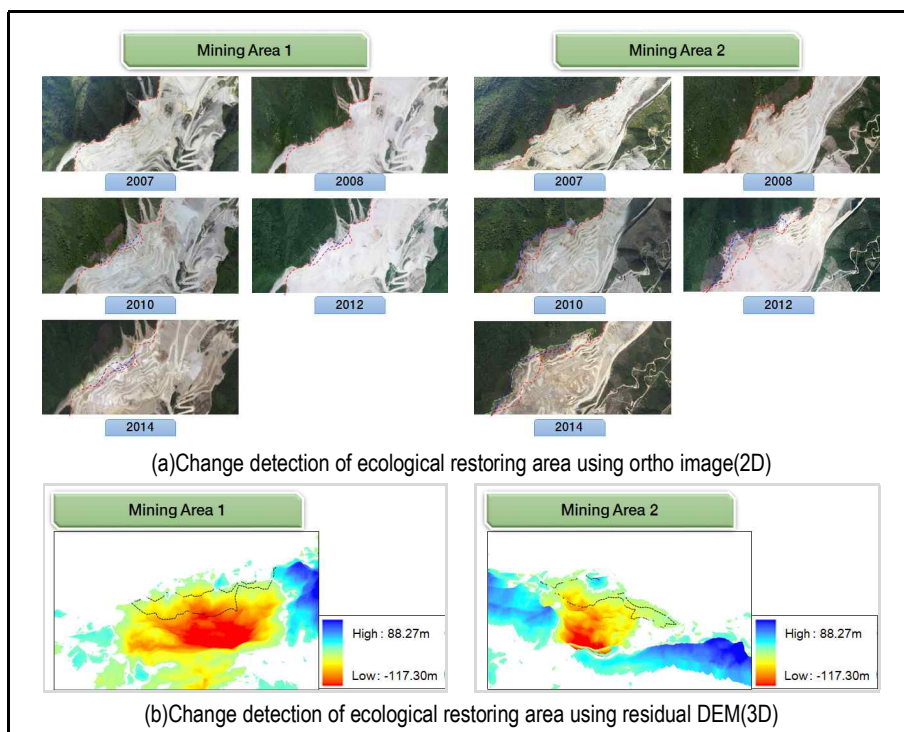
This research analyzed the change detection in the mining area, ecological restoring area and disaster restoring area in series of time, using digital image and terrain data of the open-pit mine monitoring database.

Table 3. Data inventory of monitoring Database

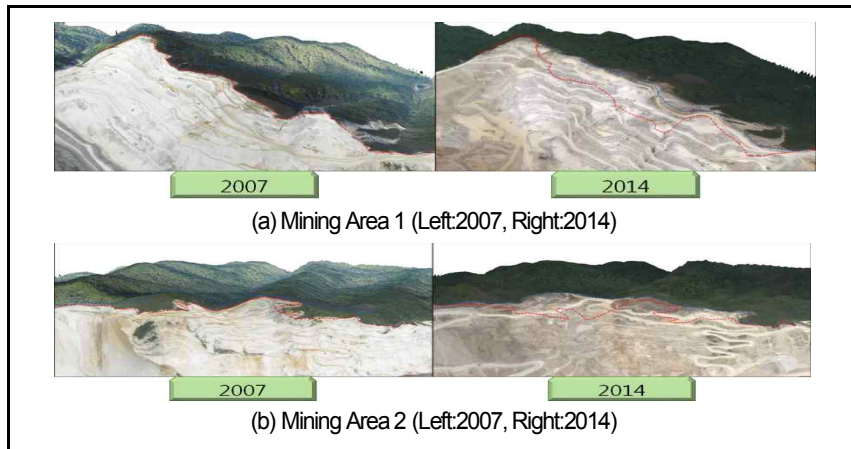
Data Acquisition Methods	Acquisition year	Characteristics of data
UAV surveying(non periodic)	2015	Fixed-wing UAV : GSD 0.3m
Airborne Laser surveying(periodic)	2014	Digital image : GSD 0.12m DEM : LiDAR 1m X 1m DEM
NGI Portal open data service (data collection)	2013	NGII Open data : GSD 0.5m ( <a href="http://air.ngii.go.kr">http://air.ngii.go.kr</a> )
terrestrial LiDAR surveying (non periodic)	2012	gird size 1m X 1m DEM
Portal site open data service (data collection)	2012	Daum map Open data - GSD 0.5m - 2 years interval
	2010	
	2008	
Airborne Laser surveying(periodic)	2007	Digital image : GSD 0.4m DEM : LiDAR 1m X 1m DEM

Figure 16 and Figure 17 shows the analysis results of the mining area according to series of time. Figure 16(a) is the result of the 2D analysis with ortho image of the mining area of 2007 and 2014, ortho images collected from portal websites in 2008, 2010 and 2012 and ortho image acquired using UAV system in 2015. Figure 16 (b) describes 3D analysis using DEM of the mining area of 2007 and 2014, while Figure 17 is a result of a 3D modeling comparison between DEM of 2007 and 2014 acquired with airborne LiDAR surveying.

As shown in Figure 16 (a), the mining area tends to increase over time; this enlargement of mining area, Figure 16 (b) and 17 proves, occur massive change in topography. Such detection of changes can be utilized in the future operation and management of open-pit mines.



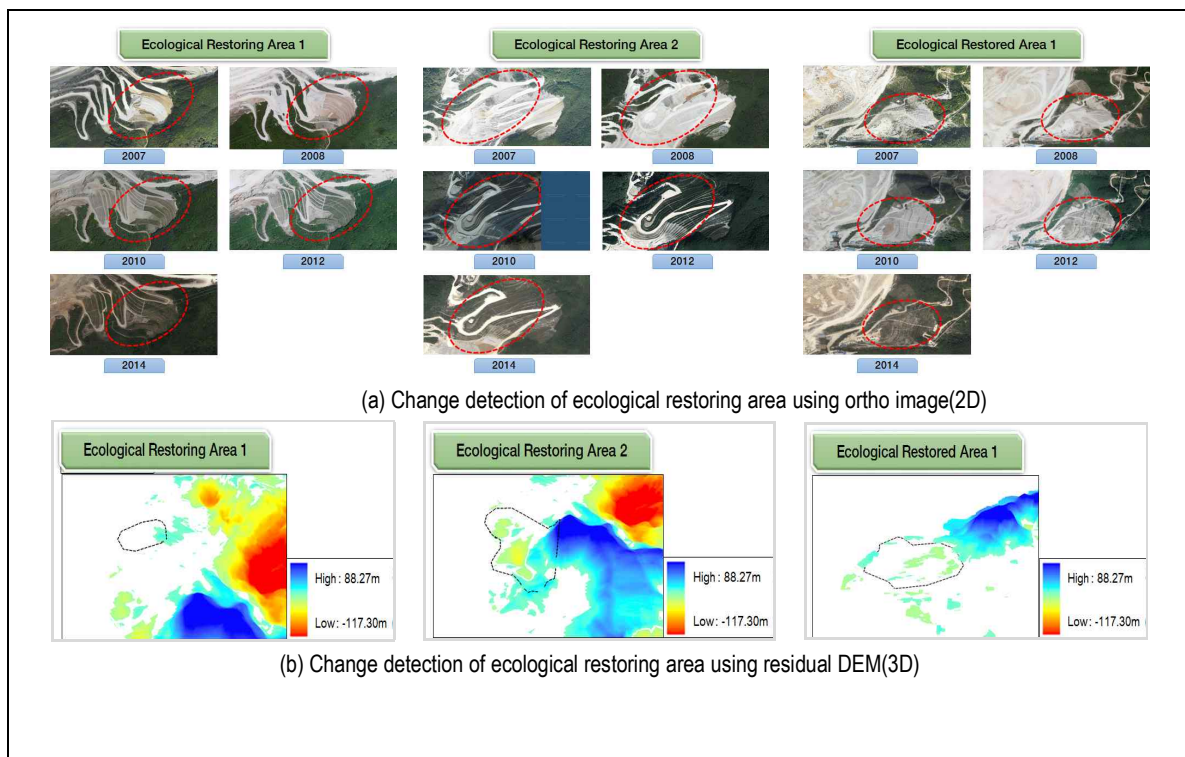
**Figure 16. Change detection of the mining Area**



**Figure 17. Change detection of mining area using 3D modeling**

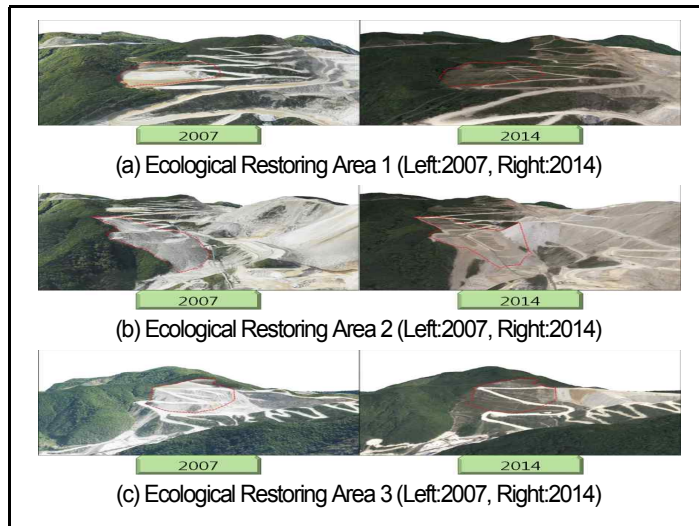
Figure 18 and Figure 19 shows the 2D and 3D analysis on change detection of ecological restoring area. Two-dimensional and three-dimensional changes of the area were analyzed using the same image and terrain information as did in the mining area.

Ecological restoring area is an area that is under ecological restoration according to restoring plan after the end of mining. Figure 18 (a) describes the change of ground coverage into vegetation under ecological restoration over time. In the areas of Figure 18 (b) and Figure 19, ecological and topographical restoration had taken place completely, showing no signs of three-dimensional topographical changes such as those of the mining area.



**Figure 18. Change detection of ecological restoring area**

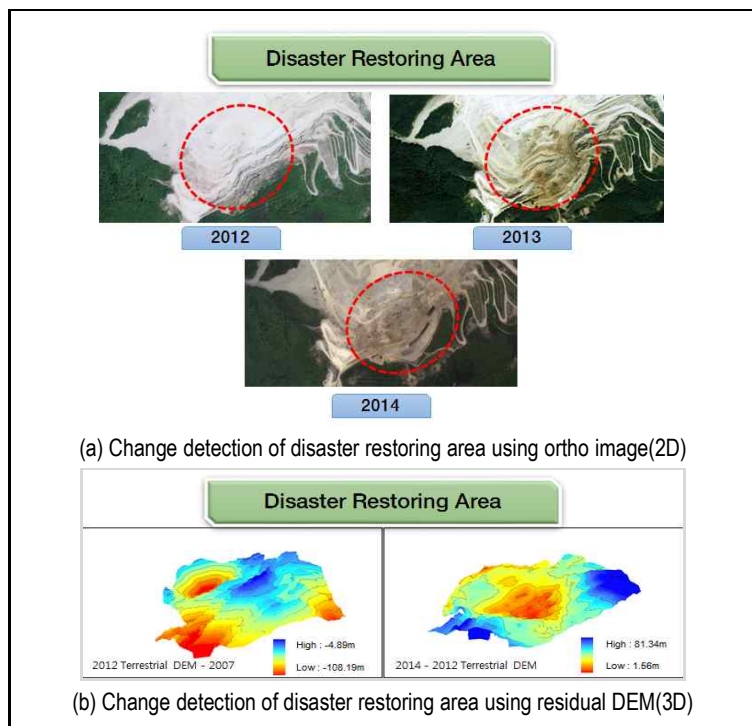




**Figure 19. Change detection of ecological restoring area using 3D modeling**

In 2013, terrestrial LiDAR surveying took place for disaster restoring area to understand the status quo and to establish a restoration plan of the disaster that had taken place in the area of interest. The topographical information of before and after the disaster were utilized for the change detection analysis. Figure 20 and Figure 21 are analyses of 2D and 3D changes of disaster restoring area.

Disaster restoring area, mining operation having finished, does not have any topographical nor ecological transition until in the event of accidents. Figure 20 (a) pictures the collapse of the mining slope through the comparison between 2012 and 2013 image, and the restoration in progress of the collapsed area with 2013 and 2014 image. Figure 20 (b) is the analysis of three-dimensional transition of mining area between 2007 and 2014 using DEM; Figure 21 shows the definite transition of topography before and after the restoration of collapse.



**Figure 20. Change detection of disaster restoring area**



**Figure 21. Change detection of disaster restoring area using 3D modeling**

As a result of a time elapsed transition analysis of the mining, ecological restoring and disaster restoring area using the open-pit mine monitoring system the research has developed and digital image and DEM data from database, two-dimensional and three-dimensional change detection analysis methods were clearly noticed, enabling the efficient utilization of the monitoring system on operation and management of mines, ecological and environmental management and disaster control. The upgrade and enhancement of the monitoring system will continue as the effective and efficient usage of the open-pit mine monitoring system is the crucial concern of the research.

#### **4. CONCLUSION**

The primary objective of this research is to develop an effective monitoring system which monitors topographical change of open-pit mines using geospatial information open platform and open source programming. This research has reached to the following conclusion:

Firstly, concepts of monitoring according to the type of mines were established. In the process, acquisition and upgrade of required data and effective monitoring were sought.

- 1) Basic data of open-pit mines was collected through geospatial information open platforms and portal open data services from worldwide,
- 2) As a periodic acquisition of updated data, airborne laser surveying that provides high-resolution ortho image and LiDAR DEM was chosen for all of the monitoring area.
- 3) For non-periodic acquisition of data which requires speed as is the case in disaster areas, terrestrial LiDAR and UAV systems were applied to meet the urgency and the characteristic of the monitoring area.
- 4) Acquired data of the monitoring region was bundled in a series of time into a database; this database was merged with the database of Cesium, the platform which this research has chosen, and utilized in the development of the monitoring system.

Secondly, this research has chosen Cesium as the geospatial information open platform of the monitoring system that is effective on 2D and 3D visualization. As the development environment, PostGIS(server)-GeoServer(middleware)-Cesium(client) were established and the system was developed in an open source environment.

Thirdly, this research has established the method to utilize ortho image and DEM for the monitoring of open-pit mines. Applying the method onto specific monitoring areas, such method was efficient in terms of change monitoring.

This research is the result of the second year of the three-year research; therefore, the degree of completion and specification of the developed system lacks perfection. The

possibility of development of open-pit mine monitoring system using geospatial information open platform and open source programming was realized, however, with this research.

### Acknowledgments

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korean Government (MSIP) (NRF-2013R1A2A2A01068391).

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