LIDAR Application for Cultural Heritage Three-dimensional Modeling and Reconstruction

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Key words: LIDAR, Cultural Heritage three-dimensional Modeling and Reconstruction, South Korea Cadastral Survey Corporation

SUMMARY

The South Korea's national treasure Number 1, Namdaemun, was completely destroyed by arson on Febuary.11, 2008. Even upon its restoration, it will not be able to have its original appearance because of not enough data to reconstruct. A number of cultural heritages have steadily been damaged by change in nature, such as acid rain, disaster and climate change, or man-made hazard(e.g. war, arson, and construction). As a result, the demand for more accurate and realistic cultural three-dimensional modeling data has been steadily increasing.

Many studies have been conducted to extract three-dimensional features from remote sensing data such as satellite images and aerial photography. These days a technique has been introduced to extract and reconstruct three-dimensional features using terrestrial laser scanner. Use of terrestrial laser scanner has the great merit that is able to obtain a large number of measurements with high precision in a short time. These measuring methods are executed based on LIDAR. In short, LIDAR is much more efficient than any other measuring methods. For this reason, South Korea Cadastral Survey Corporation recently has entered into cultural heritage three-dimensional modeling using terrestrial laser scanner. As a matter of fact, South Korea Cadastral Survey Corporation has dealt with two-dimensional survey using TS (Total Station) as a work of government. Now South Korea Cadastral Survey Corporation makes great efforts to successfully achieve three-dimensional modeling business.

In this study, the principle of LIDAR and measurement method are described. The process of three-dimensional modeling work by KCSC is explained in detail. Diverse applications using cultural heritage reconstruction are proposed

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1. INTRODUCTION

Cultural heritages regarded as a valuable legacy from ancestors contain wisdom of life and our history. There are a lot of cultural heritage out there in South Korea (e.g. metal craft, wooden buildings, stone tower, statue of Buddha, ceramics etc.). However, a number of cultural heritages have steadily been damaged by change in nature, such as acid rain, disaster and climate change, or man-made hazard (e.g. war, arson, and construction). For example, The South Korea's national treasure Number 1, Namdaemun, was completely destroyed by arson on Febuary.11, 2008.

In fact, even upon its restoration, it will not be able to have its original appearance because of not enough data to reconstruct. Since people were aware of importance of cultural heritage, they have tried to perfectly obtain apperances of cultural heritages in a variety ways for complete reconsruction. In particular, field technicians have longed for survey technology and equipment that make it fast, precise, and able to acquire abundant data at one time. As a result of effort, the acquisition method of shape information have been improved, by gaining abundant three-dimensional informaiton beyond two-dimensional information. Representative three-dimensional acquisition method of shape information has been a digital photogrammetry using satellite image and aerial photography. This mehod is able to acquire a number of data but consume lots of time, operate complicated work process, and frequently does not meet the accuracy requirement necessary for perfect reconstruction. LIDAR(Light Detection and Ranging), overcoming the weakess of previous acquisition system, able to directly obtain three-dimensional shape informaion and completely reappear real-world shape, has been released. The strength of LIDAR is that it is precise, fast, and able to obtain a number of point-cloud on the object surface in a short time. Furthermore, it can automatically generate DEM(Digital Elevation Model) and DSM(Digital Surface Model).

In this study, the principle of LIDAR and measurement method are described, and the workflow of three-dimensional modeling performed by KCSC for "Wontong bojun" traditional building, "Chilcheung Seoktab" stone tower, and "Haesu Kwanumsang" statue of the Buddah at Naksan temple, in Kanwon Province. is explained in detail. In addtion, Diverse applications using cultural heritage three-dimensional data are proposed.

2. THE CONCEPT OF LIDAR (LIGHT DETECTION AND RANGING)

2.1 The Characteristic of LIDAR

Albert Einstein' theory of "The Principle of LIDAR Movement" in 1917 set off a series of research on LIDAR over the world. Since laser beam, 694.3mm size of visible rays, was successfully transmitted using ruby by Theodore H.Maiman, diverse type of LIDAR system has been invented: writing and reading device for image storage medium, medical equipment, meteorological observation equipment, SLR (Satellite Laser Ranging), three-dimensional shape measuring instrument, communication network and so on. As mentioned above, LIDAR system is widely used everywhere in our life. The Characteristic of LIDAR is monochrome, straight, of high energy density, and more likely to be interference phenomenon. Moreover, its phase is stable.

2.2 Three-dimensional Scanning Using LIDAR

Three-dimensional laser scanning is one of LIDAR system of which principle is transmitting laser out to target area. The transmitted light interacts with and is changed by the surface of the target. Some of the light is reflected and/or scattered back to the LIDAR instrument where the return signal are analyzed. The time of the light to travel out to the targets and return back to the LIDAR instrument determine three-dimensional coordinates. In fact, LIDAR system has profound impact on geoinformatics. Total-Station, one of traditional LIDAR system, surveys one point at a time while recent LIDAR system, classified into airborne laser scanner and terrestrial laser scanner, makes it possible to measure a lot of points within one second by removing reflectors and transmitting and receiving laser beam at the same time. Using recent high technique makes three-dimensional scanning work easy, fast, and precise like 2-dimensional scanner works. In particular, Accident errors and data loss caused by equipment move and technician's skills can be got rid of by scanning targets continuously.

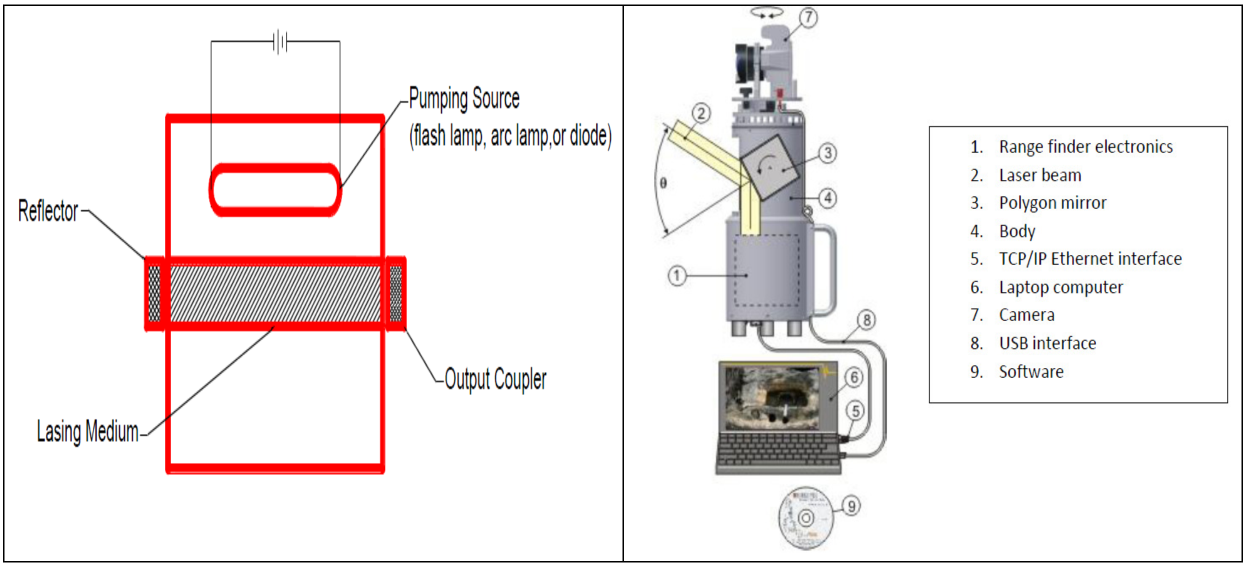


Figure 1: The Structure of LIDAR System

3. THE MEASUREMENT OF LASER SCANNER

3.1 The Principle and Method of Measurement

Although laser scanner has diverse measuring method, the common principle of measurement is transmitting laser out to the target area, receive reflected signal, and then analyze and process signal. There are two determining technologies. One is Time-of-Flight method that observes back and forth time of laser beam. The other is Triangulation method that collects reflected light and light source using camera and sensor, and then measure distance throughout triangulation. In this process, separated distance between light source and sensors should be a baseline.

3.1.1 Time-of-Flight Method

Like formula "D=ct", elapsed time that reflected lights resulting from transmitted light comes back from targets is measured, and then multiplied by the velocity of light. Finally, the distance can be examined. This kind of method is what we call Time-of-Flight of which method can be classified into the following methods.

1) Pulsed laser Method
Using laser pulse is able to resolve between 10 and 12 seconds and make surveying accuracy within "cm". It is comparatively used for long distance laser measurement and SLR (Satellite Laser Ranging) in recent years.

2) Phase Shift Method
This measurement method is to observe the phase of reflected laser wavelength. Not only its measurement speed very fast but also accuracy is more precise by 1mm than that of pulsed laser method. Even if the measurement distance is within 100m radius, it will be enough when scanning work for extracting accurate shape needed. Even large area, it is one of good way to scan divided sections in terms of saving work time because it is 100-200 times faster than pulsed laser method. However, when it is difficult to install equipment, or when rough estimate of shape is necessary, pulsed laser method will be in good location.

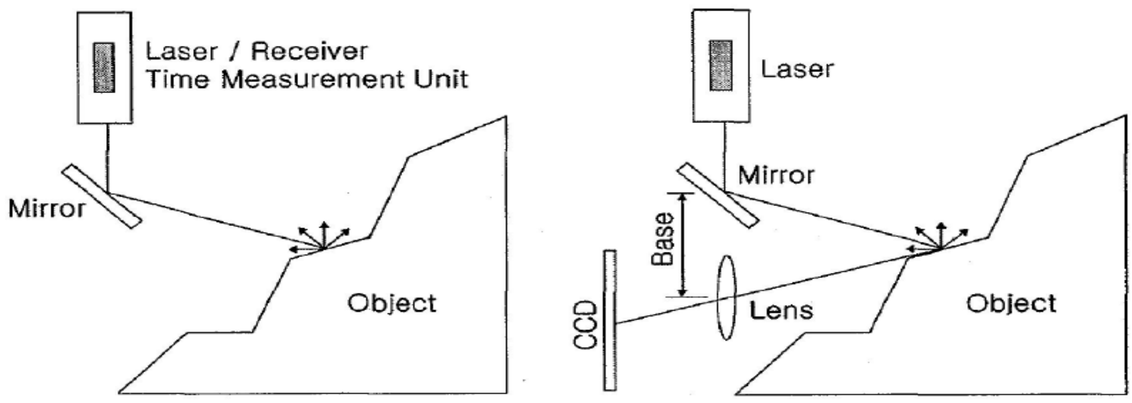


Figure 2: Time-of-Flight Method, Triangulation Method

3.1.2 Triangulation Method

Between photoelectric element (Charge-coupled device or camera) focused by reflected laser beam and the center of laser equipment, regular intervals generated becomes base line, so three-dimensional data can be acquired using triangulation. It is relatively simple, inexpensive, and fast in terms of work process. However, the angle of scanning is restricted case by case, and its accuracy is not so good when measuring long distance. In other word, the longer measurement distance is, the bigger errors will be. For this reason, small scale and short-distance targets, such as underground space, interior, and small cultural heritage and structure, are preferred.

3.1.3 Phase Measurement Method

Phase measurement method is generally adapted to laser scanner for middle distance. Limited distance is around 100m. Unlike Time-of-Flight method, accuracy is within “mm”. This kind of laser scanner is widely used for reverse engineering and tunnel surveying.

3.2 Coordinates Integration

As laser is straight, aspects of targets where laser scanner is not be able to cover is immeasurable. Thus, all data can be obtained by measuring targets from various view points. Figure 3 shows that scanned data from various view points become one object.

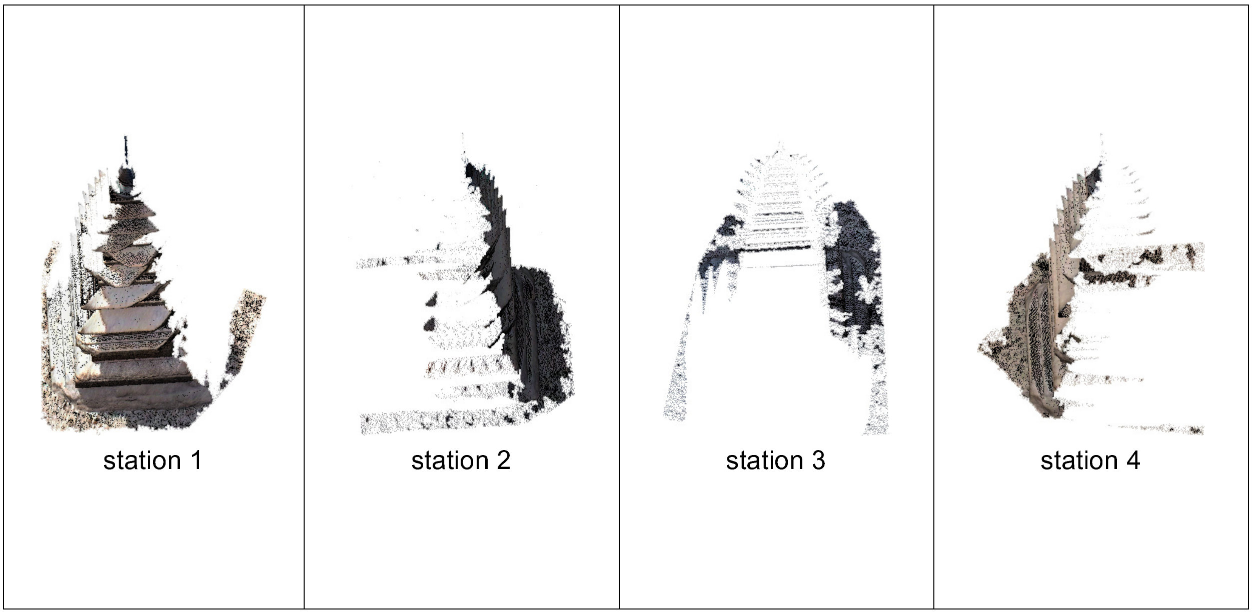


Figure 3: Scanned Data from 4 View Points and Integrated Object

When targets are scanned from various view points, the coordinate of every scanned data does not coincide. Therefore, every scanned data has to be integrated into one coordinate, which is what we call “Registration”. When it comes to “Registration”, there are two integration methods. One method is using target classified into flat target and sphere target. The merit of flat target is that it can be scanned throughout single progression method or backward intersection method. The advantage of sphere target is that some points collected from sphere are reprocessed into sphere, so that work process can be simple. In this process, it is easy to collect points from the center of sphere, however, it has disadvantage that it can not be scanned throughout single progression method or backward intersection method. The scanner is able to measure the center of target with “mm’ accuracy and if some points identified (minimum 3 points), it can integrate coordinate with space information. The other method is based upon the shape of point-cloud. The principle of this method is that coordinate can be automatically integrated by indentifying the same aspects based on the shape of target. This method enables technicians not to set up targets. As a result, the time and labor do not have to be consumed a lot because the work for setting up target location is unnecessary. However, errors can occur if located in flat area, or scanning density is low. Therefore, high-qualified registration can be generated if two methods used properly.

4. THREE-DIMENSIONAL SCANNING WORK FLOW CARRIED OUT BY SOUTH KOREA CADASTRAL SURVEY CORPORATION

Site selecting was Naksan Temple located at Kanwon Province, in South Korea, and Scanning targets are ”Wontong bojun” building, ”Chilcheung Seoktab” stone tower, and ”Haesu

Kwanumsang" statue of the Buddah. The duration of scanning project was around four days, June.23, 2009- June.27, 2009. The Scanning team consisted of four people. fact, Naksan temple, was burnt also down in a fire in April, 2005, has finished its four-year restoration. In fact, the temple was rebuilt based on historical records and also a painting of the temple by famous artist from the 17century the Joseon Dynasty(1392-1910). During restoration, there were lots of difficulties because it was rebuilt from painting and assumption without numerical recording. Hence, Naksan temple demanded KCSC to make Naksan temple three-dimensional data for the furture.

Figure4: Naksan temple and "Haesu Kwanumsang" statue of the Buddah

4.1 Planning

Trimble GX three-dimensional scanner in KCSC's possession is able to gain around 5000 points within a second. There exist 3mm errors at 50m. Furthermore, it recognizes both flat target and sphere target, so that it is possible to construct traverse between foresight and back sight based upon control point. The maximum scanning distance is around 350m, so that it is commonly used to extract structures features. If this instrument is located at control point surveyed by GPS, data at each station is able to become auto registration. Moreover, after scanning targets at random stations, surveying results can be integrated into the same coordinate derived from GPS surveying.

It is strongly necessary to investigate spot supposed to be scanned when making a scanning plan. Firstly, the control point surveyed by GPS should be occupied with respect to World Geodetic Coordinate System, and then the plan where to move and install equipment should be made. Since scanning method is variable according to the final result, it is really important to make a specific plan so that there could be no unexpected result.

4.3 GNSS (Global Navigation Satellite System) Control Point Surveying

In order to acquire the accurate three-dimensional position value, GNSS surveying is operated where scanning is supposed to be performed. GNSS (e.g. American GPS satellite, Russian GLONASS satellite, and Euro GALILEO satellite) can be defined as integrated satellite surveying system by receiving all signals used in satellite surveying such as MSAS, WAAS, EGNOS, and SBAS. GNSS surveying can be divided into post processing, real-time kinematic and differential GPS, and each type and feature are as the following.

RTK technique is most accurate real time positioning method today. In order to perform the RTK processing, it is necessary to setup a GPS receiver at the reference point with known precise coordinates, and transmit its observation data to mobile GPS receiver (so called rover). Moreover, the RTK calculation is usually performed at the rover site receiver by using transmitted observation data observed at reference point. In this process, errors generated by GPS receiver and reference station can be adjusted by correcting the different value compared with original value, and its values are almost the same. Thus, it can determine position within a few centimeters instantly, so that RTK technique is preferred to use more than other GNSS system during scanning work.

Recently a new technique has been introduced, that is VRS. The concept of the VRS is that Figure 7 illustrates the concept of the VRS A, B, C and D are GPS reference station. An RTK rover located near the center of these four reference stations would be affected by systematic errors if using any one of these four reference stations. If, however, measurements from these four stations are combined, a model of the geometric and atmospheric errors over the area can be determined and a VRS can be created adjacent to the rover's location, dramatically reducing the systematic errors (Tan Siew Song, 2001).

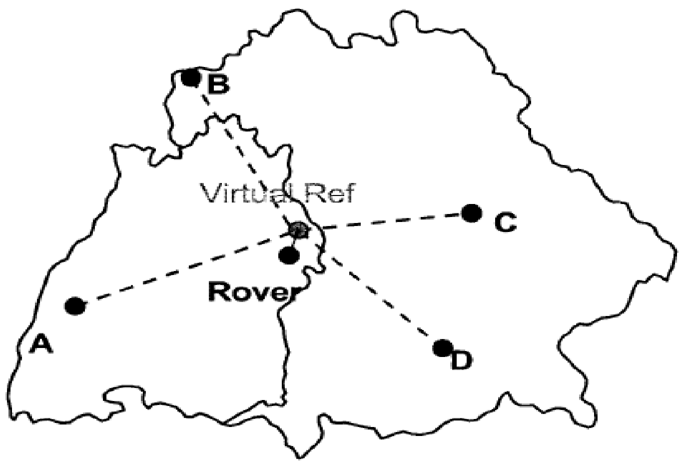


Figure5: The principle of VRS

For this reason, the control points of Naksan temple was collected using VRS technique. 2 ground control points were collected for each target, in other word total 6 control points were occupied by VRS surveying. After that, each control point was moved to near targets supposed to be scanned by traverse surveying. Even though many other organizations do not this work, KCSC occupy control point because KCSC intends to combine scanned data and cadastral map. Unless the control points occupied, scanned target should be floating over the ground without accurate coordinate with respect to real world.

4.4 Scanning in a Field and Source Collection

Scanning work should be precisely performed at least 8 times for one target according to rigorous plan. if there are errors influencing the result, scanning should be performed over and over in order to remove errors untill precise result appears. Even unspherical lense is used more than spherical lense because of reducing errors. One team is composed of 4 people, 3 people scan the objects while the other take a source image. Scanned points have three-dimensional coordinates. Consequently, the bigger object is, the more the number of points and the bigger the size of data become. There exists resolutions, some spaces among scanned points, determined by the quality and setting of equipment. Furthermore, coordinate value from scanning is not only the same as mechinery coordinate from scanner but also the same as real value of objects in terms of angle and distance.

Figure6: Scanning in a field

4.5 Three-Dimensional Data Editing

4.5.1 Point Editing

Point data collected by three-dimensional surveying has unnecessay data apart from targets data and noisy data influenced by circumstance, so that data weight should be relieved throughout filtering process deleting those data. At first, Scanning data become point cloud without any treatment. Hence, the noise of data has to be eliminated first in order to perform three-dimensional modeling. Since Laser scanning data is collected from one side, reflected side is clear but the other side is vague. When noise process dealt with, large data shoude taken care of filter redundancy that's why it will be easy to merge data later.

4.5.2 Polygon and Surface Editing

Polygon is refered to the smallest angular shape when describing solid structure in three-dimensional computer graphics. Polyline connected with starting point and last point in three-dimensional space tunrs to polygon by making some points line. Polygon data processing make every points linked to each other, so that three-dimensional shape image can be complete. Point data is just the set of points as similar as original shape, but can not consist of form as aspects. Of millions of points, three points are converted into polygon data that have three aspects and vertex untill no points left. Surface edting presents that connected polygon data are converted into aspect. In some area (e,g. Animation and engineering), polygon edting and surface edting are performed all together at once, but surveying area is different. Each process is performed step by step.

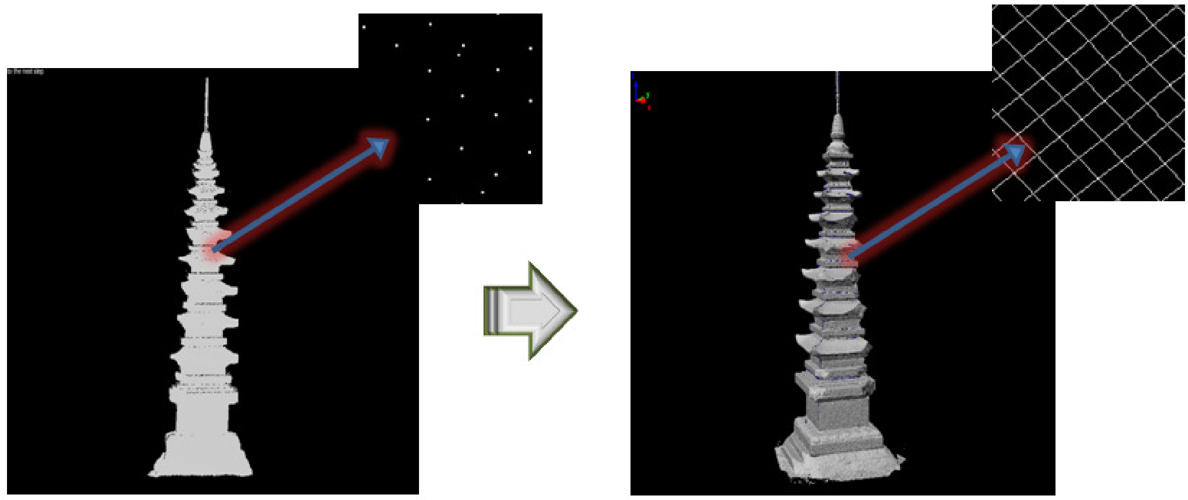


Figure 7: Polygon edting by extracting the set of points

4.5.3 Merging and Modification

After all points taken care of surface edting, each shell should be merged successively. Completed shell shoud be checked out whether there are errors inspected by computer. Modification can be classified into two process; one is smooth processing that soften the rough aspect of shell, and the other is fill holes processing that fill in empty space.

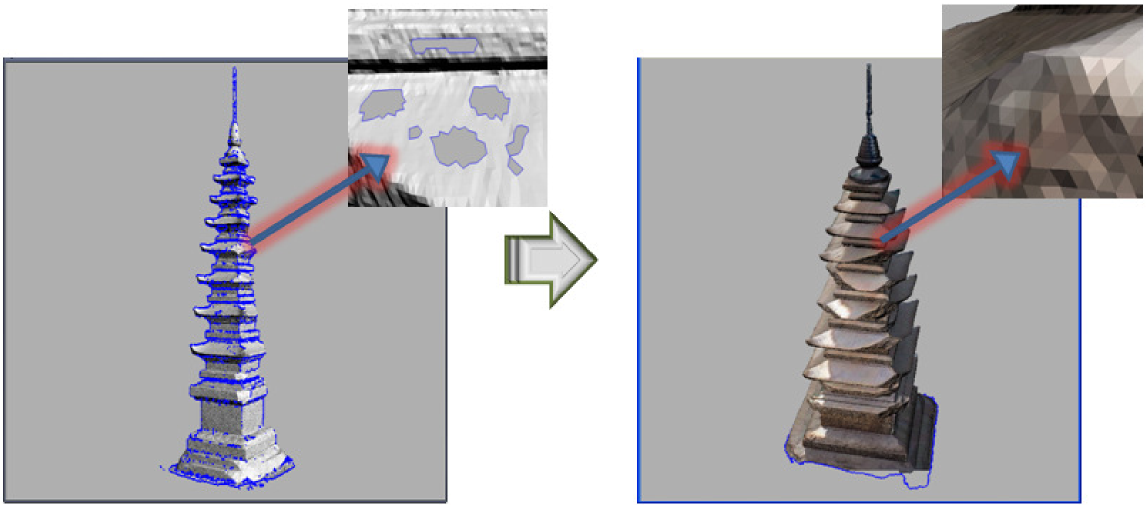


Figure8: Fill holes processing

4.5.4 Final Result

After all modification completed, three-dimensional model will be generated. As converted into surface data, the three-dimensional data can be applied to 2-dimesional or three-dimensional CAD file equivalent to basic data for recording cultural heritage structure information as **well as** security diagnosis data throughout database application and management. Based upon three-dimensional data, straight condition, radius of curvature, area and volume can be calculated, so that it can be possible to not only restore damaged parts but also collect data interpreting structure for security diagnosis.

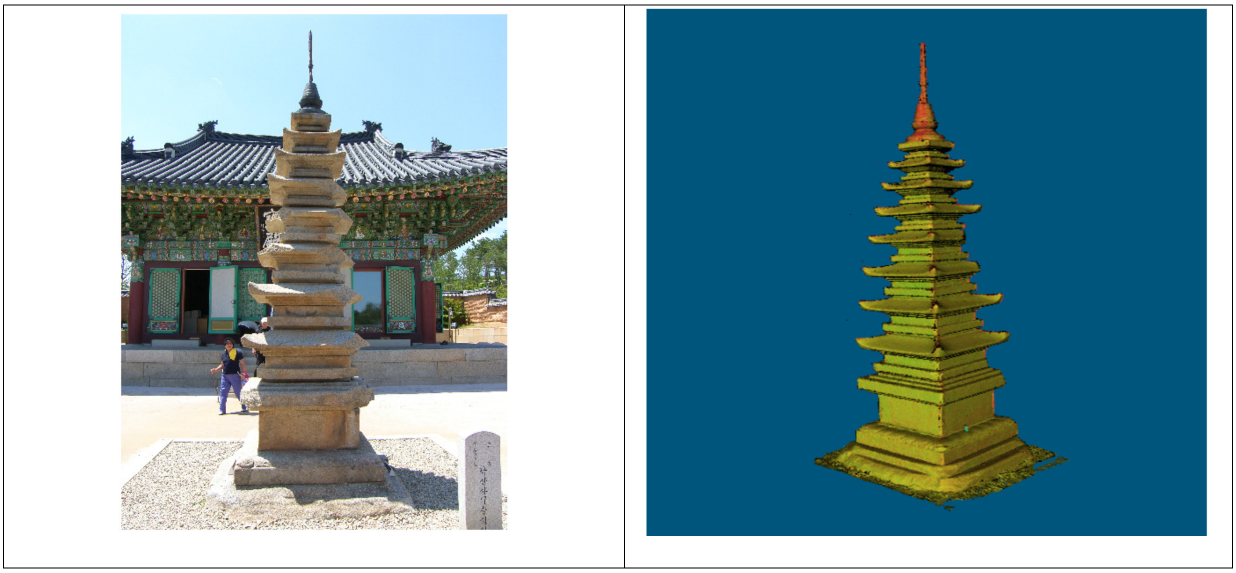


Figure9: Final Result

5. APPLICATION OF CULTURAL HERITAGE RECONSTRUCTION THROUGHOUT THREE-DIMENSIONAL DATA

5.1 Identifying Damage

Laser scanner has a great accuracy maximum within “0.01m”, so that it is possible to scan the small parts of objects that nobody can recognize in the world. Moreover, damaged surface can be described as graph by technician, so that it is also possible to examine the extent of damage throughout numerical analysis, not just assumption (Park Dong-Jing, Do Jin-Young, 2001).

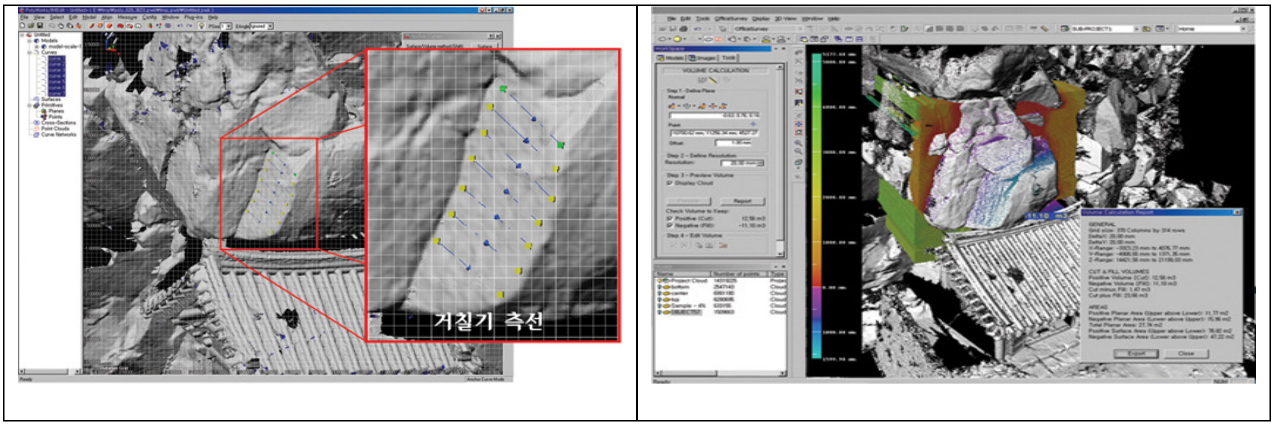


Figure10: Identifying the security diagnosis

5.2 Calculating Volume of targets and inclination for Reconstruction

Of three-dimensional cultural heritage modeling data, after the center of modeling data designated and symmetrical axis made, the volume of targets as well as inclination are able to be estimated throughout the other side of modeling data. Furthermore, it can be also possible to calculate the amount of stiffener and additive for damaged parts caused by wind or physical contact.

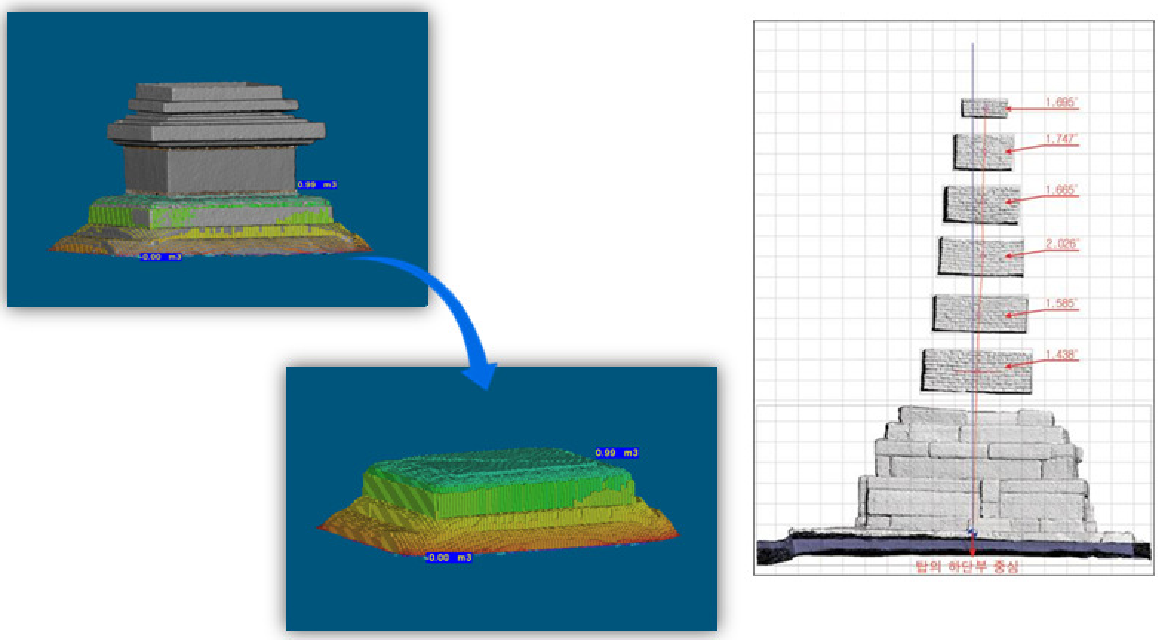
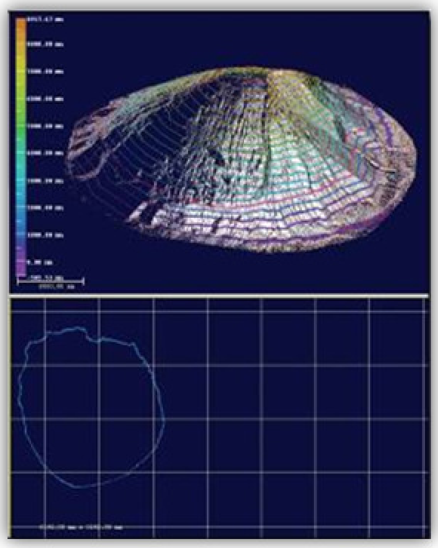


Figure11: Calculating the volume of target and inclination

5.3. Three-dimensional simulation

In fact, editor is virtually able to designate some parts and reduce numerical value if he or she intends to do. As a result, it enables technicians in fields to perform preliminary research without removing obstacle physically. Aside from scanning the surface and structure of cultural heritage, when scanning geographical feature such as a contour and soil swell near the cultural heritage, it can be estimated how long cultural heritage is able to hold out with respect to geographical feature. The power of wind can be estimated. Surrounding of cultural heritage (e.g. temperature, facility, geographical feature, etc.) linked to cultural heritage, and crack and porosity are very important clue by analyzing the change of these features.



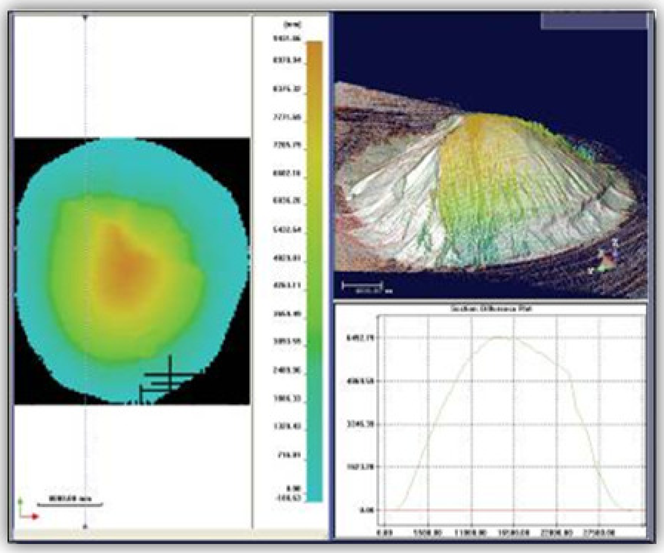


Figure 12: Estimating soil swell and contour

5.4 Estimating Accuracy and regular monitoring after Repair Work

After repair work, based upon scanned data and simulation data, it can be possible to confirm if cultural heritage is completely reconstructed by analyzing numerical value, not just assumption. Scanning cultural heritage one time is very in common. The database regarding the status of cultural heritage can be made by regularly monitoring cultural heritage and surrounding, and identify if cultural heritage is damaged, corroded, linked to man-made hazard.

6. CONCLUSION

Cultural heritages regarded as a valuable legacy from ancestors contain wisdom of life and our history. There are a lot of cultural heritage out there in South Korea (e.g. metal craft, wooden buildings, stone tower, statue of Buddha, ceramics etc.). However, a number of cultural heritages have steadily been damaged by change in nature, such as acid rain, disaster and climate change, or man-made hazard (e.g. war, arson, and construction). Since people were aware of importance of cultural heritage, they have tried to perfectly obtain apperances of cultural heritages in a variety ways for complete reconsruction.

This papaer presented application of terrestrial laser scanner for cultural heritage three-dimensional modeling and reconstruction. Use of terrestrial laser scanner has the great advantage that is able to obtain a large number of measurements with high precision in a short time. As a result, South Korea Cadastral Survey Corporation that has dealt with two-dimensional survey using TS (Total Station) as a work of government has entered into three-dimensional survey field. In this paper, The work flow of scanning ”Wontong bojun” building, ”Chilcheung Seoktab” stone tower, and ”Haesu Kwanumsang” statue of the Buddah at Naksan temple was described.

Consequently, diverse applications of three-dimensional modeling data was proposed. The followings are the summary of three-dimensional modeling data applications.

- Indentifying the damage using numerical value derived from scanned data
- Calculating volume of targets as well as inclination after the center of modeling data designated and symmetrical axis made
- three-dimensional simulation for removing obstacle virtually, estimating the balance with respect to geographical feature and the power of wind throughout surrounding of cultural heritage
- Estimating accuracy after repair work and database construction throughout regulary monitoring cultural heritages.

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BIOGRAPHICAL NOTES

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