International Journal of Advanced Culture Technology Vol.8 No.3 260-268 (2020)
DOI https://doi.org/10.17703/IJACT.2020.8.3.260

IJACT 20-9-33

Development of 3D scanner using structured light module based on variable focus lens

Kyu-Ha Kim[1], Sang-Hyun Lee[2]*

[1]*LINC+ (Leaders in Industry-university Cooperation), Honam University, Korea*
[2]*Associate Professor, Dept. of Computer Engineering, Honam University, Korea*
[1]kim9659@honam.ac.kr, [2]leesang64@honam.ac.kr

Abstract

Currently, it is usually a 3D scanner processing method as a laser method. However, the laser method has a disadvantage of slow scanning speed and poor precision. Although optical scanners are used as a method to compensate for these shortcomings, optical scanners are closely related to the distance and precision of the object, and have the disadvantage of being expensive.

In this paper, 3D scanner using variable focus lens-based structured light module with improved measurement precision was designed to be high performance, low price, and usable in industrial fields. To this end, designed a telecentric optical system based on a variable focus lens and connected to the telecentric mechanism of the step motor and lens to adjust the focus of the variable lens. Designed a connection structure with optimized scalability of hardware circuits that configures a stepper motor to form a system with a built-in processor. In addition, by applying an algorithm that can simultaneously acquire high-resolution texture image and depth information and apply image synthesis technology and GPU-based high-speed structured light processing technology, it is also stable for changes to external light. We will designed and implemented for further improving high measurement precision.

Keywords: *Variable focus lens, Structure light, Variable focus lens, Telecentric lens, Calibration, 3D Point Cloud*

1. Introduction

The modern industry has been producing products based on automated manufacturing processes due to the advancement of technology, and accordingly, a mechanism for accurately measuring product information is required. In this system [1] the telecentric lenses with a major advantage of minimized perspective error are various industrial fields, such as semiconductor lithography and machine vision. And contributes to improve product quality by acquiring product information [2]. Here, machine vision to method for 3D scanning includes confocal, structured light, and triangulation methods. Among the active sensor-based, the method that has attracted the most attention in recent years is a method using structured light. This method projects a pre-designed 2D pattern onto a stationary object and takes a camera to analyze the deformation and distortion of the pattern to extract 3D information of the object. At this time, the pattern used is various in color and shape such as binary, color, and stripes, and it is possible to acquire a model with accuracy similar to that of 3D scanner using structured light and configure a relatively low-cost system. Objects are difficult to reconstruct, and the size and resolution of the pattern image are affected by the reconstruction precision, so a high-performance projector is required. Also, camera calibration between the projector and the cameras is essential

Manuscript Received:August 05, 2020/Revised:August 26, 2020/Accepted: September 08, 2020
Corresponding Author: leesang64@honam.ac.kr
Tel: +82-62-940-5285, Fax: +82-62-940-5285
Department of Computer Engineering, Honam University

[3].

In order to compensate for this disadvantage, a study using multiple frame information on which a pattern is projected was also published. It takes a lot of processing time because it is calculated considering all the frames accumulated on the time axis, but it can restore not only a stationary object but also a moving face [4].

Recently, variable focus lenses can not only reduce the number of lenses constituting the composite lens, but because they can be small and lightly manufactured, they have been spotlighted as applicable lenses for mobile devices. In order to develop a variable focus lens, the focus was changed by adjusting the distance between a pluralities of lenses in the past. In order to solve this structural problem, motors, mechanical actuators, etc, were used. However, for this reason, the disadvantage that the volume is large and heavy occurred. To solve this problem, a small and light type smart material-based variable focal lens was developed [5-9]. Also, it is a 3D scanner as a representative device that can measure the product accurately by applying variable focus lens and structured light system. However, as a measurement method of 3D scanner, generally adopted a laser method. The laser method makes it difficult to precise measurement as the light becomes wider. Because of these shortcomings, a lot of structured light method combining 3D reconstruction technology using camera and projector is used. This structured light system projects structured light through the active light source (Active Vision) to the subject. How to get 3D information is taken by shooting through a sensor like a camera.

This paper designed 3D scanner using variable focus lens-based structured light module that improved measurement precision for use in industrial sites with high performance, low price. In order to solve this structural problem, designed a telecentric optical system based on a variable focus lens, and was connected to a telecentric mechanism of the step motor and lens for adjusting the focus of the variable lens.

In addition, we designed a connection structure with optimized scalability of hardware circuits constituting a system with a built-in processor with a stepper motor.

2. Design of variable focus lens

Three-dimensional shape restoration of objects using cameras is being applied to various fields, and many studies have been conducted to date. As a technique for restoring a three-dimensional shape, it can be roughly divided into an active technique and a passive technique. Representative technologies of active type include laser triangulation and structured-light based technology, and passive types of technology include stereo vision. It is mainly used for industrial and research because active technology has higher precision than passive technology. In addition, the process of obtaining a three-dimensional shape of the target object using active light source such as laser or structural light is called 3D scanning.

This study developed the variable focus lens to make a low price and high precision 3D scanner usable in the manufacturing industry. The variable focus lens was designed as to be able to adjust the distance of the focal point through rotational movement of the lens barrel made of a telecentric optical system. In order to adjust the lens focus, a gear and step motor is coupled to the telecentric mechanism of the lens, and control is performed on the main board of the 3D scanner.

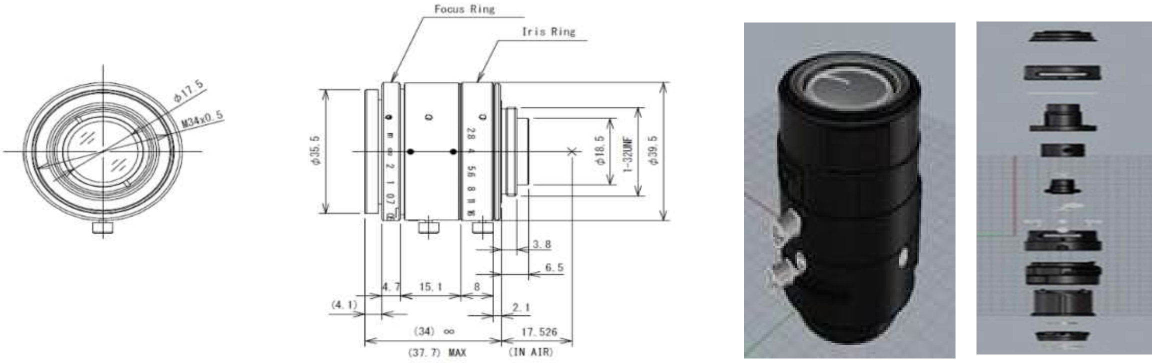

Figure 1. Variable focus lens 2D and 3D design

In order to measure the dimensions of a variable focus lens, you must acquire the image after 3D scanning. However, because telecentric lenses are real objects, there may be some residual distortion that affects measurement accuracy.

Therefore, regardless of the distance of the object to be 3D scanned, the telecentric optical lens was designed and applied by minimizing perspective distortion using the Zemax program so that it can be seen in the same size. Figure 1 is a 2D and 3D design diagram of a variable focus len.

The telecentric lens accepts parallel beams from the central optical axis, and comes in from different angles depending on the field position and arrives to the detector to show that objects at different distances appear the same size. The work distance detected in the optical system may be displayed as visual error.

3. Create structured light for focus judgment

Structural light (fringe projection) uses the image of an object that projects one or more patterns of light on it to create a 3D point cloud of the object's surface and then stereo camera inside the sensor use to increase accuracy and acquire sensor stability.

The structured light method has the advantage of high speed because it mainly uses digital projectors to project the structured light over the entire surface of the object to be restored and obtains the image of the structured light projected by the image sensor. In order to restore the shape of an object, three-dimensional scanning using structured light requires knowing the geometric relationship between a light source projecting structured light and a camera. This is called calibration between the structured light and the camera.

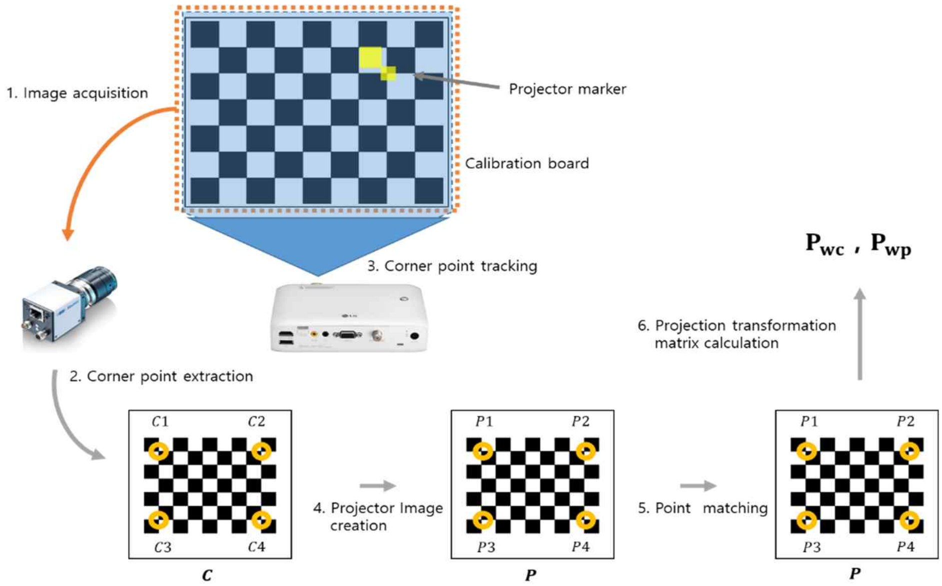

Figure 3. Camera-Process for implementing projector calibration

In camera image and projector image, track the corner point of structure light and search for the matched point. It is a technique of acquiring three-dimensional coordinates of the detected point. First, calibration of the camera and projector must be performed in order to calculate the three-dimensional coordinates of the coincidence point. In addition, the accuracy of the restored three-dimensional shape is affected by the camera and projector calibration results. Figure 2 is the camera-project calibration implementation sequence. First, an image of a correction pattern such as a checkerboard is acquired by the camera. Let's assume that the image obtained here is camera image corner: I_C. Obtain coordinates of corner points corresponding to the four corners of the correction pattern from the image corner. In order to distinguish between the coordinates of the corner point obtained in this way and distinct from another corner point, let's call it the outer corner point. In this study, *harris corner Algorithm* was used for acquisition of the outer corner point. The four external corner points obtained from the camera image are named each camera corner: C_1, camera corner: C_2, camera corner: C_3, and camera corner: C_4. The four external corner points are corner points in the camera image. It is a 2D coordinate value for. If you can know the coordinate value of 4 outer corner points in the projector image, you can convert the image corner into a projector image point. Corresponding to projector's outer corner points P_1, P_2, P_3, and P_4 must be obtained. In this study, projecting one marker into the pattern and matching the center of the marker with each corner get the projector corner point. This process is the corner point tracking [10].

3.1 Algorithm of 3D Point Cloud Generation

In this study, for the calculation of the distance according to the focus of a variable focus lens, the best focus operator is applied and the focus operator-based focus image extraction synthesis module is developed in the process shown in Figure 3. Development of depth image based on variable focus lens and module capable of conversion to 3D Point Cloud are developed. Improved the quality of the 3D model as the mesh size increases to generate a triangular mesh from point cloud in 3D global space restored through estimating camera pose for RGB camera shooting images can be increased.

For generating a 3D model suitable for real-time application, applying a high-quality texture generation technique" from color photographing a 3D point cloud for a relatively small triangle mesh. In particular, by using the mapping relationship between 3D point cloud space and 2D texture space generated through camera pose estimation, it is possible to effectively generate a texture for a 3D model reconstructed from RGB camera captured image.

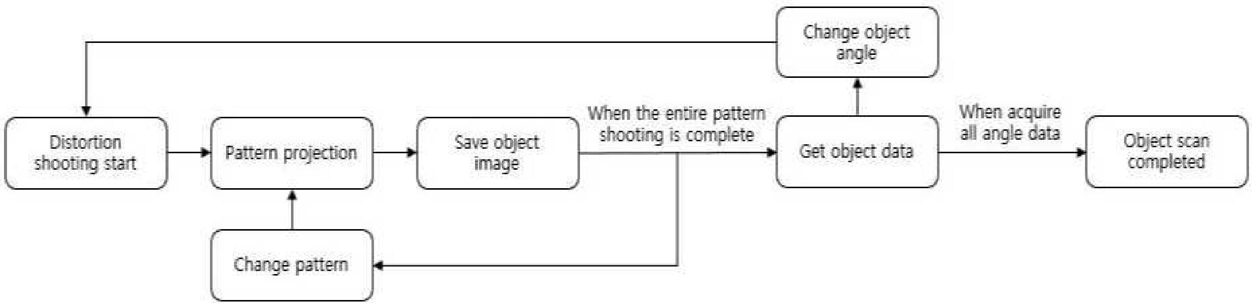

Figure 3. Process for 3D point cloud creation

Figure 4 was developed with the structural principle of structured light method 3D scanner to which 3D surface reconstruction and rendering algorithm was applied, and 3D scanner prototype of structured light method with variable focus lens.

3D scanner of structured light system with variable focus lens increased rendering performance and speed by applying division conquest algorithm. Creating cloud point refers to and complements the structured light library and applies it to development, and stores the 3D point coordinates calculated in the capture library in a 3D format in the *io until* library. These point data the storage method of match RGB color to 3D coordinates and Matched point data is stored in Vector format, where PLY is a file format known as polygon file format or standard triangle format. It is designed to store data. The storage format of data is a simple structure that expresses a single object as a polygon. Develop 3D surface reconstruction and file storage method of this development. You can store various attributes, including texture coordinates and data reliability values.

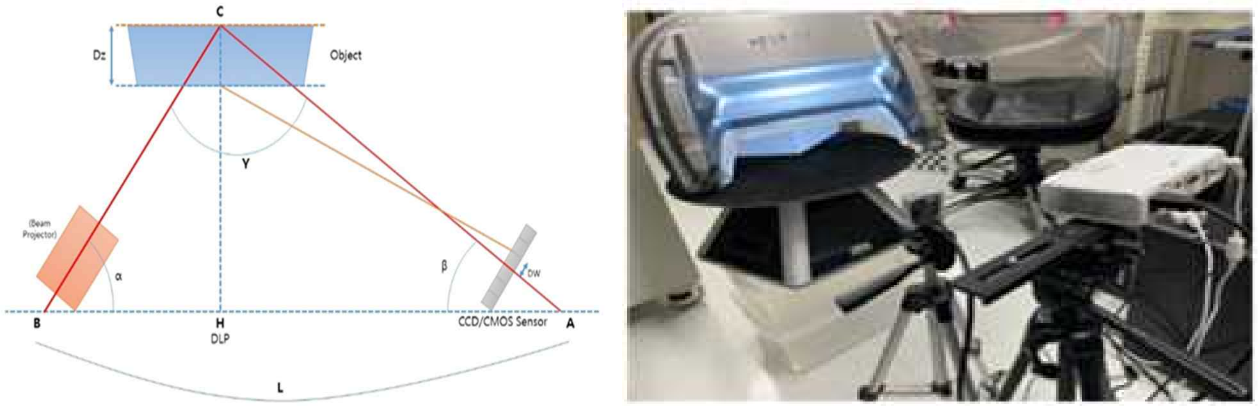

Figure 4. Triangulation principle of structured light type 3D scanner (left), prototype of structured light type 3D scanner with variable focus lens (right)

4. Development of 3D scanning based on variable focus lens

In this study, the specifications of the 3D scanning system to be developed are shown in Table 1 below.

Table 1. Development specifications of 3D scanning

Division	Specification	
3D scanning system	CPU	i5-7300U 2.6GHz
	RAM	8GB
	OS	Windows10
	VGA	Intel 620
3D Scanner (DW-1905)	Scan method	Structure Light method
	Projector resolution	WXGA(1280x720) Aspect ratio 16:9
	Camera Pixl	2592 x 1944 pixels
3D S/W	3D data processing based on OpenCV	
	3D scanner calibration	
	Structure light pattern repeated shooting	
	Object junction module	

4.1 Hardware design of variable focus lens based 3D scanner

This paper designed and manufactured 3D scanner using variable focus lens-based structured light to improve high measurement precision to be usable even in industrial sites where precise processing is performed in the manufacturing industry. In addition, designed telecentric optical system based on variable focus lens and connected to the telecentric mechanism of the step motor and lens for adjusting the focus of the variable lens.

We designed a connection structure with optimized scalability of hardware circuits that constructs a system with a built-in processor as shown in Figure 5.

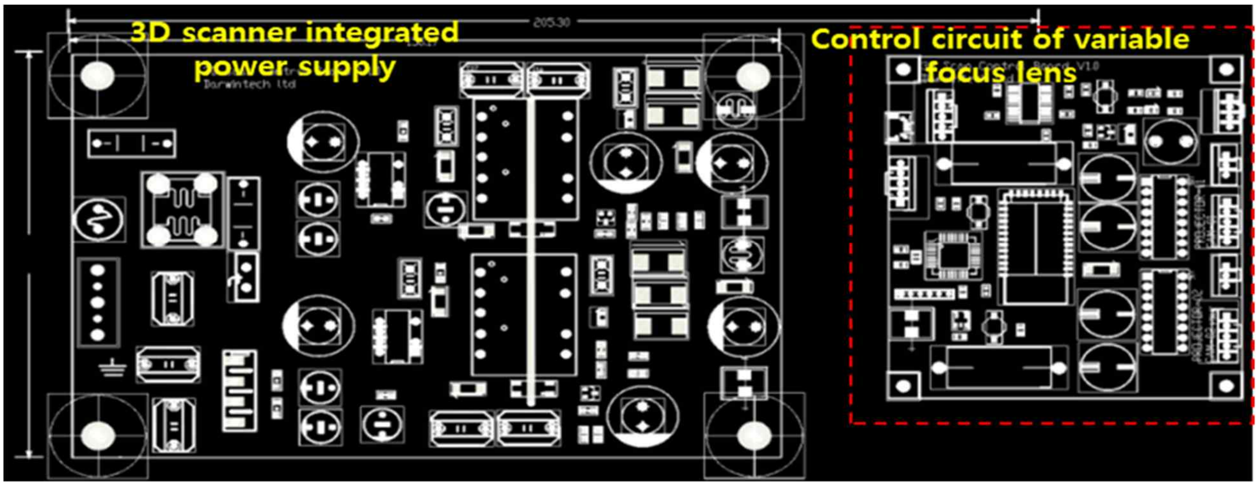

Figure 5. Embedded board circuit diagram for integrated power supply and lens control of 3D scanner

4.2 Software design of variable focus lens based 3D scanner

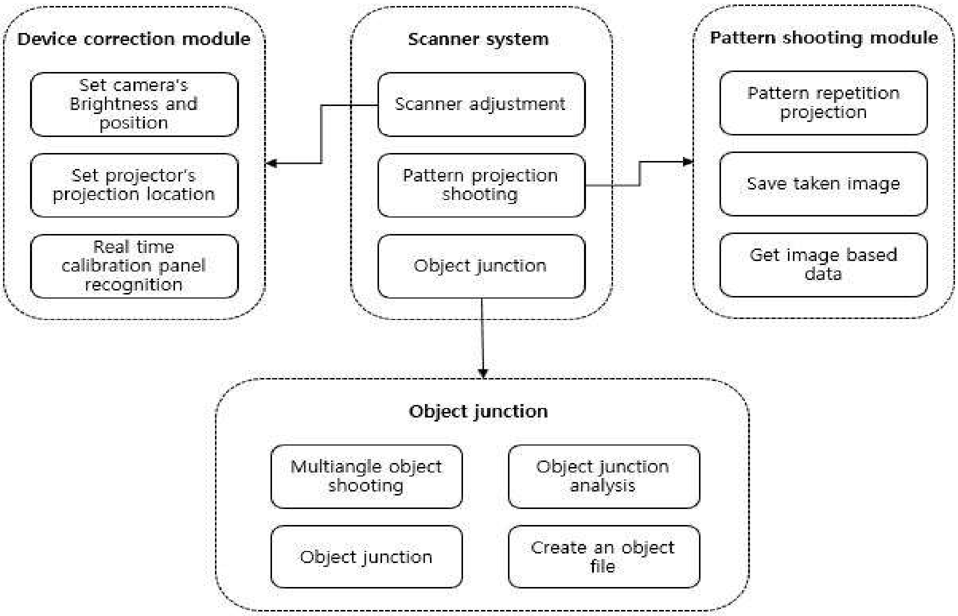

Figure 6. Sample

The image data captured by the hardware device is analyzed by software to generate three-dimensional data. The software consists of a 3D scanner calibration module, a structured light pattern repeats imaging module, and an object junction module. In order to calibrate the position and angle of the scanner devices, 3D scanner calibration was applied to correct the projection position of the projector and the camera angle using a marker based image processing technique. Obtain accurate object distortion data using a plurality of patterns for accuracy of object scanning, find matching points of objects to match objects, and match objects to complete one scan object.

The finished data was converted to surface data using point data and Meshlab was used for alignment, registration, and editing. Mesh Lab is an open source system that processes and edits 3D triangular meshes. It is a set of tools for mesh editing, cleaning, healing, inspection, rendering, and transformation [11]. Figure 6 is a software block diagram that allows scanning using structured light.

Grids and details within the figures must be clearly legible and may not be written one on top of the other.

Figures should be numbered and should have a caption which should always be positioned *under* the figures, in contrast to the caption belonging to a table, which should always appear *above* the table. Please center the captions between the margins and set them in *11-point type* and *Helvetica font*. The distance between figure and caption should be about *6pt*, and the distance between caption and text about *12pt*. Use of *600 dpi/1200 dpi* for illustrations for clarity recommended.

4.3 Development of optimization module to simplify data handling

The 3D scanner software used in this paper is configured to enable 3D scanning conveniently from the user's point of view by separating into correction and scanning parts for simple data handling [12]. Here, the correction supports a function that can be photographed by examining a stripe pattern and a screen mode capable of checking photographed image information. Also, it is developed to support camera power ON/OFF, laser ON/OFF, motor rotation, calibration value correction, camera brightness correction, and camera view function.

Data handling technology is applied to filter unnecessary point data that occurs according to changes in the surrounding environment. Segmentation and tracking to reconstruct the shape of images taken from data points obtained in cross-section, and speed up processing by mesh data generation and transformation.

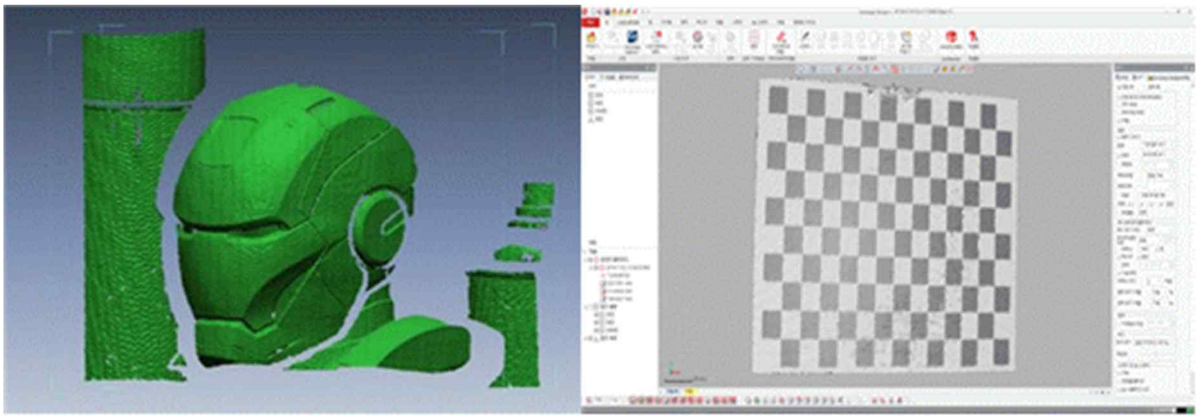

Figure 7. Filtering extraction point data screen and 3D Point Clouds

In Figure 7, the left screen is filtered and extracted point data and 3D point cloud. The 3D scanner software is divided into a correction and a scanning part, and it is configured to make 3D scanning easier for the user. The correction supports a function that allows you to examine a stripe pattern and shoot, and a screen mode to check the captured image information.

Figure 8 shows the test process on the screen using a 3D scanner that was developed in this paper. In the set window of the checker box type calibration plate, enter the horizontal/vertical size and the horizontal/vertical length (based on the actual size of the calibration plate) to calibrate the camera by putting the measured values in the calibration library as variables, and set the pattern analysis screen Has implemented an input variable window that allows you to enter threshold, distance, and pattern settings for camera calibration.

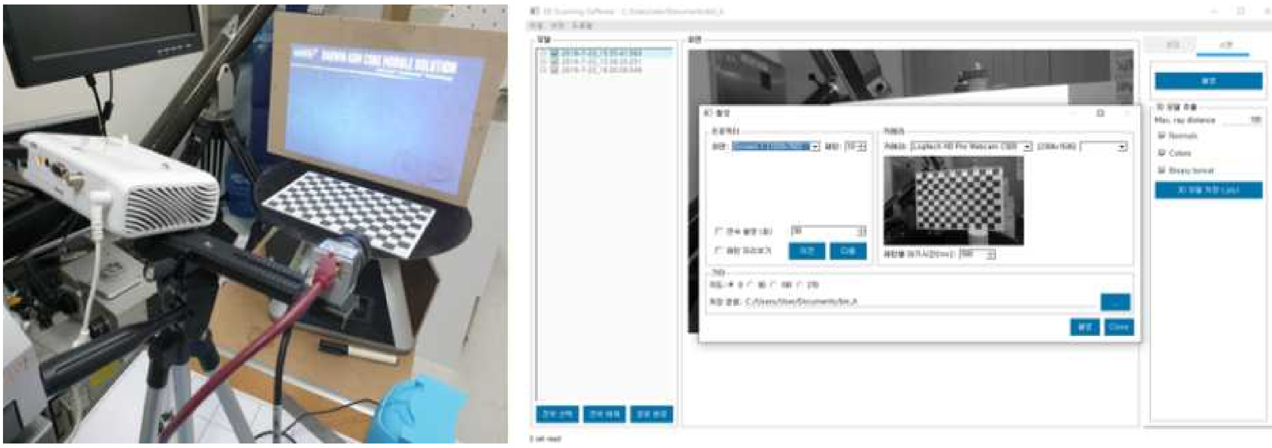

Figure 8. Manufactured 3D scanner system

4.4 Test Result

It was produced as shown in Figure 9 using the research results proposed in this paper. Figure 9 is progressing to collect 3D data and analyze the deviation of actual design data using the developed variable focus lens-based 3D scanner.

3D scan data and actually designed 3D design data of parts are required for deviation analysis by utilizing 3D scan data acquired through technology development results in this paper. In order to acquire such data, it was tested using the Geomagic tool, and by performing deviation analysis as a result of the test, it is possible to visually express the deviation between the design data and the produced product.

Figure 9. 3D Scanner system produced as a result of research

5. Conclusion

Currently, due to the development of the IT industry and advancement of technology, products are being mass-produced based on an automated manufacturing process, and accordingly, a mechanism for automatically measuring the quality of products is also required.

In accordance with the demands of these industries, this paper has produced a 3D scanner utilizing a variable focus lens-based structured light module to improve measurement accuracy to be used in industrial sites with high performance and low cost.

When the deviation analysis of the 3D scanner using the variable focus lens-based structured light module manufactured and researched in this paper performs deviation analysis, the deviation between the design data and the produced product is visually expressed, and the size of the deviation up to 10μ units. It was confirmed that it was possible to measure very accurately.

References

[1] Edmund Optics, The Advantages of Telecentricity (Application Notes, Imaging Resource Guide), Section 5.1.

[2] S. I. Son., D. Pugal., T. Hwang., H. R. Choi., J. C. Koo., Y. Lee., K. Kim., and J.-D. Nam, "Electromechanically driven variable-focus lens based on transparent dielectric elastomer," Appl. Opt., Vol. 51, No. 15, pp. 2987–2996, 2012. DOI: 10.1364/AO.51.002987

[3] L. Zhang, B. Curless, and S.M. Seitz, "Space time Stereo: Shape Recovery for Dynamic Scenes," Comput. Vision Pattern Recognit, pp. 367-374. June 2003. DOI: 10.1109/CVPR.2003.1211492

[4] O. Alexander et al., "Creating a Photoreal Digital Actor: The Digital Emily Project," Eur. Conf. Visual Media Production, 2009. DOI: 10.1109/CVMP.2009.29

[5] K. H. Jeong., G. Liu., N. Chronis., and L. Lee., "Tunable microdoublet lens array," Opt. Express, Vol. 12, No. 11, pp. 2494-2500, 2004. DOI: 10.1364/OPEX.12.002494

[6] N. T. Nguyen, "Micro-optofluidic Lenses: A review: Biomicrofluidics," Vol 4, No 3, pp. 031501(1) - 031501(15), 2010. DOI: 10.1063/1.3460392

[7] F. Carpi., G. Frediani., S. Turco., and D. Rossi., "Bioinspired tunable lens with muscle-like electroactive elastomers," Advanced Function. Mater, 21, pp. 4152-4158, 2011. DOI: 10.1002/adfm.201101253

[8] S. Shian., R. M. Diebold., and D. R. Clarke., "Tunable lenses using transparent dielectric elastomer actuators," Optics Express, Vol. 21, Issue 7, pp. 8669-8676, 2013. DOI: 10.1364/OE.21.008669

[9] Y-. C. Choi., C-. S. Rim, "Design of a Telecentric Lens with a Smartphone Camera to Utilize Machine Vision," Korean Journal of Optics and Photonics, Vol. 29, No. 4, pp. 149–158, 2018. DOI: 10.3807/KJOP.2018.29.4.149

[10] S-. Y. Park., G. G. Park., L. Zhang., "An Easy Camera-Projector Calibration Technique for Structured Light 3-D Reconstruction," The KIPS Transactions: Part B, Vol. 17B, No. 3, pp. 215-226. 2010. DOI: 10.3745/KIPSTB.2010.17B.3.215

[11] http://www.meshlab.net/

[12] Sang-Hyun Lee, "Research and development of haptic simulator for Dental education using Virtual reality and User motion," International Journal of Advanced Culture Technology(IJACT), 64, pp. 52-57, 2018. DOI: 10.17703//IJACT2018.6.4.52