APPLICATION OF TERRESTRIAL LASER SCANNING FOR SHIPBUILDING

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ABSTRACT:

Recently, a laser scanner technology has been receiving more attention. Nowadays use of terrestrial laser scanners (TLS) is continuously increasing. This technique offers the possibility of measuring millions of points within short period of time. Thus, it is possible to record complete 3D objects efficiently. In this communication the process followed to model the hull and the deck of the ship will be described. To perform this process, a point definition from a terrestrial laser – scanner Faro LS 880 was used as information source. From this data, the commercial package software Geomagic Studio 8 has been used, to obtain the three-dimensional model of two differentiated parts of the ship. The importance of this process lays on the fact that an inverse process has been followed: it is the model that has been obtained from the real ship. From these 3D models some series of analysis and verifications could be made, like diverse measurements, construction defects, determination of possible asymmetries, etc. even though these aren't presented in this communication. Another remarkable objective of this project is to calculate the volume of the underbody. The waterline which indicates the level at which the ship floats in the water (thus it's a line which separate underbody from dead works of the ship) helps us to obtain the 3D model of the underbody by means of Geomagic software and then to calculate its volume.

1. INTRODUCTION

The construction of sporting, pleasure and fishing craft has, in recent years, become an important source of revenues for the shipbuilding sector. Demand, moreover, is steadily growing, and this grow is expected to continue in the medium term. Consequently, an increasing number of businesses are entering into the sector which is made increasingly competitive.

The manufacturing process for this type of craft, which is largely manual, relies on the expertise of individual operatives, and results in products that are generally unique and different. Moreover, rigorous quality control programmes are rarely implemented and construction or assembly workflow diagrams are not generally used. Parts are on occasion wasted or re-worked due to production errors, for example, causing production delays and increased costs. This situation, combined with the urgent need to increase productivity and competitivity, is putting pressure on shipbuilders to improve production processes with the incorporation of design and new manufacturing technologies, which - without increasing costs significantly – will define a priori the quality of the final product and ensure that the different parts of the finished craft contain no asymmetries or construction defects.

The construction of accurate three-dimensional models that use terrestrial laser scanning techniques, which permit millions of points to be measured in a question of minutes, offers particular promise in terms of the design and construction of boats (Thiyagarajan, 2003), replacing other traditional, slower and more inaccurate methods based on moulds subsequently adapted to the definitive boat shape.

Terrestrial laser scanner measurement techniques generate a large quantity of information, which requires substantial processing to arrive to the point where a definitive 3D model is obtained.

2. 3D LASER SCANNER TECHNOLOGY APPLICATIONS

Cultural heritage recording (Barber, 2005; Stenberg, 2006; Vistini, 2006), architectural modelling (Levoy, 2000; Akca, 2006), building reconstruction (Alshawabkeh, 2005), accident investigation (Pagounis, 2006) and structural engineering (Gordon, 2004) are just some of the subjects now benefiting from the use of terrestrial laser scanning.

The most important area of application of laser scanning to engineering is 3D modelling of existing structures and industrial equipment (Straiger, 2002). 3D plant models are needed as basic data for design, especially when modernising industrial plants. Plant models are also used in maintenance and facility management systems of industrial plants as a 3D virtual reality. The 3D virtual model gives dimensions for efficient maintenance.

The main infrastructure applications are for modelling of buildings, bridges, tunnels, underground facilities and for virtual city modelling (Kretschmer, 2004; Böhm, 2005; Arayici, 2005). Laser scanning is also used for mining industry and modelling in the shipbuilding (Gutiérrez, 2006; Arias, 2006).

3. AIMS OF THIS PROJECT

In this paper the investigations of the 3D modelling using the terrestrial laser scanning system are presented. It describes a project whose final aim was to establish overall conditions of a wooden boat, because of the future possibility to do up it. Other important aim of the project was to calculate a volume of the underbody. To reach this goal of the work we needed to mark a waterline on the hull. The waterline refers to an imaginary line marking the level at which the boat floats in the water, thus it's a line which separate underbody from dead works of the boat. The ship speed is determined by, amongst other things, the waterline length.

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The boat is based on a structure consisting of two differentiated parts: the deck and the hull. From a mosaic of TLS point clouds we have constructed three-dimensional models of these two components using the commercial package software Geomagic Studio 8.

4. MEASURING OF THE SHIP

3.1. Instrumentation

The equipment used for the data collection is listed as follows:

- Three-dimensional terrestrial laser scanner FARO LS 880 (Figure 1). Each scan covers a 320º vertical and 360º horizontal field-of-view.
- Magnetic targets were implemented to increase the precision in assembling the different scans.
- Laptop computer. Terrestrial laser applications require the scanner to be connected to a computer in which the point clouds recorded by the laser are stored in real time.
- Tripod. A tripod provides the support necessary to ensure the terrestrial laser scanner during scanning operations.
- Software application for linking up the point clouds captured in each of the scans.
- Software for cleaning up, debugging and filtering the point clouds generated by the scans.
- Software for generating 3D surface models from the pre – processed point clouds.

Figure 1. The 3D laser scanner FARO LS 880

3.2. Data Acquisition

Preliminary steps. Prior to commencing the scanning tasks, the surroundings of the element to be modelled should be analysed in detail. The following points need to be taken under consideration:

- Suitable positions to capture data, using the laser that will minimise both the number of scan locations and information lost, must be identified.
- Elements that may prevent correct data capture or that may introduce information that could hinder subsequent processing, must be identified.
- Any possible sources of vibrations near the scanning area must be removed to avoid adverse effects on the quality of the scans.

Scanning procedure. Once these preliminary steps have been taken, the fieldwork stage can proceed. This phase is structured as follows:

1) Creation of sketches, indicating the position of elements of interest and of the scanner in each scanning session is extremely useful for subsequent information processing phases.
2) The scanner is positioned in the previously selected locations and scanning commences. The scanning procedure consisted of moving the 3D laser scanner around the ship, so that the studied object was surrounded completely. During the scanning process, the following guidelines should be followed:
   a. Ensure overlaps of about 20% between adjacent areas of interest and avoid shadow areas where there is no information. This will ensure that all areas are fully covered so that when the different scans are finally put together, no essential elements will be excluded from the final model.
   b. Once the data capture process commences, ensure that the objects to be scanned are not moved.
   c. Avoid any movement or vibration, no matter how small, of the scanner.
   d. It is recommended that targets that can be automatically recognised by the software are used as control points. In this way overlapping between scans can be minimised.
      In our case this matter was essential. Every scan was made with 10 targets always ensuring overlaps of 5 targets between two following scans. It was especially important at the moment of assembly of the hull and the deck. During the scanning process of the hull at least one of the targets was placed on the deck, which helps us during assembly process.
3) Finally, it is recommended during this phase to assemble the successive scanned models prior to leaving the site. This will avoid any subsequent problems arising as a consequence of incomplete data, corrupted files, etc. The additional time required for this work is more than compensated for by the avoidance of possible subsequent complications that may be difficult to rectify.

The measurement procedure followed for the data collection took approximately 7 working hours, scanning both elements of the boat, the hull and the deck.
The waterline that refers to an imaginary line marking the level at which the boat floats in the water, was marked by some targets to help us to recognize it on the scans (showed by Fig.2). The waterline was the essential date to calculate the volume of the underbody in this case.

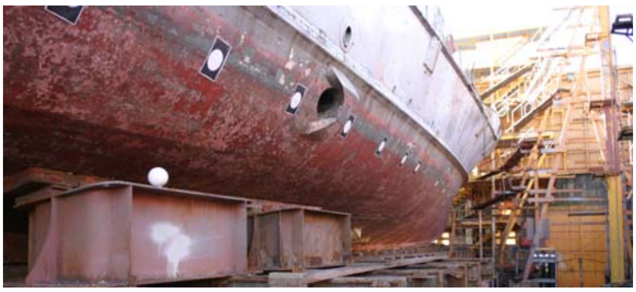

Figure 2. Waterline marked with black and white targets

Discussion. In general, our scanning procedure works quite smoothly.
Our biggest failure was the lack of calibration of the scanner before the scanning procedure that caused a standard deviation of registration accuracy of about 3-4 cm.
We have found some problems during the automatic recognition of white spherical targets by the software especially with the direct sun. It was needed to find the way to make a shadow in the place of the targets (i.e. to cover it with something dark, i.e. umbrella in our case) and repeat the scan. It takes up about one working hour in the course of our outside work. During the registration some difficulties were encountered as will be discussed in section 5.
In my opinion the registration accuracy could be improved changing direction of scanning procedure. Instead of moving the 3D laser scanner around the ship (the beginning point and the end point are the same), it could be moved from the beginning to the end along the left side of the ship and then from the beginning to the end along the right side of the ship. This procedure should be applied both to the hull and to the deck of the ship.

3.3. Data processing: 3D visualization

Data processing. Once the previous phase is completed, the next stage is data processing, which will result in the 3D surface models. This is a slow and laborious process performed using a computer and specialised software for pre-processing the 3D point clouds. This phase, in fact, represents the bulk of the work involved in the project. Therefore, the cost of this phase is largely dictated by the cost of labour for the information processing process in the laboratory.

The scans, registered in the global coordinate system, are analysed in order to locate points not relevant to the project. The scanner records measurements returned from all the elements within its field of view, many of which will not be parts of the boat (surrounding things, other boats, work tools and accessories, etc). These data are removed from the point cloud with the help of the photographs.
The “cleaning” process and data processing are made by the commercial package software Geomagic Studio 8. Our work consists of three main phases:

- Point Phase,
- Polygon Phase,
- and the last one – Shape Phase.

Point Phase. The first one is the phase of point elimination and noise reduction. In this phase redundant information is eliminated from the point cloud that is to be modelled with the intention of reducing the volume of data, thereby simplifying subsequent operations. We need to remove these stray point, known as disconnects or outliers that may exist around the object. These can be identified as points that are far away from the main point cloud and don’t represent any geometry that we want to keep. The filtering process requires a certain degree of skill and experience, as there is a risk of filtering out too much data - with the consequent loss of information – or too little data, which can cause subsequent problems due to excessive information and overly-large files.

Frequently, during the scanning process, an element of “noise” is introduced into the data. This “noisy data” is identified by a rough, uneven appearance in the surface object and is due to such factors as small vibrations in the scanning device, inaccurate scanner calibration, or the character of the surface on the object being scanned. It’s need to minimize this noise. Finally we can use sampling to reduce the number of points in the object while maintaining an accurate representation of the part. With unordered data, we can use uniform sampling to reduce the number of points and leave points organized so they produce triangles roughly the same size when wrapped.
The point cloud prepared like that (“clean point cloud”) is ready to go to the wrap phase.

Polygonal Phase. Once the point object has been cleaned and organized, it is time to wrap the object with a polygon mesh. Three-dimensional surface models comprising triangular facets are constructed for the hull and for the deck from the filtered point clouds. Correct triangulation is the basis for subsequent correct modelling of curves and surfaces, and the results will largely depend of how well the point clouds have been filtered. In regular areas with simple shapes, filtering may be more intense, resulting in a lower number of triangles with longer sides. In irregular areas with complex shapes, filtering should be less intense, resulting in a larger number of triangles with shorter sides.
The wrapping process shows us the first result of our work. Before the coming to the finish part of the project, it’s need to fill the missing data.

Shape Phase. Once the polygon model has been edited to fix any imperfections and holes, it is ready for the next phase. This would be the Shape Phase, which is the phase where it’s creating NURBS (Non-Uniform Rational B-Spline) surfaces over the polygon object using autosurfacing.

The figures 3 and 4 show the results of three main phases of the project of both parts of the ship.

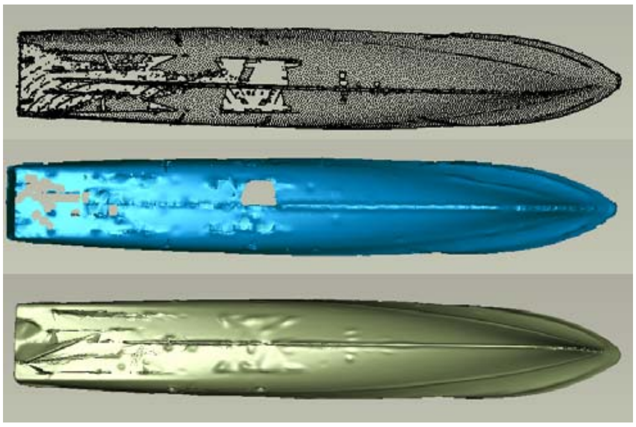

Figure 3. Results of Point Phase, Polygon Phase and Shape Phase of the hull

Discussion. How well our data processing flow works? In most cases, it works well. However, it was time-consuming because of the enormous quantity of points. Sometimes the computer works very slowly, especially in cases of surface extraction. In the worst cases the computer suspended after the long working hours and it was needed to repeat the Shape Phase, which was the most time-consuming task.
We were disappointed by the number of holes, some several centimeters in size, even with the results of the application of “fill holes” tool. The Shape Phase of the hull wasn’t very satisfactory because of the too much missing data. The deck was a more complex structure but personally we were quite more pleased with the results of the filling holes of the deck then of the hull.

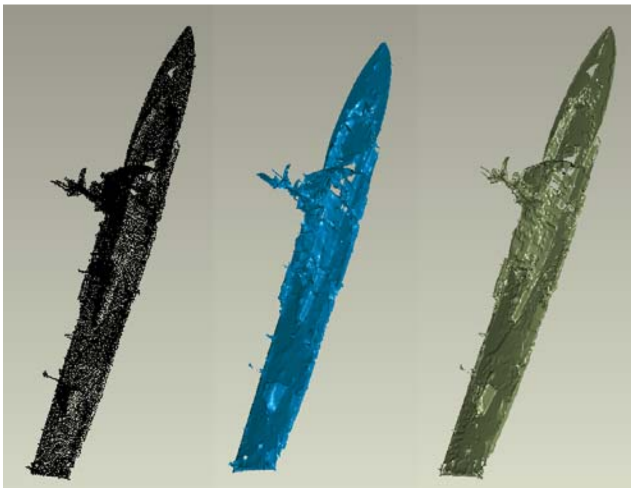

Figure 4. Results of Point Phase, Polygon Phase and Shape Phase of the deck

5. RESULTS

Scanning procedure. Fieldwork lasting approximately 7 hours was performed by a team of 3 individuals, as follows:

1) A sketch was first created of the position of the elements to be modelled, as also of the position of the scanner and of the field of vision for each scan. The scanner was prepared to capture data within its 320° x 360° field of view.
   The 360º field of view was necessary because some targets were placed around the ship to obtain the best precision possible in every scan. It helps us during the assembly process then.
2) Magnetic targets, which are automatically recognised by the software, were used to mark a series of control points on the objects. About 7 hours' fieldwork was necessary for the measurements, and over 41 million points were measured.
3) Finally all the scans were registered to object space. During this operation some difficulties were encountered, for example variation of the sea level (flow and ebb) between start and final of the scanning process, difficulties of placing the laser scanner in some scans, etc.
   There were 11 scans needed to scan the deck of the boat and 15 scans to scan the hull. 10 targets were used in every scan, always ensuring overlaps of 5 of them between two following scans. During the scanning process of the hull at least one target was place on the deck and then during the scanning of the deck, one of the targets was placed in the same site. This method works perfectly and helps us to assembly the deck and the hull during the laboratory work.
   All the scans were registered in the computer using the software FARO SCENE and the results were quite satisfactory.

Data processing. The first step before start the 3D modelling was to apply the previous filtering to the point clouds of the hull and the deck. The results of this process were the point clouds with spaces between the neighbour points of 10 cm.
The surface models were obtained as follows:

1) Point Phase. Areas of irrelevance to the project were eliminated from the scans aligned in the global coordinate system, mainly representing the surrounding things, other boats, work tools and accessories, etc. The pre-processing of the point clouds was carried out separately for the hull and the deck, with 778,742 points obtained for the hull, and 332,213 points for the deck.
   Redundant information on the point clouds and points falling outside the future model surface were eliminated to facilitate file handling. Given the simplicity of the hull surface, the noise reduction wasn't apply, only the filtering process and uniform sampling were performed, thereby reducing the number of points to a total of 139,446. Since the deck was a more complex structure, we applied the noise reduction, and then filtering process and uniform sampling were performed, resulting in a final total of 179,874 points.

The Figure 5 shows the standard deviation values along the deck of the ship after application of noise reduction. The mean value of standard deviation in shape after noise reduction was of 0.0221 m.

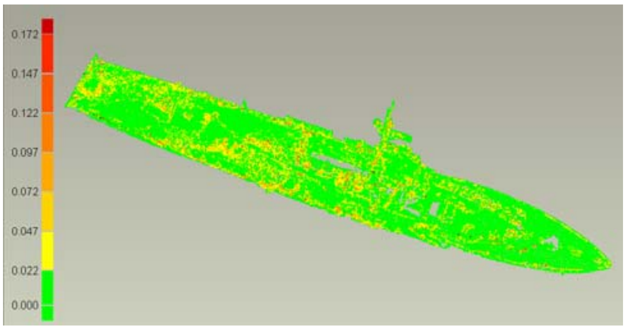

Figure 5. The standard deviation values along the deck of the ship after application of noise reduction

2) Polygonal Phase (the wrapping). The quality of this polygonal model depends directly on the filtering process. The hull, with relatively simple shapes, resulted in fewer triangles with longer sides compared to the deck (more complex shapes, therefore more triangles and shorter sides). Triangulation of the point clouds for the hull resulted with 211,794 current triangles, and for the deck, with 312,932 current triangles.

In the above Table 1 we find the results after the Polygonal Phase applied to the hull and the deck of the ship. The hull has no residuals in this case because we haven't applied the noise reduction.
The standard deviation gives the reference to deviation in shape between the point cloud data set and polygonal model.

	The hull		The deck	
Value [m]	Positive	Negative	Positive	Negative
Max. distance	0		0.008162	-0.008197
Average distance	0		0.000008	-0.005841
Standard deviation	0		0.000319	

Table 1. Values of standard deviation and the residuals after the Polygonal Phase

3) Fill Holes. Identification of missing data and manual completion. This task was mainly manual.
4) Shape Phase (autosurfacing). Using the triangles obtained, the next stage was definition of the surfaces that would form the models. This operation was again carried out separately for the deck and the hull.

The figure 6 shows the standard deviation values along the hull of the ship after application of autosurfacing. The full results after the Shape Phase applied to the hull and the deck of the ship are shown in Table 2.
The standard deviation gives the reference to deviation in shape between the point cloud data set and surface model.

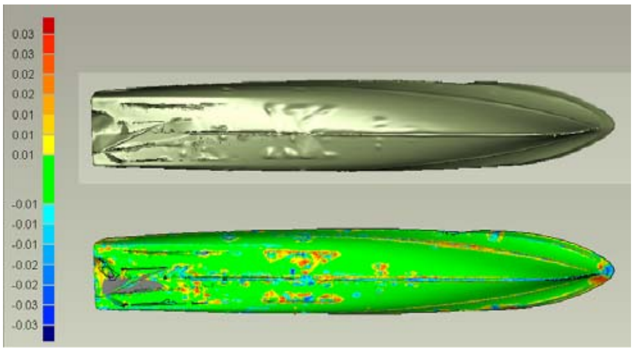

Figure 6. The standard deviation values along the hull of the ship after the autosurfacing

5) Assembly of the two main elements of the boat – the hull and the deck (first part of the Figure 7 shows the result of the assembly).

	The hull		The deck	
Value [m]	Positive	Negative	Positive	Negative
Max. distance	0.029997	-0.029840	0.059953	-0.059851
Average distance	0.004767	-0.003123	0.007784	-0.008039
Standard deviation	0.006847		0.012581	

Table 2. Values of standard deviation and the residuals after the Shape Phase

About 46 hours of laboratory work was required for above mention tasks. The results of the 3D modelling were quite satisfactory. The standard deviations of shape (between the point cloud data set and the surface model) for the 3D models resulted of 0.006847m for the hull and 0.012581m for the deck.

It's possible to apply three above mentioned phases to 3D point cloud of the whole boat.
We have started with 1,110,955 points and we applied the noise reduction. Then filtering process and uniform sampling were performed, resulting in a final total of 167,750 points in Point Phase.
Triangulation of the point cloud for the boat resulted with 323,862 current triangles, in Polygon Phase. Finally the Shape Phase resulted with 5342 patches obtained by applying the autosurfacing. The final results of every one of these phases are shown in Fig. 7.

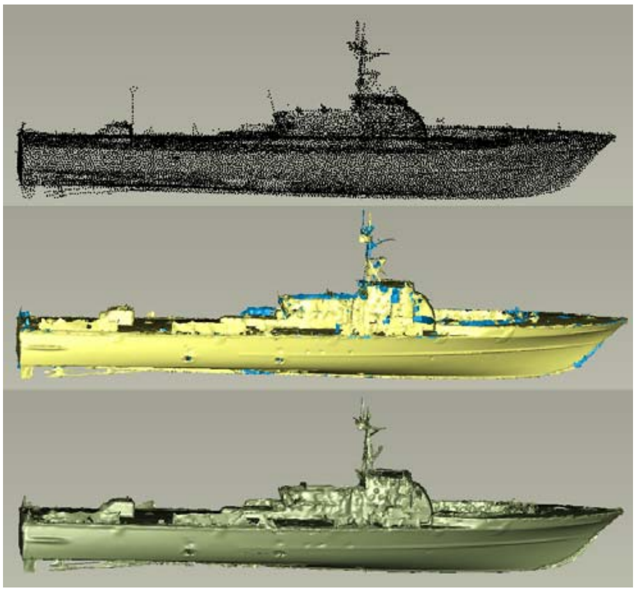

Figure 7. The results of Point Phase, Polygon Phase and Shape Phase of the ship

The standard deviation (deviation in shape between the point cloud data set and the surface model) resulted of 0.012161m for the 3D model of the whole boat.
The residuals are shown in Table 3.

Value [m]	Positive	Negative
Max. distance	0.059715	-0.059498
Average distance	0.008139	-0.006322
Standard deviation	0.012161	

Table 3. Values of standard deviation and the residuals of the whole ship after the Shape Phase

One of the most important matters when we speak about the speed of the boat it's surely the power of the engine.
The essential information to start calculating the power that we need for the boat is its length of waterline. So the length of waterline was the crucial date needed.
There exist diverse ways to obtain the power that we need in the propeller of the boat to reach the wished speed relating the length of waterline with the displacement of the boat. The length of waterline was obtained by means of marking it on the hull with black and white targets which were easily recognized on the scans.
The displacement of the boat is related with the submerged volume of underbody (in this case it was 145 m^3) and with its form. These would be easily obtained by means of use of commercial package software Geomagic Studio 8.
The underbody point cloud is demonstrated in Fig. 8.

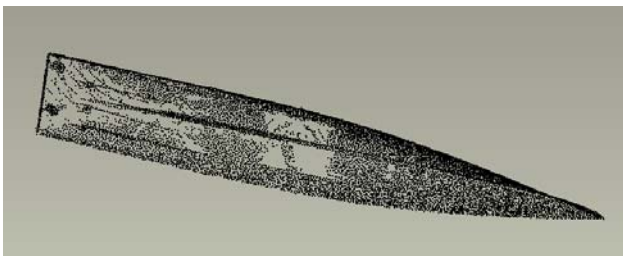

Figure 8. The form of the underbody of the ship (the point cloud)

Discussion. Our results were quite satisfactory because we obtained 6,8 mm of deviation of shape in the hull and 12,5 mm of deviation in shape in the deck case. Considering the size of the whole ship (about 40 m) the results obtained were really good. The residuals weren't so big so the stability of the laser scanner during the data acquisition was quite good.
The final results could be improved by previous calibration of the laser scanner.
Comparing the results of the whole boat with the results of the hull and the deck, which we obtained during the separate processing results of better values for the whole boat (we obtained 12,5 mm of deviation in shape for the whole model of the ship), but it can result little objective in this case because of different ways of pre – processing of the point clouds of the boat: separate handling and joint handling. The first one permits personal and separate processing of both parts of the boat and the second one requires applying of the same processing parameters to the hull and the deck what can provoke a loss of some information. Besides it's easier to work with separate parts of the boat because the point clouds contain less points and it facilitates the 3D modelling.

6. CONCLUSIONS

Nowadays, three-dimensional models can be rapidly and effectively created using laser scanning techniques, which can measure millions of points in a matter of minutes with millimetre-level precision. Moreover, they avoid the error propagation that is typical of classical topographic methods. Specific software is used to process the point clouds and to develop the final 3D surface models.
Although these techniques offer the potential for improving the working methods currently employed in most companies in the sector, they have some drawbacks. The two major disadvantages are: the cost of the equipment and the highly specialised, laborious and lengthy data processing work required to develop the 3D models. Nevertheless, it is likely that equipment costs fall, and the data processing and 3D model creation become less complex in the future.

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