Technical Paper

Trend of 3D Measurement Technology and Its Application

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Recently, 3D measurement technology has been used and applied more and more throughout the industry, and we, Komatsu Ltd., have begun its aggressive application, as well. The 3D measurement technology, which is a powerful tool for the "visualization" of the current situation and can "link" a sequence of processes, will play an important role for process improvement. This paper describes the outline (principle and use) of the 3D measurement technology as well as the actual application examples.

Key Words: *3D measurement, visualization, linkage, yield improvement, quality improvement*

1. Introduction

There is a Komatsu's own "linkage" concept in the background of Komatsu's application of 3D measurement technology. This concept is to link in real-time using ICT all the processes from production to sales aiming at the improvement of the relations of the processes. Here, the schematic view of the "linkage" of production is shown in **Fig. 1**. While previously we focused on the activities to improve each individual process, these days we are working on process improvement that could not be realized in the past by linking a sequence of processes based on the data acquired through 3D measurement.

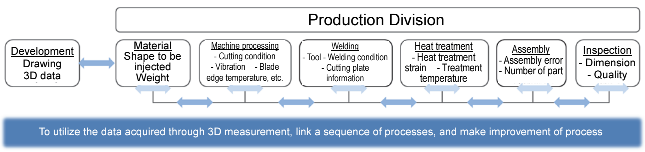


Fig. 1 "Linkage" in Production Process

2. Outline of 3D measurement technology

2.1 Survey on 3D measurement equipment in market

Recently a variety of 3D measurement equipment is put on the market so that the selection of the equipment you choose from depending on your needs becomes wider. We, therefore, first surveyed and set in order the 3D measurement equipment available in the market. The survey result is shown in **Fig. 2**.

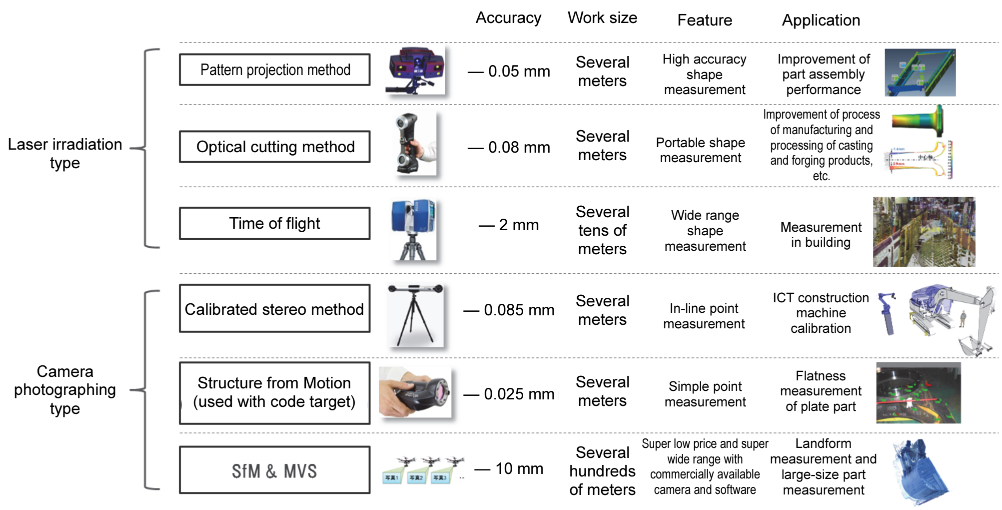


Fig. 2 A Variety of 3D Measurement Technologies
(Each photograph is cited from a Web page.)

Based on the organized information we work on the activities of improvement by suggesting an appropriate measurement equipment for the improvement needs in the company. Furthermore, organizing a liaison conference about test and measurement on a company-wide level helps share the information on the newest technology and the improvement activities of the other factories, and drive the process improvement through 3D measurement technology on a company-wide level.

2.2 3D measurement technology in use

Next, we describe the 3D measurement technologies Komatsu has introduced and is currently using.

2.2.1 Pattern projection method

A pattern projection method is the method to restore a 3D shape by projecting a stripe pattern on a measurement target, taking pictures of the stripe shape from cameras at left and right, and manipulating the images (**Fig. 3**). This method has high accuracy of 0.05 mm/m level and can measure a wide area at a time, and so is utilized in many factories of Komatsu.

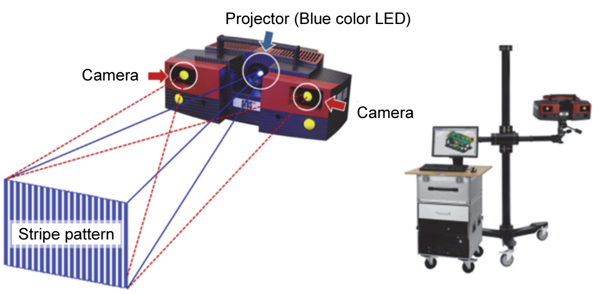


Fig. 3 Shape Measurement with Pattern Projection Method
(ATOS by GOM GmbH)

2.2.2 Optical cutting method

An optical cutting method is the method to restore a shape by irradiating a measurement target with line laser, taking pictures of reflected light with a camera, and manipulating the images. Although this method has long been used, Komatsu is using a more easy-to-use portable-type device. It is composed of a notebook PC and a light-weight chassis (1 kg or less), and the operation is very easy. First, more than one mark called positioning target is attached on or around the measurement target, and these are read with two cameras. This allows the position of the chassis to be automatically read. Then, 14 beams from line lasers are emitted, and the reflected light is captured by cameras to restore the 3D shape (**Fig. 4**).

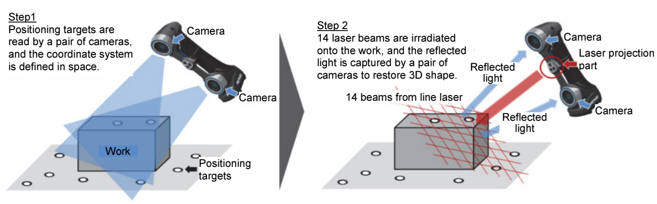


Fig. 4 Shape Measurement with Optical Cutting Method
(HandySCAN 3D by Creaform Inc.)

Since the processing is very fast, the shape irradiated with laser in the area can be restored almost in real-time. The operation is very easy-to-use, and therefore, this method starts being positively used in each factory as does the pattern projection method.

2.2.3 Structure from Motion and Multi-View Stereo

The technology to take more than one picture of a measurement target with a camera and calculate the camera position at the time of taking pictures using the characteristic points you can see in the images is called Structure from Motion (SfM). The characteristic points are three-dimensionally restored when the camera positions are calculated, however, these points are so sparse that the dense points can be restored only by applying the method called Multi-View Stereo (MVS) after the SfM. **Fig. 5** shows the example in which the construction machine is three-dimensionally restored using SfM and MVS. This method can be used as long as you have a commercially available camera and software. The accuracy is around some mm to cm, however, this method has been used whenever you would like to readily record 3D shapes because the 3D shapes can be restored as long as you have a commercially available camera and software.

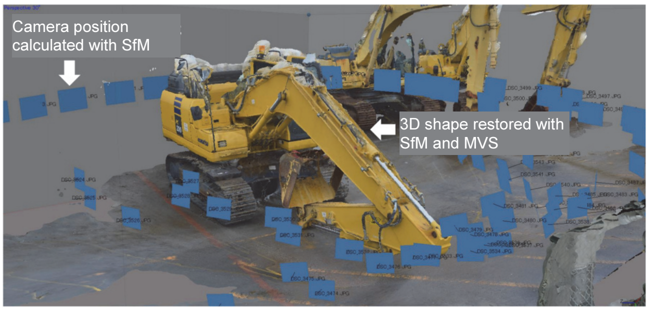


Fig. 5 Shape Measurement by SfM & MVS (PhotoScan by Agisoft LLC)

2.2.4 Structure from Motion (used with code target)

While the accuracy of the normal SfM is not so high as shown in **2.2.3**, a high accuracy (0.02 mm level) measurement will be possible as shown in **Fig. 6** if code target and positioning target are used together. How it has been used in Komatsu will be shown later.

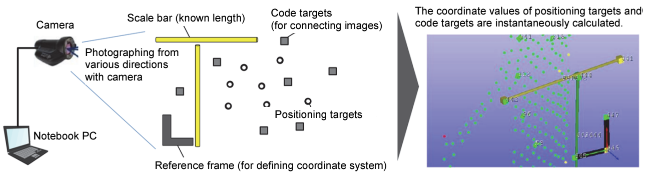


Fig. 6 SfM Used with Target (MaxSHOT 3D by Creaform Inc.)

3. Example of improvement using 3D measurement

Komatsu is working on various types of process improvement using 3D measurement technology which was shown in **2.** The process improvement using 3D measurement proceeds as shown in **Fig. 7** in the flow of the process improvement: (1) Capture of shape using 3D measurement, (2) Analysis of the difference from target shape (visualization), and (3) Difference analysis result. Many cases of process improvements can be conducted because of the simple flow and wide application range.

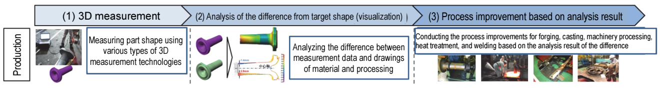


Fig. 7 Flow of Process Improvement Using 3D Measurement Technology

3.1 Process improvement of production of casting and forging material part

First, the process improvement of production of casting and forging material part is described. The target of the improvement is mainly the following three (**Fig. 8**): (1) Improvement of design, (2) Improvement of material manufacturing, and (3) Improvement of processing. The improvement of design aims at functionality improvement and productive efficiency improvement (such as no machine processing), and the improvement of material manufacturing and the improvement of processing aims at the reduction of machine allowance and air-cut, etc.

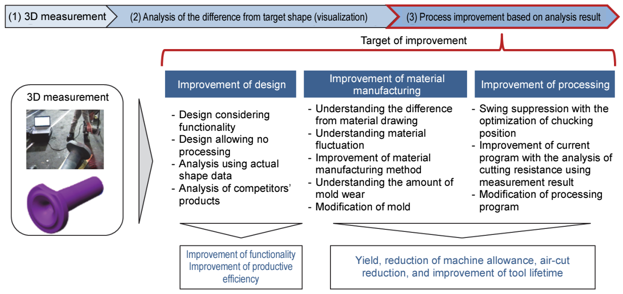


Fig. 8 Target of Casting and Forging Material Part Improvement Using 3D Measurement

The detail is described citing an example of the footing section part (forging part) of construction machine shown in **Fig. 9**. First, the part shape after forged was captured using a portable-type 3D measurement equipment introduced in **2.2.2** (leftmost in **Fig. 10**). Next, the difference between the measurement result and material drawing was analyzed using test software. As a result, it was found that a uniform bend occurred from the middle of the part to the edge (middle in **Fig. 10**).

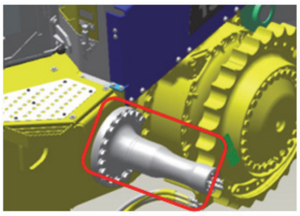


Fig. 9 Footing Section Part

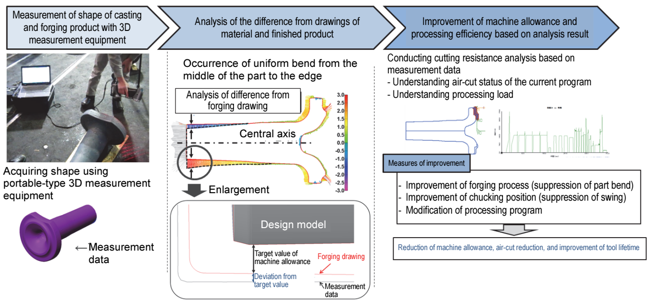


Fig. 10 Improvement Using 3D Measurement of Footing Section Part

Then, the forging process and its related processes were examined (**Fig. 11**), the cause of the part bend was identified. Correcting the identified cause could reduce the part bend (**Fig. 12**) and lower machine allowance of the forging. This increased the yield by around 10% compared to the currently used products.

Fig. 11 Process After Forging

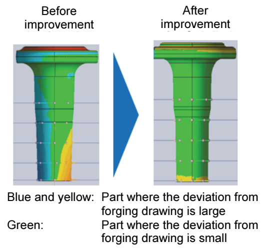


Fig. 12 Improvement Result of Part Bend

The revision of the processing program in addition to the reduction of the machine allowance could shorten the processing time.

The above improvement was conducted based on the off-line measurement result. After this, we aims at the formulation of the highly in-line performance system by making measurement in the processing machine and making correction of the chucking position and the processing program based on the measurement result.

3.2 Quality improvement of part by the improvement of welding process

The 3D measurement technology enables the improvement of the quality of construction machine part.

The detail is described citing the example of the part (seat) in the base carrier shown in **Fig. 13**.

Fig. 13 Seat Part

For the seat part shown in **Fig. 13**, the flatness is very important. Komatsu uses the 3D measurement technology as one of the methods to ensure the flatness. More than one process shown in **Fig. 14** is employed to assemble the seat into the base carrier, and we conducted the flatness measurement in the timing indicated in blue (total 5 times).

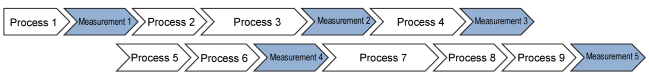


Fig. 14 Assembly Process of Seat Part

For the measurement, the SfM with target code which we described in **2.2.3** was used (**Fig. 15**).

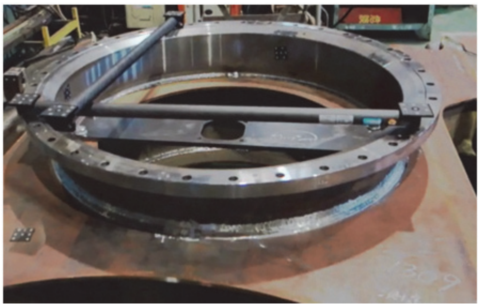


Fig. 15 Flatness Measurement with SfM with Target Code

The measurement result is shown in **Fig. 16** (blue). It was found that the flatness change from the measurement 1 to 2 was the largest. Hence, the process between the measurements 1 and 2 was modified (processes 2 and 3).

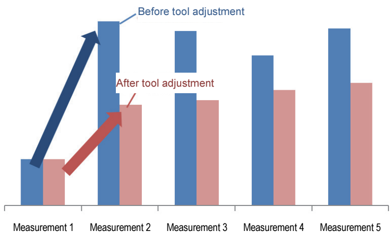


Fig. 16 Flatness Measurement Result of Seat Part

The processes 2 and 3 use a specific assembly tool, and so the 3D measurement of the tool position was carried out using the same method as the flatness measurement. Then based on the result, the tool position was readjusted into more appropriate position. This readjusting could suppress the torsion during the part assembly, and as a result, suppress the worsening of the flatness (**Fig. 16** (red)).

10. Conclusion

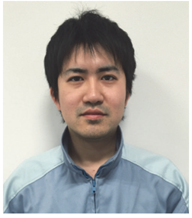
Two years have passed since we officially started the improvement using the 3D measurement, and the following is what we experienced through the improvement activities.

(1) The 3D measurement itself is relatively easy, however, the use of the software to process the measurement data requires experience, which prevents the 3D measurement from being widely used.

(2) The improvement using 3D measurement often covers more than one process, resulting in the requirement of the collaboration with other groups or departments more than ever.

(3) The development of the Komatsu's own measurement system utilizing the collaboration with vendors, industry, and academia enables differentiation from the other companies.

Introduction of the writers



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[A few words from writers]

Since the 3D measurement technology is an important tool which can trigger the Komatsu's production revolution, we would like to improve our production process with the collaboration with the other departments to this end. At the same time, to differentiate from the other competing companies we will work on the development of the Komatsu's own measurement system.