System improvements based on the operating experiences of automatic 3D measurement system

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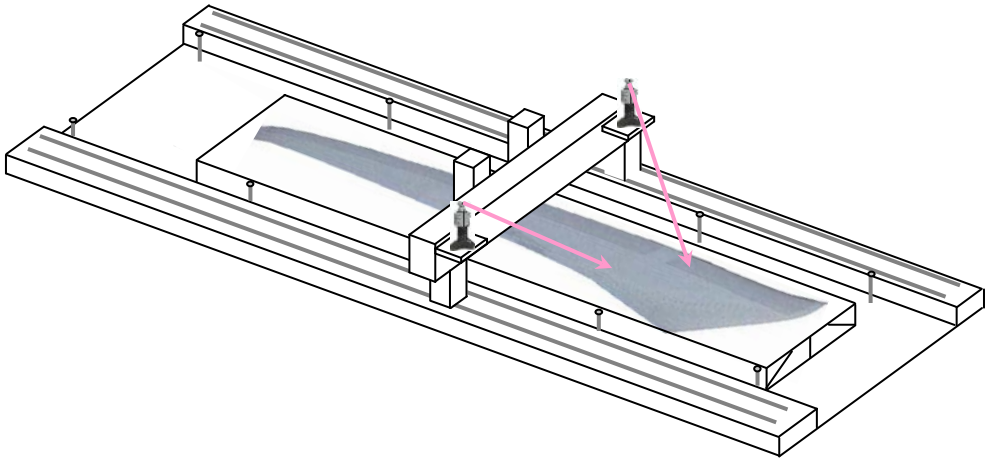


Header Image Automatic 3D measurement system

Abstract

Hitachi Engineering & Services (HES), with the collaboration of Nikon Metrology, Inc., developed the automatic 3D measurement system using the Laser Radar (LR), and started the operation in 2007.
This system was presented in the 24th CMSC (Charlotte city, July, 2008), and it was published in the CMSC journal next year[1], [2].
This system has been operating high-accuracy and high-efficient measurements since 2007. But in some cases, it had to rely on the manual operation to measure the edges which were important to measure the outer shape of the object.
The LR has functions to measure edges and outer shapes of the object by using the reflected laser from the surface of the object. However, it detected the false position depending on the particular surface conditions of the measurement object. Therefore, the improvement and strengthening the edge measurement function were planned.
1) Improved the edge measurement algorithm built in LR (Nikon Metrology Inc.)
2) Built up the systematic recovery function in case of the failure of the improved edge measurement algorithm (HES)
This enabled the high accuracy complicated outer shape measurement. From now, it is expected to expand the applicable fields of the 3D measurement system.

1. Nomenclature

- ATL: Automatic Target Locator
- CAD: Computer aided design
- CFRP: Carbon Fiber Reinforced Plastic
- EMR: Edge Measurement Recovery Function
- HES: Hitachi Engineering & Services
- LR: Laser Radar by Nikon Metrology
- PMR: PVI Measurement Recovery Function
- PVI: Plane Vector Intersection
- TB: Tooling ball, Grade25 0.25-in. diameter steel ball
- TBMR :TB Measurement Recovery Function

2. Introduction

HES with the collaboration of Nikon Metrology, developed the automatic measurement system aiming for improvement in productivity and labor-saving, and started the operation in 2007.

Figure 1 shows the general position of the measurement process in the production process. The surface measurement is performed to test the product work in the earlier process. The measurement process is the important position not only as the final inspection before handing it to the next process, but also as the judgment for the correctness of the process. The measured data are used for reprocessing if necessary. The feedback information for the performance improvement of the processing machine which is obtained by 3D measurement becomes important information to improve the production efficiency. Consequently, it generates a huge effect on the entire production process.

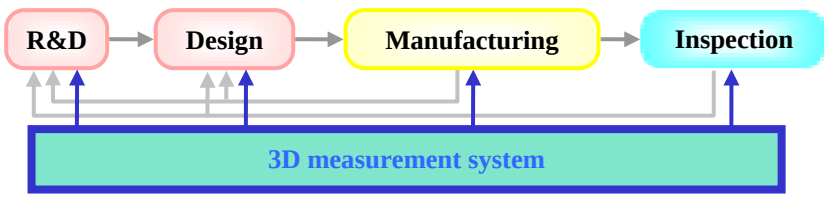


Figure 1 3D measurement in the production process

There are increasing demands on the automatic measurement in accordance with the extension of automation in production line. We designed this system to continue the automatic operation as much as possible. In addition, even when a part of each subsystem and the sub-process was not able to be operated normally, an automatic operation was designed as much as possible to continue. For instance, we had confirmed beforehand that in the case of the measurement failures with LR for some reasons, retry measuring the same position with the same parameters did also fail with high probabilities. So we did not equip the system with the re-measurement (retry) function at the same position with the same parameters, but equipped with various recovery functions in the system design phase.

Moreover, in order to inform the status of automatic measurement, it is equipped with the operation monitor screen with touch panel operation. Therefore, one-touch operation is realized by normal operator without high measurement skill. It is described below how this 3D automatic measurement system improved based on the operating experiences focused on the edge measurement recovery function.

3. Operating Experiences of the system

3.1 Recovery function

The main recovery functions to adopt with this system are shown below.

(A)Systematic recovery function

- ATL(Automatic Target Locator)
- PMR(Plane vector intersection Measurement Recovery Function)
- EMR(Edge Measurement Recovery Function)

(B)Recovery function of LR

- TBMR(Tooling Ball Measurement Recovery Function)

ATL is the automatic detect function applying the image recognition technique which is used in the case of measurement failure of the common point. An image recognition device detects a striped ring line using pattern matching algorithm and calculates quantity of deviation from the laser direction of the LR (shown in figure 2).

Figure 2
Automatic Target Locator

Next, the PMR and the EMR are the recovery functions corresponding to the PIV measurement and the edge measurement. When the measurement fails at P0 in figure 3, the nearby point (P1, 2, 3, 4 in this order) is measured. And the measured data is returned if the measurement succeeds. These functions are used by the assumption that the

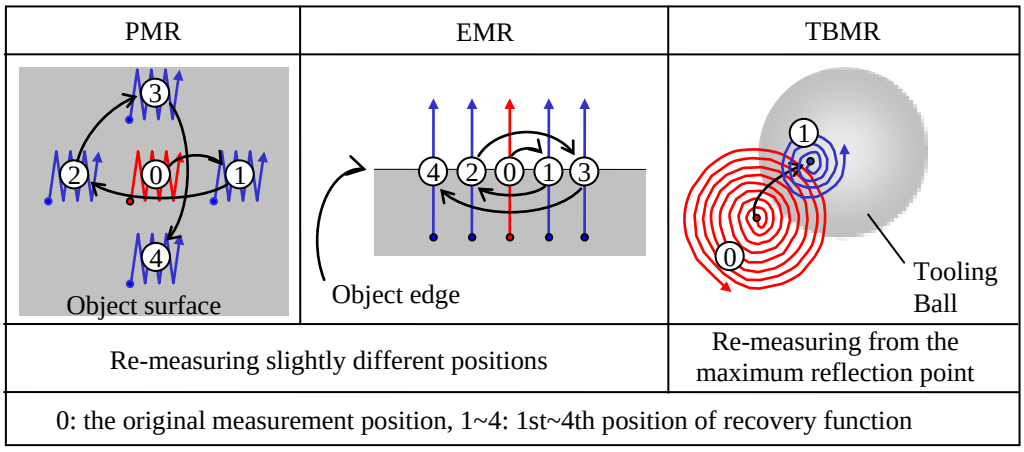


Figure 3 PMR, EMR, TBMR

measured data of the nearby point which is not equal to the original measurement position could be adopted for the inspection.

And, the TBMR is a recovery function for the TB measurement. This is the function which is used if the spiral search of the TB measurement does not find the candidate of the TB center. It makes LR to start next spiral search at the position which gives the maximum reflection power during the previous spiral search.

3.2 The operational status of the system

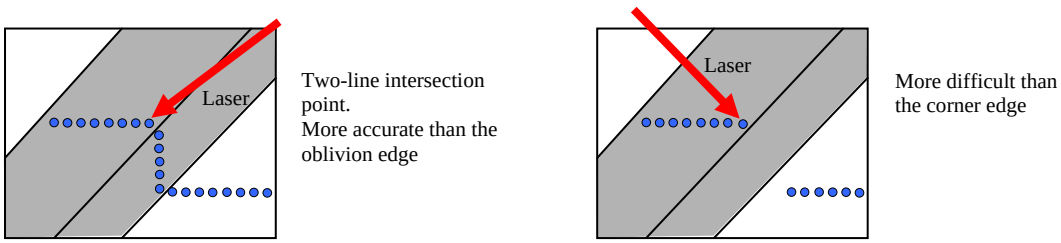
This system has been operating smoothly since the operation start in 2007, and the total operating time would be approximately 30,000 hours at the time of June 2010.
Figure 4 shows the number of measurement points of each measurement mode, the number of points measured successfully at the first time, the number of measured points required recovery function and the used recovery mode. Although there were 2-4% of measurement failures in PVI, TB and Common Point measurements, the re-measurement succeeded by the equipped recovery functions. Among the 150 points of the edge measurement, 19 points were failed. And four points in them were occurred because of the low confidence value but recovery measurements were succeeded by the EMR function. But other 15 edge measured points were out of tolerance even though the confidence values were above the threshold. So it had to rely on the manual operation to re-measure. These data analyzed from the log data show that the recovery functions equipped in this automatic measurement system covered approximately 80 percent of measurement failures. The 15 edge measurement points were confirmed within tolerance by detailed measurement of manual operation. It seemed that this was caused by the false measurement of the edge detection in LR.
It takes too much time to re-measure manually and at that time the measurement specialist is needed. Therefore the improvement of this function was required, and we investigated the issue of the edge measurement of LR.

Measurement Mode	Number of Measurement	Points passed at the first try	Points needed the recovery function	Recovery mode	Results
PVI	1373	1330 (97%)	43 (3%)	PMR	Success
TB	599	587 (98%)	12 (2%)	TBMR	Success
Common Point (TB)	194	187 (96%)	7 (4%)	ATL	Success
Edge	150	131 (87%)	4 (3%) Low Confidence value	EMR	Success
			15 (10%) (Deviation error)	-	Re-measure (by hand)
Scan	751	751 (100%)	0 (0%)	-	-
(Total)	3067	2986(97%)	81 (3%)	-	-

Figure 4 Results of one measurement (analyzed by Log Data)

3.3 Edge measurement of automatic 3D measurement system

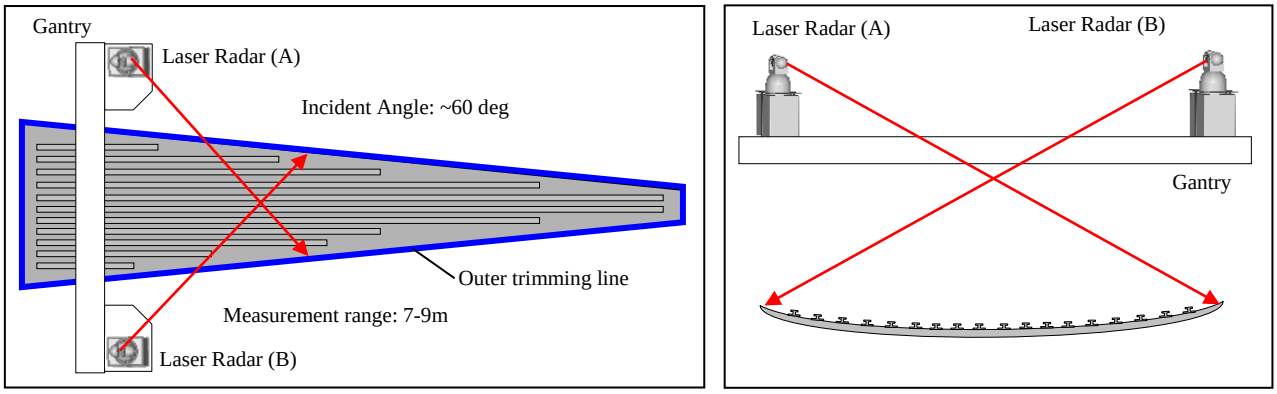
(1) The edge measurement using the LR
There are mainly two types of edge measurement using the LR as shown in figure 5. One is corner edge, that is the case LR can measure both sides of the edge, and another is the oblivion edge, that is the case LR can measure only one side of the edge. The corner edge is inherently more accurate and stable than the oblivion edge. The details of the edge measurement using the LR are described in Chapter 4.



(a) Corner Edge (b) Oblivion Edge

Figure 5 Two types of edge algorithm by the LR

(2) Edge measurement of the outer line
In this 3D automatic measurement system, the outer line edge measurement is required to inspect the results of the trimming process. The difficulty of the oblivion edge compared to the corner edge was known at the time of system design. But to measure all the outer lines by the corner edge is not possible because of the incident angle requirement of LR and the positional relation between the object and the LR as shown in figure 6. Therefore many edge points at the outer line had to be measured by oblivion edges.



(a) Top View (b) Side View

Figure 6 Edge measurement of the outer line

(3) The issue of the oblivion edge
By looking the measured data which were out of tolerance, all the edge positions were measured internally compared to the CAD data as shown in figure 7.
The scan measurement data took by manual operation indicated that the cutting process had performed nearly to the CAD data and the oblivion edge measurement mode had the false positive. Nikon Metrology and HES analyzed these data and investigated the improvement of the edge measurement function.

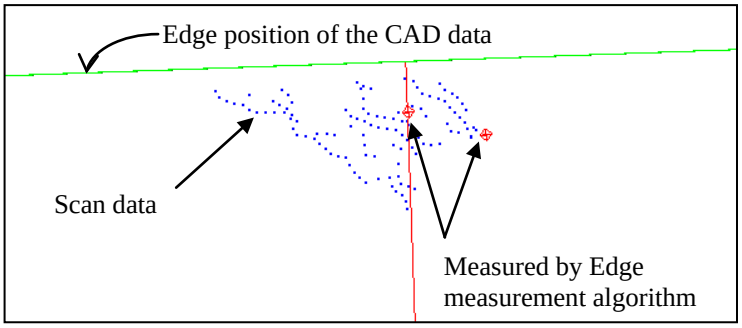


Figure 7 Edge measured internally

4. Improvement of Edge measurement using the LR

4.1 Principle of Edge Measurements using the LR

Due to the non-contact fully automated nature of the Nikon Metrology LR, measuring features such as edges is possible in an automatic measurement system. Nikon Metrology has developed advanced edge detection algorithms for measuring edges using complicated filtering and processing techniques. The edge algorithm main process is described below.

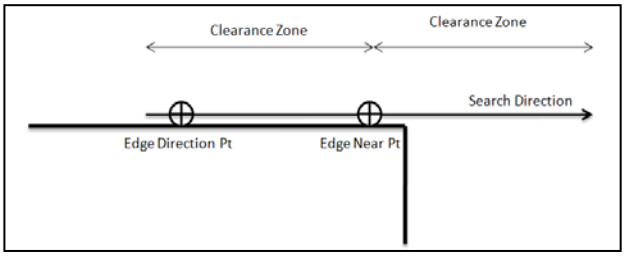


Figure 8 Input data for the edge algorithm

The LR measures edges by performing a scan of the edge of interest. Two points are required as input for the edge algorithm to perform a scan on the edge area to measure, Edge Near Pt and Edge Direction Pt. These two points will determine the scan start point as well as the scan direction as shown in figure 8.

The Clearance Zone and the Edge near point will determine how big the scan will be. The Edge direction point will determine the direction of the scan. The direction of the scan will be in the direction of a vector passing through edge direction point towards edge near point as shown in figure 8. The distance of the scan will be twice the clearance zone having the edge near point as the midpoint.

After a scan of the edge is performed, the edge algorithm will determine what type of edge is being measured. There are two types of edges, Corner Edges, and Oblivion Edges. For a Corner Edge measurement, a set of conditions need to be met. First the data needs to be split into three sections, Edge On points, Edge Off points and Wall points as shown in figure 9. If there is sufficient Wall Pts, and all the corner edge conditions are met (incident angles and point density), a line-line intersection is performed on the line fit to Edge On data and the line fit to Wall Pt data and the intersection point will be a Corner Edge measurement.

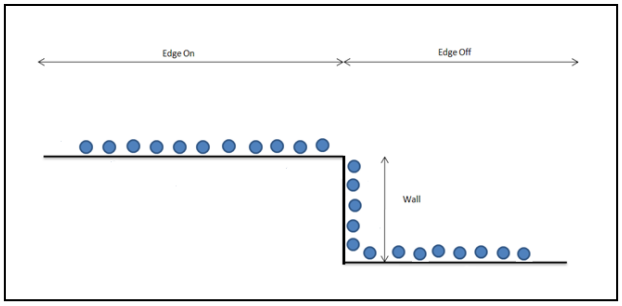


Figure 9 Corner Edge measurement

If the algorithm couldn't determine any sufficient Wall Pts and the Corner edge conditions weren't met in the initially scanned data, a corner edge measurement is not possible, and the algorithm will trigger an Oblivion edge measurement. A new refined scan will be performed on the edge of interest using the initial scan data for the refine scan setup. Since no Wall Pts were determined by the algorithm, the data was categorized as either Edge On points or Edge off points. A line is fitted to the Edge On first and last point. This line is then intersected with a line created by first Edge Off point and the scanner origin as shown in figure 10. The new refine scan length and direction will be then determined by the last valid Edge On point and the intersection point as shown in figure 10.
This process can be repeated (default is up to 5 times) till the last point on Edge On tolerance is met. The tolerance requirement is set by the user and can range from 0.5mm (for fast low accuracy edge measurements) to 0.1mm (for high accuracy edge measurements).

4.2 Difficulty of Edge Measurements using the LR

Because the LR is a non contact measuring device, it has two major difficulties that it has to overcome, the first is the line of sight, the second is the interaction of the beam with the material measured. The LR can measure only what it sees. Unfortunately always seeing the two sides of an edge for a Corner Edge measurement is not possible. So the majority of the edges measured are Oblivion edges. Due to the interaction of the infrared beam with the material surface being measured, the range data can be noisy due to different reasons such as speckle and reflectivity which both can return low quality range measurements for a LR. These two limiting factors combined can make determining an oblivion edge difficult, and makes measuring an edge sensitive and prone to false positives. Figure 11 shows a 2-D sample of a raw Oblivion edge scan data. The data clearly shows that there is only one side of an edge visible, and also shows how noisy the range data (y-axis) can be. Because it's an Oblivion Edge, the data will be split into Edge On and Edge Off data. This is initially done by performing a filter based on the signal quality and spread of the max and min quality in the data. Figure 12 shows the Edge On data candidates in red, and shows that clearly a noisy point on the edge surface was determined by the algorithm to be a valid Edge On point candidate.

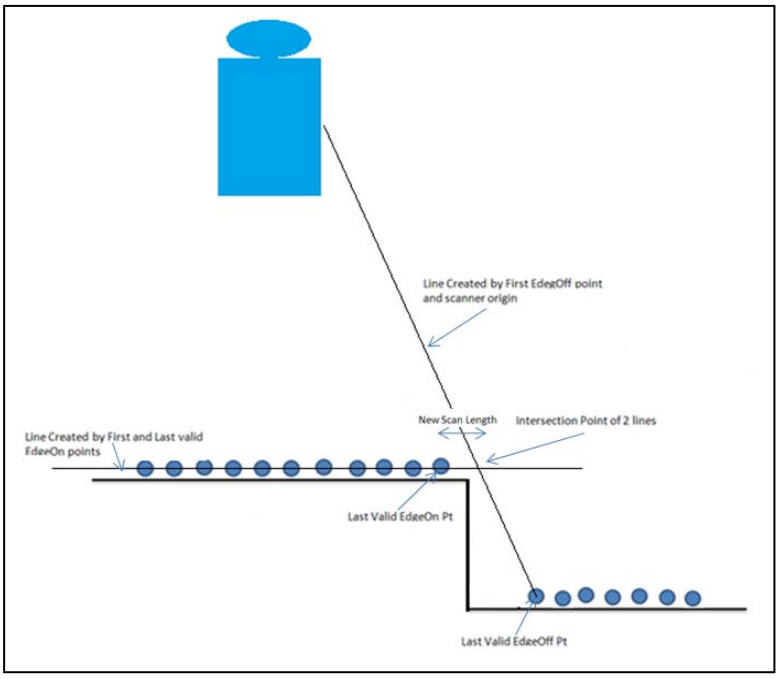


Figure 10 Oblivion Edge measurement

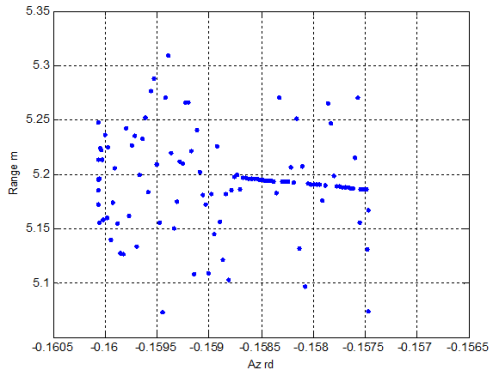


Figure 11 Raw Oblivion edge scan data

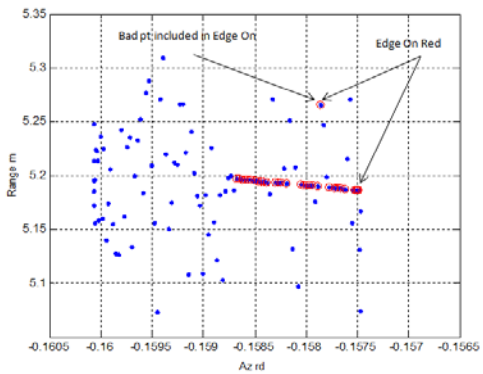


Figure 12 Edge On data candidates

After the quality filter was performed, a filter to refine the Edge On data near the edge will be performed to determine if any points on Edge On are Edge Off points. So starting with the last valid Edge On point, a line fit is performed and the line fit RMS is recorded and the number of points that are within the tolerance to the line fit is recorded. The last point is then dropped and another line fit is performed and the number of point that are within the tolerance to the line fit are recorded. This process is done on all Edge On data. Finally, only the data that had the highest number of points within tolerance to the line fit are kept as Edge On points. Clearly, because the initial Edge On data had a bad outlier, that caused the best line fit candidate to be on the right side of the data as shown in figure 13. This caused Edge On data to be split in the wrong location, and falsely declaring Edge On data to be Edge Off data. The fine scan was also performed on the wrong location as shown in figure 13. This outlier caused the algorithm to return a falsely measured edge as shown in figure 14.

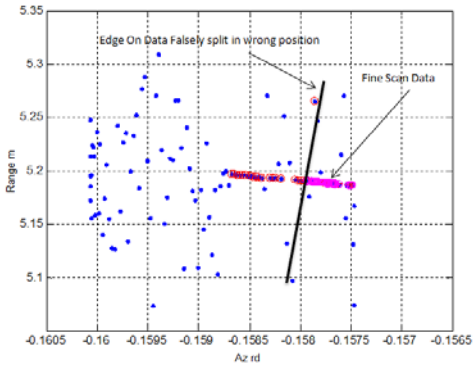


Figure 13 Falsely split Edge On Data

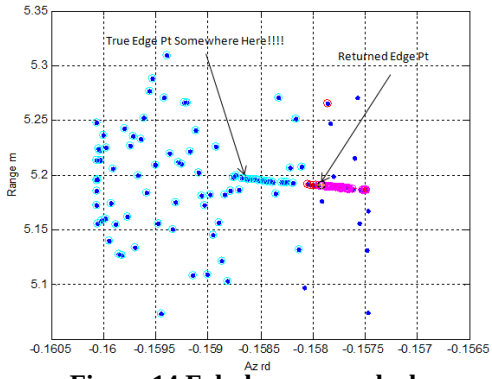


Figure 14 Falsely measured edge

4.3 Improvement to the Edge Measurements

Clearly as seen from figure 14, a single outlier in the Edge On data can cause a false positive edge measurement that can be in the millimeters and disturb the whole automated process. The algorithm had to be modified to make sure there are no outliers before attempting to split the data using a line fit filtering technique. A new geometrical filter based on neighboring points was implemented and applied to the data after a quality filter is performed. This insured that no outliers remain in the data before we attempt to split the Edge On data. Figure 15 shows the improvements and shows that the Edge On data was split correctly.

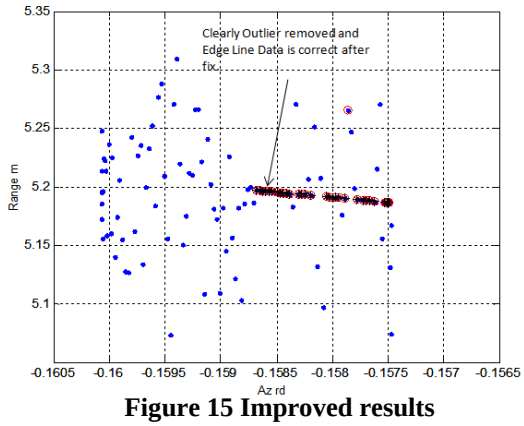


Figure 15 Improved results

5. Enhanced Edge Measurement Recovery Function

5.1 Test results of the new edge measurement algorithm using the LR

For the confirmation of the improved edge measurement function of the LR, we carried out a measurement examination using the sample which was same as the CFRP used in the object. Figure 16 is a picture of the measurement sample which we used. The CFRP surface of this sample has four types of conditions. To examine the influence on measurement by the difference of the surface conditions, we evaluated the data of each different surface type.

We measured the sample under the condition of the measurement range 7m and the incident angle 60 degrees considering the measurement conditions of the automatic 3D measurement system.

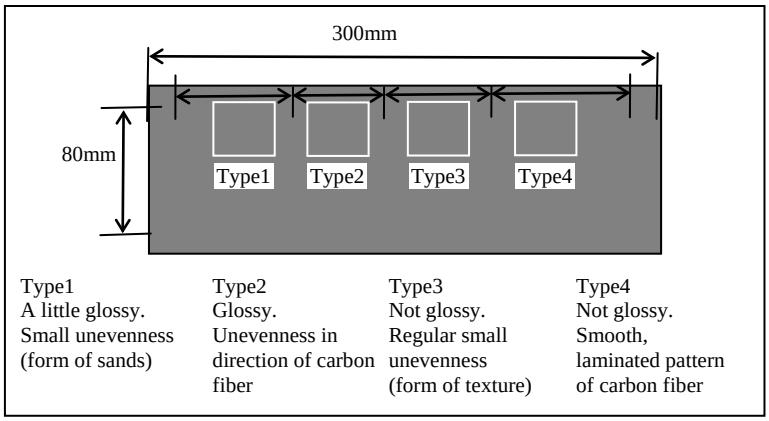


Figure 16 A picture of the CFRP sample

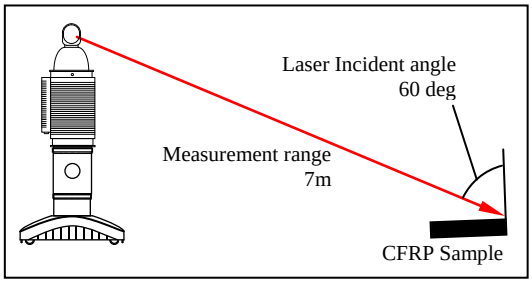


Figure 17 CFRP sample measurement conditions

In the case of using conventional edge measurement algorithm (Conventional EA) and new edge measurement algorithm (New EA), measurement failure rate, maximum deviation to the nominal data and standard deviation are shown in figure 18 for each surface type1, 2, 3, and 4. Here, the measurement failure rate is as follows.

Measurement failure rate=Number of the measured points with low confidence/Number of all measured points

The nominal data was made from the result of measuring in detail using a scan measurement mode, under the condition to be able to measure the both sides of the edge.

(Q: quality threshold)

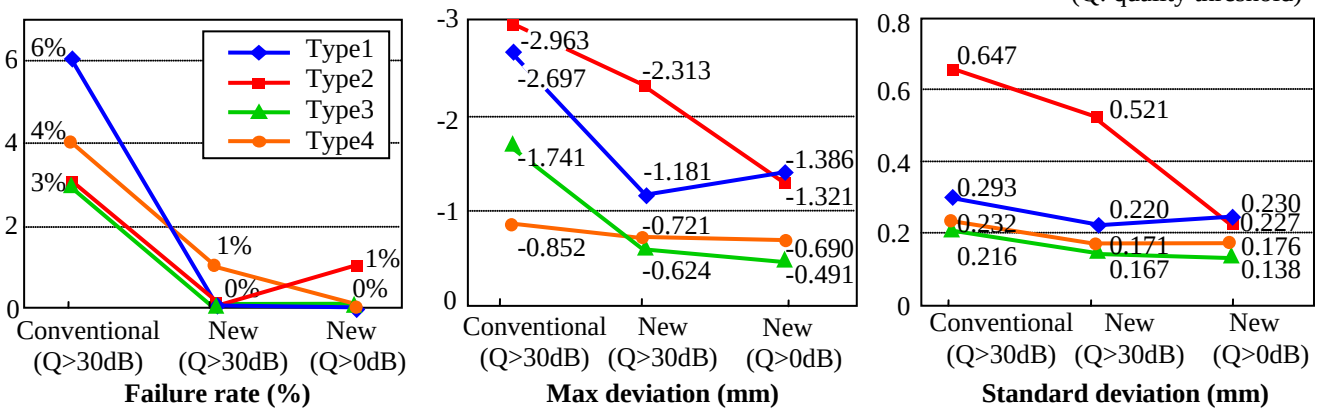


Figure 18 Test results of Conventional/New EA

In the case of using Conventional EA, measurement failure rate is 3-6% by the differences of the surface conditions. In the case of using New EA, the large reduction of the measurement failure rate is realized. In addition, the threshold of laser reflection intensity (quality) that was one of the setting parameters of the edge measurement algorithm was set to 0dB in new EA.

The line fit filtering has been improved by new EA. As a result, the new EA would work properly even if the quality threshold is set to 0dB without deleting valid data which have the quality values up to 30dB. Actually, when the threshold was set to 0dB, a great improvement was achieved especially in Type2 compared with the case when the threshold was set to 30dB.

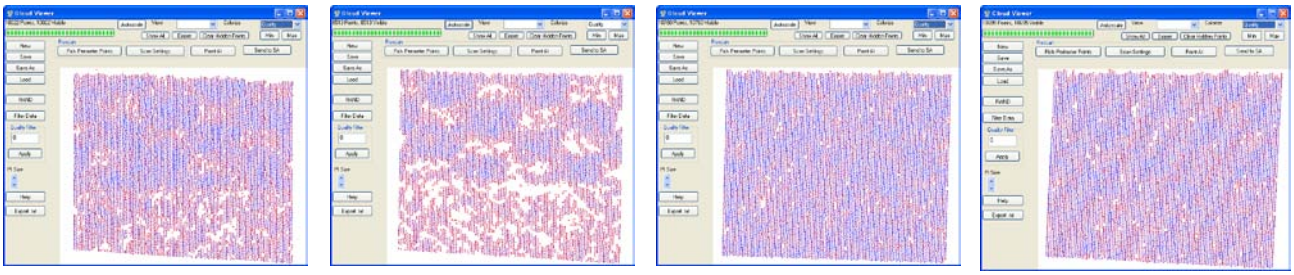
In the case of using New EA, the maximum deviation and the standard deviation were improved for all surface types compared to the Conventional EA. However, in Type1 and Type2, it still occurs the maximum deviations exceed 1mm. In this situation, re-measurements by manual operation are necessary in the actual measurement.

5.2 The evaluation of the influence of the surface conditions on the LR measurement

To investigate the cause of the above mentioned phenomena in chapter 5.1, we carried out detailed scan measurement using the LR for each different part of the surface. Figure 19 shows the result that measured the area of 10mm x 10mm of the near edge by scan measurement mode with detailed point distance of 0.1mm x 0.1mm about each different part of the surface type. We set the threshold value of the laser reflection intensity as 0dB which means all the measured points are shown. The edge of the sample is at the upper part of each figure.

The blue points show maximum quality measured points, and the red points show minimum quality measured points.

In these figures, it seems that there are no data in the white areas. It is because the measured points are noisy in these areas.



Type1 Type2 Type3 Type4

Figure 19 Scan measurement data

From figure 19, the influences of surface conditions on the measurement results are listed below.

(1) The thickness of the epoxy layer of the CFRP and influence of distortion:

The most number of data are reduced in Type2 which is the most glossy. And the second is Type1 which has the next glossy surface. The number of data reduction in Type3 and Type4 which have no epoxy layer decrease clearly in comparison with Type1 and Type2. From this, it is estimated that there is an association between the glossiness of the surface (a difference of the laser reflectivity based on the adherent epoxy layer of the surface) and the number of data reduction points.

(2) The influence of the surface asperity:
When the surface has the asperity, an incident angle of the LR laser changes depend on the position and then the intensity of the reflected laser changes, that causes the data reduction. In particular, in the upper part of Type2, there are many areas where cannot be measured by the LR. It seems that these areas correspond to the carbon fiber laminated direction. In the lower part of Type2, it is also observed that there are many areas where cannot be measured. It seems that these areas are corresponding to the irregular surface asperity. From the measurement result of Type1, we can also observe the measurement result that is considered to correspond to the change of the surface asperity.
(3) The influence of the weaving direction in the carbon fiber:
In the test results of the Type4 which has no epoxy layer, the regularity of the laser reflection intensity is corresponding to the weaving direction in the carbon fiber. It is supposed that there are areas where the intensity of the reflected laser decreases depending on the weaving direction. Because we can see the difference of the reflectivity of the visible light depending on it.
From the above, it is thought that measurement possibility using the LR is influenced by the difference of the surface conditions of the measurement object. In the case there is the area where cannot be measured by the LR near the edge and try to detect the edge position here, the LR detects false edge position internally which reflects sufficient laser power. Figure 20 shows the results of the detailed scan measurement and the results of the New EA. Certainly, the New EA detected internally at the position where the LR cannot measure by the scan mode.

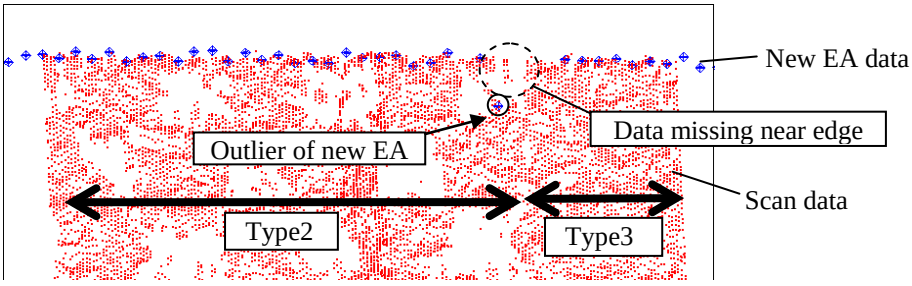


Figure 20 Vision scan data and new EA data

The countermeasure of this issue is difficult in the current edge detection method of the LR. So, we examined the systematic recovery function of the edge measurement.

5.3 Development of the enhanced edge measurement recovery function

From the scan measurement results of figure 19, there is little chance that the area where cannot be measured by the LR is spread across a wide area along the edge. These areas depend on the weaving direction which have approximately 2mm width at the maximum. Therefore it is effective to change the measurement position when the first measurement would fail. The measurement object is manufactured by the automatic processing machines based on the CAD data. So we considered to use the deviation between the CAD data and the measurement data as one of the judgment conditions of the recovery function.
Hereinafter, the developed Enhanced EMR (E-EMR) is described. Figure 21 shows the basic flow chart of the E-EMR.

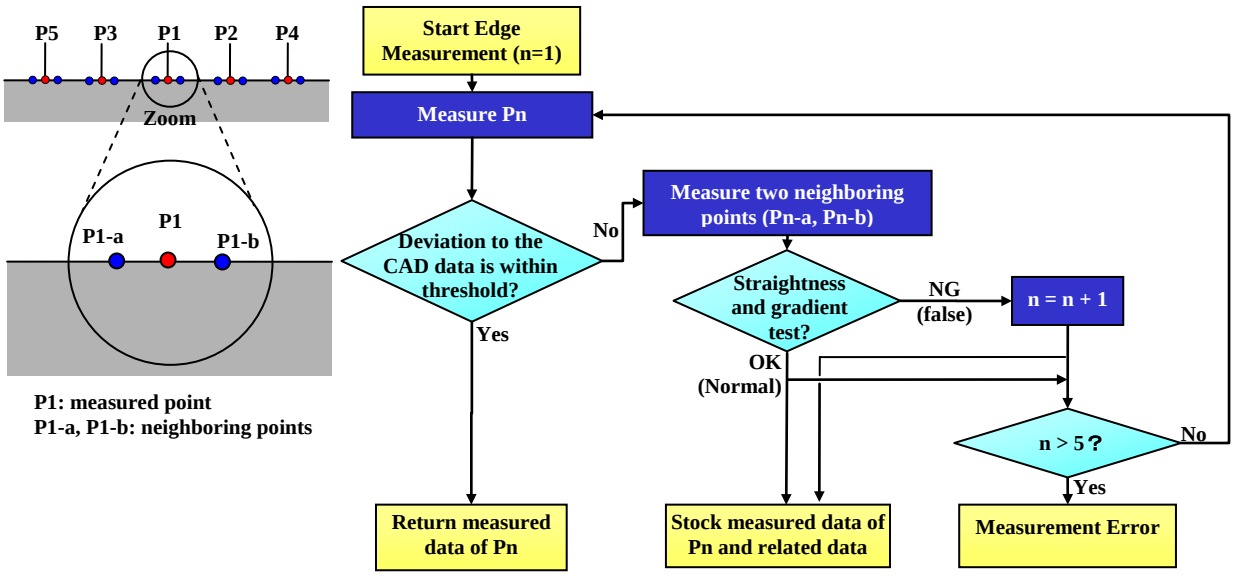


Figure 21 Flowchart of the E-EMR

The judgment conditions of the E-EMR are listed below.

(1) The threshold of the deviation to the CAD data is decided in consideration of production tolerance. When the deviation is out of the threshold, there is the possibility of the false measurement.

(2) When the deviation is out of the threshold in (1), two neighboring points (P1-a, P1-b) would be measured. The distance between a measured P1 and a line constructed from two measured points P1-a and P1-b is calculated to check the straightness of the measured data. The gradient angle is also calculated between a line from two measured points P1-a and P1-b and a line of the CAD data in the corresponding position. These calculated values are used for testing the measured result of P1. If both of these values are within the threshold, the measurement result of P1 is judged to be normal. And then to find a point which would be within the threshold, re-measurement is performed changing the position to P2. The threshold values of the straightness and the gradient are decided in consideration of measurement accuracy.

(3) When the straightness or the gradient is out of the threshold in (2), the measurement result of P1 is judged to be false. Then P2 which is close to P1 is measured and tested in the same way as (1) and (2).

(4) The process is continued to measure P3, P4 and P5 in the same way. When all the measurement data are out of the threshold, the measurement error is returned.

(5) In addition, all measurement data and related data are used for phenomenon analysis and countermeasure examination by the measurement specialist.

In an edge measurement, it is thought that the possibility of the manual operation decreases by adding the E-EMR. Furthermore, when the point other than P1 is measured, it is showed and managed to be able to distinguish the data from the data which are measured without the recovery function.

5.4 The inspection result of the E-EMR

We carried out inspection of the E-EMR with a CFRP sample same as figure 16. Figure 22 shows the results. We set the threshold of the E-EMR in consideration of the measurement accuracy and the roughness of the sample edge. Here, the measurement error rate is as follows.

Error rate=Number of error points/Number of all measured points

Surface type	Max deviation(mm)	Standard deviation(mm)	Error rate (%)
Type1	-0.195	0.106	0
Type2	-0.187	0.095	0
Type3	-0.182	0.098	0
Type4	-0.181	0.106	0

Figure 22 Test results of the E-EMR

The Max deviation is less than 0.195mm, and the Standard deviation is 0.095 - 0.106mm which means these results are greatly improved compared to the figure 18. In addition, it is possible to eliminate the manual operation as the results of the measurement error rate were 0% in all the surface types. We think that the basic effect of the E-EMR has been confirmed by evaluation. We will reflect it in this automatic 3D measurement system and confirm the effectiveness more in future.

6. Effect of automation and recovery functions strengthening of measurement system

Figure 23 shows an effect of the automation in this 3D measurement system.

The total time can be decreased to about 1/20 or less by automating the measurement and the analysis compared with the case to execute all measurements by manual operation. Because various recovery functions were installed in the current measurement system, a measurement and analytical time were able to be shortened below the half or more. It is thought that a manual measurement can be reduced to zero by executing the improvement related to this edge measurement. Thus, because a measurement and analytical time of further about 20% or more can be shortened, the improvement of a further productive efficiency can be expected.

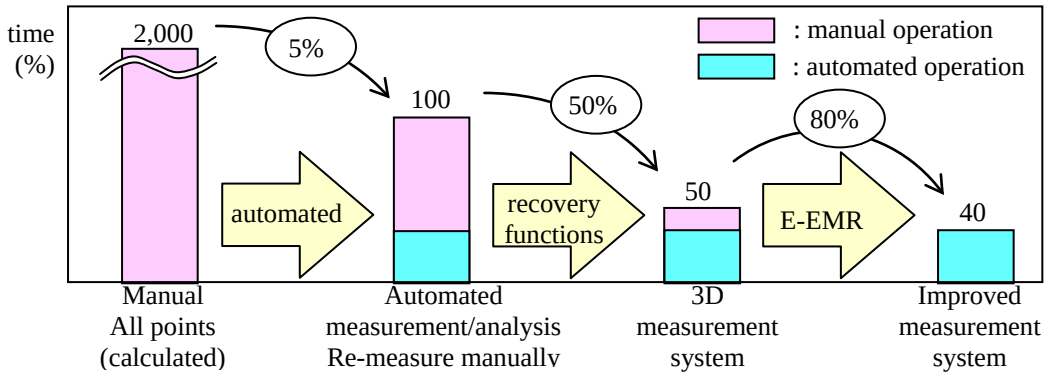


Figure 23 Effect of automation and recovery functions strengthening of measurement system

7. Application in other fields

The possibilities have increased to apply the 3D automatic measurement system to other fields by the operation experiences of this system and the various improvements as the edge measurement. The applications to other fields are outlined below.
(1)Measurement of plank large steel boards
Many jigs and a superior technique are essential to process the large size plank steel board used for the ship-building and the automobile production to fit the complicated curved CAD surface.
However, the attempt of making data in the work process starts because of the labor saving and the automation of the productive process.
The E-EMR improved this time is expected to have a big effect in the outer line shape measurement of the large size plank steel board.
(2)Processing instruction of various piping (cutting and bend, etc.) and dimensional inspections
In the process of manufacturing and the processing of the piping of the various shape used in a variety of plants, the automated dimensional inspection and the marking indicate system by the LR have already been introduced, and it is operating with stability. Previously, it took much time to do the measurement work for more than one expert worker using the gauges. After the LR system is introduced, a one-man operation becomes possible by directing the position where piping is processed by using the highly accurate pointing function by the laser of the LR, highly accurate work is achieved, and great rationalization is achieved.

8. Conclusion

This automatic 3D measurement system has been operating smoothly since the start of operation. The automatic measurement is continued in almost all cases of the measurement failures by the automatic recovery functions. However, approximately 10 percent of the edge measurement points are forced to depend on the manual measurement because the deviation to the CAD model is out of the tolerance even though the cutting is processed correctly. Therefore we improved the edge measurement algorithm of the LR, and confirmed the improved performance. In addition, the systematic edge measurement recovery function was improved and raised the probabilities to reduce the manual measurement of the edges drastically.
We will confirm to embedded the developed function to the system and establish the effectiveness. And we are trying to continue developing the automatic 3D measurement technologies to expand the applicable fields of the 3D measurement system. In recent years, the 3D measurement is automated and embedded effectively in the production system. So the 3D measurement equipment becomes more important as it plays a huge roll in the production process. It is expected that the linkage between the 3D CAD system and the automatic processing machine and the automatic assemble machine would be getting more adjacent. And the importance of the 3D measurement data would be increase aiming to avoid the risk of the low quality product and to make the investigation easy to determine the cause of the unexpected defect.
We intend to contribute willingly to promote the streamlining and improve product quality of design, manufacture, assemble, inspection processes by applying effectively our 3D measurement technologies to the automated production process obtained during the development, operating, improving of this automatic 3D measurement system.

9. References

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