3d Digitization of Ship Propeller Blade

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ABSTRACT: Reverse engineering is used in industry to create geometric models from an existing physical part. The reverse designing technique develops new products based on the improvement of existing products. The shape recovery of 3D objects is the basis of reverse product design.

The present analysis is a 3D data acquisition with advanced CCD sensor technology and projection systems with higher precision. Using triangulation technique and laser line scanning of the surface of an object, it is possible to reconstruct a highly accurate digital representation of the visible surfaces of a part.

Once a physical part is accurately digitized, finite element analysis can also be performed on actual part geometries to verify whether the part will function as designed. It also helps in complete and comprehensive studies of damaged parts.

I.   INTRODUCTION

Reverse engineering is the science of taking the existing physical model and reproducing its surface geometry in 3D data file on a CAD system. It is a process of analyzing a technology to ascertain how it was designed or how it operates.

RE enables the reconstruction of an object by capturing the components physical dimensions and geometrical features. It is the reverse product design approach. RE also enables the designer to simulate design ideas that occur during the design of the original product.

Objectives of the present work are:
- ❖ To look into the advantages and applications of 3D laser scanner.
- ❖ Performance evolution of hardware and software in the process of reverse engineering.
- ❖ Calibrating RE process through a known object.
- ❖ Applying digitizing strategy to reconstruct a 3D design from physical model of a ship propeller.
- ❖ To obtain a model of an object of complex geometry rapidly with high accuracy and minimal deviation comparative analysis done between built part and design part.

R.E. Process: This process involves digitization and collection of coordinates of every point of contact of probe with the part surface. This is called the point cloud data of the part / product. The point cloud data can be collected using either a contact type or a non-contact type of probe.

After obtaining the point cloud data using a CMM, it is converted into lines, arcs, curves and surfaces. After manipulating, the data collected is converted into surface model or a solid model. This final model so obtained can be used for analysis, mass properties, CNC program generation, etc. This data conversion depends on the software available in CMM (eg: DXF, DWG) which convert the data into CAD format, IGES and other form.

The present work has been carried out using TESA micro-hite 3D swiss made CMM. Which has a Reflex Scan pack for converting data into polyline IGES format. This IGES file is transferred to ProE / Master CAM.

Obtaining the part geometry: This can be obtained using contact type or non-contact type of probes. In the non-contact type we have 1) Laser scanning 2) Computed assisted tomography (CT) 3) Moire' interferometry and 4) white light triangulation technique is based on stereo vision. The measurement is based on the angle of the projected light, the angle of reflection captured and positions of the source and the camera.

In this technique, the source emits light and a grid of points are all scanned (triangulated) and measured in parallel. After this the different views are statically captured. If the object is either very complex or large views at varying angles are conquered and then merged to create on 3D point cloud.

The point cloud data is a random and unstructured collection of x, y, z coordinates. As CAD Software cannot handle such huge point data, reverse engineering softwares such as geomagic.

Image ware Surfaces, Magics, Pro / Scan Tools, Rapid form and STRIM are used for this purpose. Part features can be extracted by portioning the 3D data into non-intersecting homogeneous regions, referred to as segmentation. Then the convention CAD Software is employed to fit various types of surfaces to segmented data.

The point cloud thus generated will process to polygons, patch layout and grids are constructed to develop smooth surface in the Geomagic Studio Software.

3D Digitization: The 3D data of objects is acquired based on Z-axis data using linear area, laser radar, laser scanning techniques, point detectors etc. These systems incorporate the computer power to manage, process and analyze the data acquired. Apart from these tasks these systems also make decisions relating the data to the application without operator intervention which is called 3D based machine vision.

In the present work, two different commercial data acquisition, which are fairly robust to noise and which yield high accuracy measurements are used. These techniques consist of using laser lighting technique. The system used is the portable CMM with attachment of LASER LINE PROBE Range Laser Scanning System FARO Scan Arm.

Apart from the FARO Scan Arm, the following hardware and software have been utilized in carrying the present work:

➢ Geomagic Qualify Data Acquisition Software
➢ Raindrop Geomagic Studio
➢ CATIA V_5 R_{18} and
➢ CMM
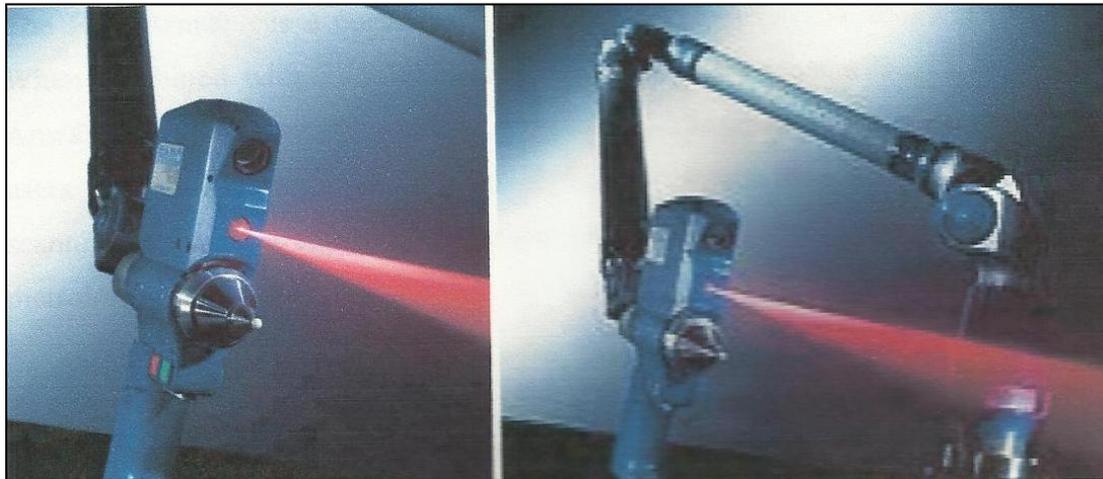
FARO Scan Arm
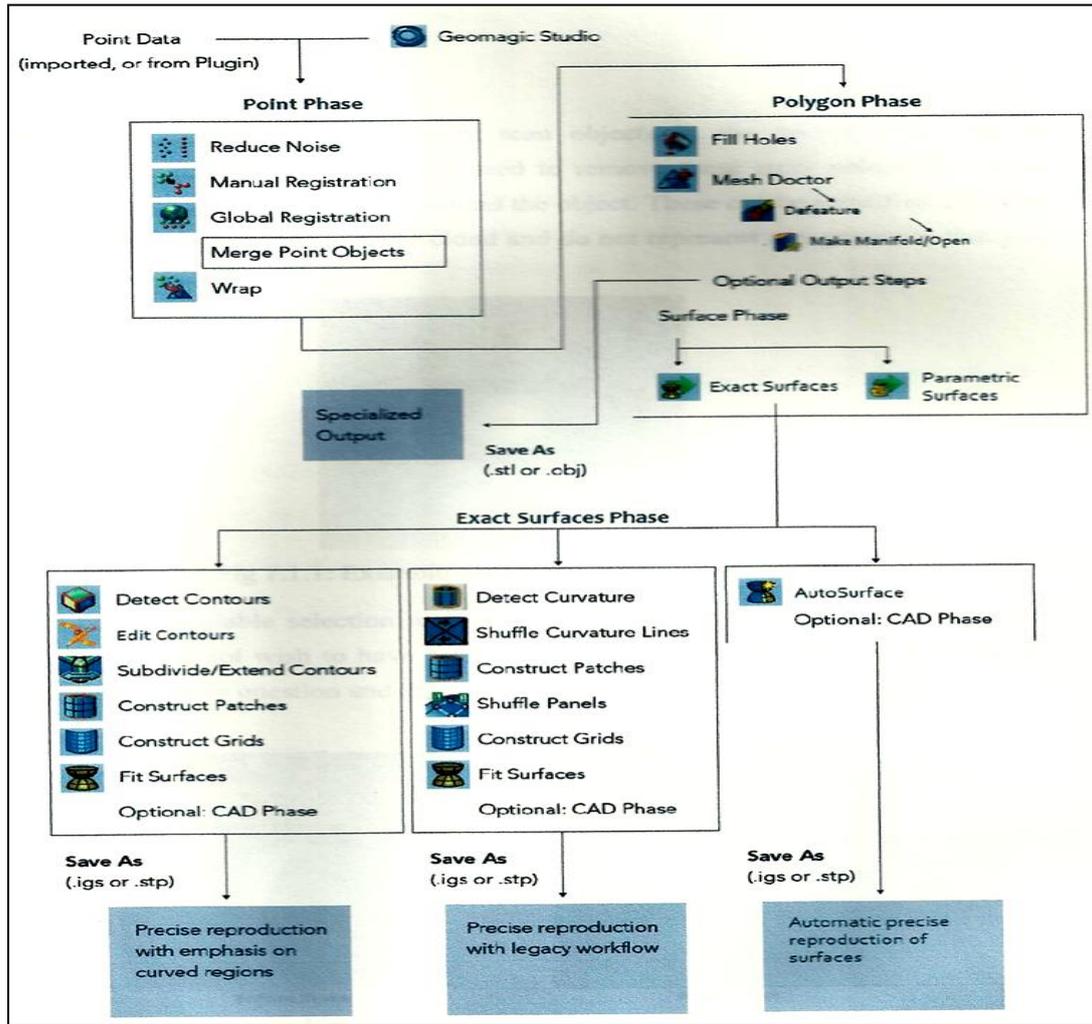
Work flow chart in Geomagic Studio for construction of surface from scanned point cloud data

Working of the Laser Line Scanners: The 3D laser scanner uses a laser light to probe objects. It projects a laser line on the object and uses a camera to look for location of the laser line silhouette.

Depending on how far the laser strikes a surface, each point on the laser line profile appears at different places in the cameras' field of view. This technique is called triangulation because the point on the laser profile, the camera and the laser emitter form a triangle.

The length of each side of the triangle determines the shape of the triangle and gives location of each point on the scanned subject corner of the triangle.
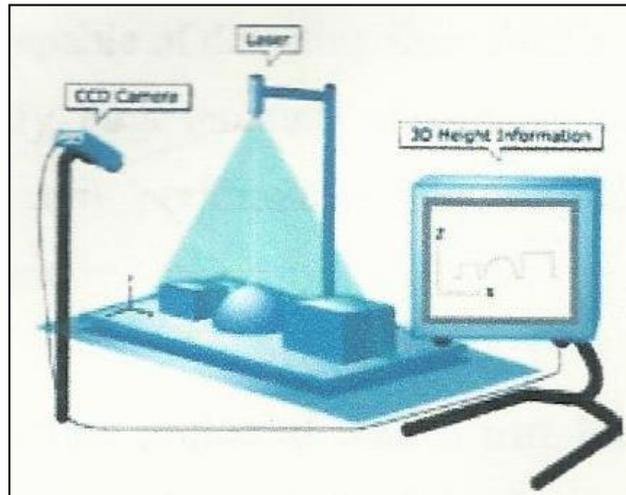
Principle of triangulation

Conversion of Light into Points: The data is collected as one "Slice" or cross-section at a time. The Faro Arm acts as a referencing device or 'Localizer' that tracks and communicates to the host application software the position of each cross-section in space. As the laser stripe is swept across an object, hundreds of cross-sections are instantly captured. They are collectively rendered in a CAD environment and the end result is a full 3D digital representation of the object. The collection of raw data is commonly referred to as a "point cloud".

Data Capture of the propeller blade: The propeller blade's 50 scans were taken with different orientations without missing and area. Scan passes were taken in different files with same coordinate system.
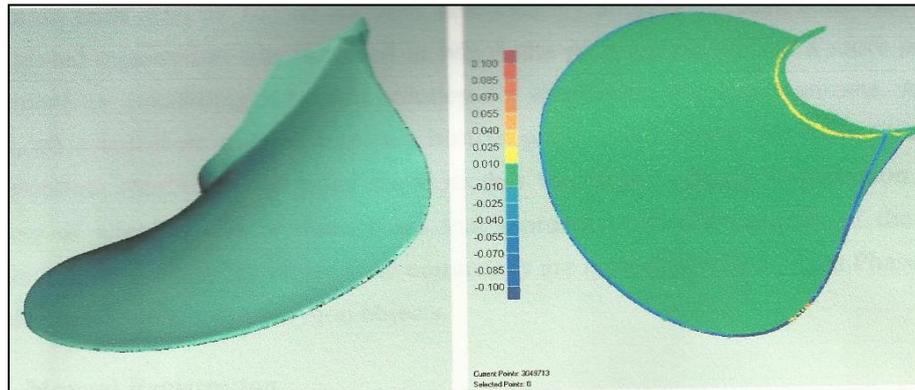
The scans from different orientations makes reverse engineering more easy and it also helps in the data to be employed in various functions.

The propeller blade is oriented at various angles and all these scans are merged to fully represent the geometrical data of the blade.
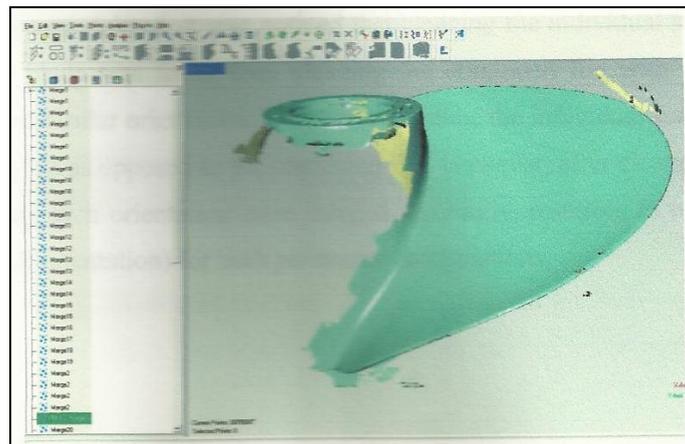

Scanned point cloud data

Data editing in Point-Cloud Phase: The scans from two parameter combinations saved by Geomagic Qualify Software were imported into Geomagic Studio 8, using compatible. wrp file format. Scans of each face of propeller blade saved individually for the same orientations were opened collectively. Unnecessary data (outliners) captured was also eliminated.

**Cleaned unwanted data (left) deviation of point cloud data
to reduce noise operation (right) from actual scanned data**

Registration: Since scans were taken with propeller blade at different orientations, the point cloud data appeared in these respective positions. Re-arrangement of all the merged sets of scans to fit into each other is done so as to get the final scanned point cloud models (for both parameter combinations) so that it can be edited in other phases. This is done by the feature of registration (manual or global).

Manual registration was performed and one merged scan set was approximated to the other by mapping similar points on each scan set to one another. This is followed by global registration to get a more precise alignment. All scans are merged into one best-fit point cloud model. Registration is the process of aligning two or more scans which represent different portions of the same physical object.
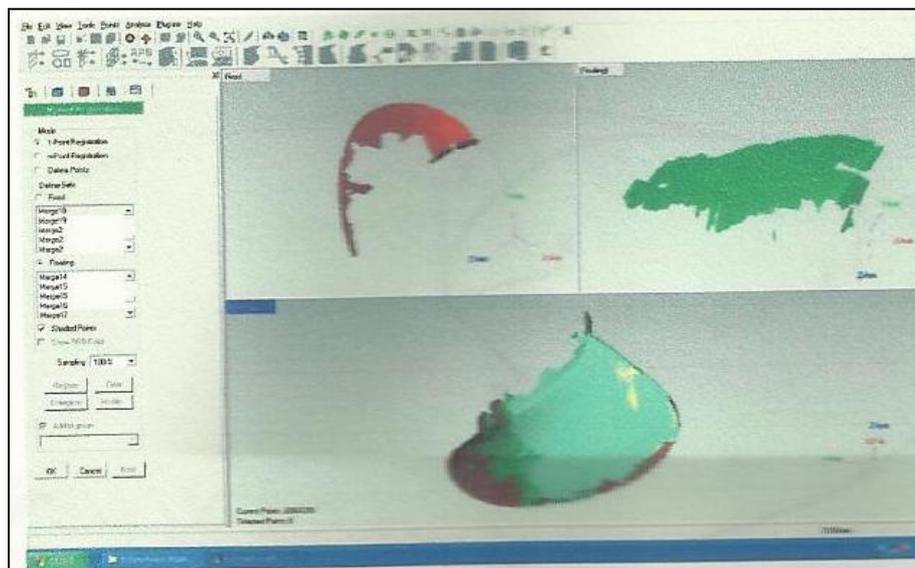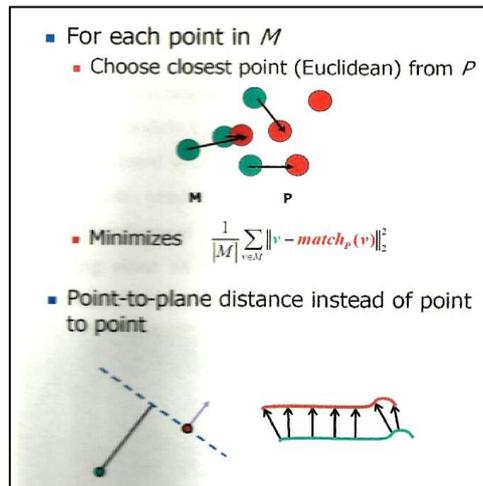

Manual registration of individual scans

The Iterative Closest Point (ICP): The ICP algorithm is employed to minimize the difference between two point clouds. This algorithm revises the transformation (translation & rotation) of each scan needed to minimize the distance between the points of two raw scans. The steps in this algorithm are:
- Associated points by nearest neighbor criteria.
- Estimate transformation parameters using a mean square cost function.
- Transform the points using the estimated parameters.
- Iterate (re-associate the points).

This comparison (ICP method) is done by two methods. Point to point comparison which is employed to align two meshes together and point to plane method to align a mesh to a surface model.

- For each point in M
  - Choose closest point (Euclidean) from P

- Minimizes $\dfrac{1}{|M|}\sum_{v \in M}\|v - match_p(v)\|_2^2$

- Point-to-plane distance instead of point to point

The point to point ICP method uses each 3D point within the scan data to maximize the alignment accuracy. The multiple scans are first roughly aligned via reference spheres and then the ICP algorithm is employed to align each scan using overlapping geometry to minimize global distortion.

After the individual scans are aligned they are combined into one mesh. Multiple surfaces are avoided for meshed data as this may lead to surface deviation readings during analysis. A complete re-triangulation is needed to produce a clean single layer mesh. The merging algorithm analyzes point redundancy and eliminates cluster of points defining the same feature. The result of using geomatic studio triangulate / merge function is shown below.
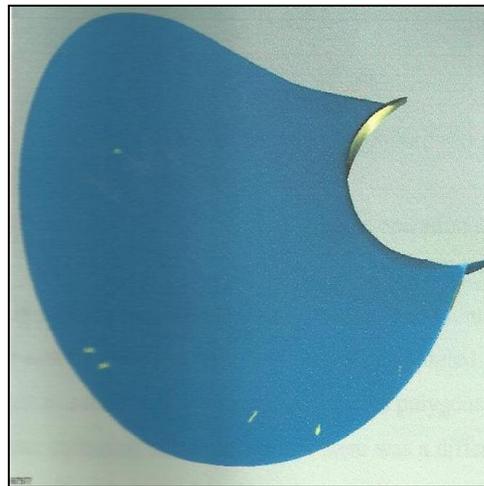
Wrapped polygon model

Polygon Model: The point cloud models so obtained were formed into triangular meshed surface by implementing the wrap function. The wrap function initiates a meshing algorithm which is incorporated in the software. The number of triangles are set according to the intent of design restoration.

Then the polygon model is subjected to geometric and surface editing to remove holes unwanted features, rough edges and intersecting triangles in both polygonal models. Surface editing algorithms integrated with geomagic studio 8 software were executed using editing tools such as "fill holes", "repair intersections", "relax" and "sandpaper".
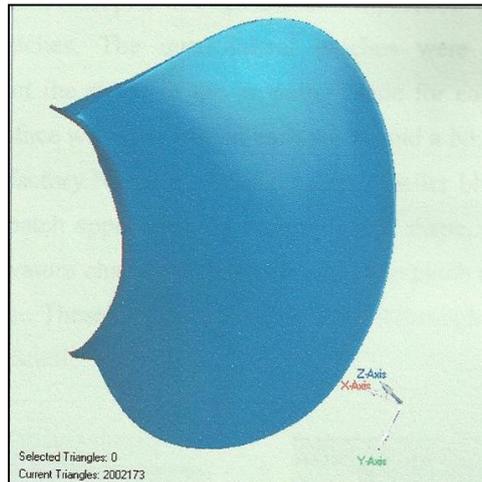
**Polygon model after hole filling and relax operation**

The mesh is scanned and intersections highlighted and repaired using "repair intersections" tools.

Complex areas on the propeller blade like root radius, edge of the blade surface needed to be filled for proper definition. There were different number of holes seen depending on the parameter combination. The parameter combination of laser power = 2 with scanning resolution = 0.05mm produced seven holes and laser power = 2 with scanning resolution = 0.10mm produced eleven holes in the polygon model.

Both models were selected and the "fill holes" tool implemented to fill the gaps. The edges of the inclined surfaces for both polygon models were roughly generated. Then the "relax" and "sandpaper" tools were used to sharpen the edges by defining the strengths to be applied. The polygon models were decimated to decrease any redundant triangles so as to decrease file size and increase the processing time.

The polygon models are transformed into NURBS surface models.

Data Fitting to NURBS Model: The NURBS surface is developed through the decomposition of the polygon model into quadrangular patches in an appropriate layout to represent the shape of the propeller blade for each polygonal model. On each patch a multiple resolution surface was laid and a NURBS surface was fitted to each patch. Using geomatic studio 9 software each patch is constructed rectangular in shape and ensuring that there were no severe or multiple curvature changes in the interior of the patch and it is seen that no unnecessary patches are created.
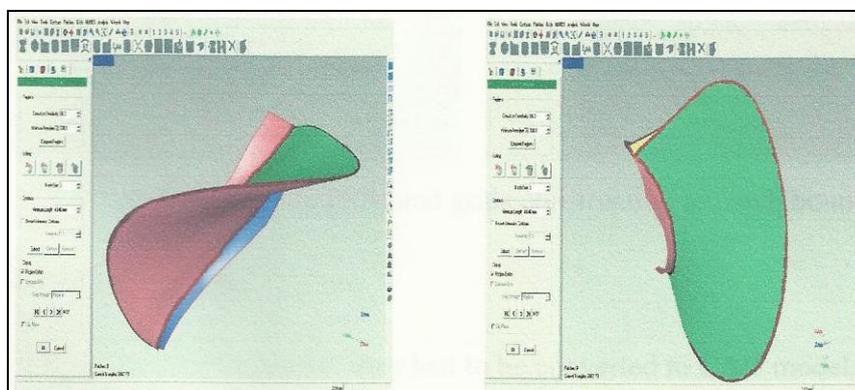
**Detection of curvature and contours**

Detection of curvature and contours was performed to identify contour lines on the propeller blade. These identified contour lines are then used to break the selected object into regions of low curvature change represented by a set of smooth patches.
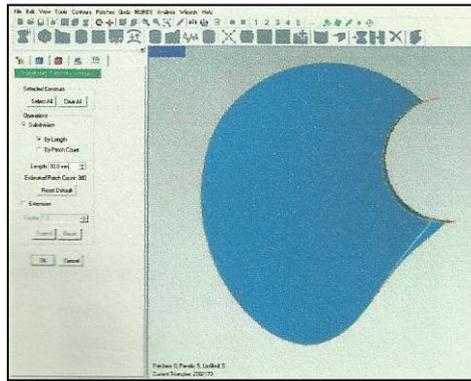
Contour lines extraction and sub division of contour lines

After patches are constructed a grid is created within each of the defined boundary patches. The intersection points of this grid lie precisely on the polygon surface model. The denser the grid, the greater the amount of detail captured from the polygonal surfaces. These can be represented in the final NURBS surfaces.

The 'Construct grids' command performs an automated parameterization of the triangular surface to a dense, quadrangular patch work. After this grid is created the 'Construct NURBS' command automatically computes the final NURBS surface.
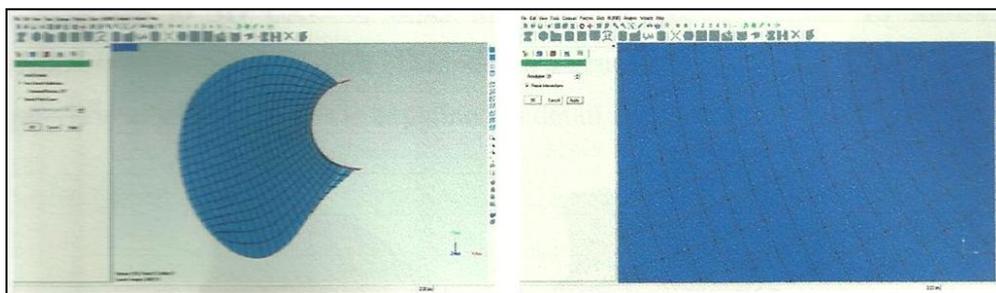
**Patch construction (left) and grids construction to patch boundry (right)**

CAD Model Generation: The NURBS models so computed are converted to CAD models. The NURBS surface model is further inspected through GD & T to recognize and parameterize the geometric features.

Geomatic studio 8 allows automatic conversion by allowing the user to activate the command, 'to CAD phase'. These CAD models are then saved as IGES files and imported into CAD package, CATIA V_5 R_{17}.
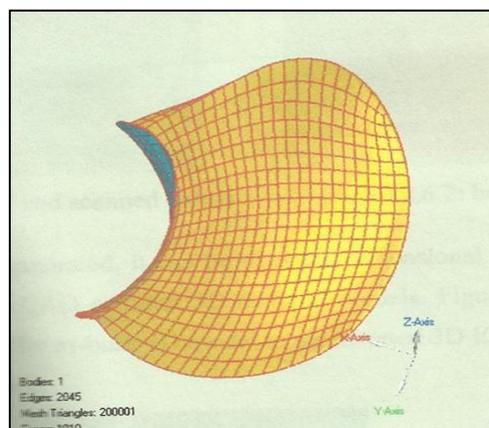

NURBS model fitted to grids polygon model

Merging the propeller hub with blade in CATIA Software: The blade model in CATIA V5 R17 is merged to hub surface without affecting the root radius of the propeller blade, which is crucial for other testing functions such as materials testing, structural and CFD analysis.
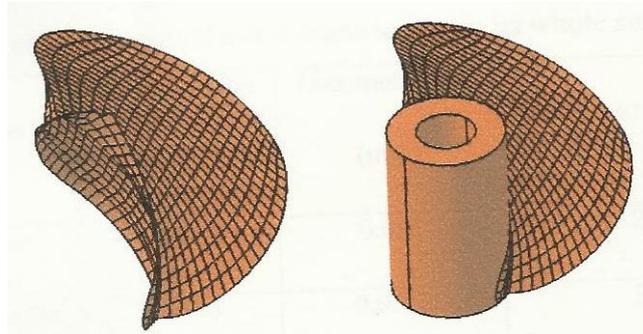
Blade model in CATIA V5 R17 software (left), model to hub surface
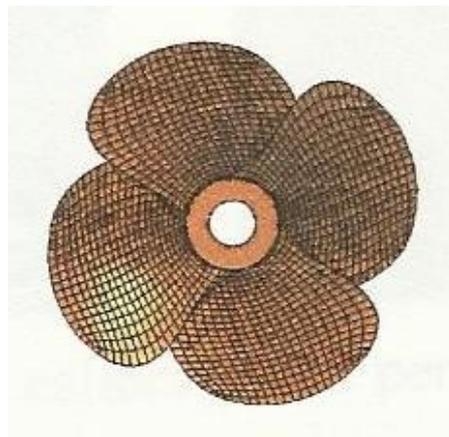

Assemble CAD model of propeller blade

II.   RESULTS AND DISCUSSIONS:

The Analysis of the 3D Laser Scanner and Software Performance: One standard gauge block of 75mm was selected to evaluate the performance of FARO laser line scanner in order to understand the detail of its applications. The scanner's operation uses Geomagic Studio Software to control scanning process. The calibration is required when the head changes, or after scanner is adjusted, or the scanner is not used for a long time. The scanner is calibrated by following instructions for the optimal height in which the plate should be located. The calibration data can be saved for next use. Then a configuration is used to set the scanning range, resolution, intensity of laser beam, and depth of measuring field. Now the scanner is ready to scan the object. A completed object is usually required a few scans to obtain its whole surface.
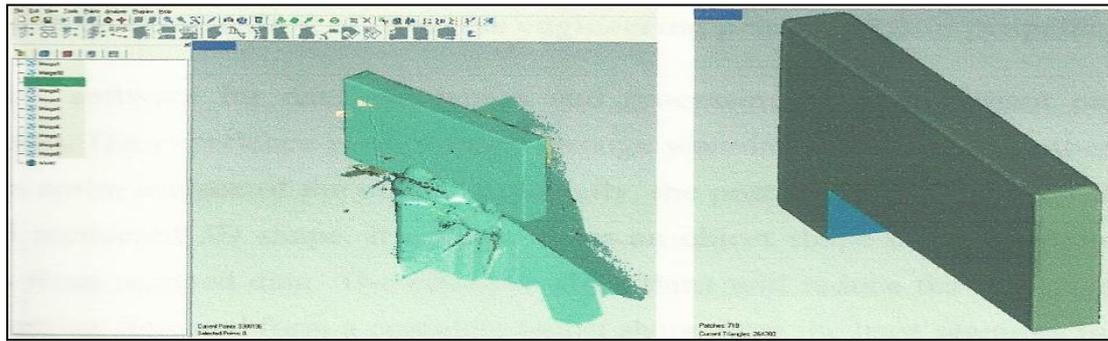
Probe Type	2 Sigma Value (MM)	Maximum Error (MM)	No. of Points Collected
Ball Probe	0.0081	0.021	200
Laser Line Probe	0.0486	0.0927	360

Results of Calibration of Ball and Laser Line Probe

A gauge block of 75mm was selected as test samples. The recovered shapes are shown in figures below.
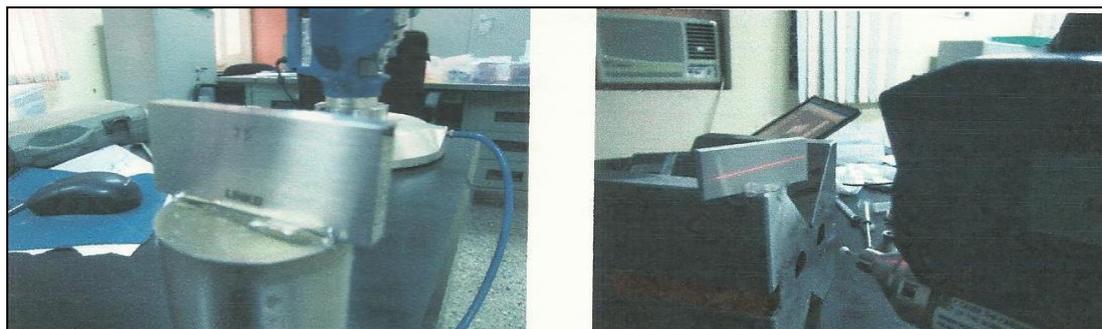
Gauge block sample to calibrate and performance measurement of software and hardware

Surface conversion gauge block (CAD) from point cloud data

The laser scanner is easier to operate than CMMs. It takes much less time to obtain the entire data. However, true industrial scanners service a much wider range of sizes and materials. Generally, an object requires multiple scans to obtain full data of the object. The acquired data from canning is a "cloud of points". Software must register one scan to another for the part completion.
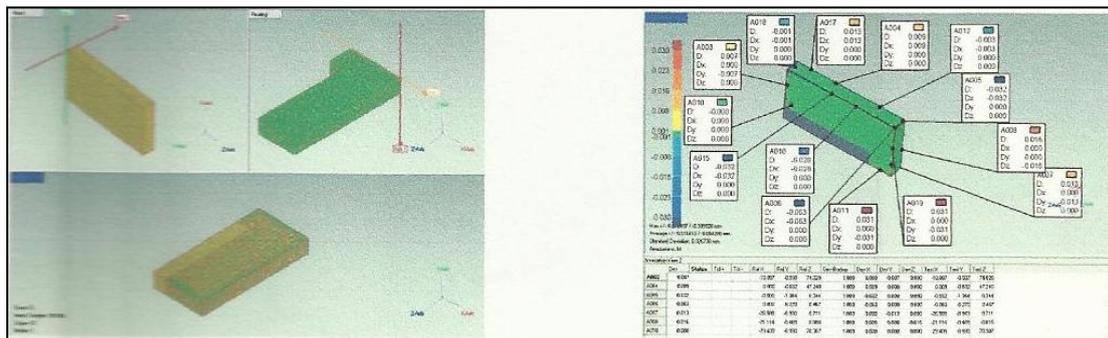
Alignment and 3D comparison of surface model with nominal CAD data

| S.No.	3D Comparison Result	
1.	Tolerances	Mm
2.	Maximum Tolerance +	0.030
3.	Minimum Tolerance +	0.001
4.	Minimum Tolerance -	-0.001
5.	Maximum Tolerance -	-0.030

3D Comparison Result between nominal CAD and generated CAD model

Discussion on method of Reverse Engineering Process of Ship Propeller Blade
Therefore, Software for data acquisition and processing is an important part of 3D digitization. The experience is required to arrange scanning process and number of scans to get an entire surface of the object. Especially, the post-processing is important to get the final recovered 3D shape. It usually forms an object shape using polygon / NURBS surfaces from scanned data. The effective algorithms will reduce the data size, shorten the processing time and form a complete object shape from the least scanning times.

Digitization Results
The propeller blade size is 1230mm diameter and hub height 470mm because of large size of blade the scanning process was done in pass by passes without over lapping scanned points by this method we can overcome system memory problem to handle large point cloud data.
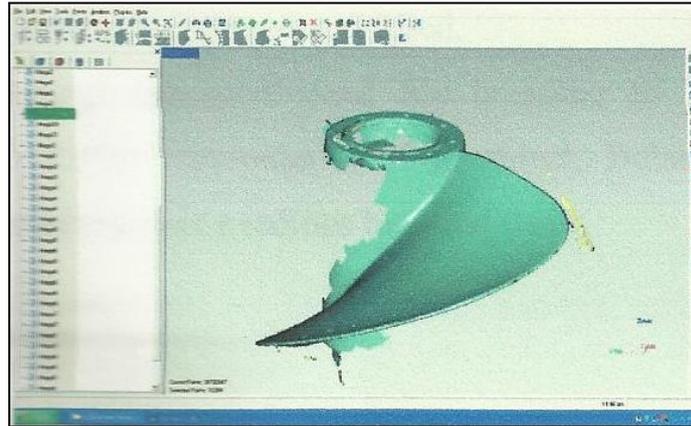
Initial scanned data

Equipment used	Faro Arm Laser Line Probe
Spacing between points	0.001
Smoothening	Max
Filter Angle	70^0
No. of Scan Passes	60
Total Number of Scan Points	4,00,50,952
Duration of Scanning	8 hours (per blade)

Faro Laser Line Probe Scanner setting and scanned data

Geomagic Studio was selected to find the need of data post-processing in this research. Geomagic Studio is a software tool for Reverse Engineering developed by Raindrop Geomagic, Inc. It has functions including the scan registration of multiple point clouds, point cloud reduction, filling holes of scanned data, polygon creation, data repair and editing, and NURBS surface creation.

Challenges in the data post-processing include as follows:
❖ Aligning point clouds together by picking out three common reference points: each scan must have enough common points to reference features that are on the previous and following scans.
❖ Control unmanageable combined point cloud: over-sized point cloud, such as more than 4 million points, may cause freezing or unacceptable rendering times.
❖ Control holes development: to reduce points with the same rate when point reducing is required. This causes holes to develop where spares clouds exist. The holes have to be relaxed and filled.
❖ Files exporting: the small-sized file is easier to be exported into CAD systems for further manipulation of the object. Balancing for small size with surface preservation is a tedious but vital work.

Data Editing: Because sensed data is subject to error, it is neither sufficient nor desirable to interpolate the data, but rather it is necessary to approximate the true curve. Data Reduction: Storage, manipulation, and reasoning needs often require that large volumes of data be replaced by a set of parameters much smaller than the original data set.

Total number of points after removed unwanted data:	3,33,20,701
Maximum Error	1.9977
Average Error	0.0124
Standard Deviation	0.04724
Number of points after uniform sample	30,49,713

Deviation in Reduction Noise Operation

We need to carefully reduce noise without affecting actual shape accuracy. If the smoothed data locks well in the dynamic preview polygon option we can get good surface conversion.
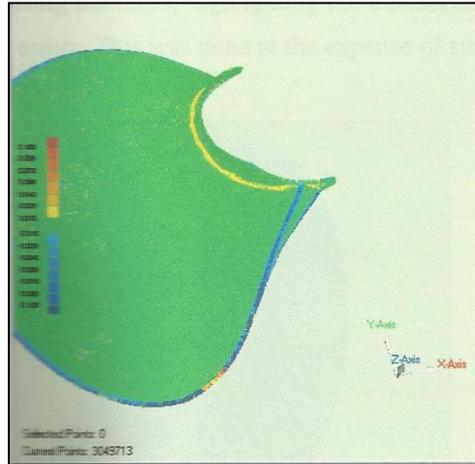
Deviation in smoothened data by reduce noise operation

There has been more iteration was done to improve data processing ability of the software. The iteration includes the new sets of parameters data reduction and smoothing settings that can improve surface reconstruction from a set of scattered 3D. The suggestion to segment data into constituent surface patches, and to generate an accurate solid model.

Polygon Data Results

Propeller scanned point cloud data converted into ordered data and made point into polygons / triangles to get smoothed results we need to different iterations. The detailed polygonal models for each parameter combination were selected for further editing since an accurate, high quality CAD model is the design intent for inspection purposes.

Number of Target Polygon	20,00,000
Number of Holes in Polygon model	150
Number of Intersections	100
Number of Polygons in processed data	2002173

**Polygon Data after converting points to polygons**

Surface editing algorithms integrated within the Geomagic Studio 9 software were easily executed through editing tools such as "fill holes," "repair intersections," "relax," and "sandpaper." First, all faulty intersections were repaired with the "repair intersections" tool by scanning the mesh, highlighting the intersections, and readjusting the mesh to eliminate any errors. This was done at the expense of surface detail, usually noticed at the areas of complexity.
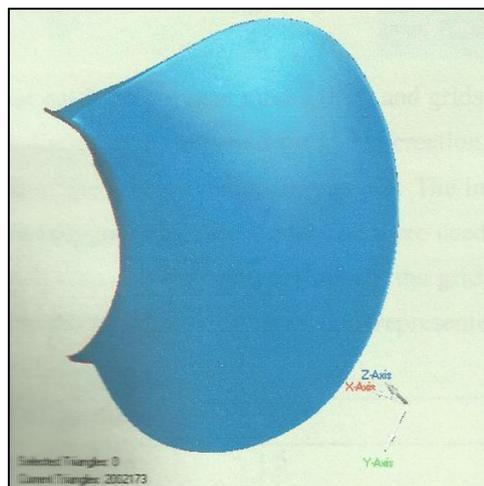
Processed polygon data

Mesh generation: The NURBS surface is developed through the decomposition of the polygonal model into quadrangular patches. The quadrilateral patches were arranged in a layout appropriate to represent the shape of the propeller blade for each polygonal model. A multiple resolution surface was then laid on each patch, and a NURBS surface was fitted to each patch. A satisfactory NURBS object for the propeller blade would be produced by constructing each patch approximately rectangular in shape, ensuring there were no severe or multiple curvature changes in the interior of the patch and preventing creation of unnecessary patches. These objectives were achieved through automatic construction using the Geomagic Studio 9 software.

First, detection of curvature and contours was performed to identify the contour lines on the electrical socket cover. The identified contour lines are then used to break the selected object into regions of low curvature change that could be easily represented by a set of smooth patches.
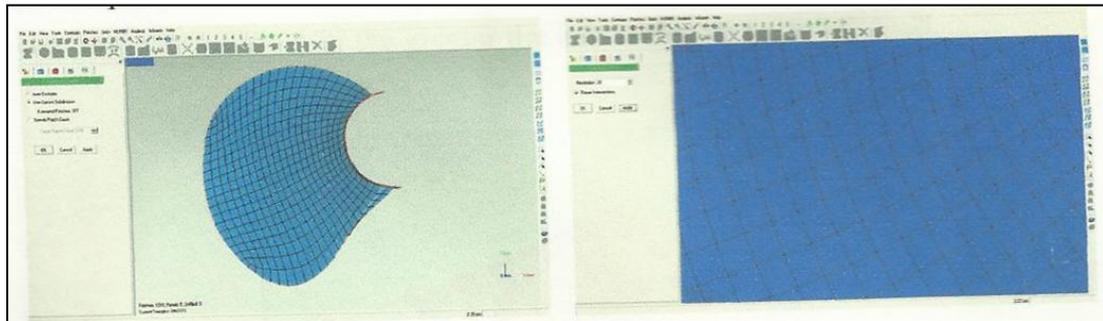
Rectangular patch on polygon model (left) and grids construction (right)

Next, the patches were constructed, followed by a grid creation process that involved a grid placed within each of the defined boundary patches. The intersection points of this grid lie precisely on the polygonal surface model and were used to calculate the splines of the NURBS surface. It was observed that the denser the grid, the greater the amount of detail captured from the polygonal surfaces and represented in the final NURBS surfaces.

| Number of counter lines	5
Number of regions	5
Number of subdivision	30
Number of grids	1010
Number of grids per patch	20

Patch and grids layout construction results

Surface fitting: The "construct grids" command performs an automated parameterization of the triangular surface to a dense, quadrangular patchwork. Once this grid was calculated, the "construct NURBS" command automatically computes the final NURBS surface; as such, the two NURBS models were developed.

Maximum control points	6
Tolerance	0.010
Surface tension	.025
Outer percentage	0.5

NURB surface fitting settings

Also, the amount of surface detail retained from the transition from point cloud model to polygonal model could be controlled by specifying the quantity of the triangular mesh. The higher the triangular mesh, the greater the intricacies were highlighted.
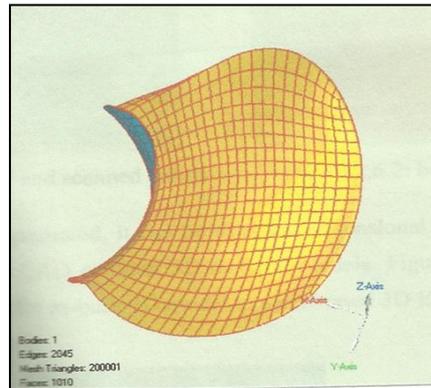
NURBS model

A Non-Uniform Rational B-Spline (NURB) Surface is a set of smoothly connected Curves imposed on an angular surface to make that surface look smooth.

Maximum deviation	0.26873
Average deviation	0.001152
Standard deviation	0.019037
Percent out of tolerance	0.002976

Surface fitting result

Surface Deviation: Geomagic Quality 7 was used for the GD&T inspection of the scanned CAD models (for both parameter combinations) generated in Geomagic Studio 8. This involved comparison between initial scanned points and built CAD file. Both files was to be loaded as the reference file surface model of propeller blade in IGES format and the other as a test file the scanned data in .wrp format. When loaded, neither of the two models was aligned, and a best-fit alignment was performed on them to allow for comparison testing.
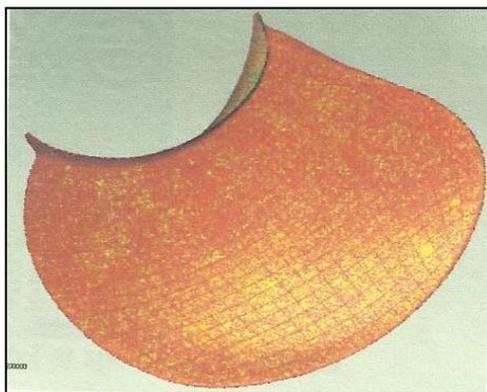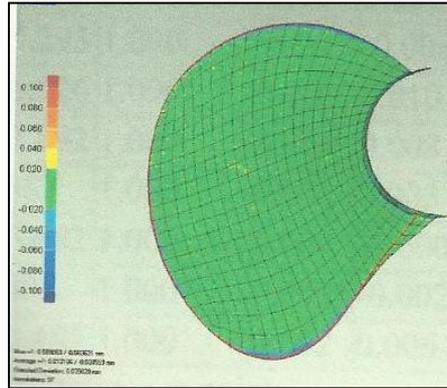

Best – fit alignment
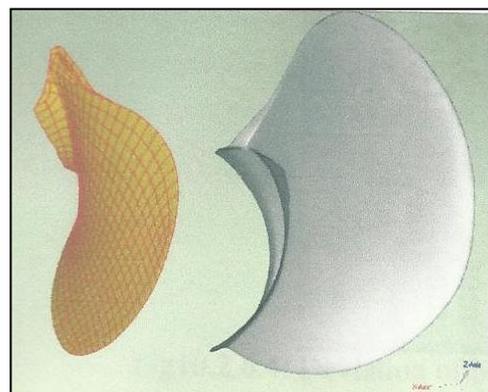
Built model and scanned points

Once this 3D model is generated, it can be used for dimensional analysis, GD&T, and color comparison to 3D CAD or other 3D as-build models. Figure 10.2.6.3 shows the comparison of the propeller as-built 3D model to a generated 3D IGES model. The IGES model provides a reference.

In order to evaluate the developed method, the recovered shape was compared with shape recovered by the 3D laser scanner (scanned points data). The laser scanner is considered as an accurate tool to get real values of the objects. X, Y, Z are width, height and depth of the objects respectively. The error was calculated by the difference between values obtained by the scanner and the values recovered by the proposed method.
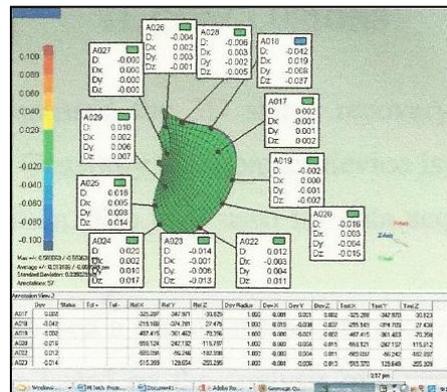
Deviation of built model at specified locations

Name	Dev	Ref X	Ref Y	Ref Z	Dev Radius	Dev X	Dev Y	Dev Z	Test X	Test Y	Test Z
A017	0.002	-325.287	-347.971	-30.825	1.000	-0.001	0.001	0.002	-325.288	-347.970	-30.823
A018	-0.042	-215.168	-374.781	27.475	1.000	0.019	-0.008	-0.037	215.149	374.789	27.438
A019	-0.002	-487.415	-361.462	-70.356	1.000	0.000	-0.001	-0.002	487.415	361.463	-70.358
A020	-0.016	-559.124	-247.192	-115.797	1.000	0.003	-0.004	-0.015	559.121	247.197	-115.812
A022	0.012	589.094	-56.246	182.908	1.000	-0.003	0.004	0.011	589.097	-56.242	182.897
A023	-0.014	515.369	129.654	255.295	1.000	-0.001	-0.006	-0.013	515.370	129.648	255.309
A024	0.020	-401.598	208.637	-306.526	1.000	0.002	0.010	0.017	401.595	208.647	-306.510
A025	0.016	-274.001	221.285	-347.892	1.000	0.005	0.008	0.014	273.996	221.293	-347.878
A026	-0.004	-79.607	-132.481	20.562	1.000	0.002	0.003	-0.001	-79.605	-132.479	20.561
A027	-0.000	150.674	-27.261	125.632	1.000	0.000	-0.000	-0.000	150.674	-27.261	125.632
A028	-0.006	117.706	235.626	47.607	1.000	0.003	-0.002	-0.005	117.702	235.628	47.602
A029	0.010	-234.176	105.739	-283.462	1.000	0.002	0.006	0.007	234.174	105.745	-283.455

Deviation of reference point

Specification	Propeller Manufactured Data	Reverse Engineered Data
Diameter	1230 mm	1231.9 mm
Pitch at 950	1360 mm	1367.709 mm
No. of blades	4	4
Blade area ratio	1.00	1.055
Pitch ratio at 0.7r	1.100	1.107
Hub diameter	300 mm	300 mm

Comparison of propeller manufactured (punched) data with reverse engineering data.

III. CONCLUSIONS

❖ This project discussed the 3D shape recovery and techniques in product reverse design. Generally, noncontact device is a convenient technology for 3D data acquisition. The time used for data acquisition is shorter than other methods.

❖ This project proposes simple method to recover 3D shape of objects using the triangulation based on the analysis of current scanning technology. The calibration for the Faro arm and laser line probe creates the line between the object and the system. The measuring accuracy was evaluated.

❖ The Reverse Engineering process was done with the help of Geomagic Studio software, the laser scanner and software process was calibrated by digitizing standard known CAD model of 75 MM Gauge Block.

❖ The Reverse Engineering technique applied to ship propeller blade of diameter 1230 mm and built part developed with minimum deviation.

❖ Laser scanning was mostly used for complex geometry components like turbine and propeller blades which has difficult to modeling by other methods.

❖ Laser scanner cannot scan transparent objects, it is necessary to spray a film on the surface of the transparent object.

❖ It is difficult produce exact sharp edges in laser scanning more mathematical edge detection algorithms need to be used to overcome.

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