REGENERATING HULL SURFACE DEFINITION FROM LASER POINT CLOUDS

M Bole, AVEVA Solutions Ltd, UK

SUMMARY

For ship hulls without plans or when rapid repairs to the shell are required laser scanning and other optical survey techniques offer an excellent method of capturing shape. The point cloud datasets captured during these surveys are large and contain areas where the hull is obscured or poorly captured due to constraints in the docking environment. As the survey may not represent the exact surface required for engineering, completely automatic fitting techniques are not suitable and the process must be guided by a software user.

This study presents an approach which augments existing surface definition techniques by providing the user with capability to fit definition geometry where the hull is cleanly visible in the survey. In poorly captured areas, the user must control definition manually based on experience utilising any additional resources that may be available. As fitting is used selectively, there is no need to remove unwanted artefacts from the point cloud which is time consuming. A case study using this approach in a shipbuilding environment is presented and highlights methods of validating the accuracy of the surface with respect to the point cloud.

1. INTRODUCTION

In the last few years, optical surveying techniques such as Laser Scanning have become an accepted approach for electronically capturing the geometry of physical objects within Engineering. The techniques offer a far quicker way of capturing shape compared with taking physical measurements particularly when the surveyed area is large and has complex shapes. It has taken some time for this technology to mature as the cost of hardware has been high, there have been limited options to integrate the survey data into popular engineering software packages and the expertise required to perform efficient surveys has had to develop.

In 2011, AVEVA acquired LFM Software Ltd, a developer of software for visualising and processing optical survey data into engineering information for import into other engineering design software. Following the acquisition, these tools have been integrated into AVEVA's flagship engineering design tool E3D allowing representations of equipment to be positioned and systems routed while immersed within a virtual scene generated from the survey data, Figure 1. The integration provides the user with a more productive and error-free design experience compared with a solutions relying on separate tools and data exchange files because the user can better appreciate the context of the engineering requirements.

The survey challenge changes depending on the application. Survey of enclosed technical spaces often captures large numbers of items that can be represented in CAD by simple shapes. This scenario had become well-supported by existing tools. The capture and representation of hull shape is different involving the survey of a single large artefact with a subtly complex shape. Scanning will frequently take place in dry or floating docks where areas of the hull are obscured, at least by supporting structures and keel blocks. Following the survey, the generation of a surface remains a process where several software applications may have to be used and the resulting surface may not be suitable for downstream engineering applications.

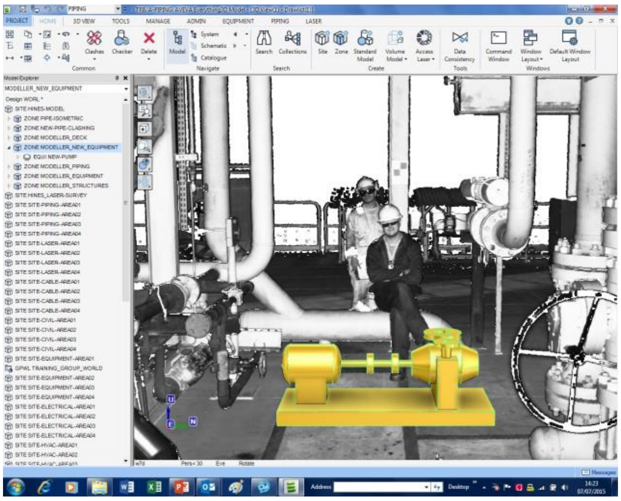


Figure 1: Laser Scan and CAD information presented in AVEVA's E3D software.

Compared with capturing the shape of a hull form by manually measuring positions on the shell, optical surveying has a clear advantage allowing the rapid capture of geometry within the period an operational vessel would be in dock. For a vessel without any trusted documentation performing an optical survey at the earliest opportunity will provide confidence to support any subsequent engineering requiring hull form data. That may mean supporting hydrodynamic calculations to improve efficiency or reduce environmental impact, structural modifications or repairs after damage.

To support these activities, the techniques described in this paper extend previous work [1] supporting the regeneration of hull surface definition from poor or corrupted surface representations. The cloud points

© 2015: The Royal Institution of Naval Architects

produced by the optical scan are effectively treated as another data source.

2. IMPACT OF USING GENERIC TOOLS TO DEFINE HULL SURFACES

Optical surveying has progressed far from the initial laboratory studies where it was used to capture small or discrete artefacts. A significant amount of research covers the generation of polygonal geometry from the survey point clouds. Subsequently, fitting processes generating mathematical surfaces directly from the point cloud or from intermediate geometry have been developed. Today there are a number of commercial and free software applications capable of producing polygonal, surface and solid geometry from this data.

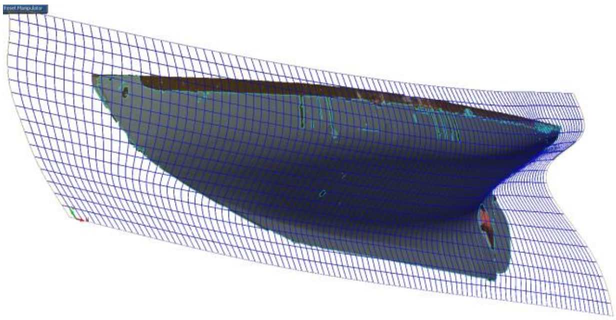


Figure 2: Single surface fit to a point cloud cleaned of unwanted artefacts. Surface is trimmed with 1800 control points, [2].

The marine industry has pioneered the use of surfaces, particularly for hull form representation, since techniques such as NURBS became a practical and cost effective way of representing shape in computer software. The impact of design, hydrodynamic and fabrication requirements has resulted in software design applications tailored to the marine domain which often contain features that cannot be found in generic surface modelling tools. Surfaces from generic tools can be transferred to other tools using standard CAD interface formats but often, as a result of algorithms used to create the surfaces, the geometry does not have the optimal structure produced by marine specific applications. Often there will be a low number of surfaces, with a high number of control points bound together with surface trimming or solid modelling, Figure 2. Large numbers of data points make it challenging to modify or correct the surface and solid modelling introduces numerical and tolerance sensitivity. Consequently, the surfaces are fixed interpretations of the scanned data and if they fail to function in a downstream engineering application there isn't much that can be done to rescue the definition.

A desirable requirement is the integration of optical survey data into marine hull surface design tools. This would allow users to reference the point cloud while creating surfaces with the correct shape and definition structure known to support all downstream engineering requirements. To achieve this it's necessary to review the entire process from survey to surface validation, understand the challenges involved allowing the proposal of a solution which provides the user with the best experience and productivity.

3. FROM SURVEY TO SURFACE DEFINTION

Producing a hull surface from scan data involved several stages and usually a number of people skilled in surveying, data processing and surface definition.

3.1 OPTICAL SURVEYING

Optical survey techniques, such as Laser Scanning, visually capture the surface geometry of an area representing it as a 'cloud' of coordinate points. In respect of surveying a hull to generate a surface this technique is limited by the fact that usually the area of interest is underwater. When it is out of the water in a dry or floating dock or on a hard standing area parts of it will be visually obscured by keel blocks and supporting structure. Scaffolding and staging may be erected around the vessel to allow maintenance work to proceed.

Figure 3: Typical floating dry-dock scenario. Although there is limited staging around the vessel, the closeness of the dock sides to the hull make surveying more challenging.

For a commercial vessel, the period out of the water is short because during this time it is not earning money and there may be limited opportunity to clear surrounding clutter just for the survey. Surveying the ship in this environment can be challenging as all visible artefacts are captured and those invisible to the survey sensor are not. Areas under supports and the keel may be poorly defined while in other areas people and even local birds are captured. Any activities or moving vehicles causing vibration may affect survey sensors, reducing the quality of the capture. If the topsides has a polished finish a scanning laser may reflect off rather than return to the sensor and standing water or puddles may create mirror images of the hull underneath the dry dock.

© 2015: The Royal Institution of Naval Architects

By convention surfaces represent the moulded characteristic of the hull form, usually the inside of the shell plating. The survey will include appendages such as bilge keels and rudders which are usually modelled as separate entities rather than as part of the main hull representation. Distortion due fabrication or operational dents and damage will be captured, although this may be the objective of the scan if effecting repair.

With the speed that this survey technology can capture the geometry of an area of interest and transform for use in a software environment it is easy to forget about the practical limitations of the optical capture process and measurement devices. Irrelevant artefacts may need to be removed, there may be missing areas that could not be seen by the sensor and there will be measurement noise in the data. In respect of these considerations it goes without saying that human interpretation is necessary to discern the portions of the survey data which support accurate surface definition. In this respect, it is somewhat naïve to expect complete accuracy from an automated surface fitting process based on data captured under these conditions.

3.2 QUANTITY OF DATA

The cloud point data generated by optical surveys can contain a very large number of data points requiring storage of the order of terabytes. Surveys of this size are not necessary when it comes to the shape of the hull and experienced operators should reduce the capture resolution. Scans of 50-80 million points appear to provide an adequate definition of the surface.

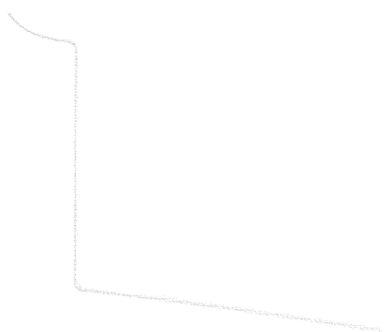


Figure 4: Section of a point cloud through the transom. Tight corners could be represented as knuckled or tight blends. It’s not obvious based on the cloud how to represent this in the surface but this might be the only data you get.

The detailed shape of corner features such as the stem and knuckles are always difficult to determine compared with the level of noise (scatter) in the point cloud, Figure 4. Point clouds can be reduced in resolution but this is often undesirable because there is a chance that small features will degrade in detail. Implementations should avoid imposing limitations on the amount of data that can be handled and provide processing and visualisation capable of dealing with these large datasets because there will always be circumstances when you need to see more detail.

Current computer operating systems supporting 64-bit file systems allow much larger files than could be used just a few years ago. Previously, individual files were limited to 2-Gigabyte and datasets would have had to be saved across multiple files. However, only a limited amount of this data can be retained in the faster computer RAM and optimal techniques for scanning and retrieving data from files are needed. Use of random access ‘database’ files where points are mapped and then stored in a spatial grid or octree can significantly reduce the amount of time required to perform geometry queries such as a plane intersections. Octrees, in particular, efficiently cope with varying spatial densities of survey points. This is important because cloud point density becomes very high when a scan sensor is placed close to a surface. Sorting the dataset into a spatial map is one of the few times the complete dataset needs to be processed but it is too large to be sorted in-memory. Successive chucks of the dataset can be sorted using techniques such as Dijkstra’s Dutch National Flag Problem [3] or quicksort algorithms that support “fat-partitions” and saved in temporary files. These files can then be combined using an External Merge Sort [4].

The most important step in the prior to use is the spatial positioning, orientation and validation of the survey dataset in 3D Space. Often this requires the use of reference documentation which details the vessel coordinate origin and orientation especially for those which have non-horizontal keel lines or unconventional Perpendicular positions. Support for interactive transformation of the survey dataset within the surface definition software allows final adjustments to be made and a number of iterations may be necessary to achieve perfect alignment. Referencing the point cloud with interactive snapping tools can significant improve positioning especially if transformations are applied to points as they are read from the database rather than used to update the data storage files.

3.3 PREPARING A PRAGMATIC APPROACH TO FIT SURFACES TO POINT CLOUDS

There are a number of challenges that prevent direct surface fitting techniques from being used to generate hull surfaces from a survey point cloud:

- Any sections of the point cloud not representing the hull surface must be removed manually during the preparation otherwise accuracy is affected.
- Ship hull forms have local features with high curvature and other area that are predominantly flat. As fitting algorithms generally produced uniformly spaced control points, ensuring of areas with high curvature are captured accurately causes those with low curvature to be

© 2015: The Royal Institution of Naval Architects

significantly over defined with control points. Surfaces with too many control points cannot be productively manipulated manually.

- If a point cloud has areas of the surface where data is poor or missing the associated control points will be under-defined. Numerical instabilities in the fitting algorithm can prevent an acceptable surface from being produced. The introduction of Smoothing can mitigate this but it has to be applied across the whole surface reducing accuracy. The chance of numerical instability occurring increases with the number of control points.

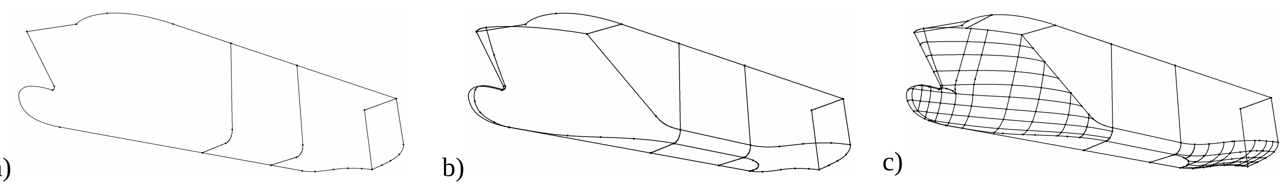
There is little opportunity to deal with the imperfections and variation in shape when using surface fitting techniques as the representation is generated in a single operation. In ship design, productive hull surface definition techniques use a number of different sized patches to represent large and small features rather than use a single entity. By integrating survey data into existing hull surface design tools with capability to snap, selectively fit and reference the point cloud, a skilled user can visually discern the areas of the survey that support fitting and use their expertise to manipulate the definition when fitting cannot. This pragmatic approach avoids the need for rigorous preparation of the survey data and make good use of the user's skills to produce a surface that is fit-for-purpose in downstream engineering activities.

4. SURFACE DEFINITION FOR SHIP HULL FORMS

NURBS are the most popular mathematical surface representations used in computer-aided design today. They are easy implementation and widely supported in data exchange formats between other software. In addition, it is relatively straightforward to develop user interface solutions where the user can directly manipulate the control point definition to control shape. However, ship hull forms have a fairly challenging structure and it is it is desirable to use a number of surface patches to represent shape. It takes skill and expertise to understand the best way to approach this style of surface definition. The precision required to introduce certain features and maintain continuity between patches make extremely difficult and unproductive address this style of representation using direct control point manipulation alone.

Cross-Sectional Design is technique for creating multiple patch surfaces and is used by a number of commercial hull surface modelling tools aimed at ship design. A network of interconnecting curves is defined where the edges between connections represent the boundaries of individual surface patches. The internal shape of these patches is generated using techniques based on the Coons Patch. The network of curve forms an intermediary between the user and the surface representation. The curve network represents cross-sections through the surface in a similar way to the traditional Lines Plan. By allowing the user to represent the shape structure of a hull surface without having to work out the precise control point positions of each patch achieves a more productive experience especially for hull forms with complex details such as those with twin skegs, for example.

The first stage of cross-sectional design introduces curves representing the boundary and features of the hull form, Figure 5. These curves connect together, often dynamically, in a network defining the layout or topology of the different characteristic shapes of a hull surface. The association of descriptive shape rules to points and curves allows the implementation of dynamic constraints on definition control points. This capture Design Intent allowing the automatic update of definition in response to changes that would otherwise have to be precisely managed by the user. Once the structure of the hull surface has been defined, the next stage introduces further curves representing the cross-sectional shapes of the hull within the initial curve network structure, Figure 5c.



a) b) c)

Figure 5: Stages of creating a hull definition with a curve network: a) Outer Boundaries and major changes in shape, b) Curves representing characteristic shapes and features, c) General shape control curves.

During design, these curves must be iteratively manipulated until the desired surface qualities are achieved. However, if a representation of the surface already exists there is no reason why this information cannot be used to generate definition curves using fitting. In [6], the author used fitting algorithms as part of a process of generating cross-sectional design curves from non-surface geometry or surface geometry that was damaged or out of tolerance and could no longer be successfully loaded into engineering CAD systems. Similarly, curves may be generated from cloud point datasets by sectioning areas of interest. Unlike the surface fitting scenario, the user can selectively determine where definition curves should be generated focusing on areas supporting good definition, avoiding those which are poor or include scanned features which

© 2015: The Royal Institution of Naval Architects

should not be included in the hull surface. Furthermore, by including smoothing capability into the fitting algorithms, curves generated in areas where data is poor or missing can be improved resulting in robust shape capturing tool which does not require perfect information from the survey dataset.

4. INTEGRATING LASER POINT CLOUDS INTO A CROSS SECTIONAL DESIGN WORKFLOW

4.1 VISUALISING THE SURVEY

Visualisation of the Point Cloud is a necessity but with such a large quantity of data it's necessary to make a selection on the number of points visualised. If the dataset has been spatially mapped sampling a smaller number of points from across the domain provides a reasonable representation of the survey data.

There are a variety of different ways of visualising point cloud data from using different size point images to incrementally rendering additional points to the scene once the user has selected a particular view point. When working with a hull surface there is limited value in visualising the entire point cloud because it can dominate the screen at the expense of the surface definition. In this respect, simply displaying each point as individual screen pixels is adequate. Often, it is preferable to select a fairly small fraction of the overall point cloud because it becomes harder to perceive the survey in 3D, given the 2D screen projection of the points. Points can be scanned in colour but ship hulls have dull shading and are often captured in poorly lighted conditions especially if surveyed during the night. Mapping point colour by its intensity to an alternative colour model can offer a slight improvement.

Being selective in the visualisation offers a much better appreciation of shape. Often it's difficult to understand detailed areas of the hull form such as the sharpness of a knuckle, the shape of the stem and its transition into the keel. Defining additional small areas of visualisation where the density of the displayed point cloud is increased can provide better view of detailed features. However, unless the resolution of the scan is high enough getting a good appreciation of specific details can be challenging especially in the case of the stem and keels where access is poor.

An alternative technique to visualise the cloud is to section it with planar cuts. By visualising all points within a certain distance of the plane a view that looks like a curve can be presented due to the large number of points collected. Cutting a sequence of sections in principle planes generates the traditional station, waterline and buttock curve views, Figure 6. In this respect the user is able to work with a familiar view of the hull surface. Significant efficiencies are available if the spatial mapping techniques described in 3.2 are used to collect points from the cloud to generate these views.

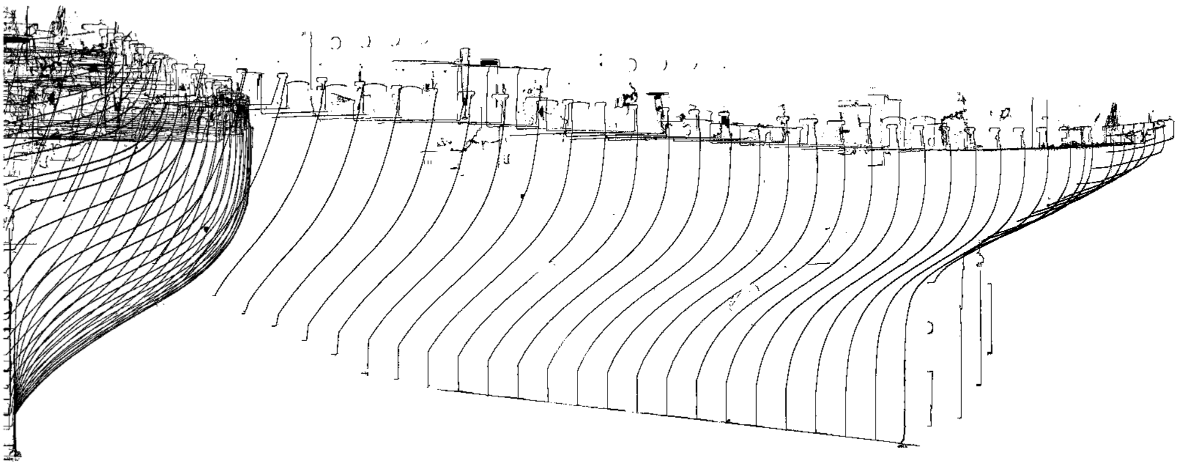


Figure 6: Sectioning a cloud by collection all points within a certain distance of a plane produces views familiar to a hull design. This representation often provides better feedback than viewing the survey data as a continuous scatter.

4.2 POINTER COORDINATE SNAPPING

Interactive snapping of control points to the point cloud provides the most basic level of reference. For surface modelling this provides a means of positioning discrete definition at key positions on the hull. Another major use of snapping is in the precise positioning and orientation of the dataset. A simple interactively drawn line representing the baseline with one end placed at the dataset origin can be used to specify a transformation that repositions the point cloud to the desired origin and orientation.

Snapping to the point cloud has to be implemented carefully to avoid a drop in performance below that considered interactive. Furthermore, it's difficult to perceive depth when the cloud is projected onto a 2D screen. Implementing snapping on the sectioned views is more successful because features are far more obvious, there are larger gaps between clusters of points and the planar cut assists with the perception of depth. As with the complete survey dataset, organising the sectioned points into a spatial map or grid improves performance by reducing the time required to find snap points when projecting the ray defined by the mouse cursor onto the section.

4.3 SAMPLING THE SURVEY TO COLLECT POINTS TO FIT CURVES

The process of parameterising sample points for fitting is simpler for curves than for surfaces. Points only have to be ordered with respect to a single parameter. Points captured in planar section cuts can be used to fit design curves. However, each can collect between 10,000 to 100,000 cloud points. If these points are used directly in a fitting algorithm it can take tens of minutes to produce a result due to the large number of equations that need to be solved. It should be kept in mind that the fitted design curve should contain approximately up to 15 control points for the best efficiency. More than 20 and it becomes challenging to maintain good curvature characteristics when the definition is manipulated.

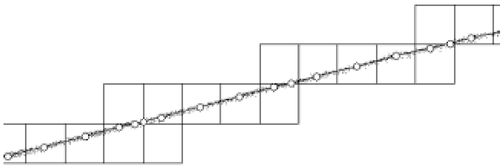
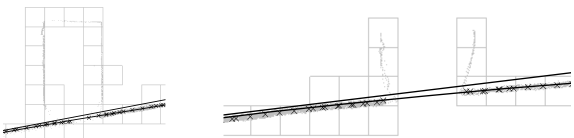


Figure 7: Fit points obtained from the centroid of cloud points within each section map cell reduces the number that need to be processed by the cuve fit algorithm.

With so many points, the influence of an individual coordinate from the survey cloud on curve shape is insignificant and there is limited value in passing all to the fitting algorithm. A smaller number of sample points may be obtained by calculating the centroid of all cloud points in the neighbourhood of each spatial map cell of the sectioned cut, Figure 7. This approach reduces the number of sample points to around a thousand and allows a fitted curve to be produced in seconds.



a) b)

Figure 8: Using the spatial map to identify a route through the section cloud allows undesirable points to be excluded and gaps connected.

An additional benefit of using the spatial map is that a further selection of sample points can be determined by calculating the shortest 'route' through the sectioned point cloud by analysing the adjacency between populated map cells. As the fitted curve should integrate with existing hull definition, the termination points of these routes can be found by intersecting existing definition curves with plane of the cut section. The parameterisation order of the fit points is identified in the sequential definition of the route. Construction of these routes will have the effect of excluding isolated or unwanted points and closing gaps caused by any supports or staging that may have been captured in the survey, Figure 8.

4.4 CURVE FITTING

Least squares fitting is an obvious choice for curve fitting for a great number of reasons:

- The algorithm used to generate B-Spline curves using the least-squares fit is well documented and easy to implement.
- The number of control points is not directly linked to the number of sample points unlike cubic spline interpolation.
- Characteristics such as constraints and smoothing can be incorporated into the solution.
- The algorithm can be extended to produce B-Spline Curves that have the same structure as user defined curves within the CAD application.

The Least Squares technique is rarely used in modern CAD tools as it can be perceived as lacking precision. Curves and surfaces produced by this approach do not necessarily intersect with the sample points but this is a benefit when fitting to large quantities of noisy data such as a point cloud. The Least Squares technique finds the best-fit of a given mathematical model to sampled data. The model, in this case, is a cubic B-Spline with a number of control points determined by the user and uniformly spaced knot vector. The curve will interpolate the sample data perfectly if the data and the model are compatible. Quality degrades if the data and model are not. The free parameters are the positions of the control points, the number of which influence the level of detail that can be captured. Too many control points makes the curve hard to control, too little means that the curve might not fit well.

A visual review of the geometric shape of the curve is seldom adequate to understand the quality of the curve with respect to the sample data. Traditional porcupine plots can be used to provide curvature feedback and a similar graphical representation used to illustrate the absolute difference between sample points and generated curve, Figure 9. Numerical feedback such as maximum and mean difference provide quantitative analysis. Both methods provide feedback allowing the user to determine the best curve configuration.

Good practice [5] suggests that keeping the same number of control points on each primary shape curve across an individual region of a surface maintains quality because it keeps mathematical definition consistent. This means that there isn't an entirely free choice on the number of control points on each curve if good practice is followed.

Smoothing can be used to improve the shape of a curve independently of the number of control points. These techniques reduce the correlation of the curve geometry to the sample data but improve curvature. A variety of different smoothing methods exist and can be easily incorporated into the least squares technique through the introduction of additional equations. In practice, smoothing methods based on minimising curvature or energy are only implemented for the 2D case where curvature is represented as a signed scalar. In the 3D case, curvature and energy are vector quantities. Smoothing based on minimising second differences [6] is easier to implement and works in the 3D case.

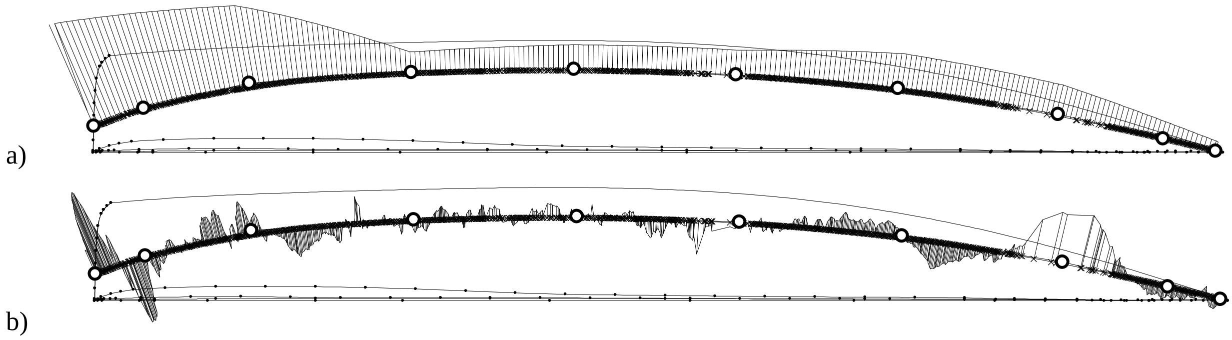


Figure 9: Reviewing the quality of a fitted design curve, a) curvature b) local closeness of fit.

While the fitting algorithm will generate a smooth curve following the trend of the sampled data it will often fail to pick up precise features of hull shape such as specific positions or tangents. This information can be introduced into the fit through the use of constraints. The initial curve network, Figure 5a, captures the topology of the hull form as well as the constraints of position and tangency that fitted curves should respect when they attach to this network.

4.7 QUALIFYING THE SURFACE DEFINITION

To qualify that the fitted surface accurately represents the scanned data it should be verified with respect to the point cloud and any other information available such as photographs. Spot checks are of limited value because they do not provide an overall impression of the accuracy of the surface and it is challenging to make a realistic judgement given the scatter of points especially around complex features. A proper systematic evaluation is required across the whole surface to guide the user to correct areas where the surface doesn't accurately represent the survey data.

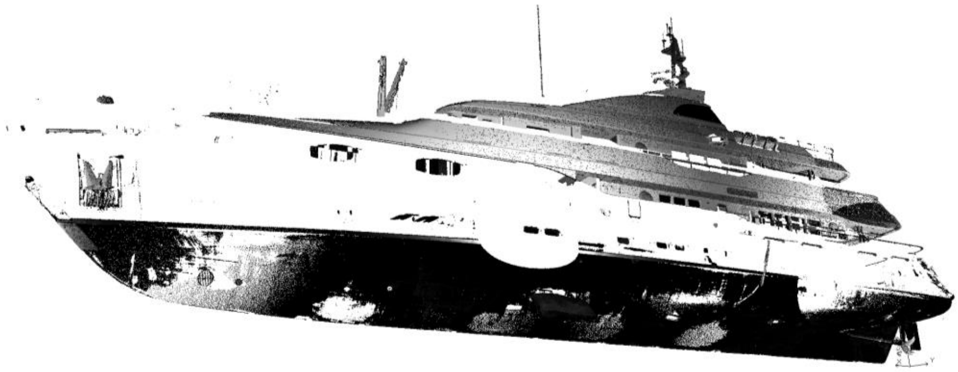
The amount of noise and scatter in an optical survey highlights that this is a statistical process and there isn't a 'precise surface' contained within the point cloud. At best, the mean position provides a guide for surface placement and standard deviation indicates the level of noise and should be consulted when selecting a meaningful tolerance. Capturing this information alone can be challenging as it's necessary to restrict the sample points to those directly neighbouring the surface. At knuckled edges, the sampling process will collect points from adjacent faces of the surface preventing any accurate qualification of these edges without introducing more elaborate evaluation. Aside from the statistical evaluation, the most challenging aspect remains the efficient capture of cloud points for each evaluation on the surface. Again, without an efficient spatial mapping approach, as discussed in 4.3, this analysis can take tens of minutes.

Statistical analysis can produce a lot of numerical data but efficient ways of presenting this information are required so that areas of the surface outside tolerance are easily recognised and can be understood by other stakeholders who may not understand the details of this process. Graphical representations with coloured banding are a very effective means of illustrating tolerance, Figure 10e. In addition to illustrating the measured offset from the mean position, tolerance relative to the standard deviation and 'thickness' of the point cloud can be displayed. Furthermore, a graphical illustration need a second dimension to illustrate regions of the surface where there is no data. This can be achieved by introducing transparency.

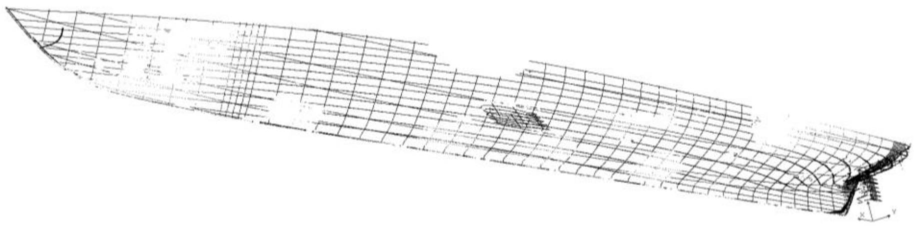
5. CASE STUDY

Figure 10 highlights the steps involved in capturing the surface definition of a 50m mega-yacht provided by Knud E. Hansen in the author's solution PolyCAD [7]. This is a good quality survey taken in on hard standing area with minimal obstructions, Figure 11. The survey, Figure 10a, is a low resolution scan consisting of 8 million points. While this is enough to capture the general shape of the surface it is insufficient to identify specific shapes such as the curvature of the stem and transition into keel. The polished hull finish above the waterline prevents capture and some underwater areas are missing. Roll stabilisers, rudders and propeller shafting included in the scan are to be excluded from the surface. The definition was generated prior to photographs being available. Figure10b, presents the survey sectioned into traditional planar contours.

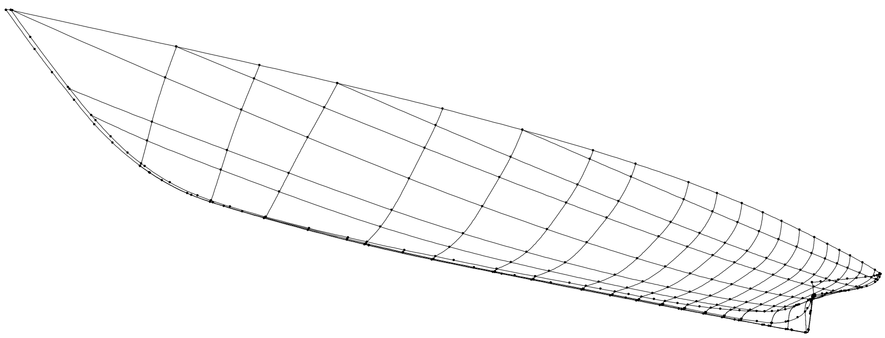
a)



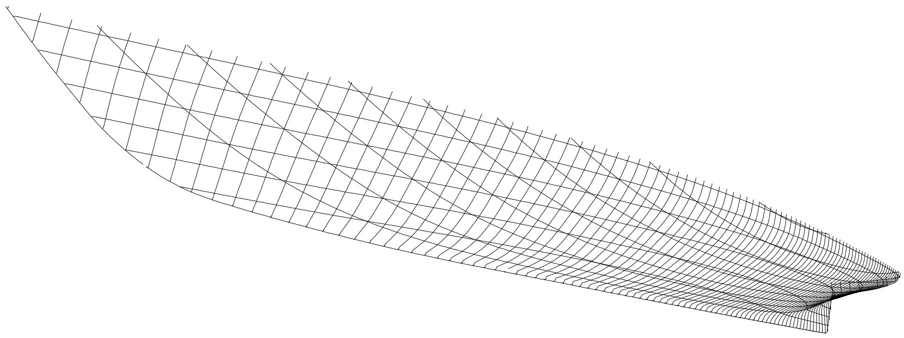
b)



c)



d)



e)

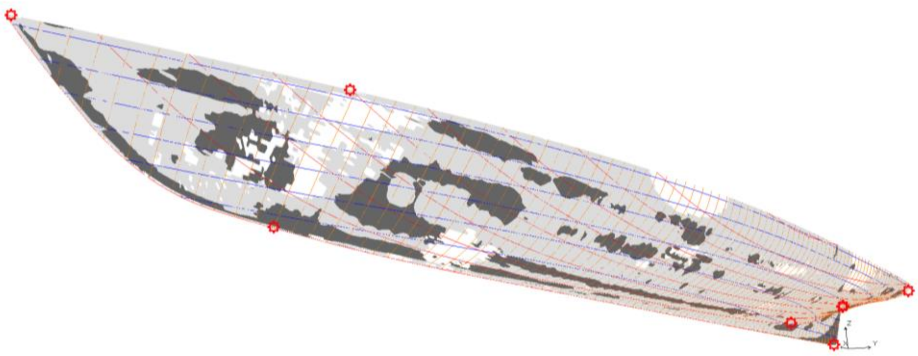


Figure 10: From Survey to hull surface with validation. a) Point Cloud, b) Contour sections, note poorly surveyed areas, c) Curve Network, d) Contours from hull surface, e) quantification, light grey < 10mm, dark grey > 10mm. White where there is not enough survey data.

© 2015: The Royal Institution of Naval Architects

Figure 11: Example survey took place on hard standing in ideal conditions with minimal obstructions. Reflective topsides prevented any measurements from being taken from this area of the vessel.

Identification of the surface boundary and feature curves such as knuckles and tangents took time since the transition between different features could not be easily seen in the low resolution scan. As these curves significantly influence shape of the surface where it transitions between the different regions it is important to get them right.

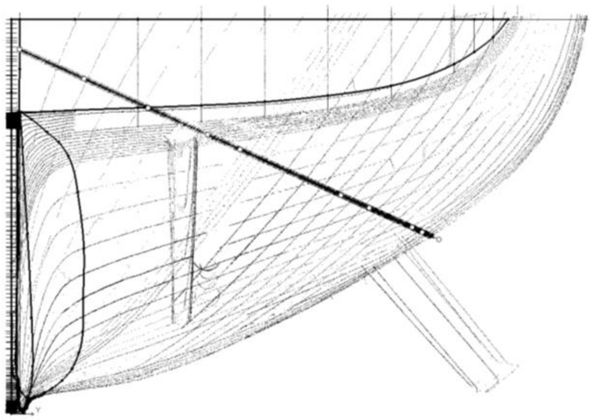


Figure 12, Survey is sectioned with diagonal planes to best capture shape for this surface configuration. Planes are positioned to avoid appendages.

Next, longitudinal shape curves are fitted to the survey. Using a diagonal arrangement of inclined planes, the cloud is sectioned and curve fitted with 10 control points each, Figure 9. The planar cuts are positioned to avoid picking up the roll stabilisers, rudders and propeller shafting, Figure 12. At the same time, the fit algorithm is tolerant of areas where there is missing survey data and separate clusters of points from hull supports. Section definition follows and completes the curve network, Figure 10c. The physical surface representation is generated and contours presented, Figure 10d. Figure 10e, qualifies the accuracy of the surface at a tolerance of 10mm. The dark regions indicate areas outside of this tolerance. Transparent areas, presented in white, highlight areas of the survey data where there isn't enough data to qualify the accuracy.

Considering the productivity of this example, it took around 2 hours to position the cloud and build up an initial structure of boundary and feature curves. The longitudinal and sections curves took around 20 minutes to select, generate and check as little input is required of the user other than to review the definition and adjust fit parameters. A further 8 hours were required review the feature curves to improve the representation. This task was by far the most challenging part of the process as the survey was not in a high enough resolution to reveal detailed shapes.

Once complete the surface definition was reviewed by the Knud E. Hansen team and compared with their earlier experience of this project. Qualifying the surface using curvature analysis tools highlighted that the surface did not appear to have the quality of that expected in a design surface. This raised the question how close the as-built vessel was to the design information or whether these observations were a result of operational incidents. Mirroring the surface representation and comparing with the survey highlighted what looked like local asymmetry. However, with a low resolution and poorly captured areas in the survey it was impossible to draw any concrete conclusion.

6. REVIEW

Point cloud surveys of hull exteriors are rarely available outside of commercial projects more so because of the large file size. The developments documented here came about with the opportunity to use the Zodiac dataset [2]. Considering that optical survey techniques have been available for more than a decade it is surprising that there is little opportunity to use this data in existing tools that create hull surface definitions. It is, after all, a logical extension of that described to derive definition from other data geometry sources [1]. The main challenge being the efficient handling of these large datasets. The implementation of this solution inside an application which supports common hull surface design techniques and analysis tools has fostered good discussion about how much is actually known about the quality of as-operated hull forms. Questions arise about whether observed inconsistencies in the hull geometry of a vessel were introduced during fabrication or as a result of operation and how much these may influence performance. However, without follow-up these observations remain just that.

The technique presented here has now been used on a range of different vessels and qualities of datasets. Operating the curve fitting process reduces the amount of time required to capture surface shape to the extent that it's no longer a significant part of the process. However, capturing characteristic features and boundaries takes

© 2015: The Royal Institution of Naval Architects

time as the precise shape of features are not always clear in the data or a there is conscious choice by the user to diverge from the shape represented in the survey to simply the surface. It's clear that to support these activities a minimum capability to manually match surface definition to the survey is necessary especially when the resolution is low or it's hard to determine the exact shape in the point cloud. With this comes a need to have expertise with hull surfaces and design software. Given that an important objective of this study is to make the process of recreating a hull surface easier and more accessible, it has been unfortunately that there has not been more enthusiasm from those with survey datasets to undertake their own independent review in favour of requesting the author to process the cloud data. So far, this solution has been promoted through direct contacts and wider public release could now allow more people to experience the solution and comment on its effectiveness.

7. CONCLUDING SUMMARY

Deriving a hull surface definition from the cloud points of an optical survey is presently accomplished by using a collection of applications. The methods used often produce surfaces that have large number of control points and use surface trimming. Although this an adequate hull form representation it limits modification and is reliant on numerical tolerances which may fail when the surface is transferred to other software systems. Scanning of hull forms presently takes place when the vessel is out of the water. It has to be supported by keel blocks and propping structures and there is normally maintenance work taking place both which can obscure the hull surface in survey. Existing fitting tools attempt to make an automatic fit of the surface to the survey dataset which means that these unwanted artefacts need to be removed from the point cloud. This takes time.

This study considers that the point cloud is captured in a challenging environment for optical surveying and many artefacts, such as hull appendages and supporting structures, will need to be excluded from the surface representation. Integrating the curve fitting from the point cloud as a user driven process into software normally used for hull design augments existing surface generation techniques and ensures that the representation produced is suitable for common downstream engineering activities such a hydrodynamic studies. Qualification of the accuracy of the surface is vital as this allows the user to manage the quality in all areas of the definition and presenting this information graphically allows all stakeholders to appreciate this regardless of technical expertise. Finally, while the main interest of this work was the fitting of surface definition to point clouds, the greatest challenge was certainly found to be the efficient organisation and retrieval of points from these large datasets.

8. ACKNOWLEDGEMENTS

The author would like to thank Giuseppe Tringali, Edwin Pang and Mirco Zoia of Knud E. Hansen for their assistance with the survey data presented in this paper and subsequent discussions. Christian Stark for providing the survey data of the Schooner Zodiac that initiated this work and sharing his experiences of turning this data into a surface.

9. REFERENCES

1. BOLE, M., 'Regenerating Hull Design Definition from Poor Surface Definitions and other Geometric Representations', *COMPIT 2014*, Redworth, UK, 2014.

2. STARK, C., 'Turn Tall Ship 3D Scan Data into a CAD Model', *https://fajexblog.wordpress.com/2013/12/26/turn-tall-ship-3d-scan-data-into-a-cad-model/, 2013*.

3. External Sort, *http://en.wikipedia.org/wiki/External_sorting*.

4. 'Dijkstra's Dutch National Flag Problem', *http://en.wikipedia.org/wiki/Dutch_national_flag_problem*.

5. BOLE, M., 'Revisiting Traditional Curve Lofting to Improve the Hull Surface Design Process', *COMPIT 2012*, Liège, Belgium, 2012.

6. FARIN, G., *Curves and Surfaces for CADG: A Practical Guide*, Morgan Kaufmann, 2002.

7. BOLE, M., PolyCAD, http://www.polycad.co.uk

9. AUTHORS BIOGRAPHY

Marcus Bole is presently a Naval Architect with AVEVA Solutions Ltd providing domain expertise and product knowledge to customers, sales and support teams. With previous experience in ship stability assessment, damage survivability and Naval Architecture software development has continued to highlight the need for effective and easy to use hull design software as well as develop solutions meeting these needs.

© 2015: The Royal Institution of Naval Architects