

# A 3-D Visualization Tool for Surface Metrology

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## **Abstract**

*Surface topography characterization is important in many industrial applications. Several parameters have been defined and included in the standards for this purpose. Many papers address the issue of whether these parameters adequately describe the geometry of the surface and their effectiveness in relating to function or the process. However, there has not been a lot of work in the area of graphical representation and visualization of surface metrology data. Visualization is a necessary tool to make sense of the flood of information that is being generated with increasing computing capability. Visualization tools help to represent the raw data and also comprehend the different parameters and related information. This paper explores the use of The Visualization Toolkit<sup>®</sup> (VTK<sup>®</sup>) to build a visualization toolbox for surface metrology. The toolbox is built on a C++ and Motif<sup>®</sup> platform using VTK<sup>®</sup> classes. Applications highlighting the value of this tool are also presented.*

## **1 Introduction**

Studying three-dimensional topography of a surface provides an understanding of the manufacturing process. The structure of most engineering components is complex with characteristic lay patterns [1] along a few directions on the surface. These patterns are clearly visible in some cases; in others, they are not observable even with careful visual inspection. In such cases, frequency domain analysis helps in better visualizing the directional properties of a surface.

Three-dimensional surface topography is typically obtained by collecting many parallel traverses of a stylus. The number of data points required to adequately represent a surface depends on the spatial resolution. A measurement process that leaves very small or no form components will require a small pitch or high resolution. On the other hand, coarse machining operations will not require a very high resolution. In any event, measuring a small square area 2.56 mm by 2.56 mm with a 10  $\mu\text{m}$  pitch in both directions involve collecting and processing 65536 data points which is certainly a large amount. Acquiring, processing and displaying such large quantities of data has been one of the major challenges in three-dimensional metrology.

Currently available commercial instruments are geared towards measuring two-dimensional profiles with increasing accuracies and have extensive data processing capability. Three-dimensional analysis is also available with limited numerical computation of parameters. However, they all lack good data visualization schemes that would pictorially represent the same numeric information. Traditionally, a single trace from a stylus instrument has been acquired and displayed. The problem with two-

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dimensional metrology is obvious. Directional information that could provide valuable insight into cutting tool marks, chatter and oil grooves among others is lost. Two-dimensional metrology however, is more popular today mainly because of the low cost of acquiring, processing and displaying data.

A surface analysis package with integrated two and three dimensional data visualization scheme is a valuable addition to the practicing engineer. The motivation for this work comes from the need for an effective tool for rendering three-dimensional surface data in a quick and effective manner. This paper explores the use of The Visualization Toolkit<sup>®</sup> (VTK<sup>®</sup>) [2] for developing a visualization toolbox for surface metrology. This paper describes the features of this toolbox, some testing results and applications.

## **2 Related work**

Rosen [3] has discussed the challenges of visualizing surface topography data. The paper discusses the use of CAD and image processing tools for visualization purposes. The drawback of CAD tools is the rendering speed. Image processing tools enable the user to have large number of points with reasonable speed. Hagedorn et al [4] present a visualization tool for atomic force microscopy data. Their system lets the user interact with the data and present the results in a meaningful form. The paper deals more with presenting surface normals and orientations. Sampling is an important issue in measurement and therefore in visualization. The normal procedure is to sample in a rectangular grid that has equal spacing in both directions. Whitehouse [5] presents a new hexagonal sampling grid. This technique however is difficult to implement in the real world. Gopalan et al [6] discuss visualizing two-dimensional profiles using a novel Internet based software tool.

## **3 Visualization, not graphics**

Computer graphics is the process of generating images using computers. This process of converting graphical data into an image is called rendering. The goal of visualization is to transform data into graphical data or primitives that can be rendered. The objective of the rendering is not so much image realism but to realize the information content by attempting interactive displays. Visualization transforms data into images that effectively and accurately represent information about the data. Hence, visualization deals with the issues of transformation and representation. Transformation is the process of converting data from its original form into graphics primitives and eventually into computers. Representation includes both the internal data structures and the graphics primitives used to display the data.

This paper explores a visualization tool for representing and visualizing surface finish data. The emphasis is not the graphics aspect but to build an interactive tool to capture information from the data set.

## 4 Data representation

Surface finish data collected from any commercial instrument typically outputs an ASCII file containing the Z height values at the sampled locations. The grid is composed of equally spaced points and measurement is often done on a square area. Instruments also report the spacing along the X and Y directions and any scaling or magnification factor used along the Z direction.

The dataset has regular topology and geometry and VTK<sup>®</sup> allows a convenient way to represent this data in the form of Structured Points. A structured point dataset is a collection of points arranged on a regular rectangular lattice. The representation scheme requires only data dimensions, an origin point and the data spacing. The simplicity and compactness of representation are desirable features of structured points. The major disadvantage is the curse of dimensionality. Increasing the dimension of the image to enhance resolution requires  $O(n^3)$  increase in memory.

## 5 Tools development

The application is built using C++ and Motif<sup>®</sup> and VTK<sup>®</sup> is interfaced for data visualization. Motif<sup>®</sup> is the industry standard graphical user interface, (as defined by the IEEE 1295 specification), used in several hardware and software platforms. It provides application developers, end users, and system vendors with the industry's most widely used environment for standardizing application presentation on a wide range of platforms. Motif is also the leading user interface for the UNIX<sup>®</sup> based operating system. Motif is selected for this application as the software is primarily intended to run in a Unix<sup>®</sup> environment.

The main application is a Motif<sup>®</sup> widget with menu options for opening a file and quitting the application. Fig. 1. shows a screen shot of the application. The different views include:

- Height Map Window (top left window in Fig. 1) displays the surface data as a height map.
- FFT Window (bottom left) shows the 2D FFT as a color map. This window lets the user pick a specific frequency and set its amplitude to zero.
- Inverse FFT Window (bottom center) shows the recreated surface as a height map suppressing the frequencies selected by the user in the FFT window.
- Animation Window (on the extreme right in Fig. 1) has an animation of the surface frequencies removed one after another. There are two plots in this window. The plot on the top is the FFT of the surface and the plot on the bottom is the recreated surface. This animation window masks frequencies one at a time and recreates and plots the inverse FFT. This occurs at a relatively fast rate to create an illusion of an animation. The user can also step frames by clicking on the “step frame” button. This successively displays one

animation frame after another. The mask to suppress the frequencies is also visible in the window as the solid circle.

Each of the windows allows the user to zoom, rotate and translate the image in that window.

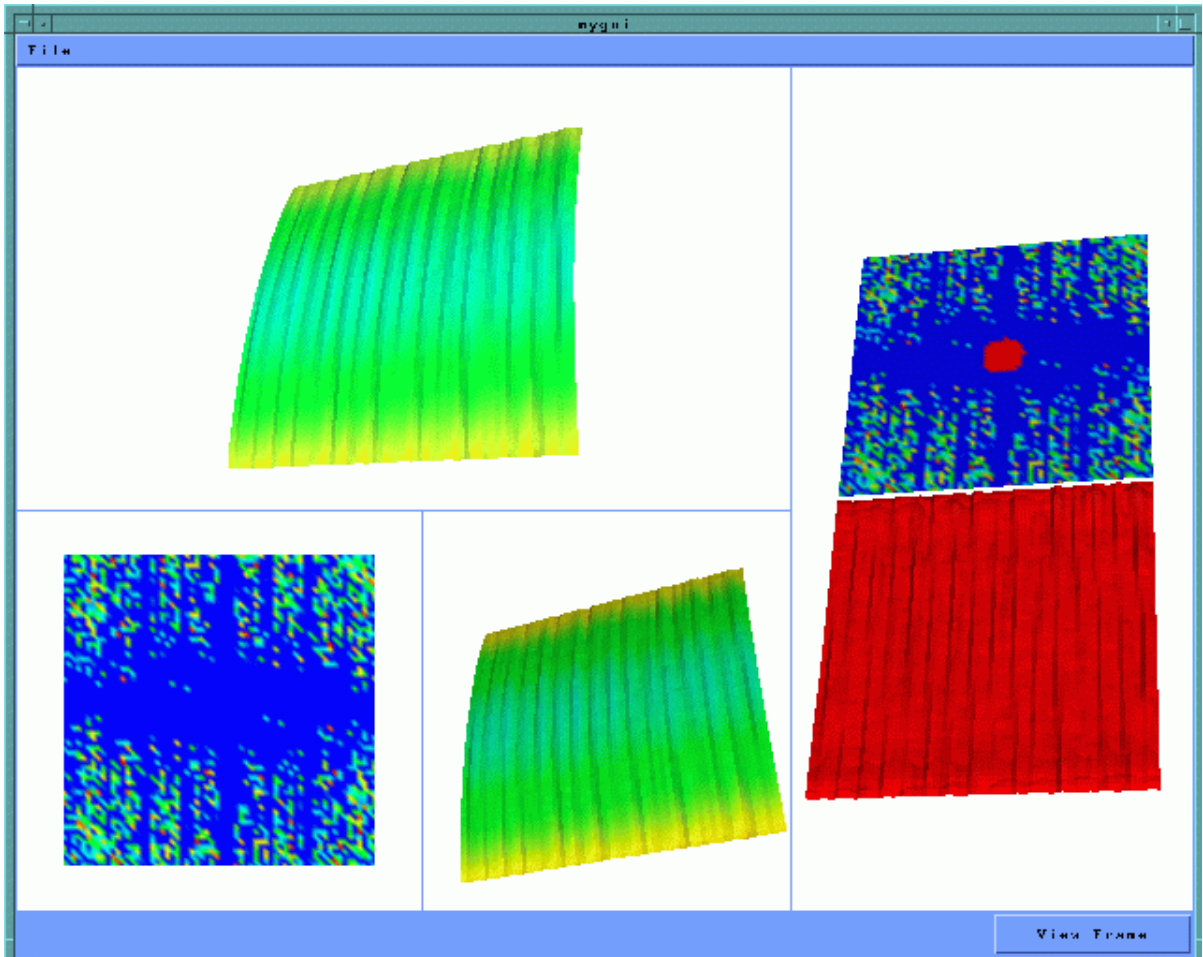


Fig. 1. Surface Metrology Visualization Application

## 6 Testing

The application is tested with data sets generated in Matlab<sup>®</sup> that have known directional properties. Sine wave surfaces are generated using Matlab<sup>®</sup> and fed to the application. This is primarily intended as a sanity check to make ensure that the FFT, inverse FFT and the animation tools function in a satisfactory manner. Three different data sets are generated using Matlab for testing. They include

- Single frequency sine wave in X, as shown in Fig. 2 for testing the FFT. The FFT plot in Fig. 3 shows two peaks and a DC term as expected.

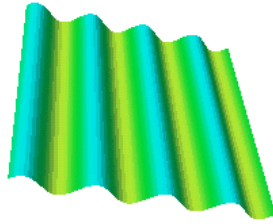


Fig. 2. Single frequency sine wave



Fig. 3. FFT of the sine wave

- A dual frequency surface is generated in Matlab. This surface is shown in Fig. 4. It is composed of a certain frequency in X and an identical frequency in Y. The FFT plot, in Fig. 5 shows 2 peaks in X and 2 in Y as expected. Suppressing the X frequencies by picking them in the FFT window should produce a pure Y frequency sine wave surface. The FFT window after picking and suppressing operation is shown in Fig 6 and the resulting surface is shown in Fig 7. This surface is designed to test the picking operation, frequency suppressing and surface recreation operation of the application.

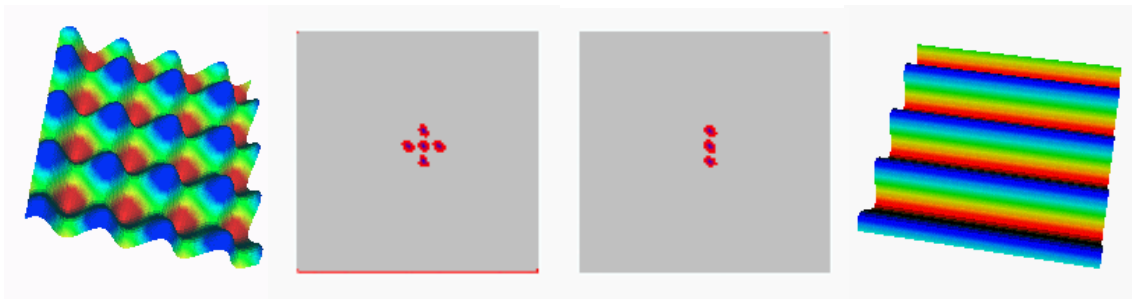


Fig. 4 2D sine wave

Fig. 5 FFT plot

Fig. 6 Suppressed FFT

Fig. 7. Recreated surface

- The third surface generated using Matlab consists of sine waves with 10 different frequencies at 45 degrees to X axis. The surface is shown in Fig 8 and the FFT is shown in Fig 9. This surface is designed to test the functioning of the FFT and animation tool for any centering and directional errors. The first animation frame removes the DC term, as shown in Fig. 10. For the

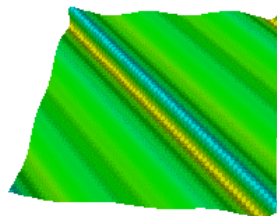


Fig. 8 Resulting surface



Fig. 9 Picking the X frequencies

purpose of illustration, the 7<sup>th</sup> frame is shown in Fig 11. The 7<sup>th</sup> frame has

removed the first 6 frequency components from the surface. Only higher frequency components remain in the surface as expected.

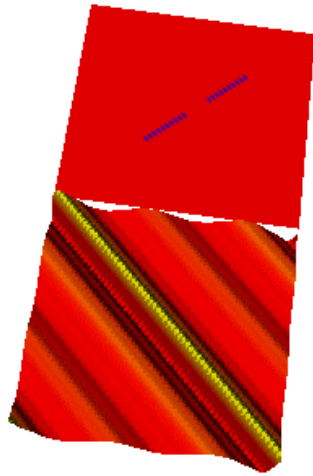


Fig. 10 First animation frame

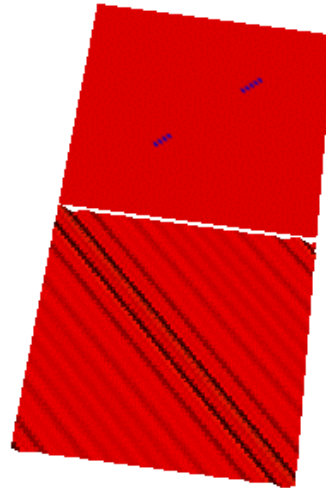


Fig. 11 7<sup>th</sup> animation frame

The tests described above have proved the validity of the results obtained from the application. The next section describes the visualization scheme obtained from real surfaces and the role of the picker and the animation tool in practical applications.

## 7 Applications

Two applications are presented here to illustrate the features of this visualization tool. One application attempts to visualize the different stages of a machining process by performing a reverse operation; that is, looking at a surface as different frequencies are slowly suppressed in the surface. This application highlights the animation aspect of the tool. The other application looks at the role of the picker tool in optical surface finish measurements where diffuser patterns are superimposed over the surface to introduce artificial features that show up in the spectral plot.

### 7.1 Observing turned surface generation process

Fig. 12 shows a typical turned surface and Fig. 13 shows the FFT of the surface. The cutting tool marks can be seen on the surface and also on the FFT plot as parallel lines. The first set of parallel lines represent the first harmonic and the other sets represent higher harmonics. A turned surface obviously produces cylindrical parts. The radius of the part is clearly seen as the curvature in Fig. 12. This curvature cannot be captured by the FFT because it is less than one sine wave and is therefore beyond the range of the FFT.

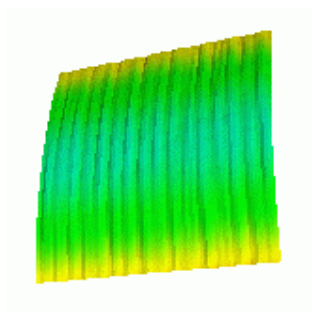


Fig. 12 Turned surface

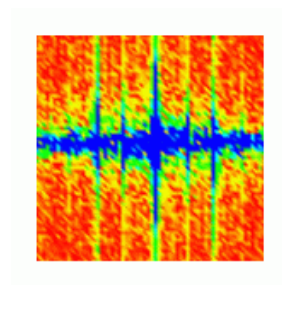


Fig. 13 FFT of turned surface

Fig. 14, 15, 16 and 17 are different stages of the animation of the turned surface. Fig. 14 and 15 clearly show the cutting marks on the surface. The FFT plot has not yet masked the surface. Fig. 16 and 17 show the mask applied on the first and second set of parallel lines on the FFT plot. Fig. 17 shows the surface after the cutting marks have been suppressed. Thus, animation tools can be used to understand the surface generation process and provide greater insight to the manufacturing process and functional nature of the surfaces.

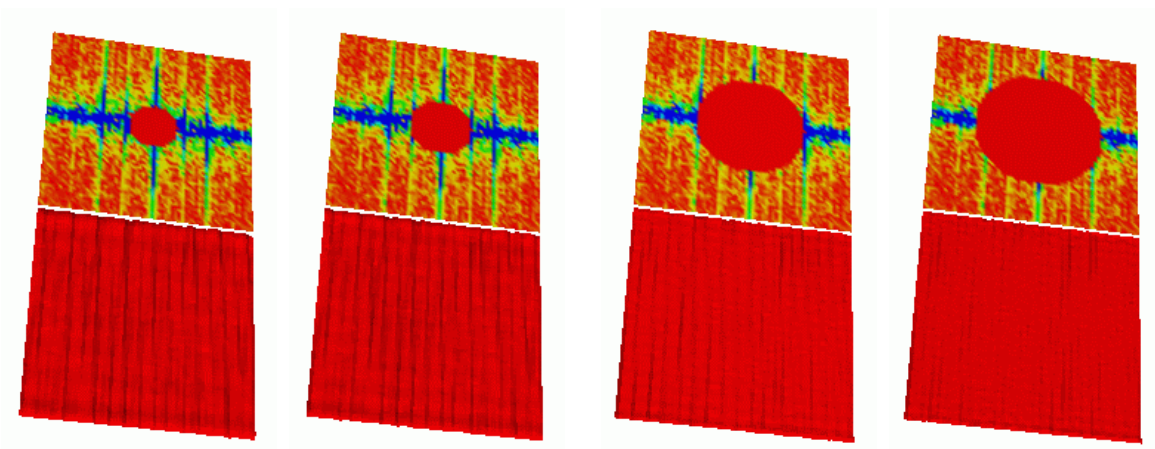


Fig. 14 Frame 5

Fig. 15 Frame 7

Fig. 16 Frame 13

Fig. 17 Frame 18

## 7.2 The role of the tool in optical surface measurements

Optical measurement of surfaces often superimposes spurious data over true surface. An optical measurement of a surface of a lens is considered for discussion here. A flat lens is produced by a lapping or finishing operation and has an extremely flat surface. In fact, lens are often used as a reference flat for comparison purposes. After a lens has been manufactured, it is taken to a test bed for measurement. A beam of light is incident on the surface normally. Some part of the light is reflected off the surface and the remaining goes through the lens, hits the rear surface and is reflected. The light reflected off the front surface is compared to the light reflected off the rear and flatness data points are recorded. Often, a diffuser is placed in the middle to control the amount of light in the



optical path and this diffuser introduces artificial patterns into the surface. A hatched pattern diffuser will superimpose its criss-cross structure over an ideally flat surface. Fig. 18 shows a measurement set up for a lens.

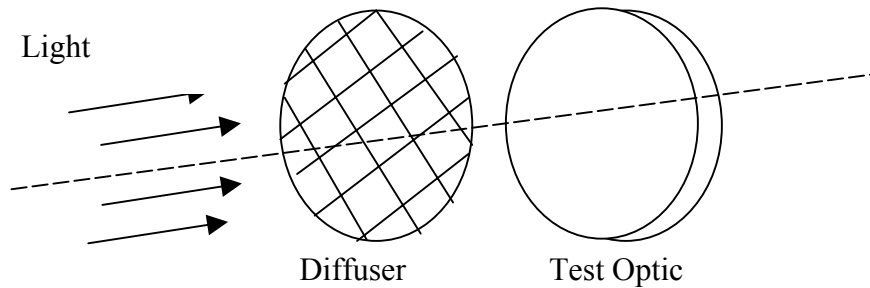


Fig. 18 Optical measurement of a lens surface

It is not easy to remove this hatch pattern because the orientation of the diffuser may not be the same in all cases. Also, different setups would require different diffusers (different pitch in the grid) resulting in different frequencies on the surface. However, it is easy to remove the pattern if it is possible to view the frequency on the FFT plot and suppress the amplitude. The picker in this application provides this facility. It lets the user pick a frequency in the FFT window and set its amplitude to zero. It is possible to easily identify the frequency that the diffuser introduces, as there is prior knowledge of the orientation of the hatch pattern. The frequency due to the diffuser is set to zero to obtain the true surface.

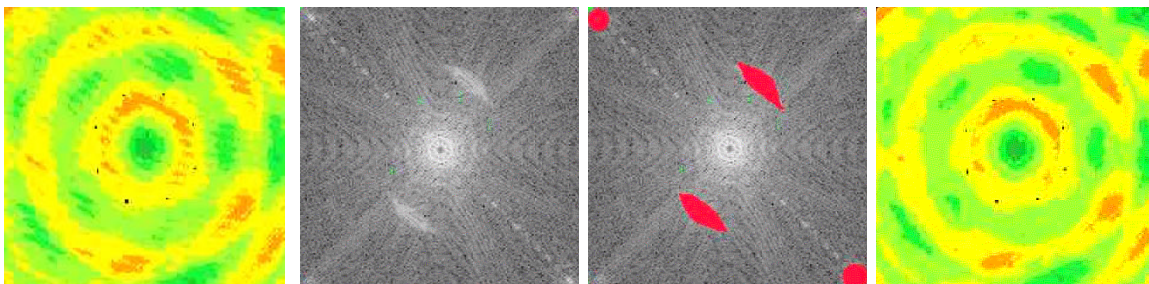


Fig. 19 Optical surface

Fig. 20 FFT plot

Fig. 21 Masked FFT

Fig. 22 Inverse FFT

An optical surface with diffuser patterns is shown in Fig. 19 and its FFT plot is shown in Fig. 20. The diagonal terms are set to zero as shown in Fig. 21. The inverse FFT is carried out and Fig. 22 shows the resulting surface. It can be seen that the hatch pattern has been removed and the measurement data is now ready for numerical evaluation.

## 8 Discussions and Conclusion

Instruments available in the market today can represent 3D surface data in a color map and also represent them as a static height map. They do not provide an interactive visualization like this application does. However, they provide abundant quantitative information that may be useful in some instances.



The application developed here aids the user in frequency analysis of surfaces by visualization. The user can see the different frequency components present in a surface by means of an animation. A turned surface is chosen to illustrate this tool. The user can also pick and remove frequencies from a surface. An optical system is chosen as an example to illustrate the value of this tool.

This paper has presented a visualization tool for frequency analysis of surfaces. It could be expanded to provide the user with analysis capabilities existing in current commercial software packages. Such a software package will provide the user with an invaluable tool for quantitative and interactive visual analysis in a single framework.

## **9 References**

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