

# SAGUARO: Data Analysis Software for Optical Engineering

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**Abstract:** SAGUARO software is written for the optical engineer and designed to simplify data analysis and visualization. SAGUARO is easy for the end-user processing optical test information as well as the developer adding new functionalities.

**OCIS codes:** (100.2000) Digital image processing; (100.2960) Image analysis; (120.6650) Surface measurements, figure

## 1. Introduction

SAGUARO [1,2] software is designed to simplify data analysis and visualization for optical fabrication and testing tasks. In today's complex optical system design and analysis, data from multiple sources such as interferometer hardware or simulation results are required. Typically each source stores data in a different format. Without careful planning, it is too easy to end up with the same functionality embodied in several pieces of code, each written for a specialized data format. Maintaining accuracy of code with this type of organization is difficult at best.

SAGUARO simplifies data analysis with over 30 open-source modules such as Zernike fitting, spatial frequency filtering, and other routines which integrate with the SAGUARO kernel to work across data sources. Developed with a user-friendly graphical interface in the MATLAB™ [3] environment, SAGUARO is intended to be easy for the end-user in search of useful optical information as well as the developer wanting to add new modules and functionalities. In this article, we present an introduction to SAGUARO and demonstrate its utility to the optical engineering society by showing an example of Zernike analysis of surface data. The latest version of the software can be downloaded from:

<http://www.loft.optics.arizona.edu/saguaro/>

## 2. SAGUARO Overview

The heart of SAGUARO is the kernel which provides quick and easy access to data information, module selection, and macros. A running list of datasets provides a clear history of data processing, and easy ability to compare different processing options. A preview window provides instant feedback on how the data appears at every step of the processing. The SAGUARO kernel is the main access point to data loading and processing. A typical preview image and list of modules is shown in figure 1.

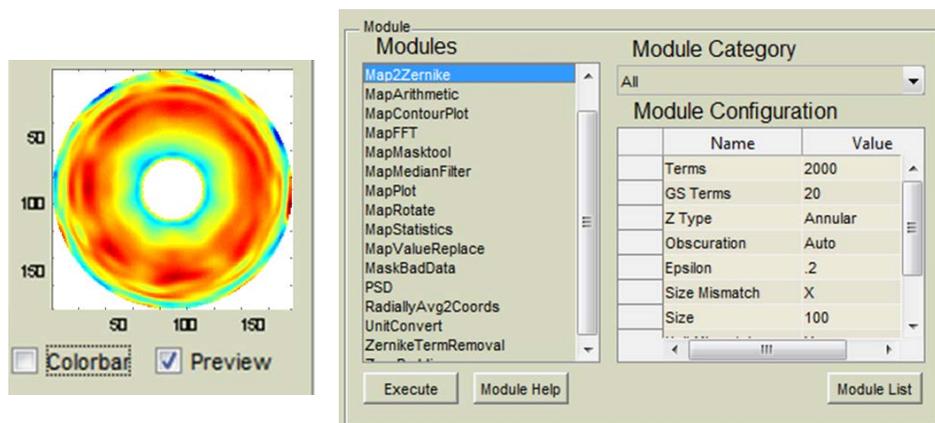


Fig. 1. Portions of the SAGUARO interface. (left) preview image. (right) List of some SAGUARO modules

While the kernel is the heart of the program, the modules and macros are the muscle. Over 30 modules come standard with SAGUARO and documentation is provided to allow customized routines to be easily added. These modules perform a variety of tasks such as masking bad data, computing surface height statistics, or removing Zernike terms. Because the modules are written in terms of optical fabrication and testing concepts, they are easy to understand and apply. Modules are sortable by category and additional help on module specifics can be easily found from the SAGUARO interface.

Stringing together modules into macro sequences is an important part of streamlining common processing steps, and is built in to SAGUARO. To simplify parameter entry, all macros, and module parameters are associated with individual user settings. This can turn otherwise tedious processing routines into a few simple clicks of the mouse.

Accuracy of SAGUARO calculations is of paramount importance. At the Large Optics Fabrication and Testing (LOFT) group at the University of Arizona, we rely upon SAGUARO daily for polishing of large optics such as the Giant Magellan Telescope (GMT) [4]. It is used by both scientists and technicians in a place where calculation errors can be very costly. We continually evaluate and verify SAGUARO modules for accuracy.

### 3. Example: Zernike Filtering with SAGUARO

To illustrate SAGUARO's utility in analyzing optical testing data, we present an example of filtering Zernike terms from a measured telescope mirror. The raw data, stored in a simple tab-delimited text file, is read into SAGUARO and processed into a standard "map" data type with two clicks and entry of a couple of parameters to describe the physical size and units of the imported data. The result is shown in the preview image of figure 1.

SAGUARO has several standard data types, including a map data type typically used for surface maps, a Zernike data type which contains a list of Zernike polynomials, and other types for masking data or working in the frequency domain. When those are unsuitable, a general data type can be used for specialized routines. The modules available for each data type are automatically selected by SAGUARO to only provide features that make sense in the context of the data. Some modules can convert between data types, such as the "Map2Zernike" module which extracts Zernike polynomials from surface measurements.

In this example, we select the "ZernikeTermRemoval" module from our list of available modules. The help for this module explains that both annular and standard zernikes are supported, and describes a few details about the calculation. Because modules may be written by a variety of people, author and contact information is provided with each module. We encourage modules to be freely shared and provide a "SAGUARO Garden" web forum which can be found on our website [1]. SAGUARO is intended for the optical fabrication and testing community and we encourage the community to contribute. Modules submitted by users which are of sufficient quality or popularity will be included with the standard release after testing and review.

Upon running the module, a series of dialog boxes prompt us for configuration parameters. In this case, we want to remove the first 11 Zernike terms due to measurement uncertainties of low order aberrations. This process is shown in figure 2. After parameter entry, SAGUARO goes to work and generates a new data map.

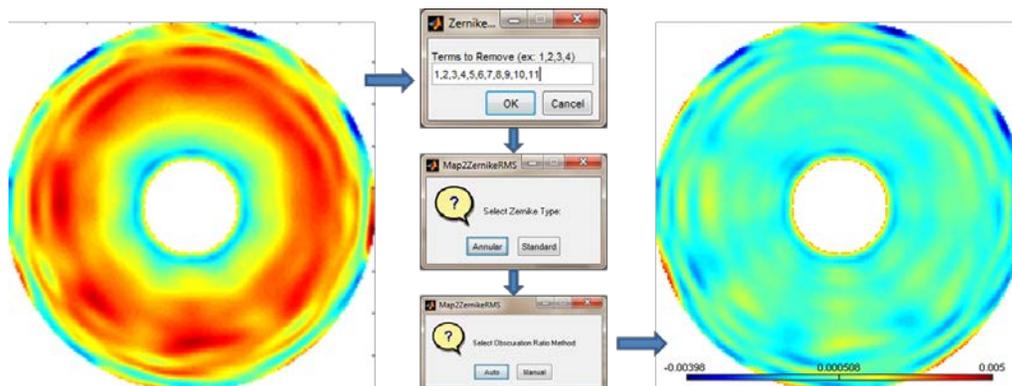


Fig. 2. Removing low order aberrations from a surface map requires a few parameters and a couple of mouse clicks

From here, there are several options available. The “MapStatistics” module output (see figure 3) displays surface height and slope information that can feed into the next polishing run. If imaging were the primary concern, the “MapFFT” module could be used to examine spot-size quality. Perhaps the preview image indicates the processing is pretty good as-is, and it just needs to be included in a report or presentation. In that case, the “MapPlot” module will provide options to add a title, detailed axis labels, or other annotations. At any point, the data can be exported to a file, or even to a variable in the MATLAB<sup>TM</sup> environment for more complicated processing.

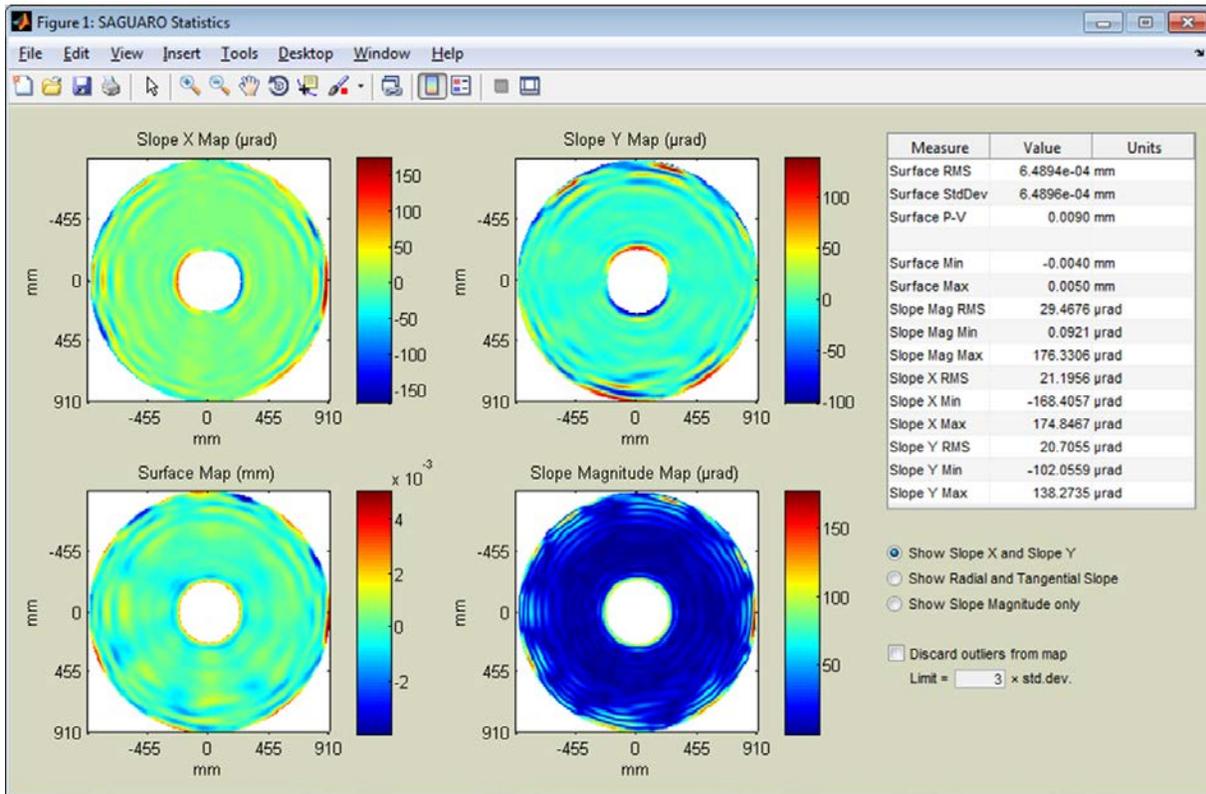


Fig. 3. Output from the “MapStatistics” module displaying height and slope information of the processed data.

#### 4. Conclusion

SAGUARO is a free, platform designed to translate the computation power of MATLAB<sup>TM</sup> into a program easily accessible to those working in optical engineering. The example of Zernike term removal demonstrates how a few parameters and a couple of mouse clicks in SAGUARO can streamline data processing. Perhaps the best feature of SAGUARO is that it is as easy to develop new modules as it is to use the well-tested, open-source routines that come standard with the SAGUARO download.

[1] For more information about SAGUARO including the latest version and a forum for exchange of modules, please visit <http://www.loft.optics.arizona.edu/saguaro/>. Please send questions to the corresponding author of this paper.

[2] Dae Wook Kim, Benjamin J. Lewis and James H. Burge, "Open-source data analysis and visualization software platform: SAGUARO", Proc. SPIE 8126, 81260B (2011).

[3] Mathworks, "MATLAB - The Language Of Technical Computing", <http://www.mathworks.com/products/matlab/> Note that some SAGUARO modules require specific MATLAB toolboxes which may need to be purchased separately.

[4] H. M. Martin, R. G. Allen, J. H. Burge, D. W. Kim, J. S. Kingsley, M. T. Tuell, S. C. West, C. Zhao and T. Zobrist, "Fabrication and testing of the first 8.4-m off-axis segment for the Giant Magellan Telescope", Proc. SPIE 7739, 77390A (2010).