Contrast Transfer Function Analysis Tool for Head Mounted Displays - User's Manual

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1 Introduction

The Contrast Transfer Function (CTF) is an important image quality parameter for head-mounted displays (HMDs), as it quantifies the Michelson contrast as a function of spatial frequency of the horizontal or vertical grille patterns displayed on the HMD. Computing the CTF for head-mounted displays can be challenging due to the technical differences among various HMDs, including the display technology and optical components.

The CTF analysis tool processes the acquired images from the HMD display. To compute CTF of the HMD, a grille pattern with equal width white and black bars in the vertical or horizontal direction are displayed on the HMD screen. The varying widths of the bars correspond to different spatial frequency values, representing different cycles per degree, allowing for the measurement of Michelson contrast at these spatial frequencies.

We developed an general method that can be applied to a wide variety of HMDs, encompassing different design and display technologies to generate reproducible CTFs. The analysis tool we developed automates the CTF analysis and calculations with minimal user interaction. The developed method has been tested on the following HMDs:

HTC Vive Pro and Vive XR Elite

Meta Quest 2 and Quest 3

Magic Leap 2

The output results of the CTF analysis tool are listed as follows:

- The CTF curve shows the contrast values as a function of spatial frequency (cycles per degree).
- Standard deviation of luminance/signal from bright (white pixels) and dark (black pixels) areas displayed in the HMD.
- Average luminance/signal from bright (white pixels) and dark (black pixels) areas displayed in the HMD.
- CTF cutoff point at the highest spatial frequency value allowed by HMD resolution and/or rendering limits of the HMD.
- Data table of all outputs saved in CSV format.

2 Installation

The software package contains an executable file called "CTF Tool Installer". Run the installer file and follow the instructions that pop-up during the installation of the CTF analysis tool. Here are some important points to consider while installing the CTF analysis tool:

- Locate the program on your computer's local drive. By default, the program installs to this directory "C:\Program Files\FDA\Contrast_Transfer_Function_Analysis_Tool" as shown in the figure 1.

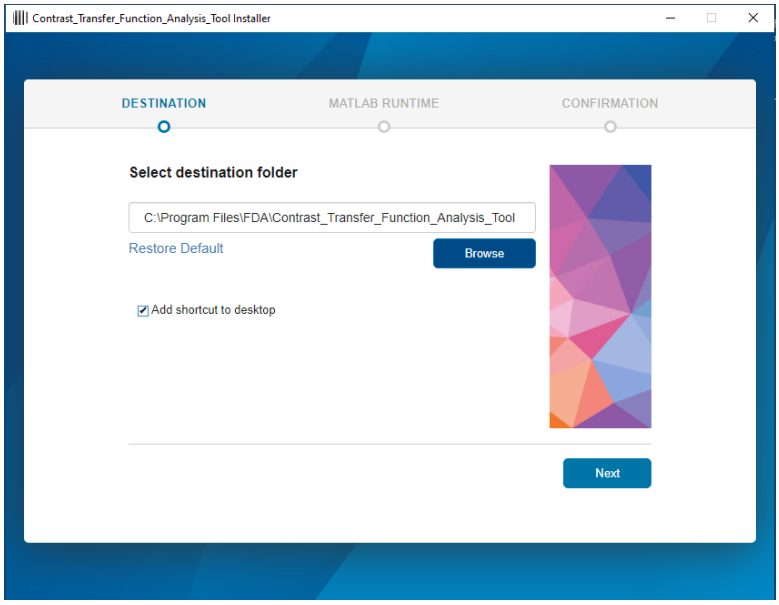


Figure 1: This figure shows the destination folder prompt to choose the directory path to install the CTF tool. By default it is located in "C:\Program Files\FDA". Also, the user can add a shortcut to desktop.

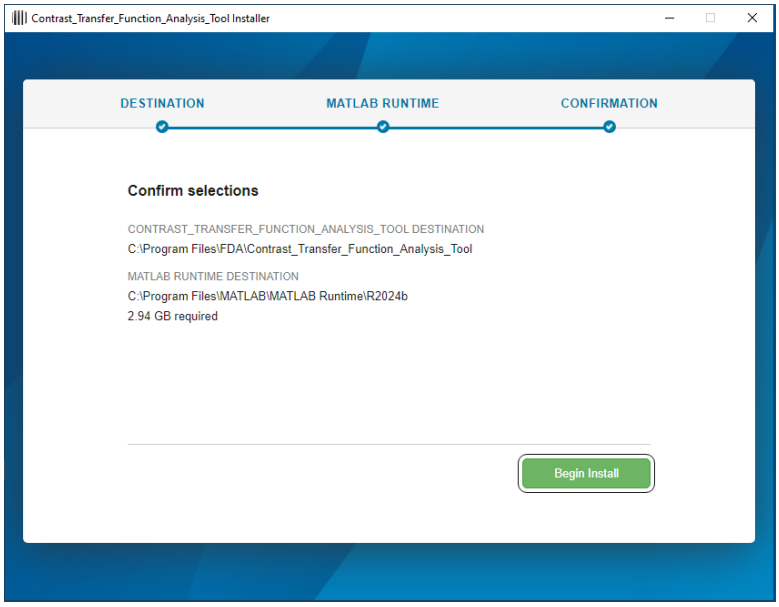


Figure 2: This figure shows the confirm selections prompt for the destination folder and Runtime version for installation. The CTF tool has been tested on this version "Runtime version R2024b (24.2)".

- Check the box to add shortcuts to the desktop, if needed as shown in the figure 1.
- You may be prompted to download the Runtime version R2024b (24.2). This is the tested version for the tool as shown in the figure 2 (Note: Installing MATLAB 2024B is not required).
- Open the installed program to start using the CTF analysis tool located at "C:\Program Files\FDA\Contrast_Transfer_Function_Analysis_Tool".

Figure 3: This figure shows the desktop shortcut icon for the CTF analysis tool. Clicking this icon will open the tool's graphical user interface, as shown in Figure 4.

3 Usage

3.1 Getting Started

To start using the CTF analysis tool, open the installed application icon, as shown in figure 3, this will pop-up the graphic user interface, as shown in figure 4.

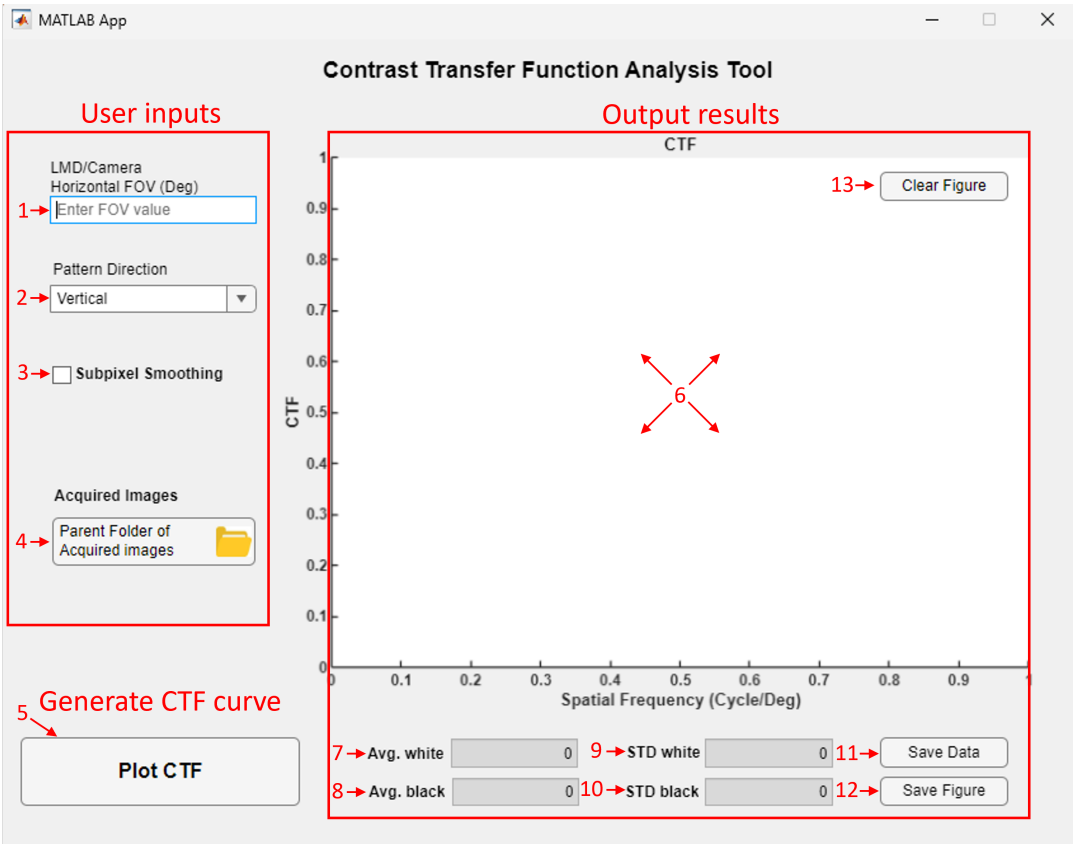


Figure 4: This figure shows the graphic user interface (GUI) of CTF analysis tool. The left section of GUI is for user inputs. The bottom left side is "Plot CTF" button for processing the acquired images and generate the CTF. The right section of GUI is for output results. The description of the numbering labels is in section 3.1.

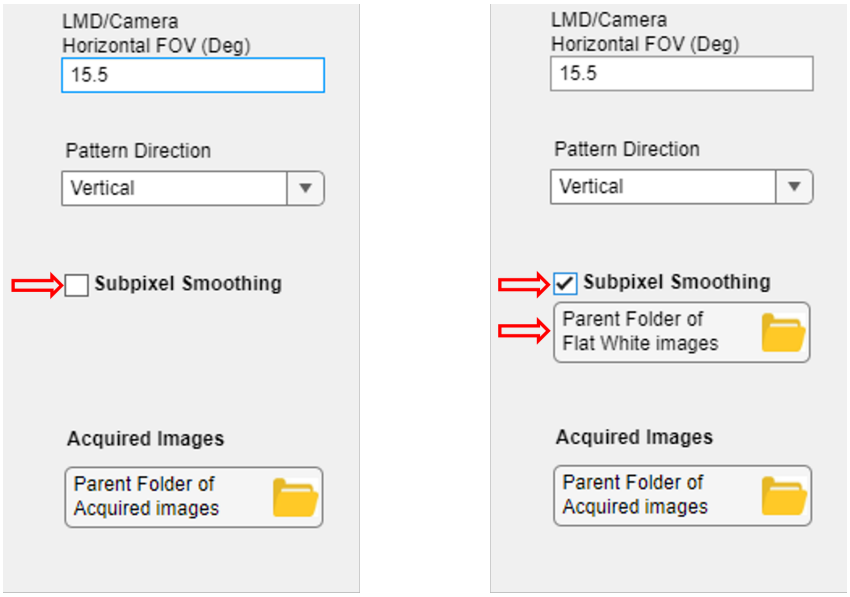


Figure 5: "Subpixel Smoothing" feature is to resolve the subpixel issue by smoothing the data. (a) "Subpixel Smoothing" is not checked therefore the parent folder browser is not appear. (b) Once "Subpixel Smoothing" is selected, folder browser appears to locate the folder contains flat white images.

The following list outlines the inputs required to run the CTF analysis tool, as labeled in the figure4 :

1. LMD/Camera Horizontal FOV (Deg): This is the horizontal field of view (FOV) value of the camera or light measuring device (LMD) used to acquire the images. Minimum acceptable FOV value is two degrees.

2. Pattern Direction: This drop-down menu offers two options, Vertical or Horizontal, indicating the direction of the grille pattern displayed in the HMD and acquired images. The default selection is set to Vertical pattern direction.

3. Subpixel Smoothing: This feature smooths the acquired images where subpixels are visible due to the HMD display technology. For example, HMDs with traditional stripe RGB or Pentile subpixel arrangements may have subpixel effects that influence processing results. Smoothing these images addresses this issue.

    - If Subpixel Smoothing is selected, the "Parent Folder of Flat White Image" option will appear, as shown in Figure 5, allowing the user to select the location where the Flat White Images are saved. The flat white images are used to compute the subpixel spacing, which is then used to determine the optimal filter size. This filter size is applied to smooth the signal.
    - If Subpixel Smoothing is not selected, no action is required.

4. Parent Folder of Acquired Images: Locate the folder that contains the sub-folders of acquired images, as shown in Figure 7.

Once the input parameters are entered, click the "Plot CTF" button, as labeled with number "5" in the figure4, to generate the CTF curve and compute the output results, which are displayed in the output results section of the GUI.

The following list outlines the output results after running the CTF analysis tool, as labeled in the figure4:

6. CTF plot : This is the plot area where the axes are displayed. The x-axis represents the spatial frequency (cycles/deg), and the y-axis represents the CTF values.

7. Avg white: The average luminance/signal value for the bright area of the image (white pixels).

8. Avg black: The average luminance/signal value for the dark area of the image (black pixels).

9. STD white: The standard deviation of luminance/signal value for the bright area of the image (white pixels).

10. STD black: The standard deviation of luminance/signal value for the dark area of the image (black pixels).

11. Save Data: Allows the user to save the data in CSV format. Once the user clicks on "Save Data", a destination folder prompt will appear, allowing the user to name and locate the file.

12. Save Figure: Allows the user to save the figure in PDF format. Once the user clicks on "Save Figure", a destination folder prompt will appear, allowing the user to name and locate the file.

13. Clear Figure: Allows the user to clear the figure area and prepare for a new run. If a new CTF run is conducted, the current figure will be overwritten with the new one.

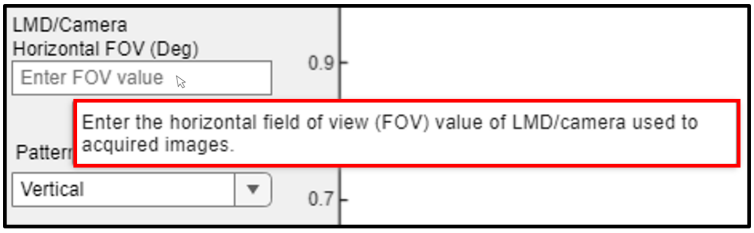
3.2 Interactive Tooltips and Error Messages

The CTF analysis tool GUI is designed to display help messages and error notifications. Figure 6(a) shows the help message that appears when the user's mouse cursor hovers over the label of "Enter FOV value" in the tool's GUI. These pop-up messages are provided for all input and output sections. Additionally, Figure 6(b) shows an error notification indicating that the camera resolution is below the required threshold to process the data. Similar error notifications will appear in case of other issues, such as missing inputs.

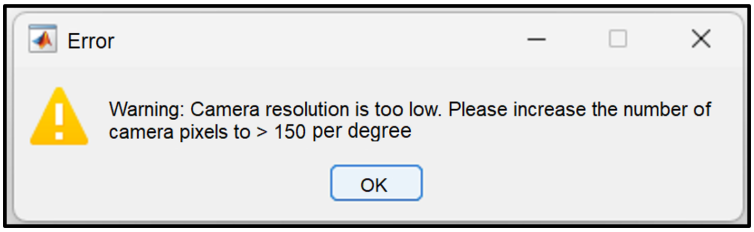
3.3 Camera Settings for Image Acquisition

The CTF analysis tool only accepts images with a resolution greater than 150 pixels per degree. If a low-resolution camera is used, an error message will appear, as shown in Figure 6(b). The following are the recommended instructions and camera settings for image acquisition:

- The camera must be centered and focused to the center of the image displayed on HMD screen.



(a)



(b)

Figure 6: This figure shows the help messages and error notifications. (a) is a help message appears when user hovers over "Enter FOV value". (b) shows an example of error notification, for example, the camera resolution is low.

- The camera's gain of the camera must set to 0.
- The camera's gamma value must set to 1.
- Set integration time of the camera to maximum without saturating any pixels.

3.4 Naming Conventions of Acquired Image Sub Folders

All images at the same spatial frequency must be located in a single subfolder. Only numbers must be used to name these subfolders, starting with the number "1" as shown in figure 7. The subfolders must be ordered either from the lowest to the highest spatial frequency or vice versa. The CTF analysis tool will read all the images inside these subfolders, regardless of their names.

Note: it is recommended to order the subfolders from the lowest to highest spatial frequency as shown in figure 7. Please find the example attached with software package.

3.5 Example

The CTF analysis tool package has an example for testing. The input values of this example are FOV ="15.5" and the pattern direction is "Vertical". The flat white images saved at "Example\FlatWhite_Images".
The second folder is for the acquired images saved at "Example\Acquired_Images".

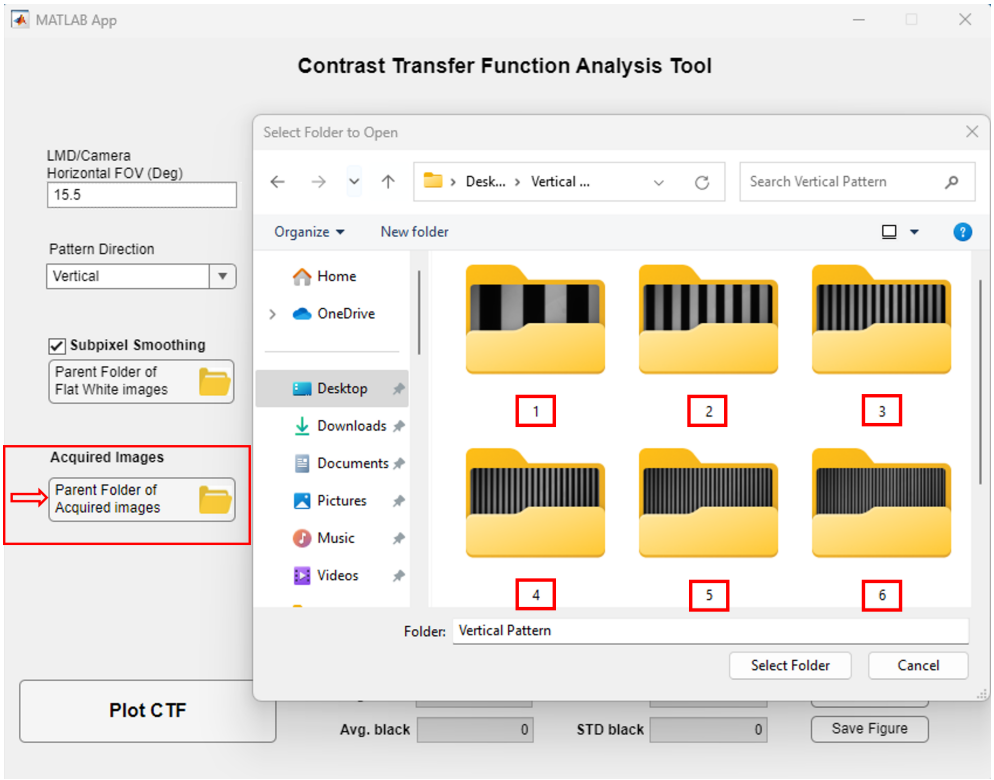


Figure 7: This figure illustrates the naming conventions for subfolders located under the parent folder of acquired images. Only numbers are allowed for subfolder names. Subfolder names must follow a sequential order, starting with "1". It is recommended to place the acquired images of the lowest spatial frequency in subfolder "1" and continue to higher frequencies in sequential order, as shown in this figure.

4 Troubleshooting

4.1 Common Error

To avoid common errors, the user should pay attention to the following:

- Use a camera with a resolution greater than 150 pixels per degree.
- Enter an accurate FOV value.
- Select the appropriate pattern direction: "Vertical" or "Horizontal".
- Specify the path to the parent folder containing the acquired images and flat white images, if applicable.
- Enable the "Smoothing Subpixel" feature, if needed, to resolve potential subpixel issues.
- Name the subfolders of the acquired images as explained in the "Naming Convention" section 3.4.
- Order the subfolders sequentially, from the lowest to the highest spatial frequency, or vice versa.

4.2 Contact Support

If you encounter issues not covered in this manual, please contact our support team at RST_CDRH@fda.hhs.gov.

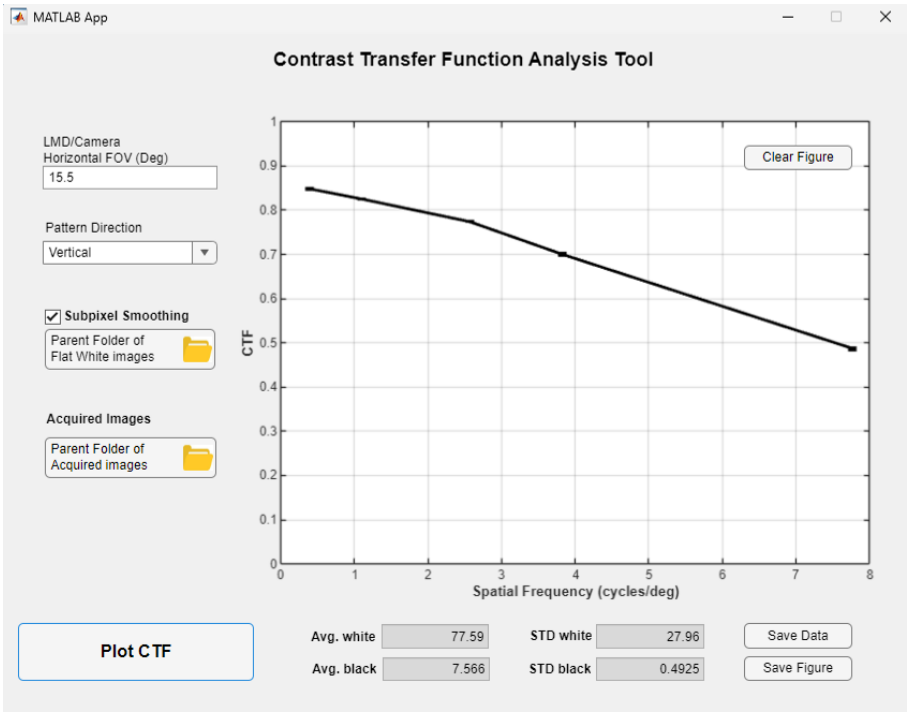


Figure 8: This figure shows the input values of the FOV and pattern direction. Also this figure shows the output results of the example attached with CTF analysis tool package.

5 Conclusion

Thank you for using Contrast Transfer Function Analysis Tool. We hope this manual helps you make the most of your product.