Zemax® "User-Defined Surface" DLL for simulation of Micromachined Membrane Deformable Mirrors (MMDM) manufactured by Flexible Optical B.V.

User's Guide

April 7, 2017 (version 1.4)

1 Introduction

Through user-defined surfaces (UDS) Zemax provides powerful mechanism for simulating of optical elements which are not covered by built-in surface types [4]. UDS is a software module (more specifically DLL, dynamic link library) which internally can simulate any phenomena (reflection, refraction, absorption, diffraction etc.) occurring at the surface of interest.

This particular UDS is designed to simulate membrane-based deformable mirrors manufactured by Flexible Optical B.V. We provide this UDS to facilitate design by customers of their systems utilizing our deformable mirrors. Thus it is possible to evaluate parameters of a particular model of deformable mirror and assess it applicability to some particular application and setup. Also it makes easier to choose between several available mirror models. It is also possible to test some custom actuator configurations by generating some new configuration files.

This software is developed by Flexible Optical B.V. in collaboration with Fraunhofer Institute for Laser Technology ILT/ Chair for Technology of Optical Systems TOS RWTH Aachen University. Part of the development was carried out within the framework of UltraSURFACE European project (H2020-ICT-2015, Project no. 687222).

Deflection $S(x, y)$ of the membrane in response to a voltage distribution $V(x, y)$ applied to the actuator structure positioned at a distance d below the membrane is described by Poisson equation (Δ denotes Laplace operator) [3]:

$$\Delta S(x, y) = P/T,$$

where T is a uniform surface tension and electrostatic pressure P is given by:

$$P = \frac{\varepsilon\varepsilon_0 V(x, y)^2}{d(x, y)^2}.$$

The voltage distribution is defined by geometry of actuators and applied control signals, while boundary conditions are determined by a shape of membrane contour. In general case, the equation can be only solved numerically and this implementation utilizes pre-calculated response functions (separate set for each mirror model) for better performance. The finite-difference version of Poisson equation is solved numerically by relaxation method [2].

2 System requirements

Only 64-bit versions of Zemax on Windows platform are currently supported. This software is tested to work with Zemax 13 release 2, but should function properly with any recent version of the software. It exports `UserDefinedSurface4` function and would not work with some [very old] legacy versions of Zemax which expect only `UserDefinedSurface`, `UserDefinedSurface2` or `UserDefinedSurface3`. Please refer to corresponing section of Zemax manual and to thier support for details. The requirements for personal computer hardware and operation system are implied by Zemax software itself, but most resonably modern systems running Windows 7 or newer will work.

3 Files and installation

The library is compatible with both "classic" Zemax and "modern" Zemax OpticsStudio. Since those packages maintain their files in separate directory trees, it is necessary to choose correct directory during

Table 1: Files included in the distribution

`us_mmdm.dll`	Main executable dll file, required
`mmdm15-37.bin`	Support file for MMDM 15mm, 37 channels ([1], section 7.3)
`mmdm15-17.bin`	Support file for MMDM15-17-TT ([1], section 7.4)
`mmdm30-39.bin`	Support file for MMDM 30mm, 39 channels ([1], section 7.5)
`mmdm30-59.bin`	Support file for MMDM 30mm, 59 channels ([1], section 7.5)
`mmdm30-79.bin`	Support file for MMDM 30mm, 79 channels ([1], section 7.5)
`mmdm40-59.bin`	Support file for MMDM 40mm, 59 channels ([1], section 7.6)
`mmdm40-79.bin`	Support file for MMDM 40mm, 79 channels ([1], section 7.6)
`mmdm50-79.bin`	Support file for MMDM 50mm, 79 channels ([1], section 7.7)
`mdm96.bin`	Support file for membrane-based 96-channel deformable mirror with embedded electronics and USB interface (25.4mm aperture)
`mmdm15-39.bin`	Support file for MMDM 15mm, 39 channels (custom-built)
`mdm96_test_sph.zmx`, `mdm96_test_sph.ses`	Example model and session file demonstrating use of a deformable mirror for compensation of spherical aberration caused by a simple plane-convex lens.
`mmdm_set.zpl`	Zemax macro for setting all (or a group) of the mirror control channels to a specified value
`mmdm_set_var.zpl`	Zemax macro for setting variable status of control channels (extra data)
`mmdm_merit_limits.zpl`	Zemax macro for inserting merit function operators limiting range of control signals to desired values
`mmdm_load.zpl`	Zemax macro for loading control values from a text file
`mmdm_save.zpl`	Zemax macro for saving of control values to a text file
`mmdm_smile37.zpl`	Zemax macro for making "smile" test pattern on the surface of MMDM37
`response8.py`	Python script for generating mirror support files
`mmdm*_actuators.txt`	Actuators geometry description files, used by `response` script
`mmdm*_vias.txt`	Actuator vias geometry description files, used by `response` script
`response_mmdm_all.bat`	Batch file to generate all (or some) mirror support files
`us_mmdm_ug.pdf`	This User's Guide

installation. If it is desired to use both programs, it is required to either copy the files manually, or run the installer twice, separately for each package.

The main DLL file is named `us_mmdm.dll` and it should be placed into appropriate directory for user defined surfaces within Zemax program tree (default is `c:\Program Files\Zemax\DLL\Surfaces\`). Zemax does not allow to load UDS files from any other place. The DLL requires separate binary files for each mirror model. They named accordingly to the model, have `.bin` extention (for example `mmdm15-37.bin`, `mmdm50-79`, `mdm96` etc.), and have to be placed into the same directory as the DLL. Several examples are included along with useful macros. They are not strictly neccessary for module functioning and in general may be placed in any convenient place. The summary of the files incuded is given in Table 1.

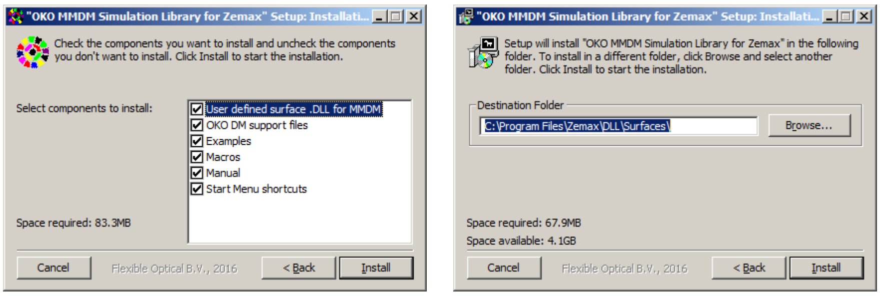
The software is supplied in the form of single-file executable installer which copies files automatically (Fig 1). It is also possible to manually extract files with an archiving utility (such as 7-zip) and copy them into desired place. This method might be useful for some non-standard or network installations. Please note that coping files into subfoldres of `Program files` directory normally requires administrator access rights, so (depending on the system settings) it might be required to invoke the installer "as administrator".

4 Using the UDS with your model

After adding a new surface into your model, please perform the following steps.

1. In the lens parameter table double-clik with the left mouse button on the surface type field to invoke surface type dialog. In the field "Surface type" select "User-defined" and in the field "File name" choose "`us_mmdm.dll`". Click "OK" to confirm (Fig 2).

2. In the field "Comment" of the corresponding surface enter name of the deformable mirror model (it should correspond to the filename without extension) (Fig 3).



"OKO MMDM Simulation Library for Zemax" Setup: Installati...

Check the components you want to install and uncheck the components you don't want to install. Click Install to start the installation.

Select components to install:

☑ User defined surface .DLL for MMDM
☑ OKO DM support files
☑ Examples
☑ Macros
☑ Manual
☑ Start Menu shortcuts

Space required: 83.3MB

"OKO MMDM Simulation Library for Zemax" Setup: Installati...

Setup will install "OKO MMDM Simulation Library for Zemax" in the following folder. To install in a different folder, click Browse and select another folder. Click Install to start the installation.

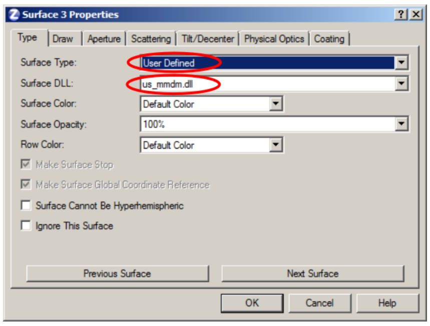
Destination Folder: C:\Program Files\Zemax\DLL\Surfaces\

Space required: 67.9MB
Space available: 4.1GB

Figure 1: Installation dialog

3. Set Semi-diameter of the surface to correct value (depends on the model of the mirror).

4. Now you can use "Extra data editor" to set control values and variable status (if required) for all control channels (Fig 4). Those parameters represent normalized values and can take values from -1 to 1. If the value outside this range is entered, it is clamped internally, but that change is not reflected in Zemax editor, since there is no technical possibility to pass parameter in from DLL to the main application. Please note that Zemax OpticsStudio has slightly different (supposedly more "user-friendly") interface compared to original Zemax. It lacks "Extra data editor" and uses lens editor to edit extra parameters. The user needs to scroll right in the window to get access to those columns.

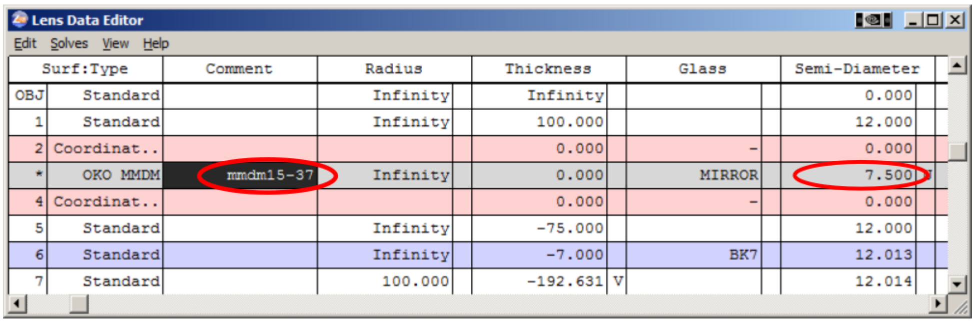


Surface 3 Properties

Surface Type: User Defined
Surface DLL: us_mmdm.dll
Surface Color: Default Color
Surface Opacity: 100%
Row Color: Default Color

☑ Make Surface Stop
☑ Make Surface Global Coordinate Reference
□ Surface Cannot Be Hyperhemispheric
□ Ignore This Surface

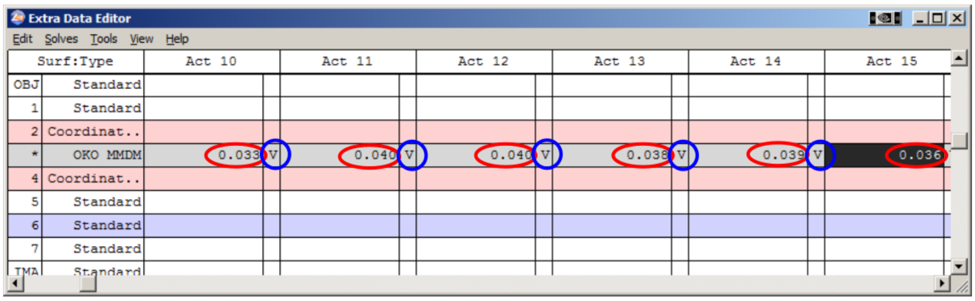
Figure 2: Settings in "Surface type" dialog



Lens Data Editor

Surf:Type		Comment	Radius	Thickness		Glass		Semi-Diameter
OBJ	Standard		Infinity	Infinity				0.000
1	Standard		Infinity	100.000				12.000
2	Coordinat..			0.000		-		0.000
*	OKO MMDM	mmdm15-37	Infinity	0.000		MIRROR		7.500
4	Coordinat..			0.000		-		0.000
5	Standard		Infinity	-75.000				12.000
6	Standard		Infinity	-7.000		BK7		12.013
7	Standard		100.000	-192.631	V			12.014

Figure 3: Selecting of DM model

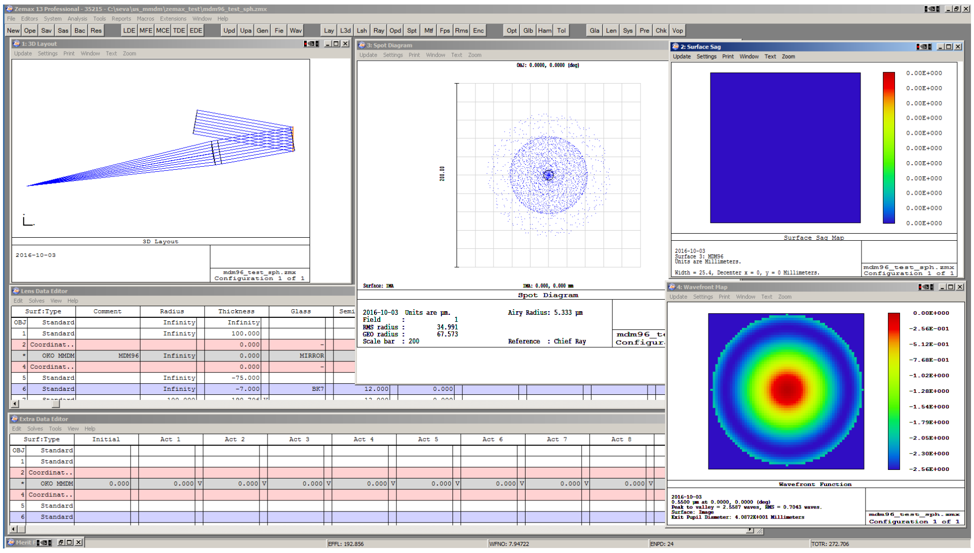


Surf:Type		Act 10	Act 11	Act 12	Act 13	Act 14	Act 15
OBJ	Standard						
1	Standard						
2	Coordinat..						
*	OKO MMDM	0.033 V	0.040 V	0.040 V	0.038 V	0.039 V	0.036
4	Coordinat..						
5	Standard						
6	Standard						
7	Standard						
IMA	Standard						

Figure 4: Setting DM control values in “Extra data editor”

5 Usage example

The example Zemax file is supplied along with the package demonstrating how to use `us_mmdm.dll` user defined surface in optical design. In this example, parallel beam is reflected by the mirror and focused with a thick plane-convex lens. One can see appreciable amount of the spherical aberration (Fig. 5). After optimization (all deformable mirror control values are taken as variables), focusing quality is drastically imroved and has reached the diffractioin limit (Fig. 6).



2016-10-03
mdm96_test_sph.zmx
Configuration 1 of 1

Surface: IMA
IMA: 0.000, 0.000 mm

```
2016-10-03  Units are µm.              Airy Radius: 5.333 µm
Field      :         1
RMS radius :    34.991
GEO radius :    67.573
Scale bar  : 200                       Reference  : Chief Ray
```

```
2016-10-03
Surface 3: MDM96
Units are Millimeters.

Width = 25.4, Decenter x = 0, y = 0 Millimeters.
```

```
2016-10-03
0.5500 µm at 0.0000, 0.0000 (deg)
Peak to valley = 2.5587 waves, RMS = 0.7043 waves.
Surface: Image
Exit Pupil Diameter: 4.0872E+001 Millimeters
```

Surf:Type		Comment	Radius	Thickness	Glass
OBJ	Standard		Infinity	Infinity	
1	Standard		Infinity	100.000	
2	Coordinat..			0.000	-
*	OKO MMDM	MDM96	Infinity	0.000	MIRROR
4	Coordinat..			0.000	-
5	Standard		Infinity	-75.000	
6	Standard		Infinity	-7.000	BK7

Surf:Type		Initial	Act 1	Act 2	Act 3	Act 4	Act 5	Act 6	Act 7	Act 8
OBJ	Standard									
1	Standard									
2	Coordinat..									
*	OKO MMDM	0.000	0.000 V	0.000 V	0.000 V	0.000 V	0.000 V	0.000 V	0.000 V	0.000 V
4	Coordinat..									
5	Standard									
6	Standard									

EFFL: 192.856 WFNO: 7.94722 ENPD: 24 TOTR: 272.706

Figure 5: Example mmdm96_test_sph. Initial state, appreciable amount of spheric aberration is clearly visible.

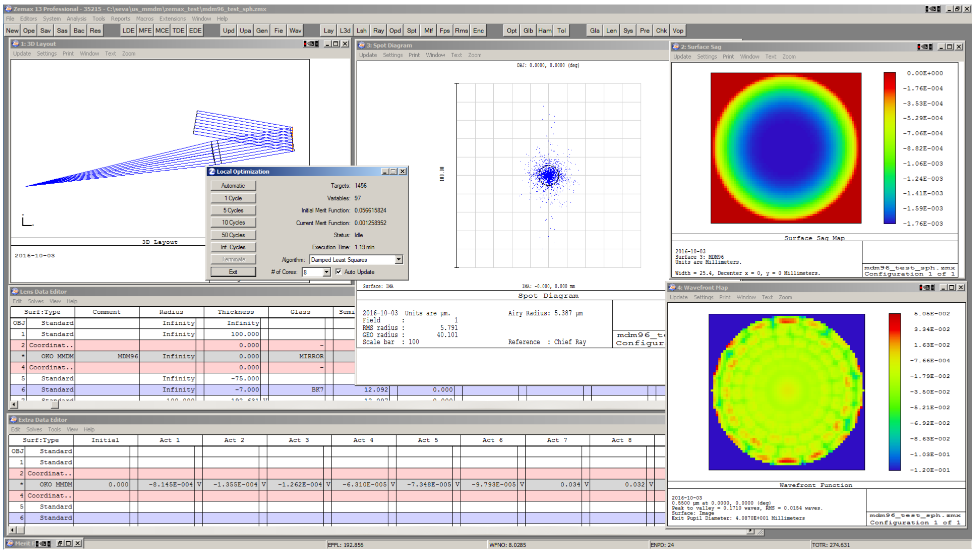
6 Data formats

In order to add support for some custom membrane mirror, it is necessary to create binary support file containing response functions for individual actuators. File format is given in Table 2 below. All parameters are in Intel little-endian byte order. The data can be obtained either experimentally, by wavefront measurement, or by simulation.

Please note that current version of the library expects only files with `grid_x`=`grid_y`, thus second of those parameters is redundant.

7 Generating mirror support files

A Python script is provided for generation of mirror support files along with data file describing MMDM actuators geometry for several standard models of deformable mirrors. Thus, it is possible for the user to propose and test their own actuators design. The utility accepts a number of command line parameters (which are documented inside the source) and produces data files to be used by `us_mmdm` module as well



Zemax 13 Professional - 35215 - C:\seva\us_mmdm\zemax_test\mdm96_test_sph.zmx

Targets: 1456
Variables: 97
Initial Merit Function: 0.056615824
Current Merit Function: 0.001258952
Status: Idle
Execution Time: 1.19 min
Algorithm: Damped Least Squares
# of Cores: 8 ☑ Auto Update

```
2016-10-03  Units are µm.              Airy Radius: 5.387 µm
Field      :          1
RMS radius :      5.791
GEO radius :     40.101
Scale bar  : 100                        Reference  : Chief Ray
mdm96_t
Configur
```

```
2016-10-03
Surface 3: MDM96
Units are Millimeters.

Width = 25.4, Decenter x = 0, y = 0 Millimeters.
mdm96_test_sph.zmx
Configuration 1 of 1
```

```
2016-10-03
0.5500 µm at 0.0000, 0.0000 (deg)
Peak to valley = 0.1710 waves, RMS = 0.0154 waves.
Surface: Image
Exit Pupil Diameter: 4.0870E+001 Millimeters
mdm96_test_sph.zmx
Configuration 1 of 1
```

	Surf:Type	Comment	Radius	Thickness	Glass	Semi	
OBJ	Standard		Infinity	Infinity			
1	Standard		Infinity	100.000			
2	Coordinat..			0.000	-		
*	OKO MMDM	MDM96	Infinity	0.000	MIRROR		
4	Coordinat..			0.000	-		
5	Standard		Infinity	-75.000			
6	Standard		Infinity	-7.000	BK7	12.092	0.000

	Surf:Type	Initial	Act 1	Act 2	Act 3	Act 4	Act 5	Act 6	Act 7	Act 8
OBJ	Standard									
1	Standard									
2	Coordinat..									
*	OKO MMDM	0.000	-8.145E-004 V	-1.355E-004 V	-1.262E-004 V	-6.310E-005 V	-7.348E-005 V	-9.793E-005 V	0.034 V	0.032 V
4	Coordinat..									
5	Standard									
6	Standard									

EFFL: 192.856 WFNO: 8.0285 ENPD: 24 TOTR: 274.631

Figure 6: Example mmdm96_test_sph. Deformable mirror control channeles were set as variables. After optimization the spot diagram and wavefront map indicate that almost difraction quality of focusing is achieved.

Table 2: Mirror support file structure definition.

Offset (bytes)	Type	Length (bytes)	Parameter name	Description
0		16		Reserved
16	uint32	4	`act_n`	Number of actuators
20	uint32	4	`grid_x`	Horizontal grid dimension (pixels)
24	uint32	4	`grid_y`	Vertical grid dimension (pixels)
28	float	4	`aperture_r`	Semi-diameter of the mirror aperture (mm)
32	float	`grid_x`×`grid_y`×4		Flat configuration
…	…	…	…	…
32+`grid_x`×`grid_y`×4×i	float	`grid_x`×`grid_y`×4		Response function for the i-th actuator, $i \in [1 \ldots$ `act_n`$]$
…	…	…	…	…

as several byproducts like graphical representation of the actuators with correct numnering. The program is able to generate inline graphics when called from interactive console (for example, ipythone qtconsole). It worsk silently if executed as a part of batch file.

8 Differences between Zemax versions

The software can be used with both "classic" *Zemax* and *Zemax OpticStudio*. The following potential issues should be taken into consideration.

- The packages are installed into different directories. Default is `c:\Program Files\Zemax\` for Zemax (64-bit) and `c:\Program Files\Zemax OpticStudio\` for OpticStudio (64-bit). Please choose appropriate directory during installation. If it is desired to used both versions sid-by-side you can either copy files manually or install our simulation software twice, for each version separately.
- Zemax OpticStudio does not have "Extra Data Editor" as a separate window. This functionality is provided by "Lens Data Editor", additional columns for extra data are located far to the right. In the case of `us_mmdm` user-defined surface relevant paramters are marked as *Act 1*, *Act 2* and so on.
- It seems that due to software bug (or feature?) OpticsStudio lacks some merit function operators, `XDLT` and `XDGT` are among them. When optimization procedure is used during simula-

tion and actuator control voltages are often defined as variables. Naturally, there are physical limits on those parameters and they are normally implemented with merit function operators (`mmdm_merit_limits.zpl` macro can be used to make those settings easyer). This works in Zemax but not in OpticsStudio. Please contact Zemax technical support to learn about possible solutions.

- Comment field is used to pass model of the deformable mirror into the DLL. In Zemax this field is initially left empty, while OpticsStudio pre-fills the field with some information. It is still possible to enter correct data in OpticsStudio.

References

[1] Flexible Optical B.V. OKO guide to adaptive optics. http://www.okotech.com/images/pdfs/catwww4.pdf, 2013.

[2] William H. Press, Saul A. Teukolsky, William T. Vetterling, and Brian P. Flannery. *Numerical recipes in C (2nd ed.): the art of scientific computing.* Cambridge University Press, New York, NY, USA, 1992.

[3] S. Timoshenko and S. Woinowsky-Krieger. *Theory of plates and shells.* McGraw-Hill, 1953.

[4] Zemax LLC. Zemax 13 optical design program. User's manual. (supplied with the software), 2014.