İSTANBUL TEKNİK ÜNİVERSİTESİ

FEN-EDEBİYAT FAKÜLTESİ

GRADUATION PROJECT

MATLAB-based Nonlinear Optical Z-Scan Data Analysis Programming

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ABSTRACT

This thesis presents a MATLAB-based application designed for analyzing experimental data from Z-scan measurements. Z-scan measurements are a critical technique for exploring nonlinear optical properties in materials, such as doped thin films and various types of glasses. The software's primary purpose is to aid in the importation and manipulation of raw data, allowing researchers to gain valuable insights into the optical characteristics of the materials under examination. The application features an intuitive user interface that simplifies the process of data manipulation, converting complex raw measurements into an easily analyzable format.

The software has advanced visualization tools that enable the graphical representation of scattering profiles. This allows for a direct visual assessment of sample behaviors under varying conditions. The application utilizes advanced fitting algorithms calibrated to align with theoretical models for phenomena such as open aperture Z-scan, closed aperture Z-scan, two-photon absorption and three-photon absorption processes. These algorithms accurately calculate critical material parameters, including the nonlinear absorption coefficient (β) and the nonlinear refractive index (n_2).

A MATLAB tool is available for this purpose, which integrates data importation, manipulation, and analysis in a user-friendly interface. This tool optimizes the research workflow. By streamlining these processes, the application not only enhances the efficiency and precision of nonlinear optical property studies but also contributes significantly to advancing the field of photonics research. The implementation of this application represents a significant step forward in the quest for a deeper understanding of nonlinear optical phenomena, offering researchers a powerful tool to expedite their discoveries in the realm of optical materials science.

ACKNOWLEDGMENTS

I would like to express my deepest gratitude to Assoc. Dr. Murat ERDEM, my thesis advisor, for his unwavering support and guidance throughout this research.

I cannot forget the incredible emotional support provided by my family, especially my grandparents, who have always believed in me.

MUHAMMED BEKTAŞOĞLU July, 2024

FIGURES

ABBREVIATIONS AND SYBOMLS

β	:	Nonlinear absorption coefficient
n_2	:	Nonlinear refractive index
Z	:	Rayleigh Range
L_{eff}	:	Effective Length of the Sample
α	:	Linear absorption coefficient
L	:	Thickness of the sample
i	:	Intensity of the incident laser beam
ω_0	:	Intensity of the incident laser beam
λ	:	Wavelength of laser

1. INTRODUCTION

Nonlinear optics is the study of the behavior of light in nonlinear media, where the response of the material to light is not directly proportional to the light intensity. This field has revolutionized the way we manipulate light, leading to advancements in a wide range of applications from high-speed communication to medical imaging. Understanding the nonlinear optical properties of materials is crucial for the development of devices such as lasers, optical switches, and modulators.

Z-Scan Technique: A Tool for Nonlinear Optics Exploration

The Z-scan technique is a simple yet powerful experimental method to measure the nonlinear optical properties of materials. It involves moving a sample through the focus of a laser beam and measuring the transmitted light intensity as a function of the sample position relative to the focal plane. This technique can distinguish between different types of nonlinearities, making it invaluable for characterizing materials for photonics applications.

The open aperture Z-scan method is used to measure nonlinear absorption, including phenomena like two-photon absorption and saturation absorption. In an open aperture setup, the entire transmitted beam is detected, allowing for the analysis of materials' absorptive nonlinearities without the influence of nonlinear refraction.

Contrastingly, the closed aperture Z-scan technique is utilized to assess nonlinear refraction. A small aperture is placed in the far field to partially block the transmitted beam. This setup enables the measurement of the phase distortion induced by the sample, providing insights into the refractive nonlinearities of the material.

Two-photon and three-photon absorptions are nonlinear optical process where photons are absorbed simultaneously, transitioning an electron from a lower to a higher energy state. These phenomena are crucial for applications requiring controlled light-matter interactions, such as in optical limiting and photodynamic therapy.

This thesis introduces a MATLAB-based application designed to simplify the analysis of experimental data from Z-scan measurements, enhancing the study of nonlinear optical properties in materials. By offering an intuitive platform for data manipulation, visualization, and fitting to theoretical models, this work contributes significantly to the field of photonics research. The application not only streamlines the experimental workflow but also provides a robust tool for the accurate characterization of nonlinear optical phenomena, thereby facilitating the advancement of optical materials science.

2. THEORETICAL PERSPECTIVE

2.1. Open Aperture Z-Scan

The Open-Aperture Z-Scan technique is used to measure the nonlinear absorption properties of materials by keeping the aperture fully open to capture all transmitted light. It is particularly effective at the focal point where light concentration is highest. Significant reductions in light transmission at this point indicate strong nonlinear absorption, such as two-photon absorption. This method is valuable for exploring the optical limiting capabilities of rare-earth ion-doped glasses and thin films, crucial for photonic and optoelectronic applications. Understanding these properties helps in designing optical limiters to protect sensitive equipment from intense laser pulses and in developing more efficient optical amplifiers. The open-aperture Z-Scan is noted for its sensitivity and versatility, making it a superior and essential tool in the study of optical nonlinearities compared to traditional methods. [9] Theoretical-experimental method of nonlinear optics: the Z-scan technique South Florida Journal of Development, Miami, v.4, n.4. p. 1807-1827, 2023. ISSN 2675-5459

$$Y = 1 - 2\left(\frac{(\frac{x}{z})^2+3}{(\frac{x}{z})^2+9}\right)\left(\left(\frac{x}{z}\right)^2 + 1\right)\left(\frac{\beta i}{2}\right) L_{eff} \qquad (2.1)$$

$$L_{eff} = (1 - e^{-\alpha L})/\alpha \qquad (2.2)$$

$$z = \frac{\pi w_0^2}{\lambda} \qquad (2.3)$$

2.2. Closed Aperture Z-Scan

The Closed-Aperture Z-Scan method is a precise experimental technique for determining the nonlinear refractive index (n_2) of materials. In this method, a sample is positioned at the focal point of a laser beam that passes through an aperture. As the beam travels through the sample, it either expands or contracts due to changes in the refractive index, which are then detected at a second aperture set at twice the focal length from the lens. The technique utilizes changes in beam size to measure the nonlinear refractive index as the sample moves along the z-axis. Introduced by Sheik-Bahae et al. in 1990, it's known for its simplicity and effectiveness in quantifying nonlinear optical properties. The method operates on the principles of self-focusing and self-defocusing, which indicate whether a material has a positive or negative n_2. The detector measures changes in the transmitted beam's intensity to create a characteristic transmittance curve, which reflects the material's nonlinear properties. The curve's peaks and troughs help determine the sign and magnitude of n_2, providing valuable insights into the material's optical behavior.

[8] Sheik-Bahae, M., Said, A. A., & van Stryland, E. W. (1990). Sensitive measurement of optical nonlinearities with a single beam Z-scan. Optics Letters, 14(11), 955-957.

$$Y = 1 + \frac{\left(\frac{4xD}{z}\right)}{\left(\left(\frac{x}{z}\right)^2+9\right)\left(\left(\frac{x}{z}\right)^2+1\right)} \qquad (2.4)$$

2.3. Two Photon Absorption

Two-photon absorption (TPA) is a distinct nonlinear optical phenomenon that involves a direct transition from the ground state to higher energy states facilitated by the simultaneous absorption of two photons. This process allows molecules to absorb energy from two photons concurrently, which is crucial for applications that require high precision and control over the absorption process.

In TPA, the typical energy states involved are quite different from those in single-photon absorption, making it a useful technique for studying materials with unique electronic properties. The challenge in distinguishing between two successive single-photon excitations and direct two-photon absorption lies in their similar end results; however, the mechanisms and implications of these processes can significantly influence the efficiency and resolution of optical systems. This makes understanding the nuances of TPA essential for advancing optical technologies.

Atomically Precise Metal Nanoclusters. (2022). In section 4.6.1 Two-photon absorption and emission.

$$1/(1 + \beta L_{eff}(i/(1 + (\frac{x}{z})^2)) \qquad (2.)$$

$$L_{eff} = (1 - e^{-\alpha L})/\alpha \qquad (2.)$$

$$z = \frac{\pi w_0^2}{\lambda} \qquad (2.)$$

2.4. Three Photon Absorption

Three-photon absorption (3PA) is an advanced nonlinear optical phenomenon where three photons are simultaneously absorbed by a molecule, resulting in a transition from the ground state to an excited state. This process requires the simultaneous interaction of three photons whose combined energy is sufficient to reach an excited state without the need for intermediate state stabilization. 3PA is particularly significant in materials science and photonics, as it allows for deeper penetration and less scattering in biological tissues and other materials, making it ideal for deep-tissue imaging and photodynamic therapy.

$$1/(1 + 2\beta L_{eff}(i/(1 + (\frac{x}{z})^2))^2 \quad (2.)$$

$$L_{eff} = (1 - e^{-2\alpha L})/2\alpha \quad (2.)$$

$$z = \frac{\pi w_0^2}{\lambda} \quad (2.)$$

Femtosecond and nanosecond nonlinear optical properties of alkyl phthalocyanines studied using Z-scan technique

3. PROGRAM MANUAL

3.1. Installation

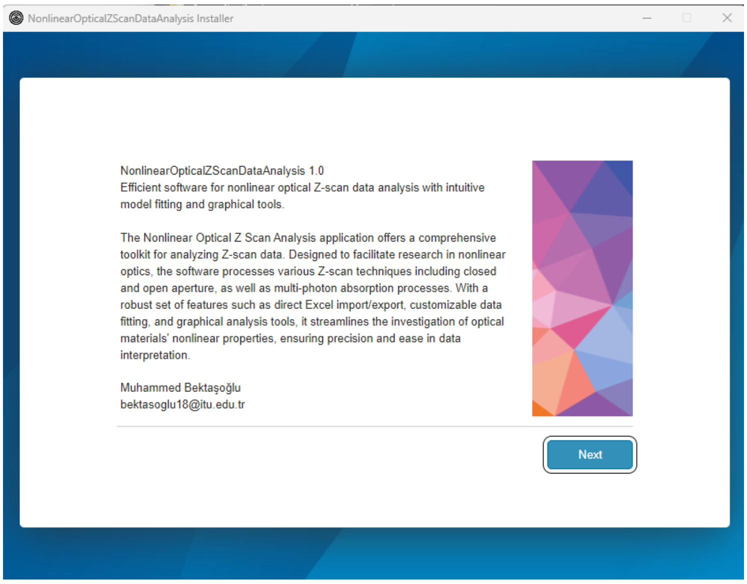


Figure 1: General Information

1. Review the general information of the application and proceed by clicking the 'Next' button.

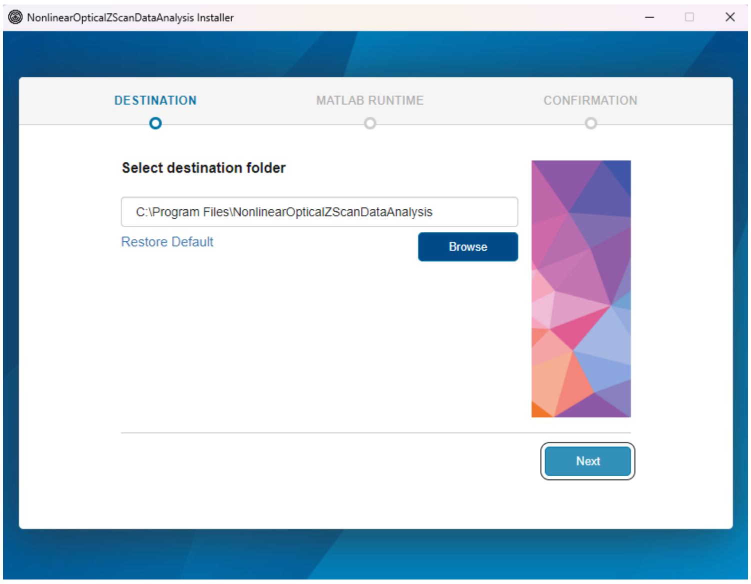


Figure 2: Installation Directory Selection

2. Select the directory where the installation will take place. It is recommended to leave it in the default **Program Files**.

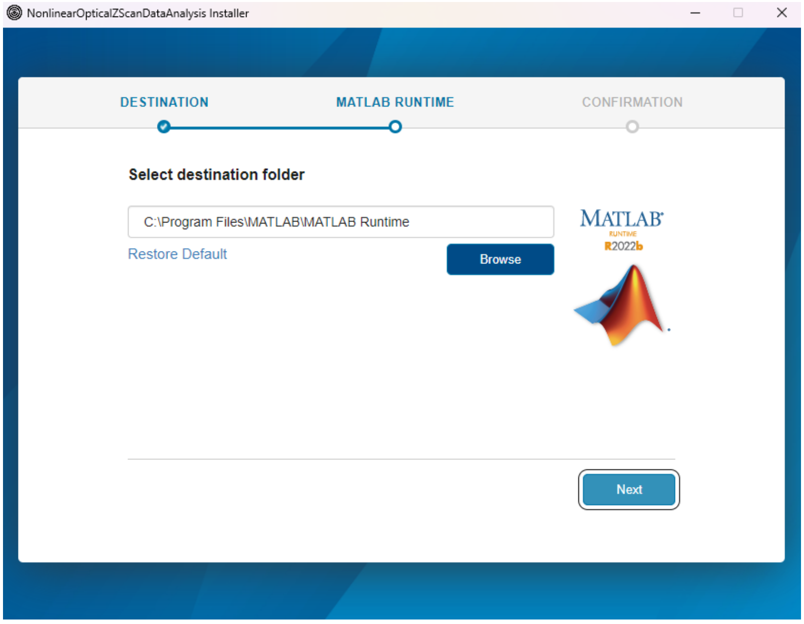


Figure 3: MATLAB Runtime Installation

3. The MATLAB Runtime, necessary for running applications written in MATLAB, will be installed automatically. If MATLAB Runtime is already present on your system, this step will be skipped.

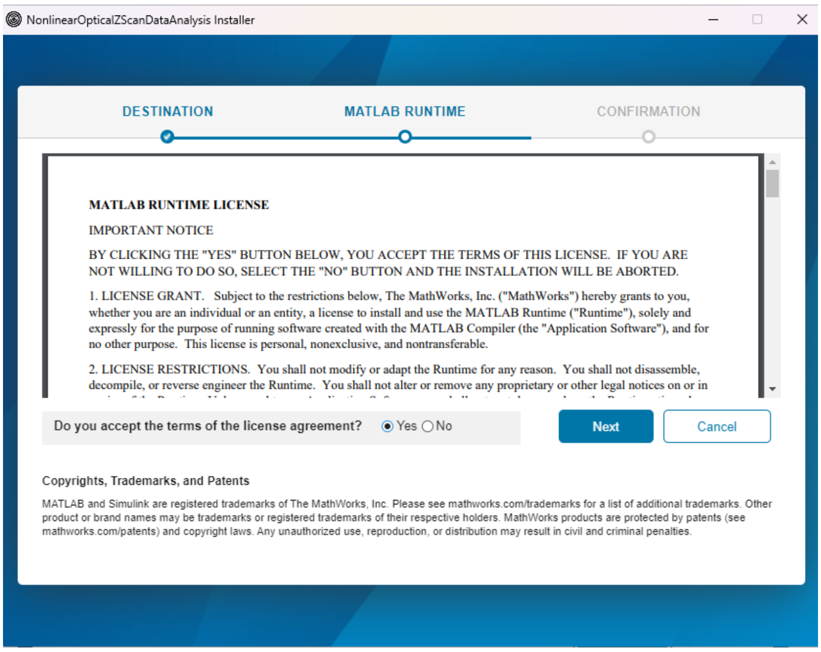


Figure 4: User Agreement

4. Accept the user agreement and click the 'Next' button.

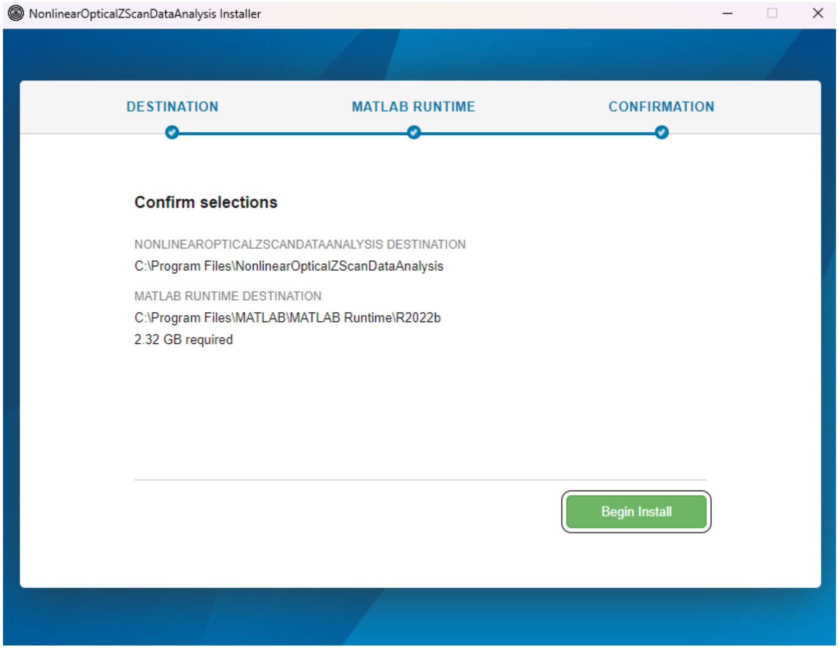


Figure 5: Installation Confirmation

5. Confirm your selections and start the installation by clicking 'Begin Install'.

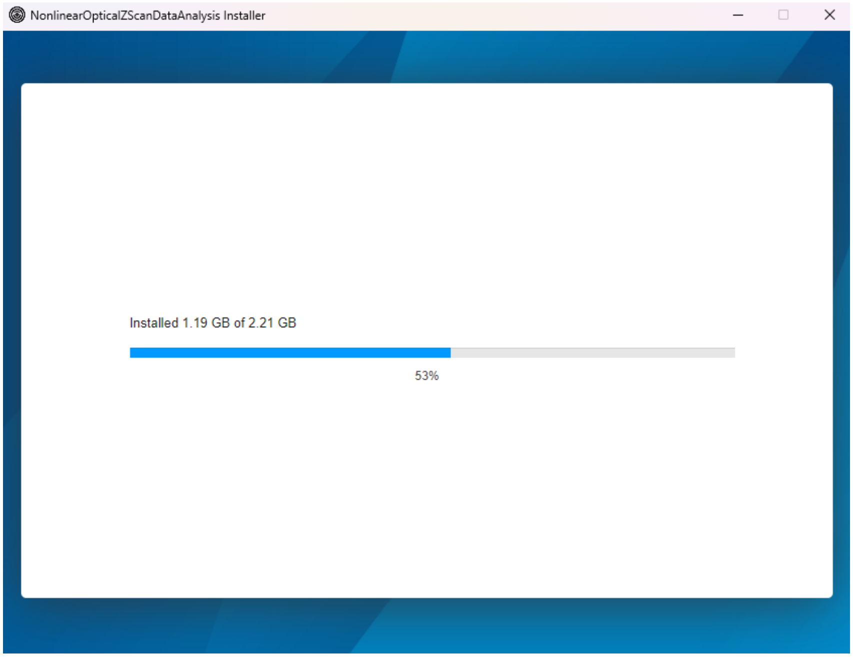


Figure 6: Installation Process

The installation will take a few minutes.

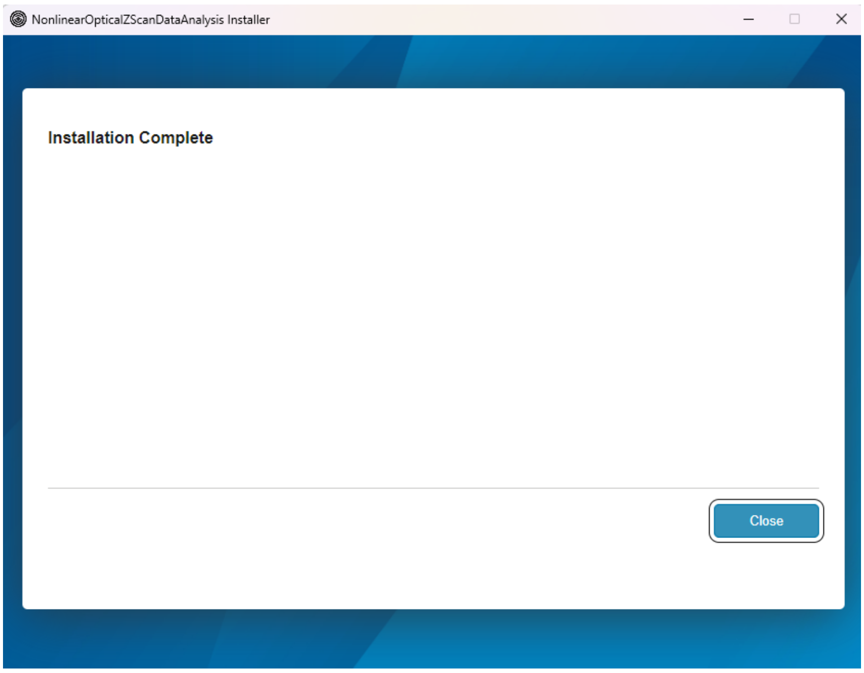


Figure 7: Completion of Installation

7. Once the installation is complete, exit by clicking the 'Close' button.

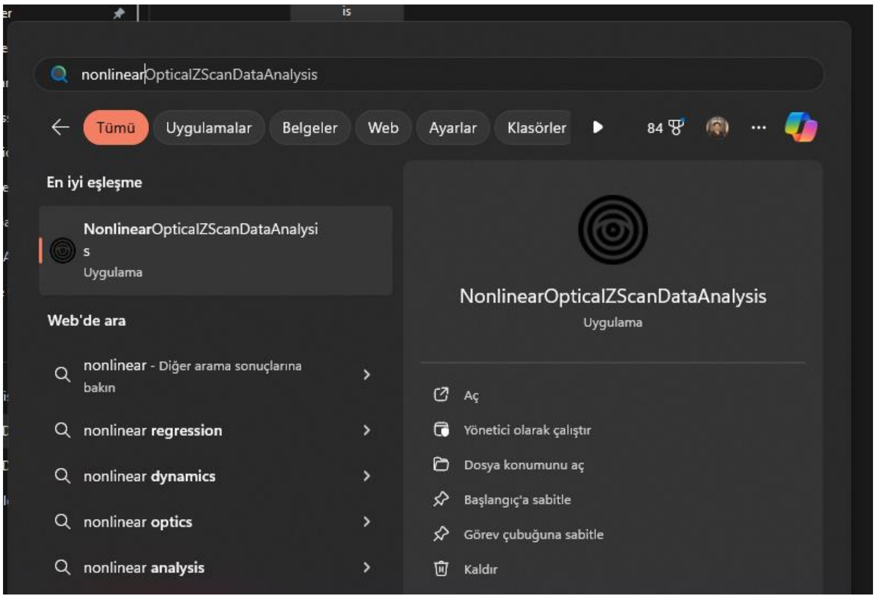


Figure 8: Launching the Application

8. To start the application, type "NonlinearOpticalZScanDataAnalysis" into the Windows search bar and click on it to launch.

3.2. User Interface

This software is engineered for the meticulous analysis of nonlinear optical Z-scan data, catering to an array of experimental evaluations such as closed aperture, open aperture, two-photon absorption, and three-photon absorption. The platform's intuitive interface facilitates the seamless importation, modification, and scrutiny of experimental data, aligning it with sophisticated modeling techniques.

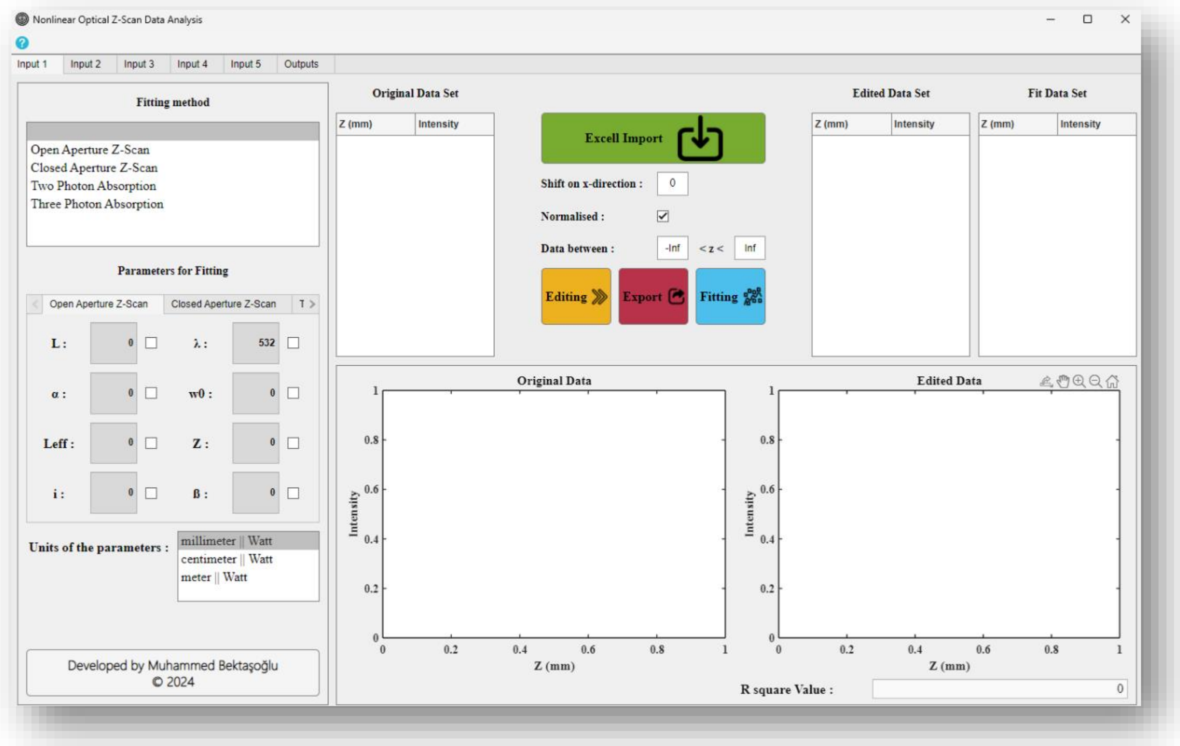
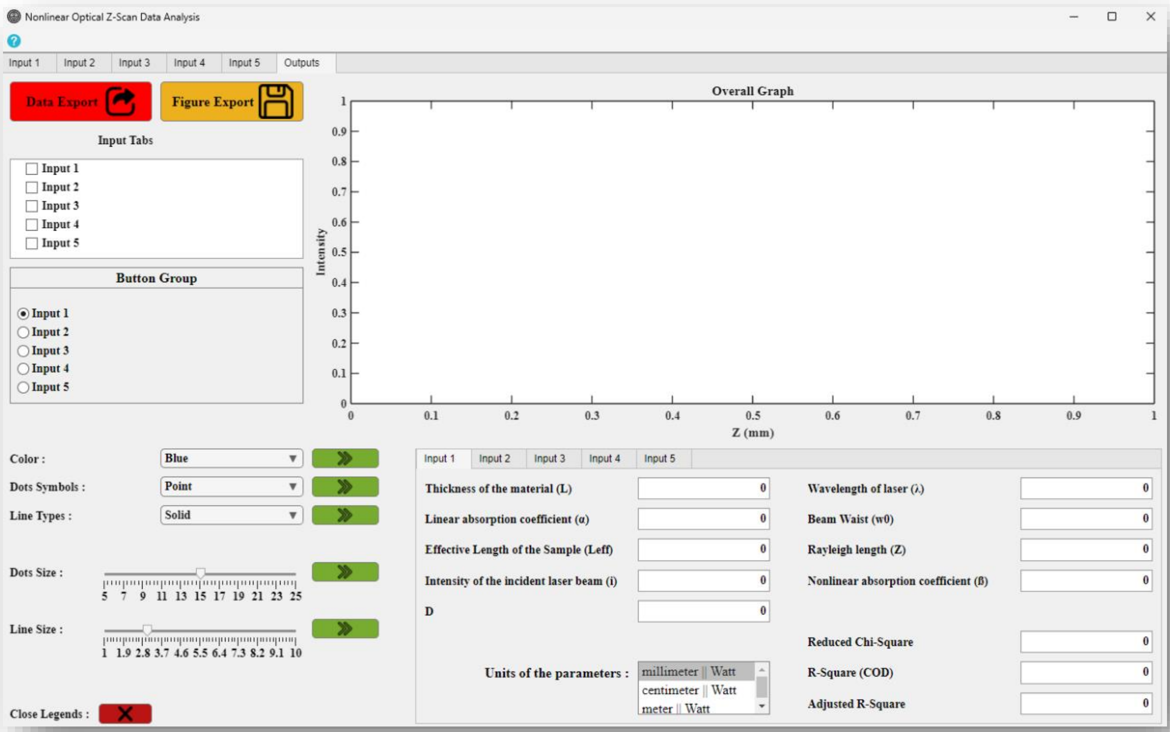


Figure 9: interface presents an advanced Z-scan data processing platform for the swift and efficient analysis of nonlinear optical properties.

This interface serves to expedite and enhance the evaluation of optical materials' nonlinear attributes by streamlining the data analysis process, thereby yielding significant time efficiencies.


Nonlinear Optical Z-Scan Data Analysis
Input 1
Input 2
Input 3
Input 4
Input 5
Outputs
Data Export
Figure Export
Input Tabs
Button Group
Overall Graph
Intensity
Z (mm)
Color :
Blue
Dots Symbols :
Point
Line Types :
Solid
Dots Size :
Line Size :
Close Legends :
Thickness of the material (L)
Linear absorption coefficient (α)
Effective Length of the Sample (Leff)
Intensity of the incident laser beam (i)
D
Units of the parameters :
millimeter || Watt
centimeter || Watt
meter || Watt
Wavelength of laser (λ)
Beam Waist (w0)
Rayleigh length (Z)
Nonlinear absorption coefficient (β)
Reduced Chi-Square
R-Square (COD)
Adjusted R-Square

3.3. Data Import

The *Data Import* functionality is a critical component of the program that allows for seamless integration of measurement data into the application. To ensure efficient data handling, the application supports importing data through the following steps:

Multiple Independent Tabs:

The application is designed with five independent Input tabs, each capable of handling separate measurement data. This design enables concurrent processing of up to five distinct measurements within the same session, significantly enhancing productivity and multitasking capabilities.

Exclusive Use of Excel:

Data importation relies exclusively on Microsoft Excel files. Users are required to prepare their measurement data in an Excel file format before initiating the import process.

Data Format Specifications:

The data must be arranged in two columns, reflecting the dependency of Intensity on Z (mm) observed in Z-Scan configurations. It is crucial for the first column of data to reside in column A (representing Z(mm)), and the second column to be in column B (representing Intensity) within the Excel sheet.

Headers Flexibility:

The presence or absence of axis headers in the Excel file is accommodated by the application. The import process is designed to recognize and correctly handle data with or without these headers, providing flexibility in data formatting.

Single Observation Requirement:

Each Excel file should contain only the data for a single observation. This ensures clarity and prevents any potential confusion during the data analysis process. To maintain data integrity and simplicity, the Excel file should consist of a single worksheet. Data contained in secondary or multiple worksheets will not be recognized and hence should be avoided.

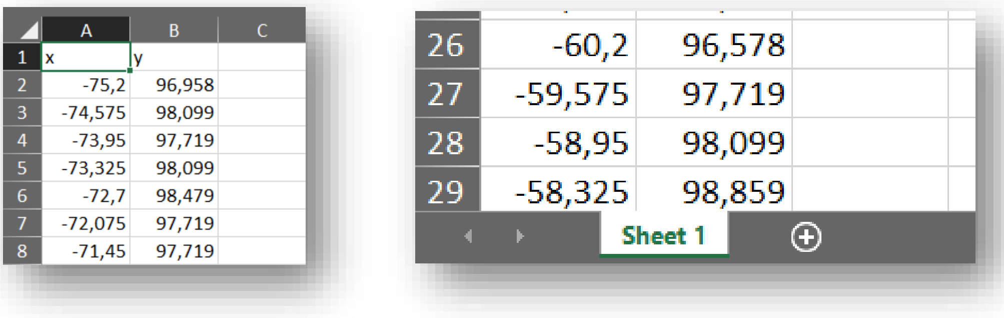


Figure 10: Sample Excel Spreadsheet Format

By adhering to the above guidelines, users can ensure a smooth and error-free data import experience into the application. To initiate the import, simply click on the green "Excel Import" button, conveniently located within each Input tab.

Figure 11: The Excel Import Button

Once the "Excel Import" button is activated, a file selector will appear, guiding users to select and import the desired Excel file from the computer.

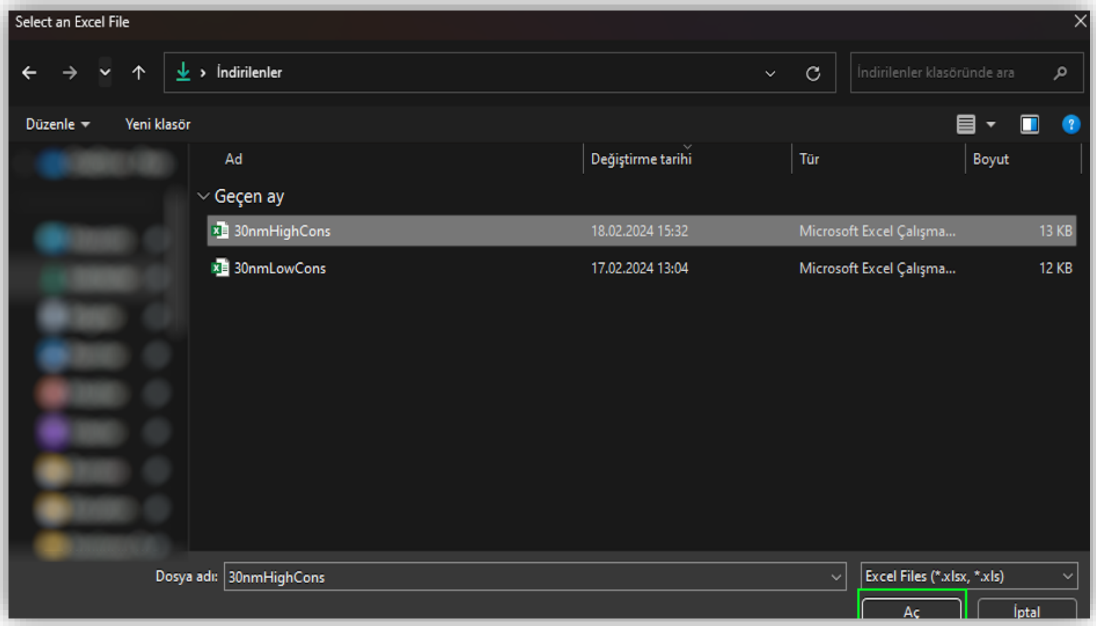
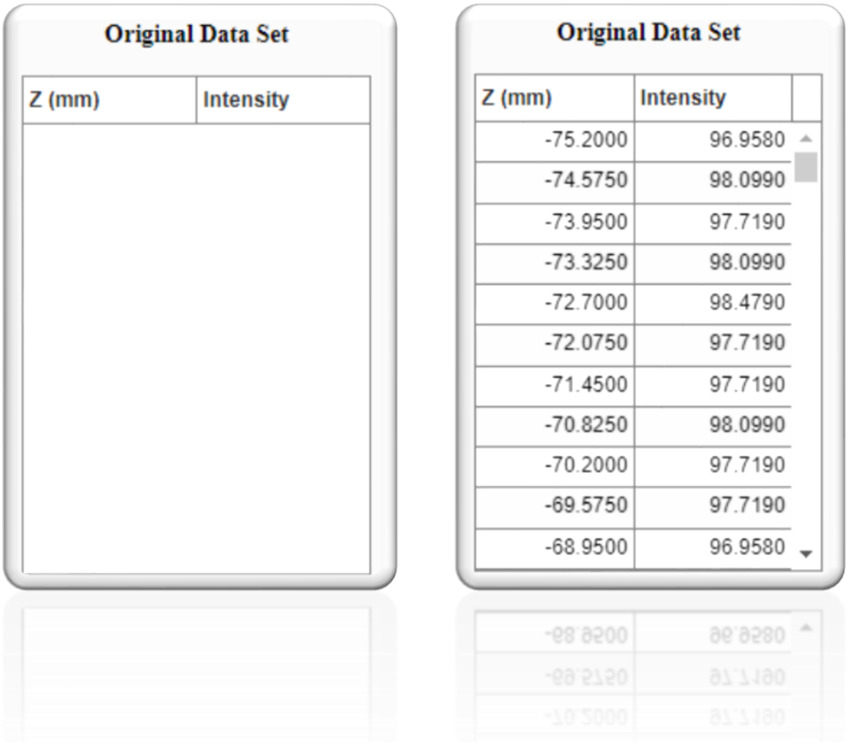


Figure 12: File Selection Dialog

When the Excel file is selected, the data it contains is automatically transferred to the 'Original Data Set' section within the application. The import process seamlessly populates the table with data from the file and organizes them under predefined column headings such as 'Z (mm)' for distance measurement and ‘Intensity’ for observed values.



Original Data Set

Z (mm)	Intensity

Original Data Set

Z (mm)	Intensity
-75.2000	96.9580
-74.5750	98.0990
-73.9500	97.7190
-73.3250	98.0990
-72.7000	98.4790
-72.0750	97.7190
-71.4500	97.7190
-70.8250	98.0990
-70.2000	97.7190
-69.5750	97.7190
-68.9500	96.9580

Figure 13: Importing Data Set to Original Table

It is also instantly displayed as a scatter plot on the graph. This visual representation provides an immediate and intuitive view of the data points, allowing users to assess the distribution and key patterns in their dataset before proceeding with further analysis

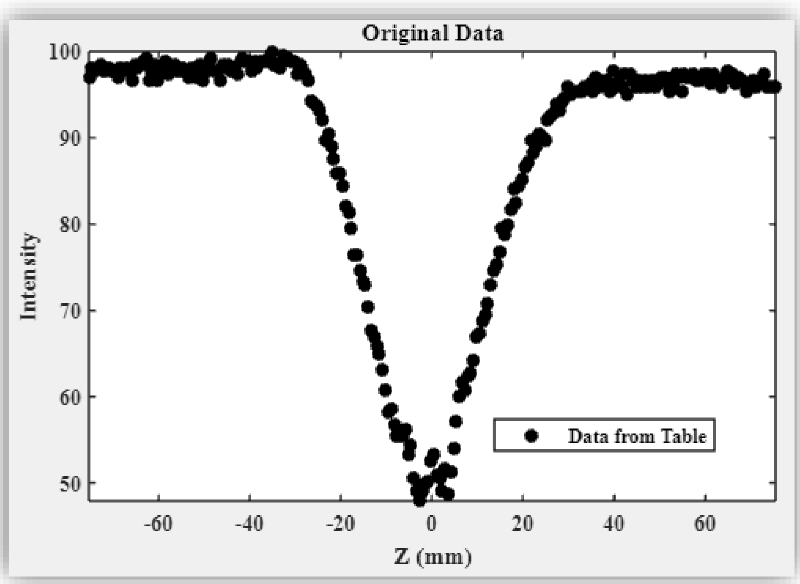


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Figure 14: Scatter Plot of Imported Data

3.4. Data Analysis and Processing

Following the successful import of data from Excel into the application, users can begin to manipulate and process the data for detailed analysis. This section of the manual guides you through the data manipulation features available after import.

Adjusting Data Alignment with Shift on x-direction:

The Z-Scan setup typically alters the distance starting from x = 0 mm. If the central point of the graph is to be aligned at x = 0 mm, users can achieve this by inputting a non-zero value in the "Shift on x-direction" field. This action will shift the Z(mm) values in the first column of the table, effectively re-centering the dataset around the desired midpoint.

Data Truncation for Focused Analysis:

At times, observational data may exhibit undesired behavior beyond a certain range. To address this, users can specify their range of interest by replacing the default -Inf and Inf values in the "Data Between -Inf < z < Inf" section with the desired numerical limits. Only the data within the defined range will be retained for subsequent analysis, allowing users to exclude any portion of data that might distort the fitting process.

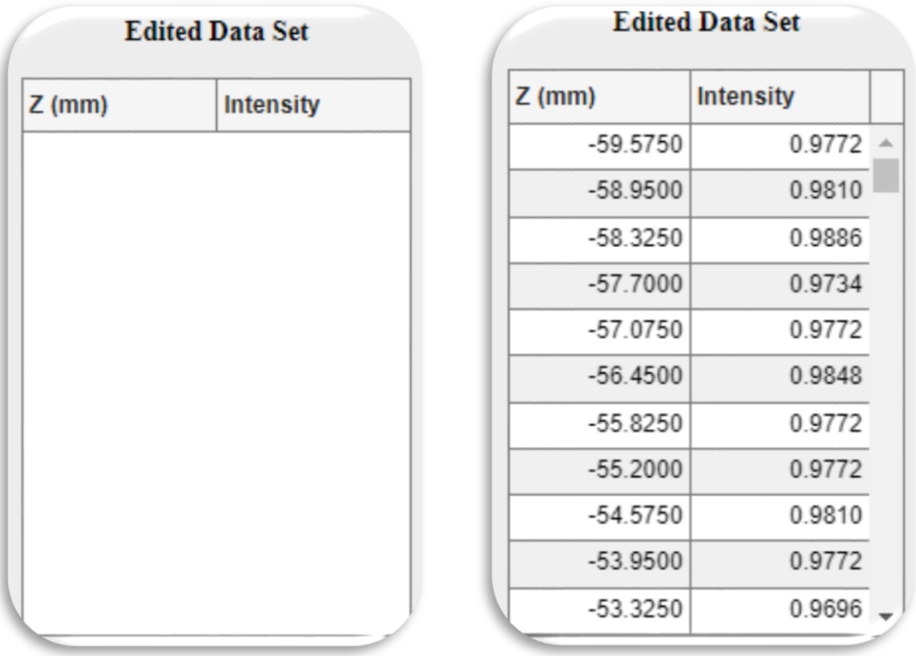
Normalization of Intensity Data:

By engaging the Normalized button, the Intensity data is normalized to scale between 0 and 1. This feature is particularly recommended if the data has not been previously normalized, ensuring uniformity and comparability within the dataset.

Figure 15: Data Manipulation Controls – The interface displays the main controls for data manipulation

Finalizing Data Manipulation:

Once the desired data manipulation has been completed, users can finalize their edits by clicking the **Editing** button. This action commits the changes and transfers the modified data to the **Edited Data Set** section, where users can visually confirm the updates to their data set, now ready for further processing or analysis.



Z (mm)	Intensity
-59.5750	0.9772
-58.9500	0.9810
-58.3250	0.9886
-57.7000	0.9734
-57.0750	0.9772
-56.4500	0.9848
-55.8250	0.9772
-55.2000	0.9772
-54.5750	0.9810
-53.9500	0.9772
-53.3250	0.9696

Figure 16: Edited Data Set Preview – This figure shows a sample of the Edited Data Set with two columns: Z (mm) and Intensity.

The prepared "Edited Data Set" serves as the foundation for fitting algorithms. The fitting function will interface with the "Edited Data Set" to perform regression or curve fitting, depending on the analysis required.

3.5. Determination of Fitting Method and Parameters

Creating a precise fit for your data is crucial to accurately interpret your experimental results. In this section of the application, you will select a fitting method and define parameters that match your experimental setup.

Selecting the Fitting Method:

Firstly, choose the fitting method that aligns with the type of data you have. You'll see options like:

- Open Aperture Z-Scan
- Closed Aperture Z-Scan
- Two Photon Absorption
- Three Photon Absorption

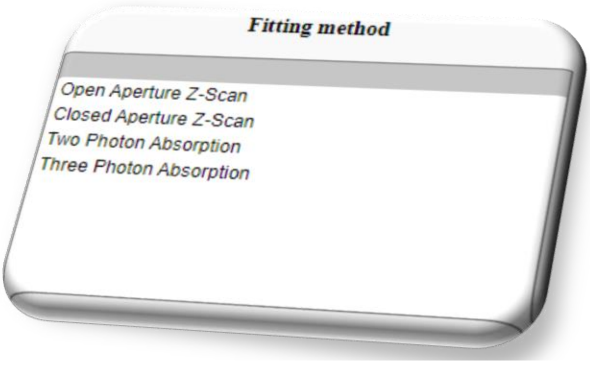


Figure 17: Selection Menu for Fitting Methods

After choosing the fitting method that best represents your experiment, the next critical step is to input the parameters that will be used to tailor the fit to your data.

Entering the Parameters:

Inputting parameters in the application is flexible, you do not need to fill in every field. The program is designed to work with either direct inputs from you or to calculate necessary values based on the information you provide. Here's how you decide which parameters to enter:

If you input the sample's thickness (L) and the linear absorption coefficient (α), the application will automatically compute the effective length of the sample (L_{eff}). In this case, you should not enter L_{eff} directly because the application calculates it for you.

Conversely, if you prefer to provide L_{eff} directly based on your calculations or knowledge, you should then leave the L and α fields empty. The app is set up to prevent contradictory inputs.

For the wavelength (λ) and beam waist (ω_0), inputting values will automatically restrict you from entering the Rayleigh range (Z) as the program is designed to prevent the simultaneous input of these parameters. If you instead choose to enter a value for Z first, the application will then disable the entry fields for λ and ω_0 to ensure the consistency of data required for the fitting process.

To perform a fit, the application must have an L_{eff} value. It can be either calculated by the app or input directly by you. Also, at least one of the following parameters must be provided for the fit to proceed: Z, i (Intensity), or β (Nonlinear absorption coefficient). Without at least one of these, the fit cannot be performed.

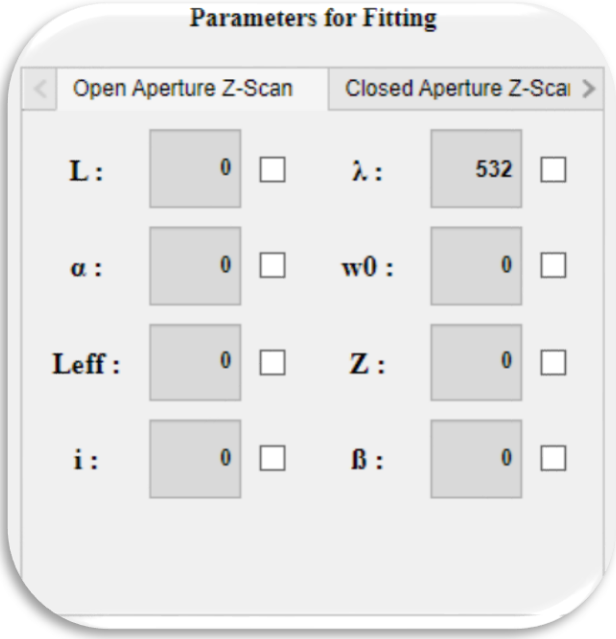


Figure 18: Fitting Parameters Input – A graphical user interface presenting a set of input fields for parameters used in fitting procedures

3.6. Obtaining Graphical Output

After selecting the fitting method and entering the necessary parameters, it is crucial to ensure that data manipulation has been completed. This means that the "Edit Data Set" button must have been clicked to prepare the data in the "Edited Data Set" section.

If there are no issues with adhering to the rules for fit parameters, clicking on the **Get the scattering and fitting** checkbox initiates the application's calculation process.

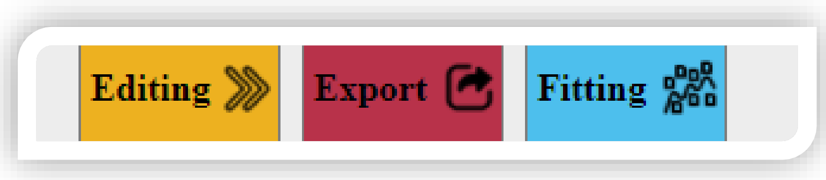


Figure 19: Scattering and Fitting Selection – An interface checkbox element

The algorithm then proceeds to plot the optimal fit and scattering graph within the "Edited Data" graph and displays the results under the "Fit Data Set" section.

With these steps, the results are successfully obtained, showcasing the application's capability to seamlessly integrate data manipulation, parameter setting, and fitting processes to produce and display the fitting and scattering data comprehensively. This streamlined approach facilitates an intuitive and efficient analysis workflow, enabling users to derive meaningful insights from their data with ease.

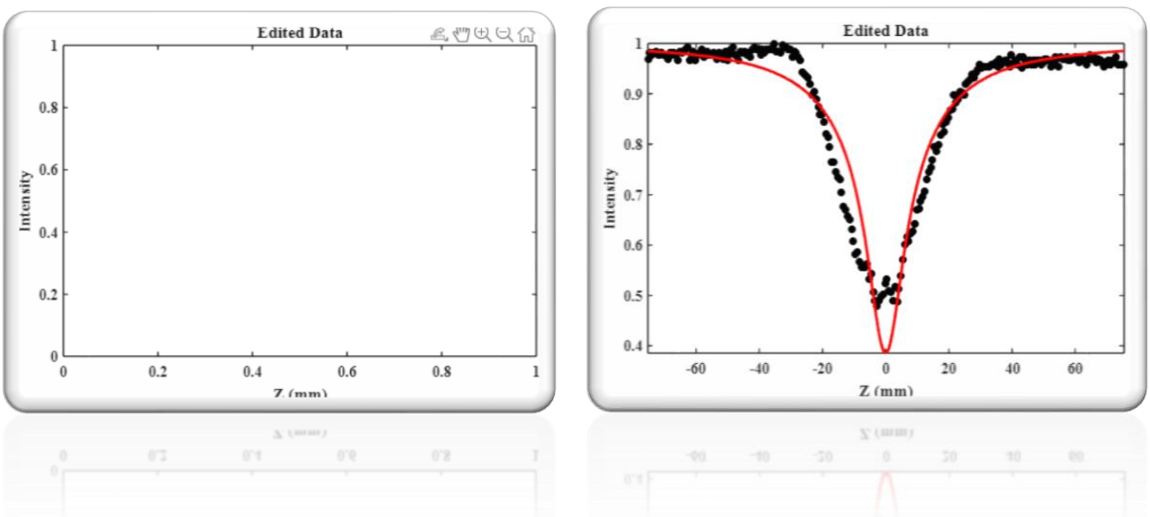


Figure 20: Edited Data Graphs – The left graph displays an empty plot titled "Edited Data", prepared for data visualization. The right graph shows intensity data as a function of Z (mm), with a fitted curve overlaid on the scatter plot, demonstrating the results

Once the fitting process is complete, the coefficient of determination, R^2 , which illustrates the compatibility between the scattering and fitting data, can be found in the lower right corner of the application. This R^2 value is updated upon the completion of the fitting process, providing a quantitative measure of how well the fitted curve matches the original data points.

Figure 21: Coefficient of Determination Display

The context menu may be accessed by right-clicking on the chart. Within this menu, adjustments to the axis titles and chart title can be made. This context menu serves as a portal to various properties of the chart, typically initiated by a right-click action. It provides a convenient means to modify

Figure 22: Chart's Context Menu

After completing the data import and manipulation process, and once the fitting curve has been applied to your dataset, you will have a comprehensive set of data ready to be utilized for further analysis, reporting, or presentation. To facilitate this transition, the application provides an "Excel Export" feature,

Figure 23: The button is used to export all processed data, including the original dataset, the manipulated entries, and the results of the fitting analysis, to an Excel file for further use and sharing.

3.7. Comprehensive Analysis and Export Features

The functionality of data export buttons located on both the Input and Outputs tabs is detailed. These export buttons enable the extraction of measurement data either individually or in group into Excel.

The following example images illustrate the results from the Data Export button located on the Outputs tab. This functionality depends on which input tabs are selected; specifically, it exports the data corresponding to the samples represented on the Overall Graph above the Outputs tab.

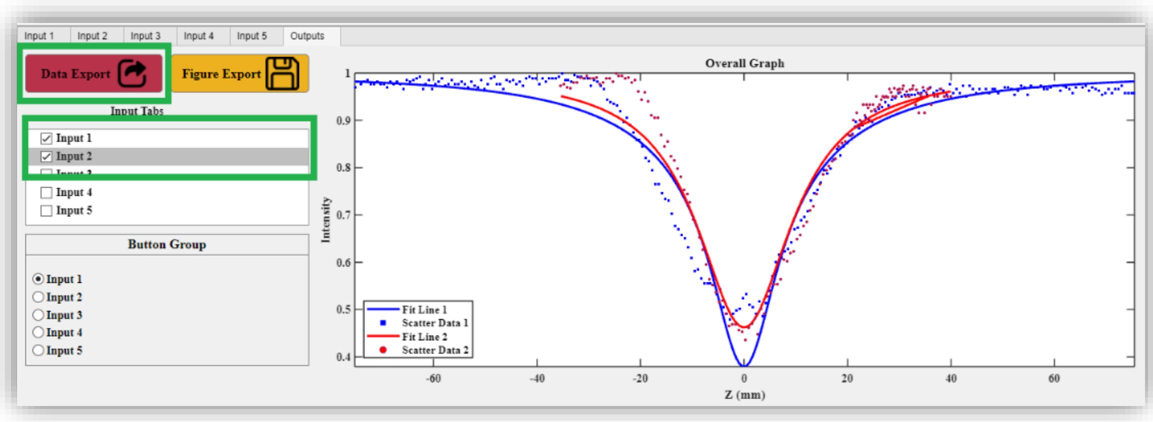
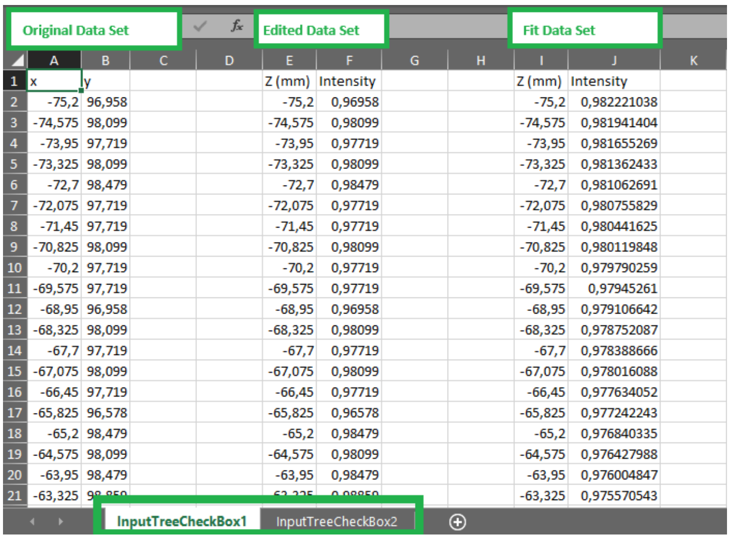


Figure 24: interface with "Data Export" and "Figure Export" buttons, selectable data inputs, and an "Overall Graph" displaying two fit lines and corresponding scatter data for comprehensive data analysis and visualization.

The resulting Excel file contains several columns organized as follows:

- Column A/B contains the Original Data Set,
- Columns E/F include the Edited Data Set,
- Columns I/J present the Fit Data Set, which is generated using a fit equation.

Additionally, users can navigate between different Excel sheets to explore various measurement results.



Original Data Set | Edited Data Set | Fit Data Set

	A	B	C	D	E	F	G	H	I	J	K
1	x	y			Z (mm)	Intensity			Z (mm)	Intensity	
2	-75,2	96,958			-75,2	0,96958			-75,2	0,982221038	
3	-74,575	98,099			-74,575	0,98099			-74,575	0,981941404	
4	-73,95	97,719			-73,95	0,97719			-73,95	0,981655269	
5	-73,325	98,099			-73,325	0,98099			-73,325	0,981362433	
6	-72,7	98,479			-72,7	0,98479			-72,7	0,981062691	
7	-72,075	97,719			-72,075	0,97719			-72,075	0,980755829	
8	-71,45	97,719			-71,45	0,97719			-71,45	0,980441625	
9	-70,825	98,099			-70,825	0,98099			-70,825	0,980119848	
10	-70,2	97,719			-70,2	0,97719			-70,2	0,979790259	
11	-69,575	97,719			-69,575	0,97719			-69,575	0,97945261	
12	-68,95	96,958			-68,95	0,96958			-68,95	0,979106642	
13	-68,325	98,099			-68,325	0,98099			-68,325	0,978752087	
14	-67,7	97,719			-67,7	0,97719			-67,7	0,978388666	
15	-67,075	98,099			-67,075	0,98099			-67,075	0,978016088	
16	-66,45	97,719			-66,45	0,97719			-66,45	0,977634052	
17	-65,825	96,578			-65,825	0,96578			-65,825	0,977242243	
18	-65,2	98,479			-65,2	0,98479			-65,2	0,976840335	
19	-64,575	98,099			-64,575	0,98099			-64,575	0,976427988	
20	-63,95	98,479			-63,95	0,98479			-63,95	0,976004847	
21	-63,325	[illegible]			[illegible]	[illegible]			-63,325	0,975570543	

InputTreeCheckBox1 | InputTreeCheckBox2

Figure 25: Excel spreadsheet illustrating the export results for a data analysis process

4. ANALYSIS AND RESULTS

4.1. Application Scenarios

4.2. Analysis of Results

5. CONCLUSION

The development and implementation of the MATLAB-based application described in this thesis significantly enhances the analysis of Z-scan measurement data, a cornerstone technique in the study of nonlinear optical properties. The comprehensive suite of features, including data importation, advanced fitting algorithms, and intuitive visualization tools, enables the application to successfully address the complexities involved in decoding the nonlinear optical behavior of various materials.

The software offers a streamlined, user-friendly platform that not only simplifies the research process but also enables more accurate and efficient exploration of critical parameters such as the nonlinear absorption coefficient and the nonlinear refractive index. The inclusion of both open and closed aperture Z-scan techniques, in addition to the capabilities for analyzing multi-photon absorption phenomena, ensures that researchers can conduct a thorough investigation of material properties under diverse experimental conditions.

This thesis has demonstrated that the application considerably reduces the time and effort required to process and interpret experimental data, allowing researchers to focus more on the implications of their findings rather than the intricacies of data handling. Moreover, the graphical output generated by the software facilitates a better understanding and communication of results.

REFERENCES

BIOGRAPHY

Muhammed was born in Istanbul in the year 2000. He spent his childhood and teenage years and completed his primary, secondary, and high school education in Sariyer, İstanbul. In 2018, he commenced his studies in Physics Engineering at Istanbul Technical University, where he had the opportunity to merge theoretical knowledge with practical application.

Additionally, he participated in the Erasmus exchange program at Umeå University in Sweden, in the third year of the study, further broadening his academic and cultural perspectives.

During his university studies, Muhammed gained professional experience by working as a full-stack web developer and system analyst at Turkish Airlines and Amadeus IT Service. These experiences helped enhance his passion and skills in technology and software.

Currently, in the final year of his undergraduate degree, he is engaged in significant research in the field of optics, collaborating with his advisor, Assoc. Dr. Murat Erdem.