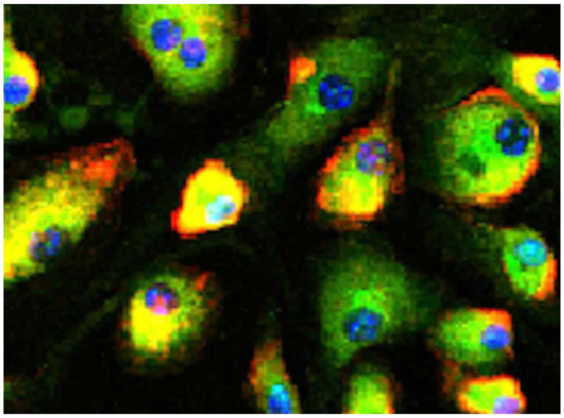
Ansys + Imperial College London

"With the solution we built using the ZOS-API in Ansys Zemax OpticStudio, optical design teams and researchers can now 'try out' thousands of doublet combinations in just a few seconds per combination, and then only buy the ones that they know will deliver the best performance — there's no need to resort to guesswork or spending time on laborious manual modelling of different lens pairs to find what works."

— **Christopher Dunsby**
Research Professor in Photonics / Department of Physics
Imperial College London

CASE STUDY

Imperial College London Speeds Up Microscopy Design by Automating Stock Lens selection for Remote Refocusing Projects



Photonics Team Builds Time-Saving Apps Using OpticStudio Stock Lens Libraries, MATLAB Interface, and the ZOS-API

3D imaging typically requires optical scientists to follow one of two common tactics: scanning the sample you're imaging with respect to its objective, or else moving the objective back and forth with respect to the sample, either manually or with a mechanical actuator. These methods work for some types of optical systems, but they fall short in the development of some types of fluorescent microscope, where movement can produce vibrations or can require outsized actuators in order to achieve the required image acquisition speed.

Remote refocusing in microscopy refers to an optical system where an optical relay is used to produce a true 3D image of a specimen (as opposed to simply a magnified image) with equal lateral and axial magnification. Achieving this fidelity requires adherence to a precise formula: the overall magnification of your system must equal to the ratio of the sample medium's refractive index to the refractive index in which you're forming the image.

"For example, if your sample is in water and you're trying to make a remote image in air, then you need the optical system magnification to be equal to the refractive index of water, or 1.33," said Chris Dunsby, Professor in the Photonics Group, Department of Physics at Imperial College London. "Not a very big magnification in this case, but it will yield a true 3D image, where say a spherical object results in a matching spherical image."

Dunsby has worked in the area of biomedical optics for his whole career, and his research team at Imperial College London focuses on developing novel technologies to address real-world applications of photonics. In the course of their work, the team uses Ansys Zemax OpticStudio in a variety of capacities. Recently, he and Wenzhi Hong, a graduate research fellow in Dunsby's department and a PhD candidate in the Photonics Group, examined ways of leveraging OpticStudio's capabilities to make the design of remote refocusing system more feasible and accessible to optical scientists. Their results provide a new method for overcoming the practical limitations of lens selection for remote refocusing projects.

Ansys Products Used

- Ansys Zemax OpticStudio

Key capabilities

- Dynamic catalog of stock manufactured lenses.
- Ansys Zemax application programming interface (ZOS-API).
- Built-in, seamless programming interface with MATLAB.

Results

- Built easy-to-use applications for rapidly identifying lens doublets to use with remote refocusing systems in 3D fluorescent microscopes.
- Reduced the time-intensive process of identifying available stock lenses for a project to only a few seconds per lens combination using automated cataloging, specification checking, and lens pairing.
- Optimized performance without resorting to costly custom lens development.

Designing a Remote Refocusing System for use in Microscopes

Modern microscope objectives are infinity-corrected, with a microscope objective that creates an image at infinity and a tube lens that receives the light from the objective lens at infinity and produces a well-corrected image at the desired focal length. Working together, the microscope objective and tube lens enable generation of a magnified image. In this way, a remote refocusing system is essentially two microscopes back-to-back, as shown in Figure 1.

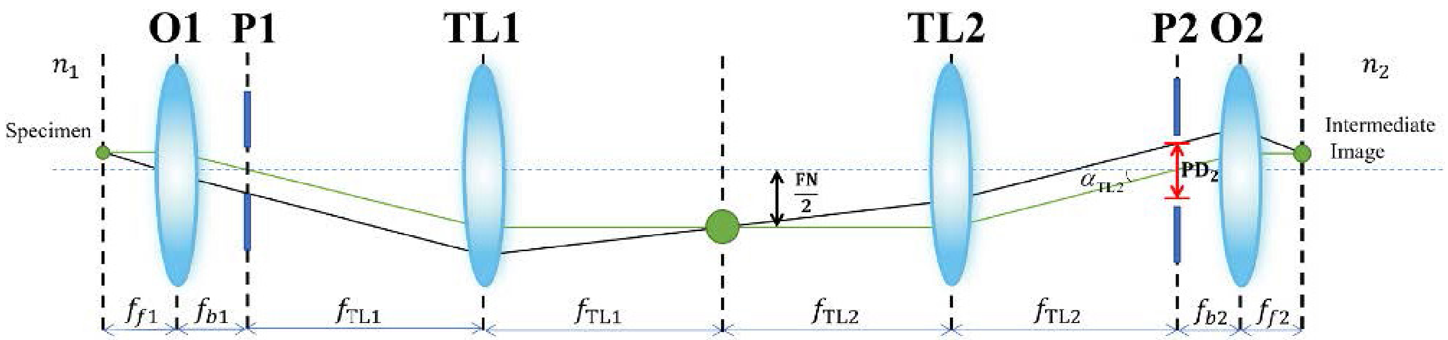


Figure 1. Principal ray and ray just passing the edge of the limiting aperture, traced through the remote refocusing system. Here, the limiting aperture at P1, and the image of the limiting aperture is indicated in the P2 plane in red. O: objective; TL: tube lens; ff and fb : front and back focal length; FN: field number; P: pupil plane; n: refractive index; and PD: pupil diameter.

To meet this mathematical requirement, a remote refocusing system needs the right combination of a pair of tube lenses to use with a pair of microscope objectives — one objective for collecting light from the subject, and another for producing the remote image. In a perfect scenario, a scientist would determine the optimal specifications and commission development of a custom lens. In reality, a tube lens of a particular focal length can be generated by a pair of stock achromatic doublets, which are more affordable and take less time to acquire. Therefore, the challenge becomes a practical one: How to choose the right two stock lenses, based on project design parameters, cost, and functional compatibility between each lens and the other.

"As scientists, we want to build systems quickly and flexibly," said Dunsby. "Commercially available parts are great, but it takes a lot of time to choose the right ones for a design. We don't usually have the time or other resources to go through a formal lens design process to produce custom lenses, especially when we want the ability to change them out quickly on a regular basis for purposes of experimentation."

Lens performance is also an important consideration. But the more time a research or development team spends fine-tuning their search for the perfectly performing pair of stock lenses, the less time they have to spend on innovation and scientific discovery.

Before the development of the new software, Dunsby's team would try out many lens pairs in software manually before deciding which lenses to purchase. "This could take a lot of time and we wouldn't be sure if we'd chosen the best doublet option," he said.

Choosing the Right Lenses: An Opportunity for Automation

Based on these challenges, speeding up the research and development cycle for remote refocusing systems comes down to enabling the more rapid — yet still intelligent — selection of stock tube lenses to use in a design. Dunsby and Hong set about devising a comprehensive, performance-focused selection method for these lenses using programmatic automation.

To enable faster, more rigorous lens selection, Hong used the ZOS-API in OpticStudio to create two software applications designed for sequential use. The first app, Catalog Generator, looks at the entire field of lenses commercially available as represented in the dynamically updated OpticStudio libraries, and produces a list of lenses that meet the user's needs. The second app then tries all the various permutations of these lenses to see which doublet best meets the user's specific project. (See page 4)

By using these applications in sequence, Dunsby's team — or any other scientists — can now be far more agile, intentional, and precise in how they proceed with their design. The automatic lens selection enables them to get to a design much faster than they were able to before.

"The lenses you ultimately select are still subject to slight performance limitations within the range of capabilities that manufacturers offer," said Dunsby, "but even if it's not as good as the performance you'd get by designing a lens from scratch, you've saved time and money by shortening the development cycle of your design. You also have the knowledge that you've selected the best commercially available pairing from the comprehensive list available in OpticStudio."

/ Achieving Results with Key OpticStudio Capabilities

Several OpticStudio features helped Hong and Dunsby evolve lens selection from a time-limited, highly manual "best guess" method to the automated process enabled by Hong's applications. First of all, Hong and Dunsby credit the availability of OpticStudio's extensive, authoritative lens catalog, without which the applications would have far less meaningful data to work with. Second, the ZOS-API enabled easy development of Hong's apps. Last but not least, OpticStudio interfaces with MATLAB — the programming platform Hong used for app development.

"It was fundamental to be able to interface between OpticStudio and MATLAB" said Hong. "Ansys Zemax facilitates getting the data from OpticStudio and transferring it into MATLAB so the Doublet Selector could easily compare all of the different options."

The availability of Catalog Generator and Doublet Selector has broad, positive implications for the optics community, and in particular microscopy instrumentation research teams like the one at Imperial College London. Dunsby and Hong have shared their results with colleagues everywhere by making Hong's apps available on **GitHub**. Hong also published his results as a **paper** in the peer-reviewed Optica journal Optics Express.

"With the solution we built using the Ansys Zemax ZOS-API in Ansys Zemax OpticStudio, optical design teams and researchers can now 'try out' thousands of doublet combinations in just a few seconds per combination, and then only buy the ones that they know will deliver the best performance," said Dunsby. "The apps Wenzhi built do this efficiently and effectively — there's no resorting to repetitive manual testing of different lens pairs."

/ Two Sequential Apps for Auto-Selecting Lens Doublets in Remote Refocusing Projects

The Imperial College London team built two apps for identifying the best stock optics lenses to use for microscope tube lens designs based on minimal design input. (Note that these tools complement the functionality of the Stock Lens Matching tool in OpticStudio, which replaces custom-designed lenses with their nearest stock optics equivalents.)

Catalog Generator creates a catalog of commercially available achromatic doublet lenses matching a user's requirements by querying the stock lens libraries built into OpticStudio.

How it works:

1. The user enters the focal length and diameter ranges for their project, along with their preferred lens vendor (if they have one).

2. The app queries the OpticStudio libraries and generates a list of lenses based on the user's input criteria.

3. For each qualifying lens, the app records the wavelength range and applies metadata within the query results for air-space doublets, cemented doublets, and other relevant identifiers. The app also correlates lenses that share identical properties, including curvature, thickness, or material type, and then assigns each query result a unique identifier so that other software can interact with it programmatically.

4. The app writes a "lens list" output file containing the full list of applicable lenses, sortable by parameters such as effective focal length, entrance pupil diameter, part number, flag (metadata) values, and vendor name. The second app, Doublet Selector, uses this output file to help the user choose which lenses to include in the doublet.

Doublet Selector filters the results of the user's Catalog Generator query and uses additional user input to recommend optimal lens doublets for use with their design.

How it works:

1. In the UI, the user points Doublet Selector to the Catalog Generator output file for their project, and specifies design wavelength ranges, specific flag values, and other parameters they want to include or exclude for consideration.

2. The app filters the lens list file based on these criteria, and then cycles through the filtered results, checking every possibility of lens combination and orientation to determine the optimal combination to recommend by calculating the required lens diameters and separation distance of each lens in each combination, then checking to see if a pair is a potential match. If it is, it creates a Zemax file based on that pairing. If not, it moves on to the next permutation of lenses.

3. The app runs additional analysis to determine optimal pairing parameters for each winning combination, and records relevant data such as the lens numbers, cut-off field angle, and root-mean-square (RMS) wavefront error.

4. At the end of this process, Doublet Selector produces a new list — this time containing the lens combinations that are best suited to the user's requirements. The user can then consult this list to determine the optimal lens doublet for use with their project.

/ About Zemax

Zemax's industry-leading optical product design and simulation software, OpticStudio®, OpticStudio® STAR Module, OpticsBuilder™, and OpticsViewer™, helps optical, mechanical, and manufacturing engineering teams turn their ideas into reality. Standardizing on Zemax software reduces design iterations and repeated prototypes, speeding time to market and reducing development costs. Zemax is headquartered in Kirkland, Washington, USA and has offices in the United Kingdom, Germany, Japan, Taiwan, and China. For more information: www.zemax.com.

ANSYS, Inc.
Southpointe
2600 Ansys Drive
Canonsburg, PA 15317
U.S.A.
724-746-3304
ansysinfo@ansys.com