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Researchers achieve major improvement for lensless computational microscopy

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Scientists from ITMO University and Tampere University of Technology have improved computational imaging of optical signals in lensless microscopes. By employing special algorithms, they increased the resolution of obtained images without any changes in the technical characteristics of microscopes.

Lensless computational microscopy makes it possible to visualize transparent objects or measure their shape in three dimensions. Such microscopes have no lenses or objectives that focus light on an image sensor. Instead, lensless microscopes rely on measuring diffraction patterns that result from illuminating an object with laser or LED light. The image obtained from these patterns is generated by using a computational approach. Special algorithms allow generating an optical image and improving the optical signal itself. It thus produces images with higher resolution using only mathematical methods without any physical changes to microscopes.

An international team of scientists from Russia and Finland turned to computational methods in order to expand the field of view, a crucial feature of any microscope. In traditional microscopy, an objective focuses light from a small object area to a bigger area where the image is captured. Thus, the image size appears to be increased. It is impossible, however, to change the size of the image sensor itself. This is where computational means come into play, allowing researchers to overcome this physical limitation and expand the field of view.

To this end, several different diffraction patterns must be registered by camera. To perform the task, scientists used special filters called phase masks, which are usually synthesized on a computer and fed into the optical path of the microscope using a spatial light modulator. Once the diffraction patterns were processed, the scientists artificially increased the field of view and consequently the resolution of the retrieved image.

"We used the mathematical method of sparse representation of signal. A simple example may help understand how it works. Imagine that you have a grid paper and you choose a square area of eight by eight. If you register the signal in this eight by eight square, then the retrieved image will be discretized in the same way. But if the signal meets certain requirements of sparsity, you can potentially use the same eight by eight signal to restore all the missing information regarding the same object, but with a smaller discrete mesh of 16x16 or even 32x32. At the same time, the resolution will increase twofold or fourfold correspondingly. Moreover, our computational algorithm expands the signal beyond the registration area. This essentially implies the appearance of extra pixels around our eight by eight square, which therefore expands the field of view," says Nikolay Petrov, one of the authors of the study and head of the Laboratory of Digital and Display Holography at ITMO University.

The new approach enables scientists to improve image resolution without any modifications in the quality of the image sensor and other microscope components. This, in turn, suggests significant economy and cheaper microscopes in the future.

"What seems to be the trend in this area of research is the simplification and optimization of optical systems. To achieve even more optimization, we need to remove the spatial light modulator from the system and reduce the amount of masks-filters. One of the obvious paths to achieve these goals is to use a single filter with sequential movement. This will make our lensless computational microscope even cheaper, as the spatial light modulator is the most expensive element in such systems," says Igor Shevkunov, co-author of the study and researcher at the Laboratory of Digital and Display Holography and Fellow at the Tampere University of Technology.

Improvement of lensless computational microscopy is a step toward higher quality research in biology, chemistry, medicine and other fields.

More information: Vladimir Katkovnik et al, Computational super-resolution phase retrieval from multiple phase-coded diffraction patterns: simulation study and experiments, *Optica* (2017). DOI: 10.1364/OPTICA.4.000786