Technical Note

3D microscopy with a plenoptic eyepice

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ABSTRACT
This technical note introduces the Plenoptic Eyepiece, a 3D imaging device that can be coupled to the eyepiece port of an optical microscope to transforms it into a 3D digital microscope. The note also explains, briefly, the technology on which it is based.

RESUMEN
Esta nota técnica presenta el ocular plenóptico, un dispositivo de imagen 3D que se acopla en el puerto ocular de un microscopio óptico y lo transforma en un microscopio digital de imagen 3D. Asi mismo, en esta nota explicamos, de forma muy breve, la tecnología en la que se basa.

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DOITPLENOPTIC (www.doitplenoptic.com) is a spin-off founded in July 2018 by three researchers from the Optics, Optometry and Vision Sciences department of the University of Valencia and the venture capital firm Beable Capital. DOITPLENOPTIC designs and manufactures 3D imaging systems based on a new optical design concept of the lightfield capture. The novelty design is ideal for instruments dedicated to visual inspection, as microscopes, telescopes, fundus cameras, etc. DOIT® (Digital Optical Imaging Technology) patent-pending technology is a new paradigm for any subjective observation instrument that provides them full 3D capabilities. On this basis, DOITPLENOPTIC focus on both the design and development of the opto-mechanical system and the development of the algorithms that allow the reconstruction, visualization and analysis of the three-dimensional images.

DOITPLENOPTIC aims to democratize the scientific use of the plenoptic technology with a product with high capacity of 3D analysis. We offer an economical, plug & play and easy-to-use accessory to increase the performance of conventional instrumentation for visual inspection. We will make this sophisticated image technology accessible to society by providing SMART product for clinical, biological, industrial and metrological applications.

The Plenoptic Eyepiece

The plenoptic eyepiece is a small and manageable device that is attached to the eyepiece port of the optical instrumental. The plenoptic eyepiece is inserted and removed just like a conventional eyepiece, so going from visual inspection to 3D inspection and vice versa is immediate: just to replace one eyepiece with the other.

Our first device, the DOIT 3D Micro shown in Figure 1 (top), is the first plenoptic eyepiece for 3D microscopy that transforms any optical microscope into a full 3D digital microscope coupled , as can be seen in Figure 1 (down). The DOIT 3D Micro provides full color images and has been designed for bright field and fluorescent microscopy. The lateral resolution and depth of field achieved with the DOIT 3D Micro depend on the native properties of the microscope objective as well as the hardware configuration of the device. We have developed four prototypes whose main properties are listed in Table 1.

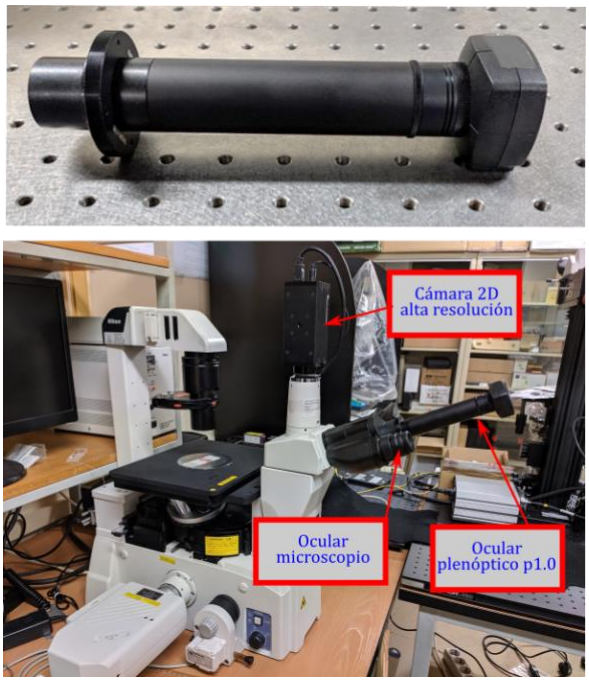

Figure 1: Pictures of the DOIT 3D Micro lab prototype (top) and the prototype coupled in the eyepiece port of a microscope (down).

Table 1: Optical properties of the DOIT 3D Micro lab prototype

Parameter		DOIT 3D Micro 1	DOIT 3D Micro 2	DOIT 3D Micro 3	DOIT 3D Micro 4
Optical properties on a Nikon Eclipse microscope with 200 mm focal length tube lens					
Effective Resolution at Objecte plane (Lp/mm)	20x / NA 0.5	203	239	239	276
	40x / NA 0.75	462	498	525	532
Effective Resolution at Objecte plane (microns)	20x / NA 0.5	2.5	2.1	2.1	1.8
	40x / NA 0.75	1.1	1.0	1.0	0.9
Depth of field (microns)	20x / NA 0.5	160	145	140	130
	40x / NA 0.75	35	30	30	30
Lateral field of view (microns)	20x / NA 0.5	776	630	776	630
	40x / NA 0.75	349	284	349	284

The DOIT 3D Micro is based on the lightfield imaging technology, also known as plenoptic technology. This technology enables to register many perspectives at once in a conventional sensor with an array of small lenses, or microlenses. As the 3D image is captured instantly, video records are possible, so you can monitor three-dimensional samples in motion. In addition, the eyepiece of DOITPLENOPTIC can do this with any light source to which the sensor is sensitive; in general, visible light and infrared with conventional CCD or CMOS sensors. The key difference with the conventional methods for lightfield capture is that the DOIT 3D Micro images the aperture stop of the objective on the microlens array instead of behind each microlens. In this way, DOITPLENOPTIC technology directly registers a set of orthogonal

views, which leads to increased resolution, and it enables to be used with objectives of different numerical apertures.

In order to display the images, the eyepiece is connected to a computer with a screen. Through an owned powerful software, the perspectives are processed, and the 3D images are presented to the user in different ways, as we show in Figure 2. In the standard mode, the image is displayed flat, as in a conventional 2D digital microscope. In 3D mode, different modules enhance different characteristics for a detailed analysis according to the techniques and standards required for each application. These characteristics can be: views from different observation points, a volumetric reconstruction of the sample, occluded parts of the scene, a selection at will of the focus plane —this with great optical sectioning capacity—, or a depth map or a topography of the surface of the sample, among others. In addition, the views can be transformed into a stereo pair that allows seeing the three-dimensional scene with virtual reality glasses. Moreover, they can also be transformed into an integral 3D image that can be seen from an autostereoscopic display.

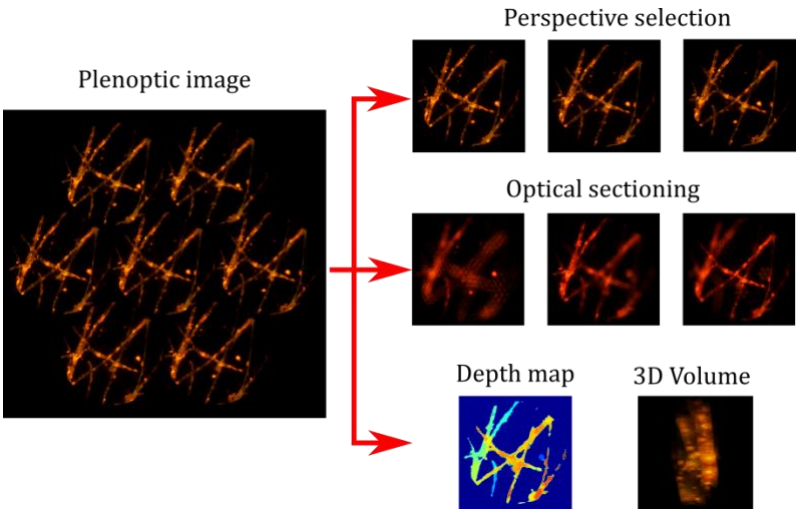

Figure 2: Plenoptic image of cotton fibers captured with the DOIT 3D Micro 1 using fluorescent illumination and different types of optical processing from that plenoptic image. From the plenoptic image, the point of view of interest can be selected, as well as a specific focused section in depth; or it can be calculated a depth map (in the figure red es close and blue far)

From a practical point of view, the ease of coupling and removal of the plenoptic eyepiece in the ocular port gives to the user a set of advantages that clearly differentiates it from the plenoptic imaging techniques for microscopy with which DOITPLENOPTIC competes. The main one is that it can be used with any microscope that has an eyepiece port (we notice that, except for some exclusively digital, these are the vast majority), so it is interchangeable and valid for a group of microscopes that were in a laboratory.

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