Lensless Imaging

A ‘sci-fi’ technique to a new world of recording beauty

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In the past few centuries, we humans have been trying to record the most beautiful scenery in our eyes. We are pursuing better image quality and resolution from the first trackable record of cave painting to the latest camera.

The oldest known cave art in the world is drawn on a face of rock in Spain near 73,000 years ago, acknowledged as being Paleolithic (meaning from the stone age). This primitive drawing leads us to share the same beautiful view our ancestors did.

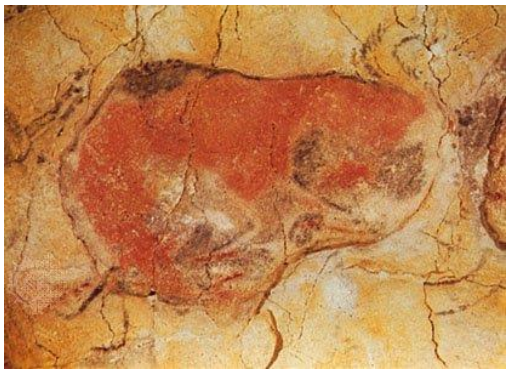

Fig 1, bison drawing at Altamira cave [1]

However, stone painting requires a strict atmosphere to start. With the development of human society and technology, people have turned their eyes to painting on paper since this medium is easy to store and sustain the originality of dyes. Even though paper is much softer and more portable than stones, it is still hard for people to paint instantly. Every stoke needs much time to paint on the paper, while some scenarios described by poetry spark in seconds. Thus, the digital camera was born after humans entered the industrial period.

The imaging tools are making massive progress from the rocks to the heavy, precision instrument. The image itself is no longer recorded by human brains and hands in the second hand. Still, it is recorded by the light the object itself emits. The evolution

of getting information can be summarized as transforming from subjective Imaging to objective Imaging.

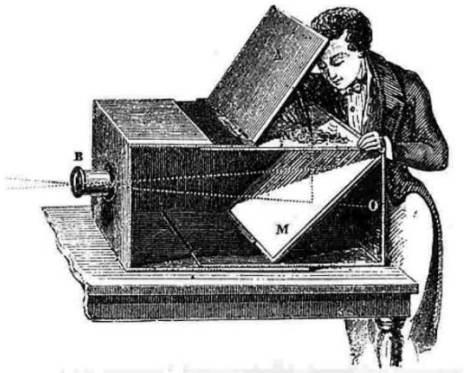

Fig 2, An artist using an 18th-century camera obscura to trace an image [2]

At this time, thanks to the evolution in optics, this secondary revolution liberates people from using heavy, line-relied machines (Fig 2) to smartphones with small imaging units held in our hands. Before the lensless Imaging came to life, we had portable, small devices like phones, or we needed to carry on large lenses like Sony or Canon.

Lensless Imaging is taken as the most important invention in my perspective. A charge-Coupled Device (CCD) is now widely used in our smartphones and cameras to transfer light information into electronic information and show it on the screen. On the other hand, it can be taken as an eye for our devices. Traditional optics is like wearing glasses to help us get a clearer view. Still, it is heavy and uncomfortable under certain circumstances, such as swimming or showering. Amazingly, Lensless Imaging is getting rid of the glasses and helps electronic devices to 'watch' the object using CCD. Abandoning the long, heavy lenses will be more portable and have a much smaller volume.

Since we have already got portable devices like smartphones, people may wonder why it is impossible for the traditional optic system to evolute further? Technically, the information collected by digital sensors is limited by the Space Bandwidth Product (SBP). Like the Heisenberg Uncertainty Principle, we cannot get an image with high resolution with fruitful information, which means we cannot have a portable device. In contrast, this device has strong power for Imaging. This SBP measures the capability

of the imaging system, defined as the equation below,

$$SBP = 2\frac{FOV}{r^2}, r = 0.61\frac{\lambda}{NA}$$

FOV represents the field of view, λ is the wavelength, and NA is the numerical aperture. NA can be analogized as the open eye ability, affecting the angles of view and how wide the object can be seen.

Based on this theory, the traditional optical system is hard to lift SBP, especially if we want to increase the resolution to get more information. Seeing as the table 1. The left row shows our object's magnification through the lens system to our eyes. And the second indicates how precise the object is. In optics, a smaller wavelength means a better resolution to show every detail. Combining these indexes, SBP is born to balance them. We want to enlarge SBP as possible.

Table 1. Spatial bandwidth product of typical microscopic objectives [3]

Objective (Magnification/ numerical aperture/field number)	Resolution (incident wavelength: 532 nm)	SBP/megapixel
1.25x/0.04/26.5	8113 nm	21.5
2x/0.08/26.5	4057 nm	33.5
10x/0.3/26.5	1082 nm	18.9
40x/0.75/26.5	433 nm	7.4
100x/1.3/26.5	250 nm	3.5

Theoretically, to some extent, lensless Imaging abandons the traditional imaging lens. Still, it uses the CCD to get the diffraction light directly.

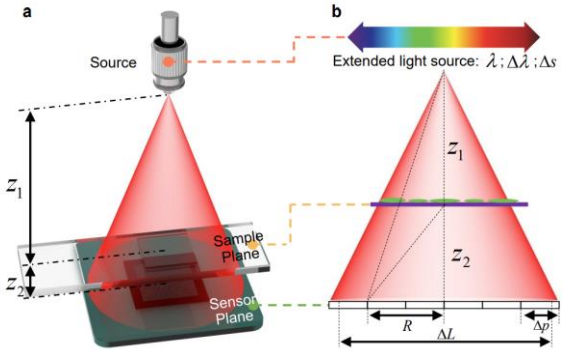

Fig 3. Lens-free on-chip Imaging [4]

We use a laser to illuminate the samples. The scattered and transmitted light travels in the same direction forming interference fringes, a specific picture with hidden regulation on the final sensor plane. The object information is inside the picture. Optics theory suggests that light routines can be reversed, which means every picture we obtain on CCD can be tracked to its original light source. With the power of physics and math, we can have a description of the function to build the procedure.

Due to the technology limitation, the lensless Imaging can only take a shot in a short distance due to the coherence limitation. The light is not trackable at a certain distance because mixing like mixed juice cannot be distinguished from its original component. However, this lensless optical system can theoretically enhance the SBP over 100 times more than a traditional imaging system. Nevertheless, in the future, with the promising progress made in algorithms and nanotechnologies, it will not be limited anymore.

At this time, the lensless system has been used in many real applications. In 2011, Coskun A F et al. used the lensless technology to detect transgenic Caenorhabditis, a super tiny bug [5]. In 2009, Granero L et al. used the lensless technology combining the superresolution method to image holographic [6].

This technology is quite promising but ignored by the public due to its existing application within a short distance. However, the existing obstacles to lensless Imaging are CCD fabrication and algorithm design. It has no theoretical drawbacks compared to traditional and other research optical systems. In the future, with mature lensless technology, we can get ourselves free from bulky optical devices or cameras. Still, just a little piece of a chip to capture both clear and informative photos. These photos will meet the need for our proof of existence.

Reference

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